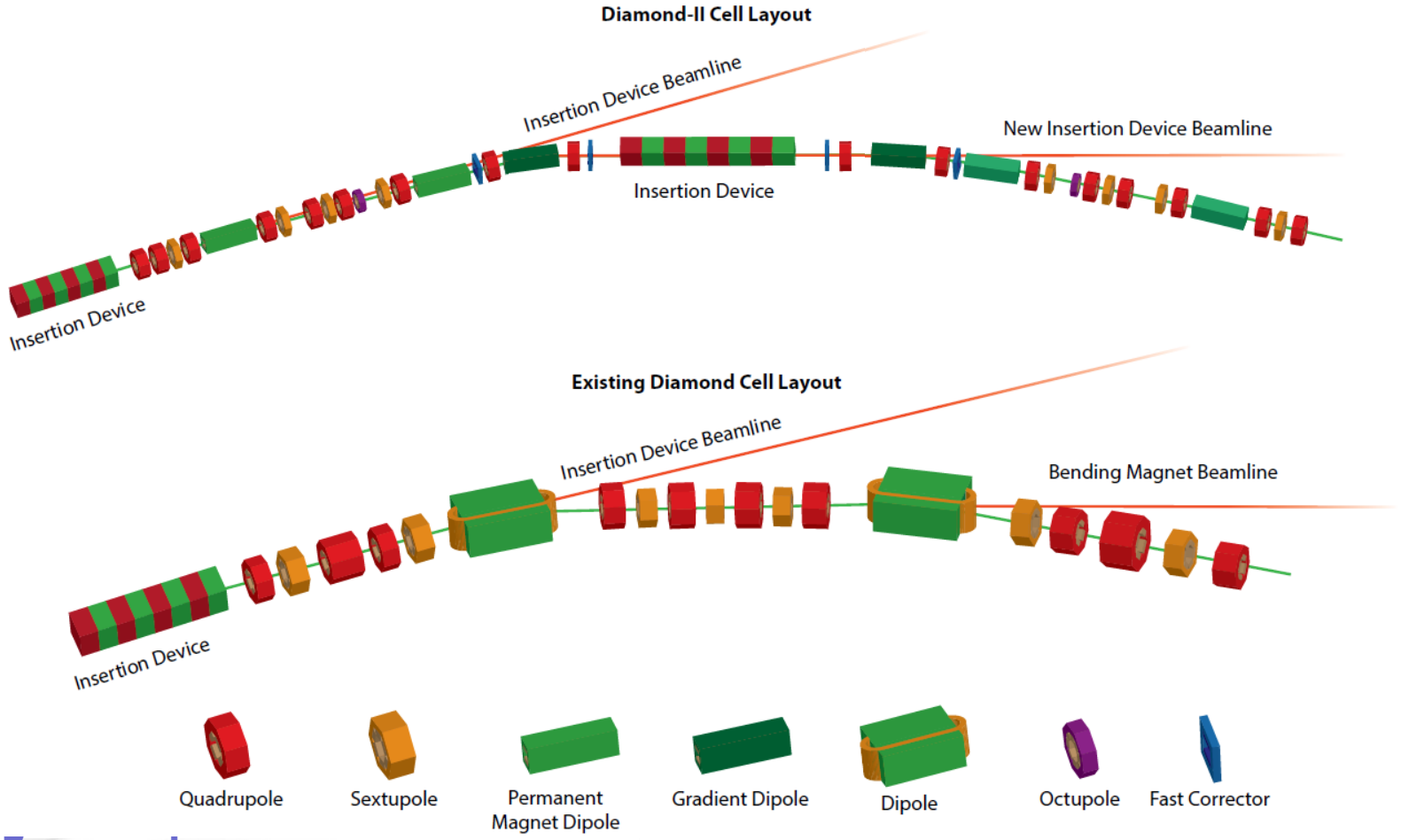
Coherent Soft X-Ray Imaging and Diffraction

A new, advanced imaging beamline for Diamond-II

Case for change – September 2018

Diamond-II

$$\epsilon \propto E^2 \Phi^3$$



1. Low-emittance
   (Increased Coherent Flux)
2. Increased capacity
3. Higher energy

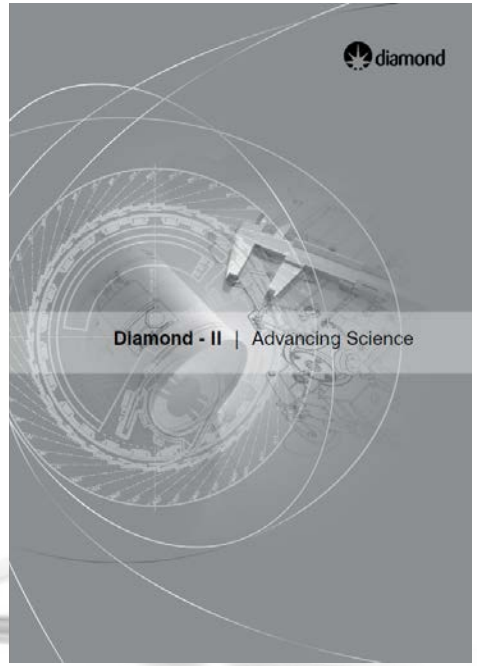
2.7 nm.rad

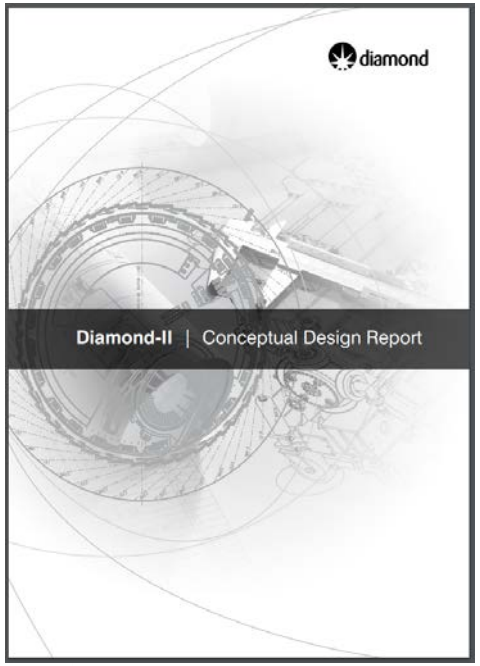
See presentation by Prof. Laurent Chapon

diamond

CSXID Timeline

Diamond-II is a co-ordinated programme of development that combines a major machine upgrade with complementary improvements to optics, detectors, sample delivery, detectors, and computing.





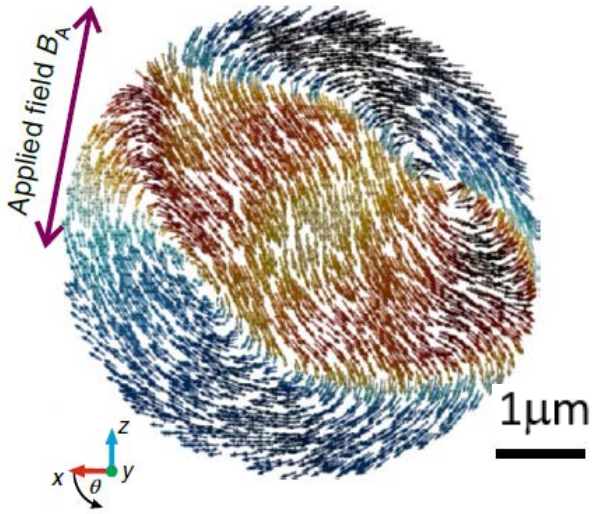
CSXID Timeline

- QM workshop – September 2018
- Science case – March 2019
- Outline proposal SAC/DISCo review – May 2020
- User working group (UWG) formed – Sept. 2020

UWG Members	Institutions
Paolo Radaelli (Chair)	University of Oxford
Claire Donnelly	University of Cambridge
Massimo Ghidini	University of Cambridge/Parma and Diamond
Kevin Edmonds (DUC)	University of Nottingham
Jörg Wunderlich	University of Regensburg
Andy Beale	University College London
Olga Kazakova (DISCo)	National Physical Laboratory
Robert Weatherup	University of Oxford
Benedikt Daurer	Diamond
Burkhard Kaulich	Diamond
Dirk Backes	Diamond
Hongchang Wang	Diamond
Martin Burt	Diamond
Sarnjeet Dhesi	Diamond

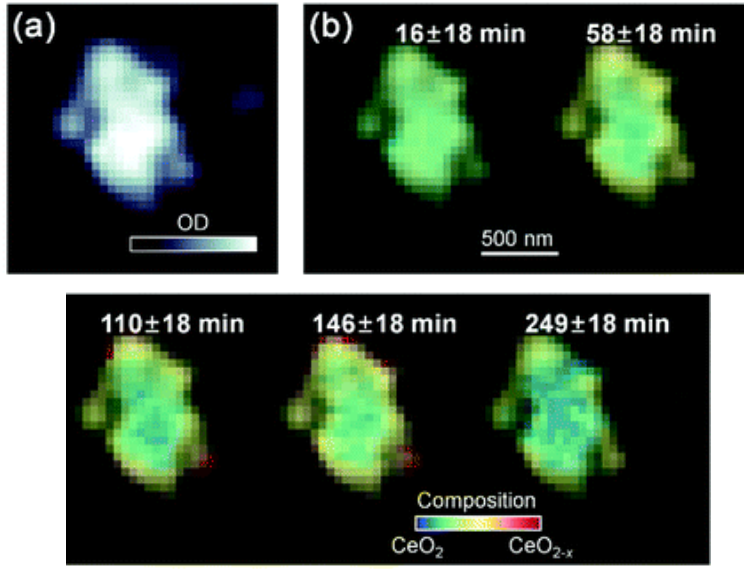
Functional and quantum materials

Domain motion



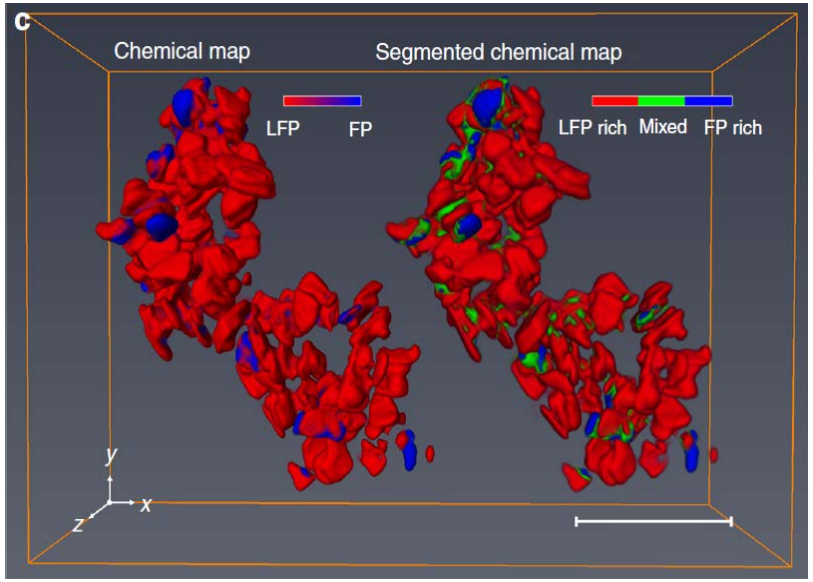
C. Donnelly *et al.*, Nature Nanotech. **15**, 356 (2020)

Operando catalysis



M. Yoo et al., Energy Environ. Sci. **13**, 1231 (2020)

Battery cycling



Y.–S. Yu et al., Nat. Commun. **9**, 921 (2018)

Quantum materials

Energy materials

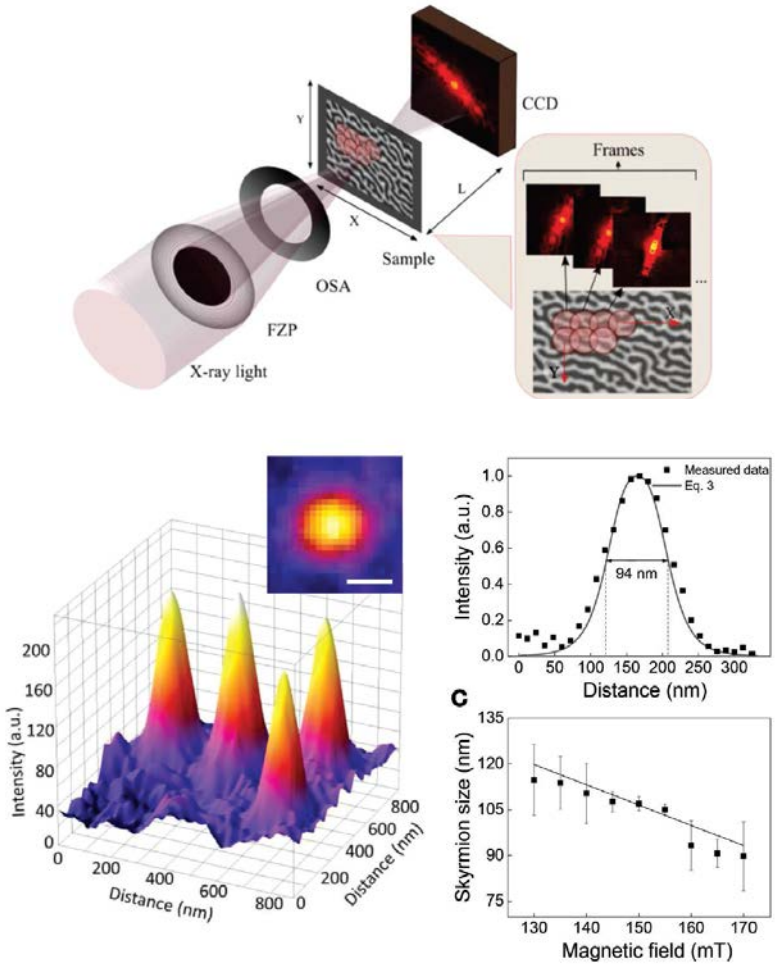
Chemistry & Catalysis

Environment

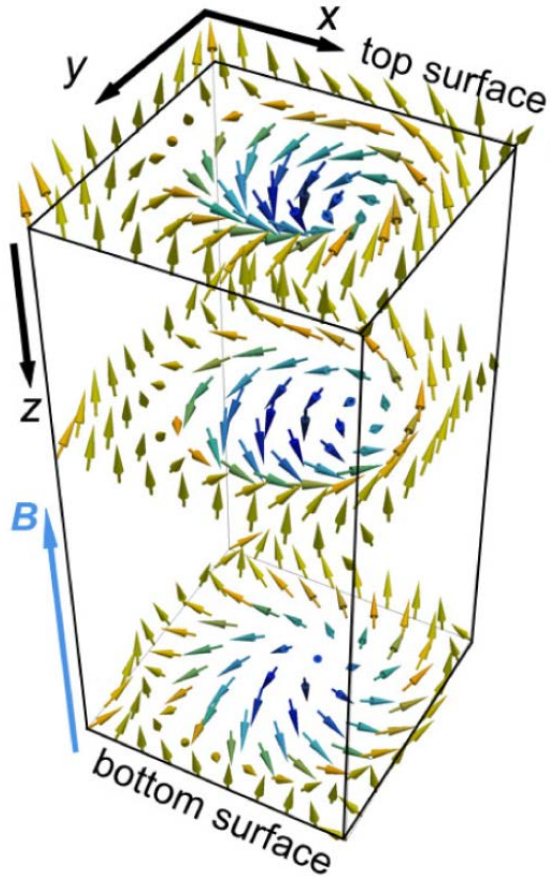
Materials Engineering & Processes

diamond

Profiling Skyrmions



W. Li *et al.*, Adv. Mater. **31**, 1807683 (2019)



S. L . Zhang *et al.*, Phys. Rev. Lett. **120**, 227202 (2018)

Skyrmions are an example of topologically protected spin textures that are now being discovered or developed in materials because of their novel physical properties.

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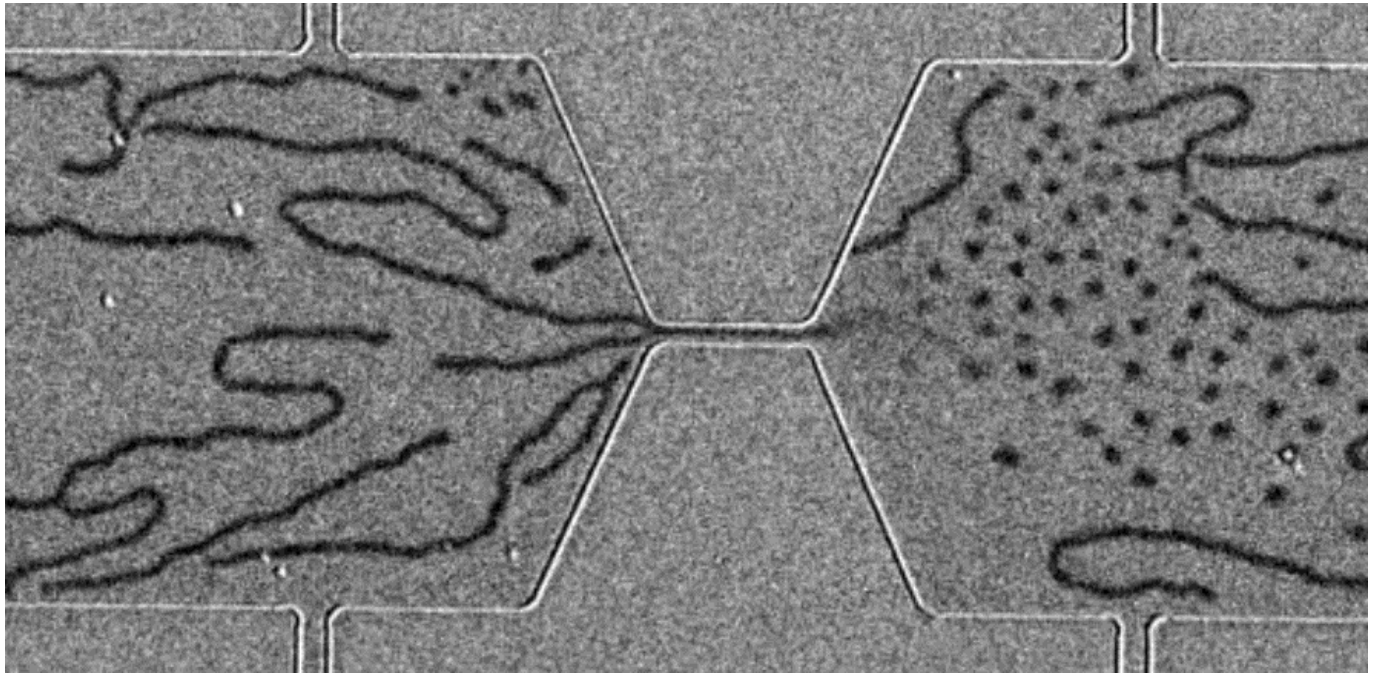
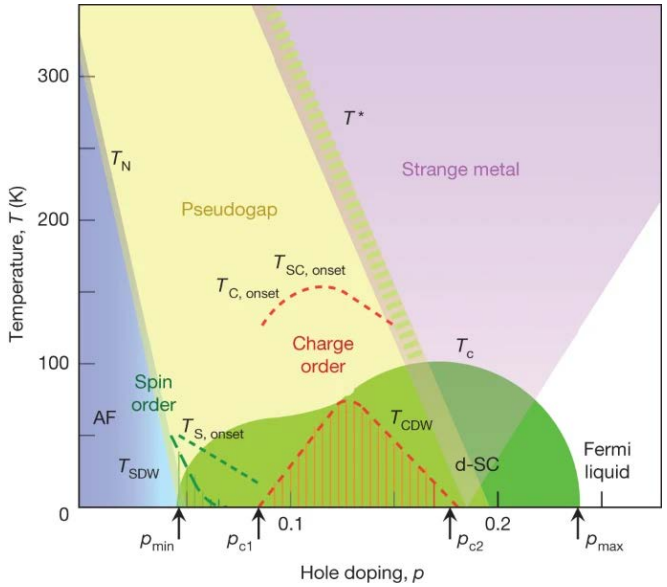
Controlling Skyrmions



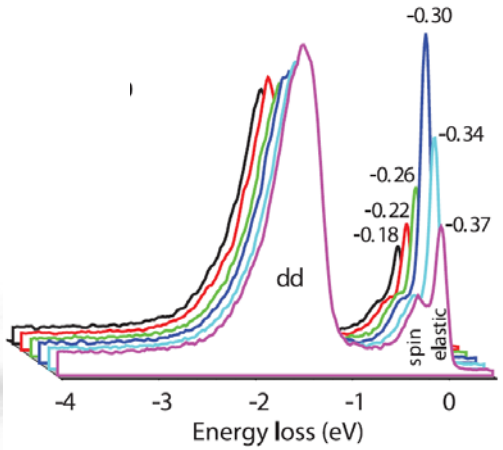
Blowing magnetic skyrmion bubbles W. Jiang *et al*., *Science* **349**, 283 (2015)

Phase Separation in Quantum Materials

Charge Density Waves and Superconductivity

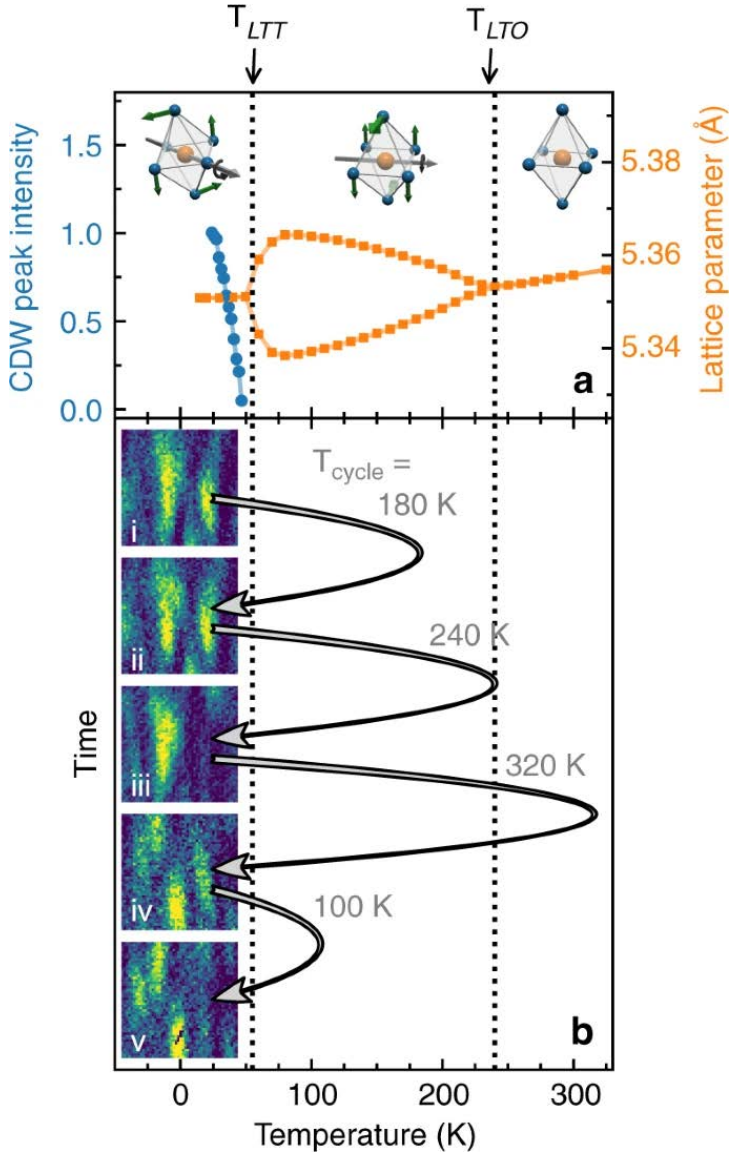


B. Keimer et al., Nature **518**, 179 (2015)



G. Ghiringhelli et al., Science **337**, 821 (2012)

Charge Density Wave memory using Coherent Diffraction



X. M. Chen et al., Nat. Commun. **10**, 1435 (2019)

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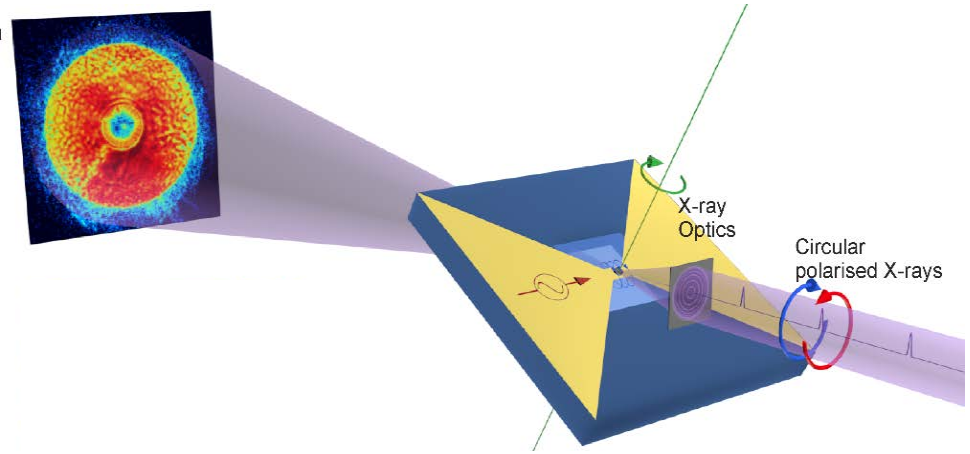
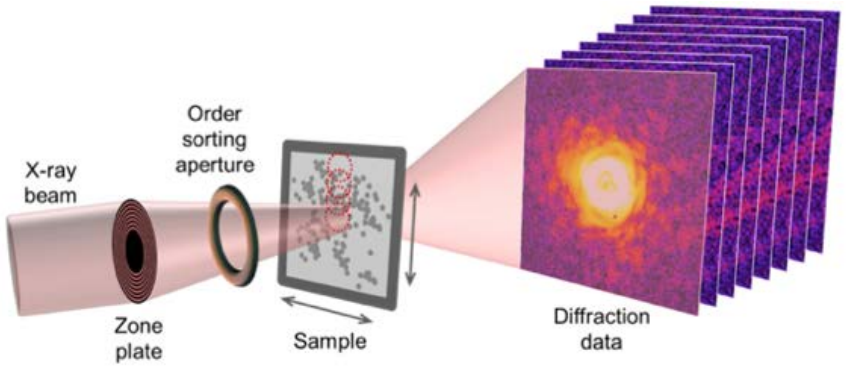
Imaging mode

Laminography

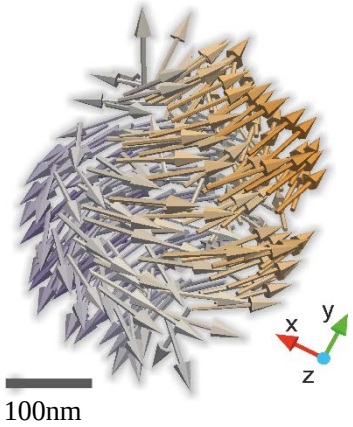


Ptychography



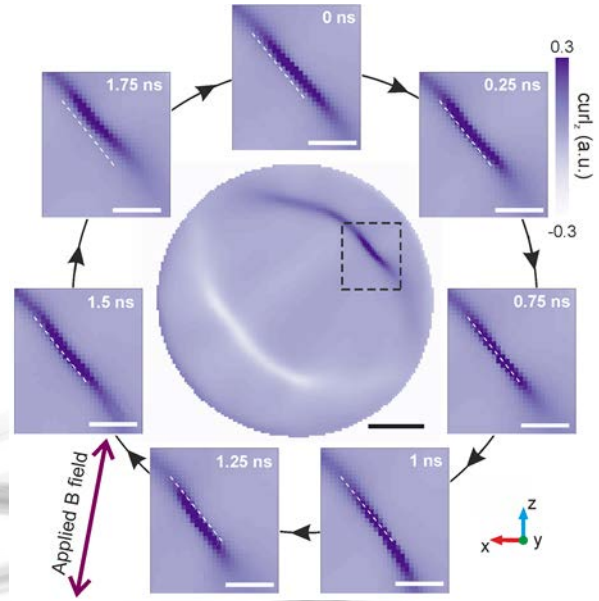
Weker Group.
https://sites.slac.stanford.edu/wekergroup/ptychography

Tomography



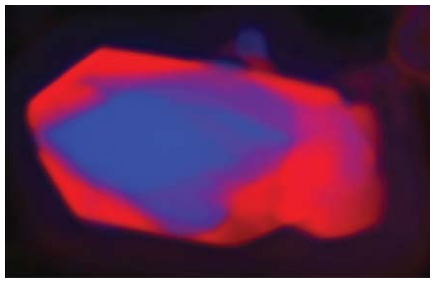
C. Donnelly et al., Nature **547**, 328 (2017)

Time-dependent Imaging - STXM

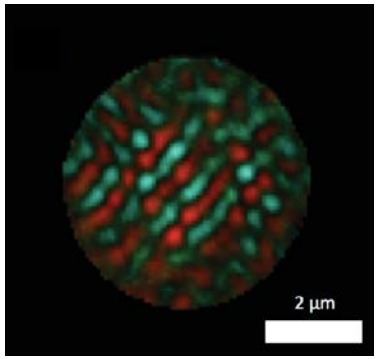


C. Donnelly et al., Nature Nanotech. **15**, 356 (2020)

Ptychography & Coherent Diffraction Imaging



Shapiro et al., Nat. Photonics **8**, 765 (2014)



J. J. Turner et al., Phys. Rev. Lett. **107**, 033904 (2011)

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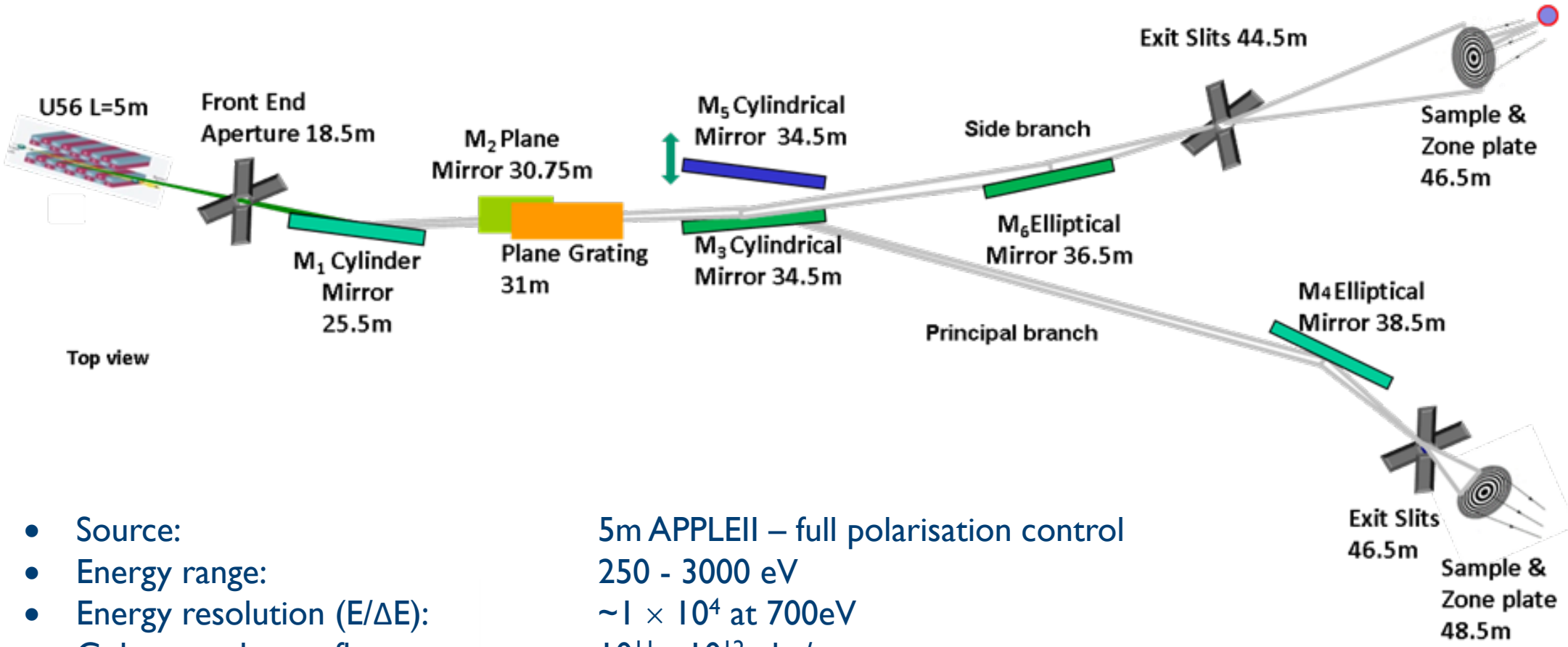
Coherent Soft X-Ray Imaging and Diffraction Beamline (CSXID)



- Source: 5m APPLEII – full polarisation control
- Energy range: 250 - 3000 eV
- Energy resolution (E/ΔE): ~1×10^4 at 700eV
- Coherent photon flux: 10^{11} - 10^{12} phs/s
- Beam-size at sample spot: 50nm on principal branch
- Preparation chamber: high-temperature, liquid cells, in-situ preparation
- Enhancement of throughput: up to ×100 compared to current capability
- Spatial resolution: < 10 nm with ptychography

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Beamline Performance

- **CSXID** will have **higher coherent flux:**
  CSXID: 7.6×10^{11} phs/s
  Other sources: 1×10^{9} phs/s
- **CSXID** will provide **~760x more photons*** than best in class**
- **CSXID** will give **5x higher spatial resolution** than best in class**
- **CSXID** will use intuitive software for **real time 3D reconstructions** with chemical and magnetic contrast

→ A new, fast and efficient, 3D operando imaging facility to aid the understanding and development of advanced functional materials.

*for measurements limited by photon flux

**see Hung Lo et al., arXiv:2009.01093

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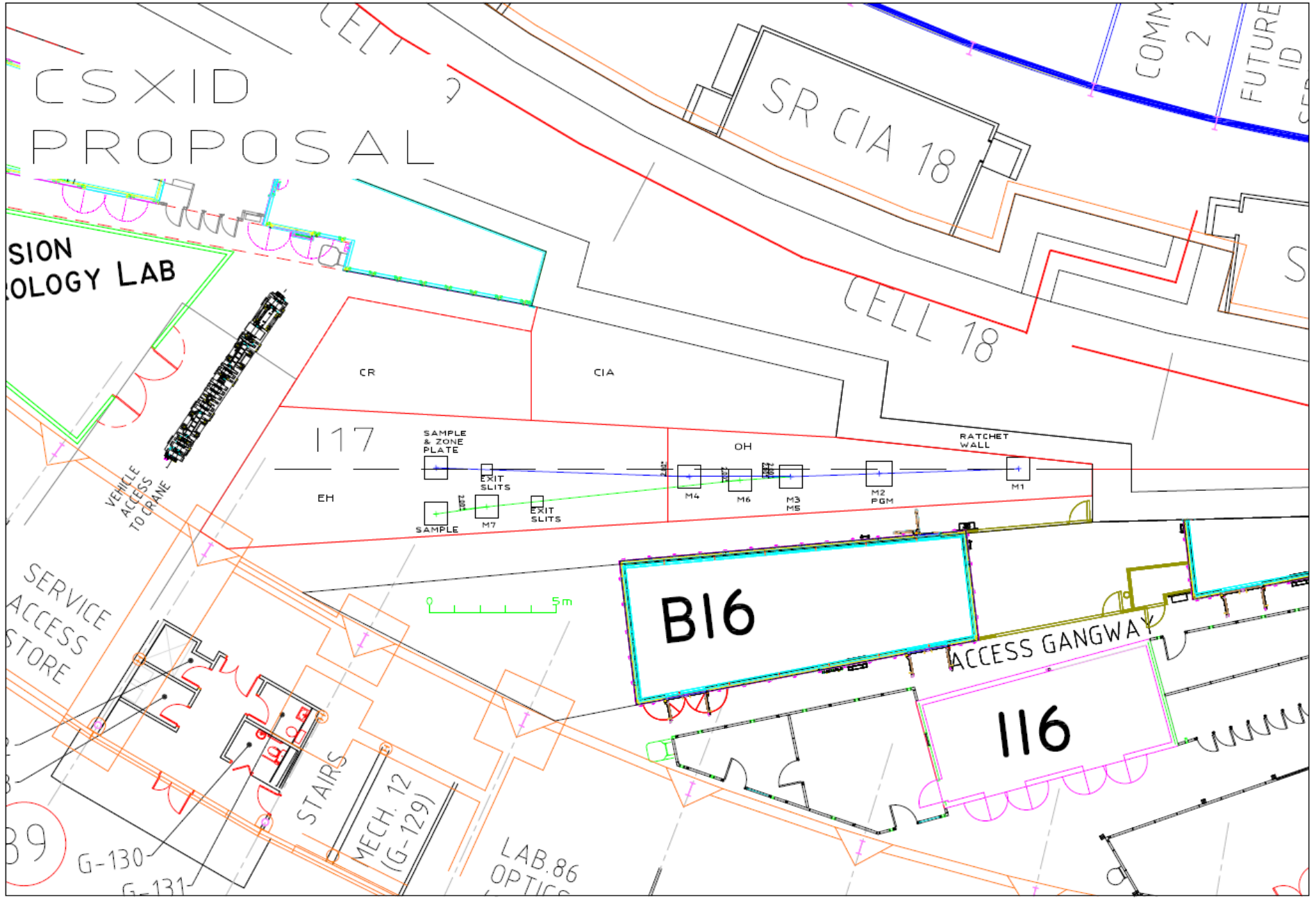
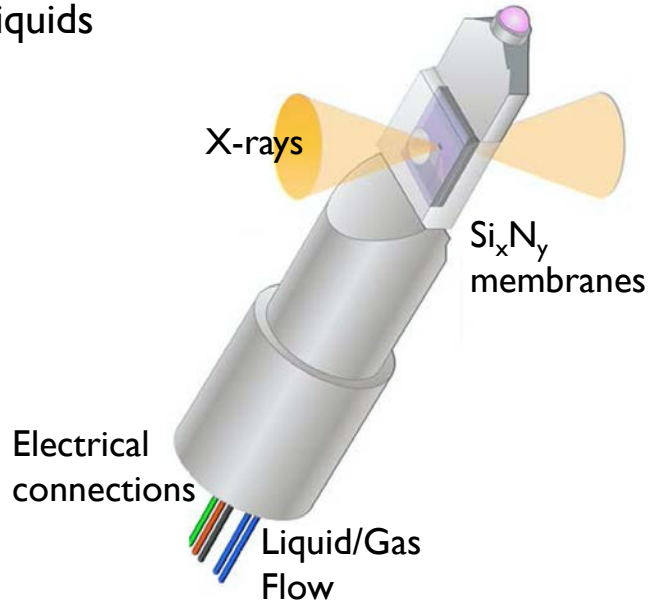
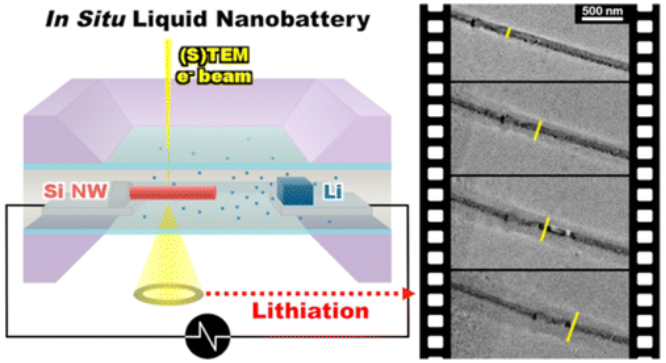
Coherent Soft X-Ray Imaging and Diffraction Beamline (CSXID)



Sample preparation & environment

TEM-style environmental cells
- Atmospheric pressure gases
- Liquids



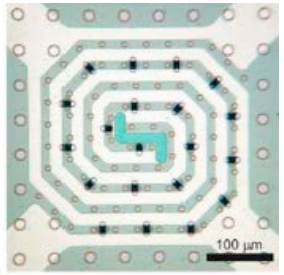


M. Gu et al., Nano Lett. **13**, 6106 (2013)

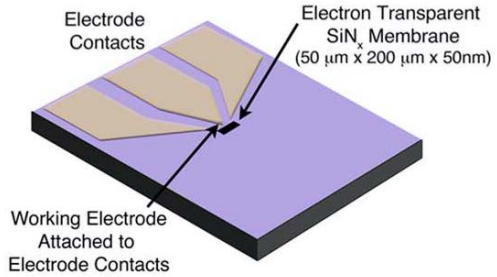
SEM/FIB in eBIC Centre

MPMS3 in I10

SEM/FIB in ePSIC Centre



Resistive/Laser heaters (up to 1200 °C)



Patterned contacts for operando biasing and e-chem

R. Unocic et al., Microsc. Microanal. **20**, 1029 (2014)

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Summary

- **CSXID** will have a **high coherent flux** enabling **faster** 3D imaging with **higher spatial resolution** compared to best in class
- Future research enabled by **CSXID**:
  - Imaging of skyrmions, hopfions, and 3D-printed nanostructure
  - Element-specific characterisation of 'frontier' catalytic materials such as those containing single-(metal)atom/ion and clusters
  - Imaging Néel vector distribution in novel oxide-based antiferromagnets for racetrack-type applications
  - Strain engineering of stacked multiferroic 3D-heterostructures using laminography
  - 3D nanoscale insights into electronic phases separation
  - Imaging of spin-polarisation in future 3D nanoscale topological insulators and non-magnetic spintronic devices