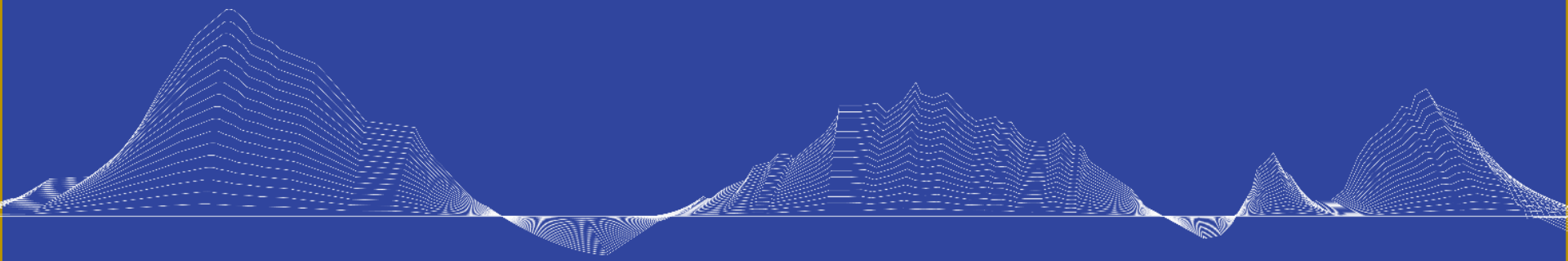
WELCOME

State of the art and future of Ptychography:
a follow-up to the previous Ptychography webinar



YOUR HOSTS TODAY



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State of the art and future directions for ptychography

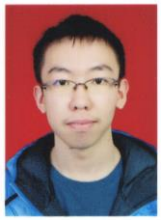
Dectris Application Webinar 2020

Who are we? The Coherent X-ray Scattering Group


Christian Appel


Ana Diaz


Xavier Donath

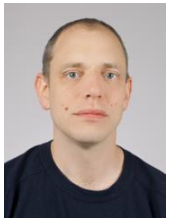

Zirui Gao

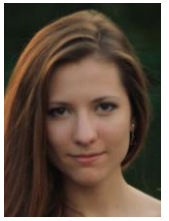

Mirko Holler


Manuel Guizar-Sicairos


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Dmitry Karpov


Andreas Menzel


Mariana Verezhak

Funding

FNSNF
FONDS NATIONAL SUISSE
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SWISS NATIONAL SCIENCE FOUNDATION

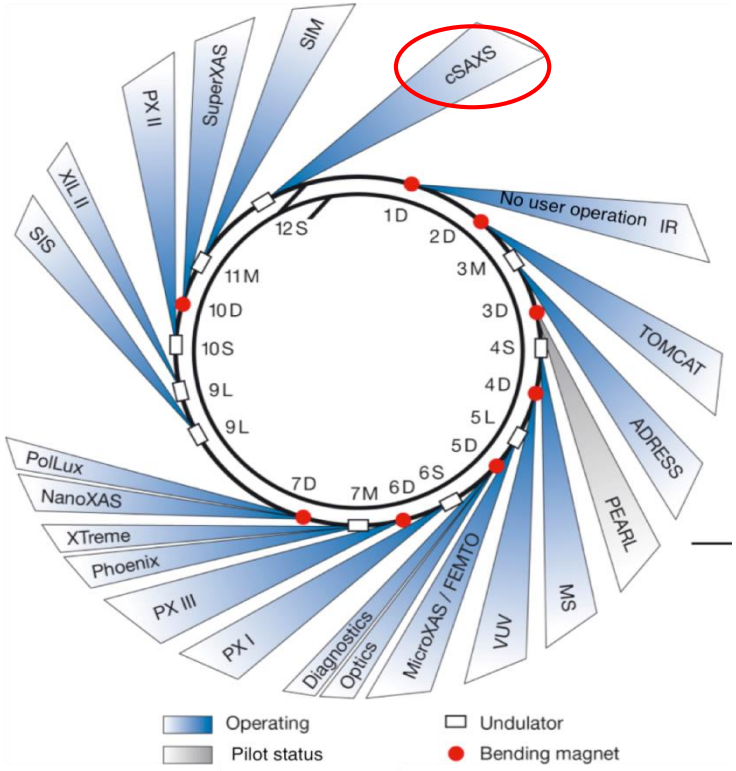
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O. Bunk, G. Aeppli, H.-C. Stadler, C. David, L. Heyderman, …

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Swiss Light Source





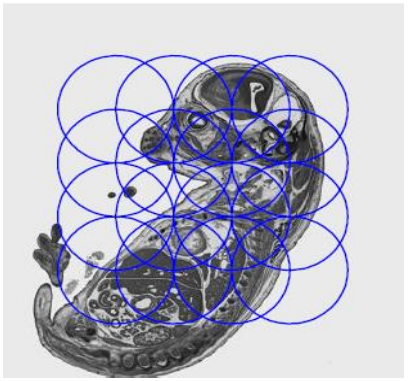


Ptychography (transverse translation diversity)

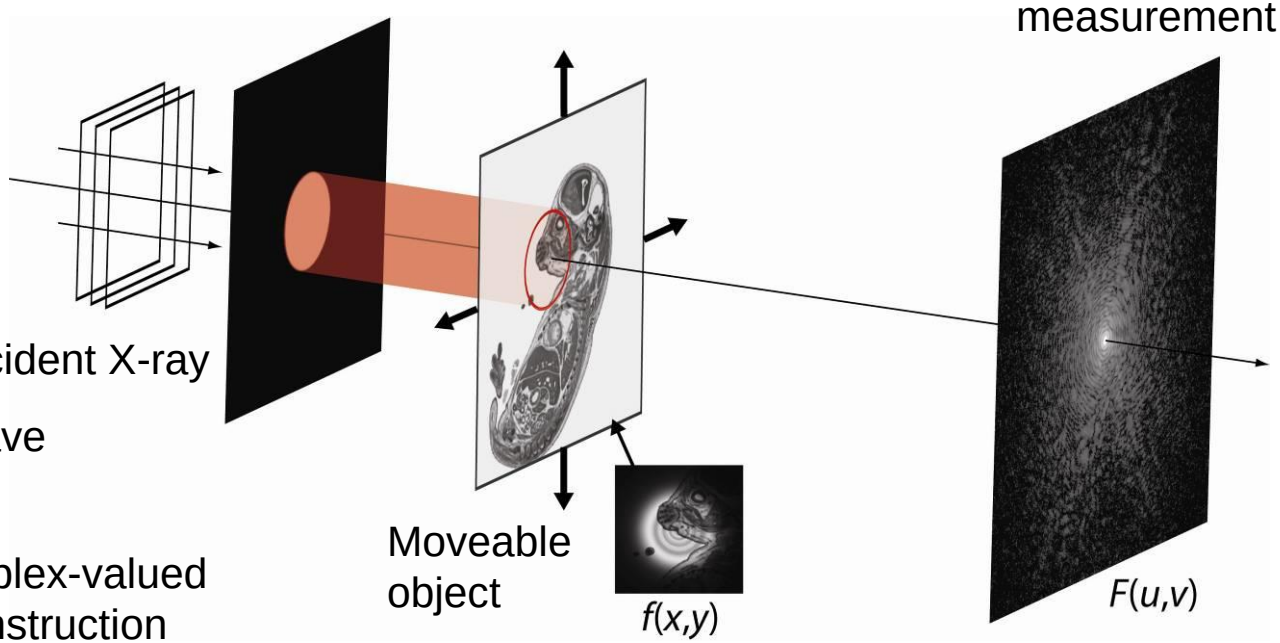
Moving the sample with respect to a known illumination pattern can provide suitably diverse measurements

Makes phase retrieval more robust to stagnation, noise and ambiguities

Allows for extended samples, resolution is finer than the illumination and translations







Complex-valued reconstruction

H. M. L. Faulkner et al. Phys. Rev. Lett. 93, 023903 (2004)

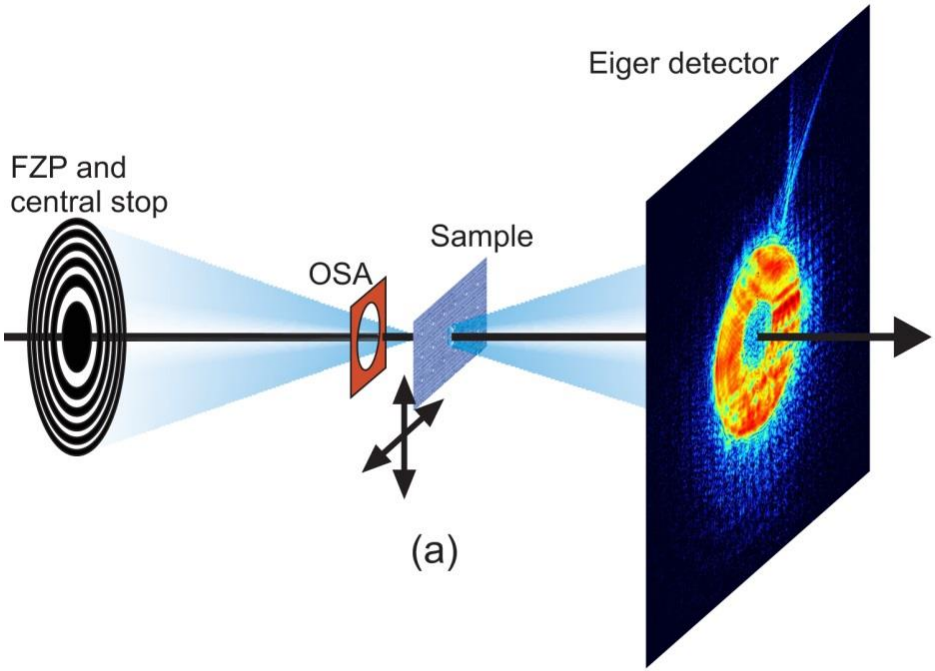
Imaging throughput – The Eiger self portrait

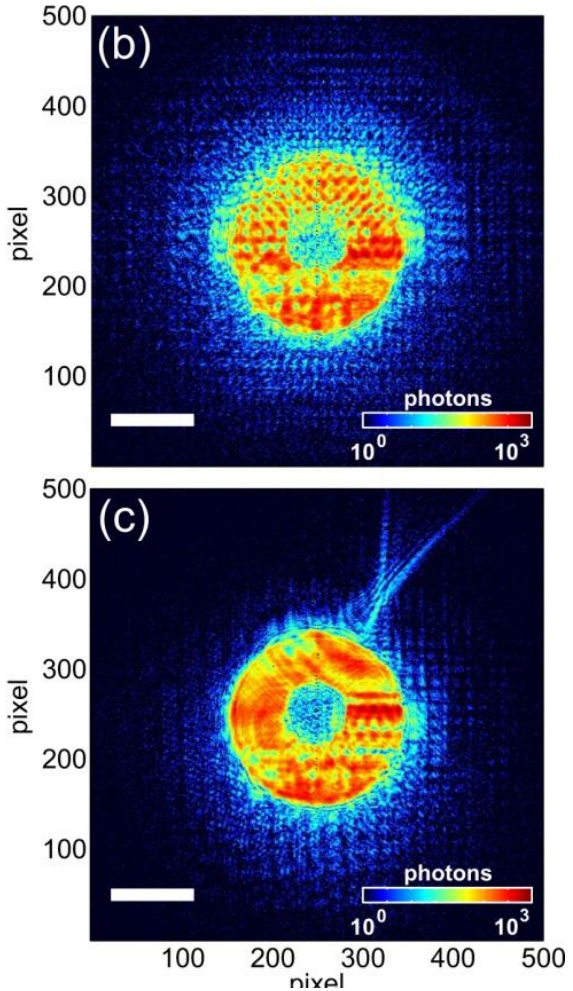
Sample 5 mm downstream of focus

Beam at sample ~ 10 microns

Scanning average step 3.5 microns

Eiger as sample and detector





M. Guizar-Sicairos *et al.*, Opt. Express **22**, 14859 (2014)

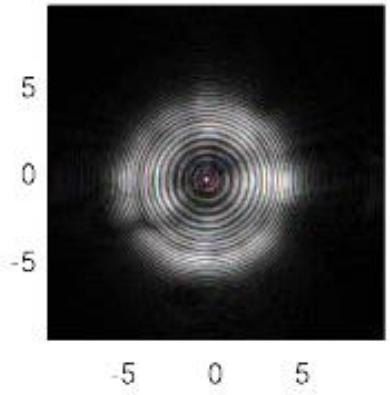
Imaging throughput – The Eiger self portrait

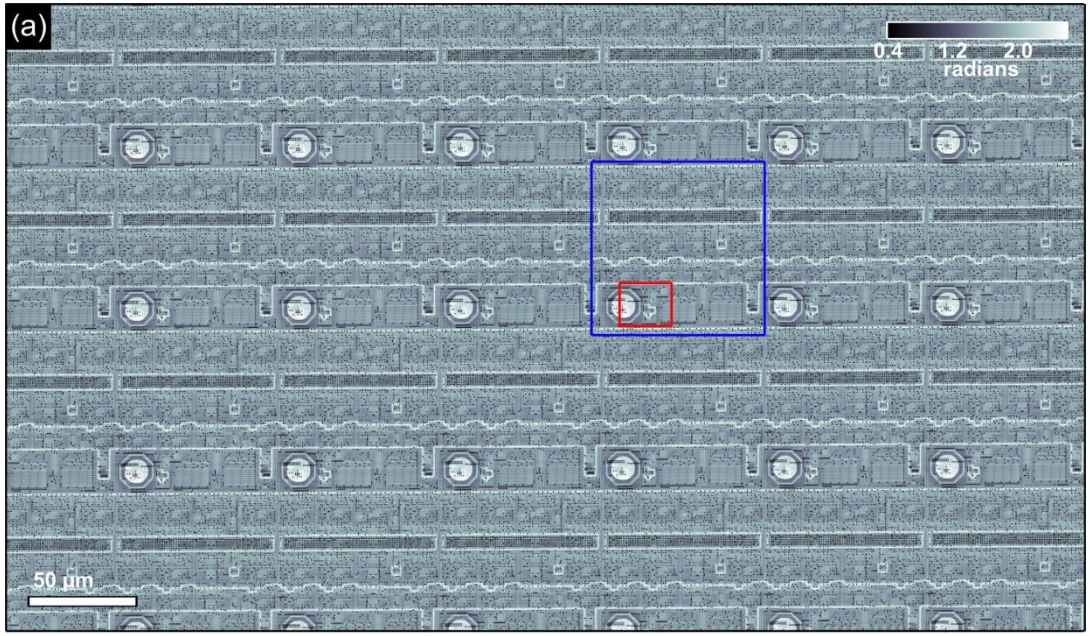
98.4 Mpixel (13,028 x 7,556)

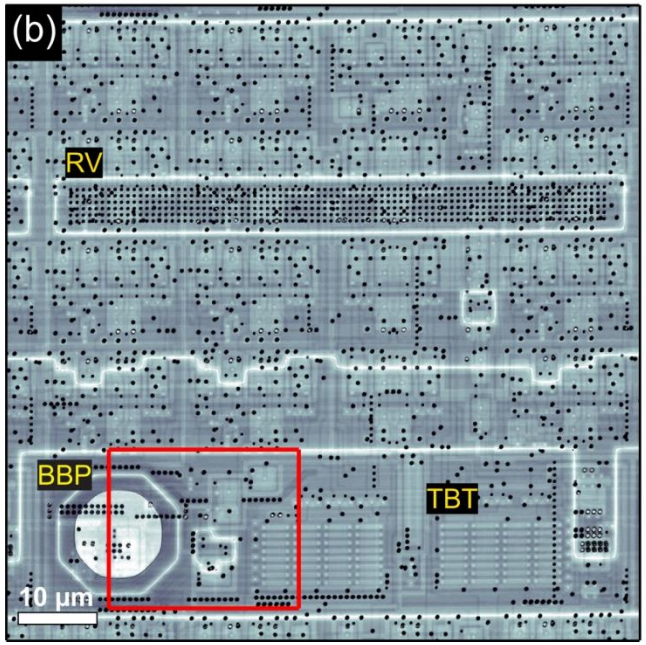
Resolution 41 nm, 38.4 nm pixel

> **25,000** resolution elements / second

40 microsecond per resolution element







M. Guizar-Sicairos *et al.*, Opt. Express **22**, 14859 (2014)

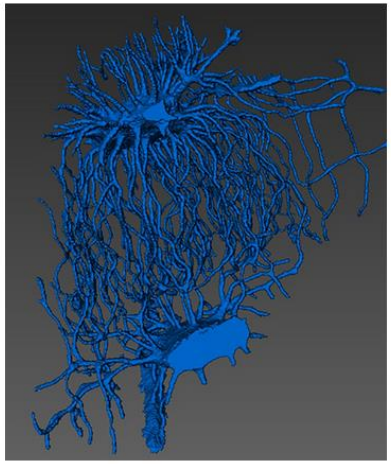
Time resolved ptychography

Cameron Kewish webinar addresses many topics in ptychography. Including motivation for fast imaging of dynamic processes and a 2D example

In the future nanoscale 3D images could be pursued. New algorithms to deal with ptychography on dynamic samples may be needed

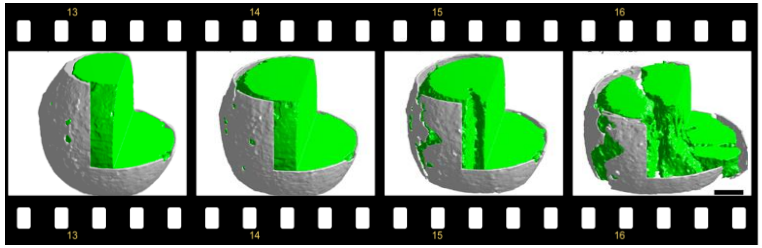
Fast-Scanning Ptychography: The implementation at the Australian Synchrotron XFM Beamline with an EIGER2 X 1M Detector

Ptychography is a super-resolution imaging method based on coherent diffractive imaging, which produces quantitative images with contrasts in their phase and absorption. A phase contrast provides morphological information and is exceptionally useful in the hard X-ray imaging regime, where absorption is comparatively weak – high-contrast ultrastructural images can be obtained even from single-component specimens. In our fourth webinar, **Dr. Cameron M. Kewish**, a research scientist at the ANSTO Australian Synchrotron, demonstrated how fast-scanning ptychography and other microanalysis methods had been implemented with an EIGER2 X 1M detector at the Australian Synchrotron XFM beamline.



View the recording

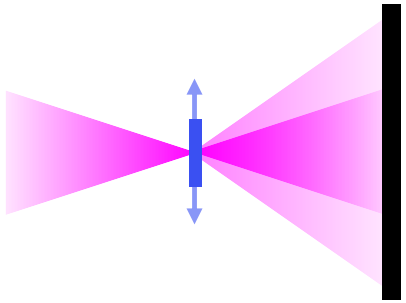
Time – Nanoscale 3D movies



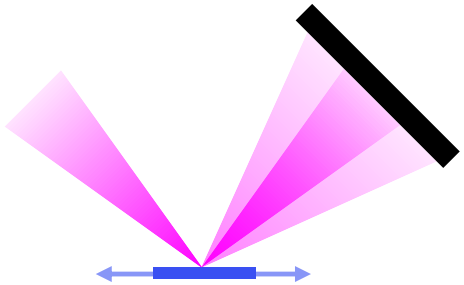
Evolution of dynamic samples,
In situ temperature, compression, reduction

Images from Fløystad *et al.,* Adv. Eng. Mater. **17**, 545 (2015)

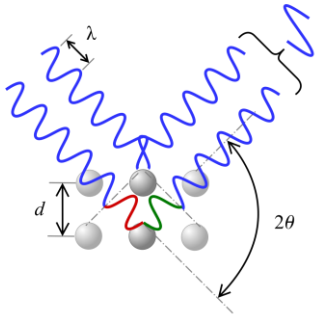
Reflection geometry



Forward geometry



Reflection geometry

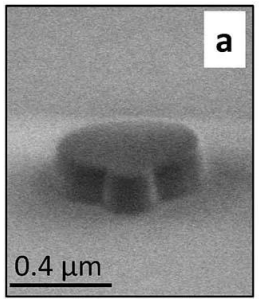


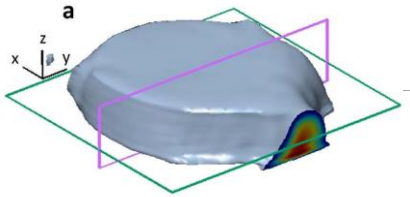
Bragg reflection – High sensitivity to crystalline lattice deformations or defects

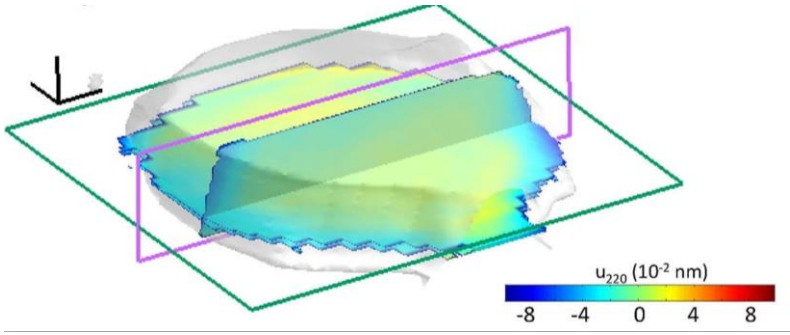
Silicon-on-insulator nanostructure

Strain component (220) reconstructed in 3D using Bragg ptychography combined with rocking curve

Measurements at ESRF ID13 beamline







Based on Chamard *et al.*, Sci. Rep. **5**, 9827 (2015).
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Image based on https://en.wikipedia.org/wiki/Bragg%27s_law#/media/File:Braggs_Law.svg (CC BY-SA 3.0)

Combining ptychography and fluorescence

Adding a fluorescence detector provides information about local elemental composition.

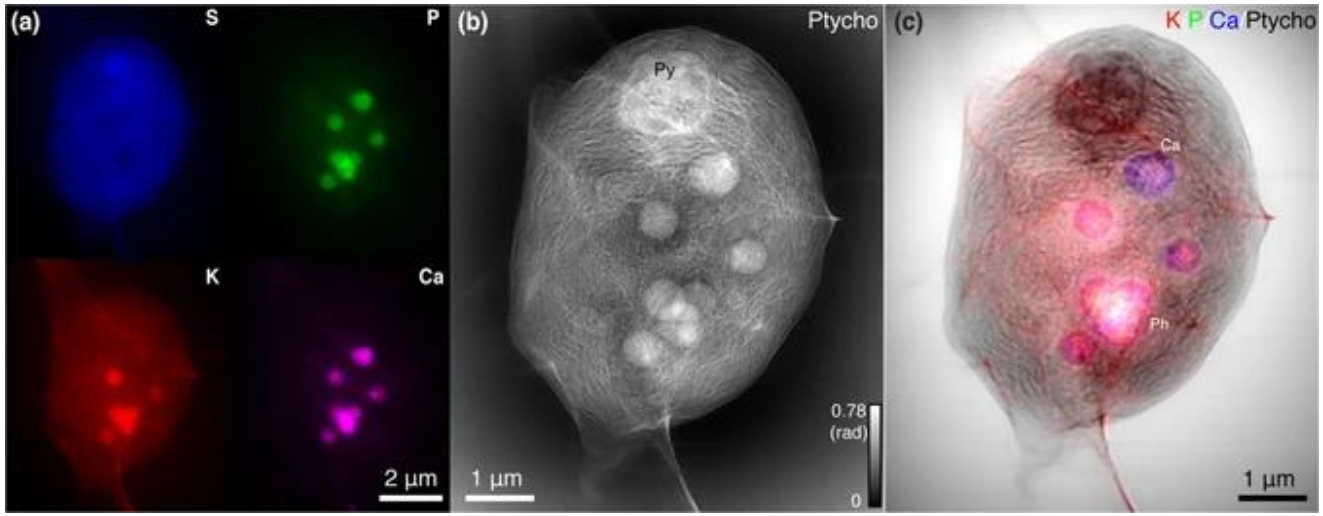
Deng et al., "Simultaneous cryo X-ray ptychographic and fluorescence microscopy of green algae," PNAS 112, 2314 (2015). https://doi.org/10.1073/pnas.1413003112

Almost every beamline that does ptychography has implemented or plans to implement this.

Works for 2D and 3D.

Deng et al., "Correlative 3D x-ray fluorescence and ptychographic tomography of frozen-hydrated green algae," Sci. Adv. 4, eaau4548 (2018). https://doi.org/10.1126/sciadv.aau4548

Both cannot be currently optimized simultaneously. Need faster detectors, improved scanning, and vast computational resources. Efforts in this direction are undergoing.



Images from Deng *et al.,* Sci. Rep. 7, 445 (2017). Under Creative Commons Attribution 4.0 International License. Measurements in APS beamline 21-ID-D.

Nanoscale 3D imaging

Combining ptychography and a sample rotation enables 3D imaging

Laminography geometry allows for extended flat samples to be imaged, enabling 3D zooming into regions of interest and facilitating in situ and in operando studies

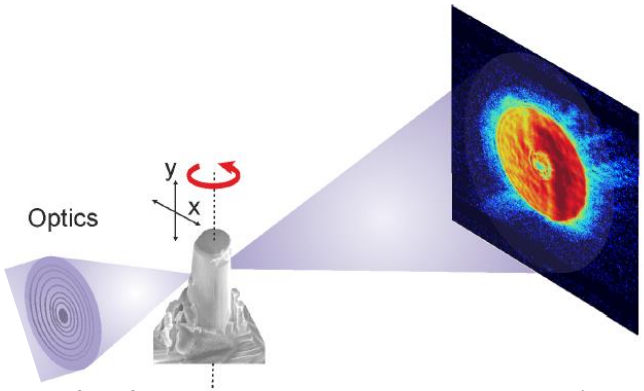
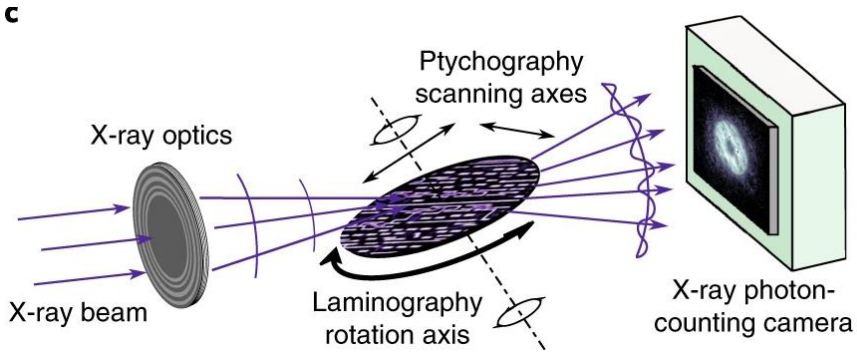


Image modified from Donnelly *et al*. Nature 547, 328 (2017)

Ptychographic X-ray computed tomography (PXCT)

Dierolf *et al.* "Ptychographic X-ray computed tomography at the nanoscale," Nature, **467** 436 (2010)

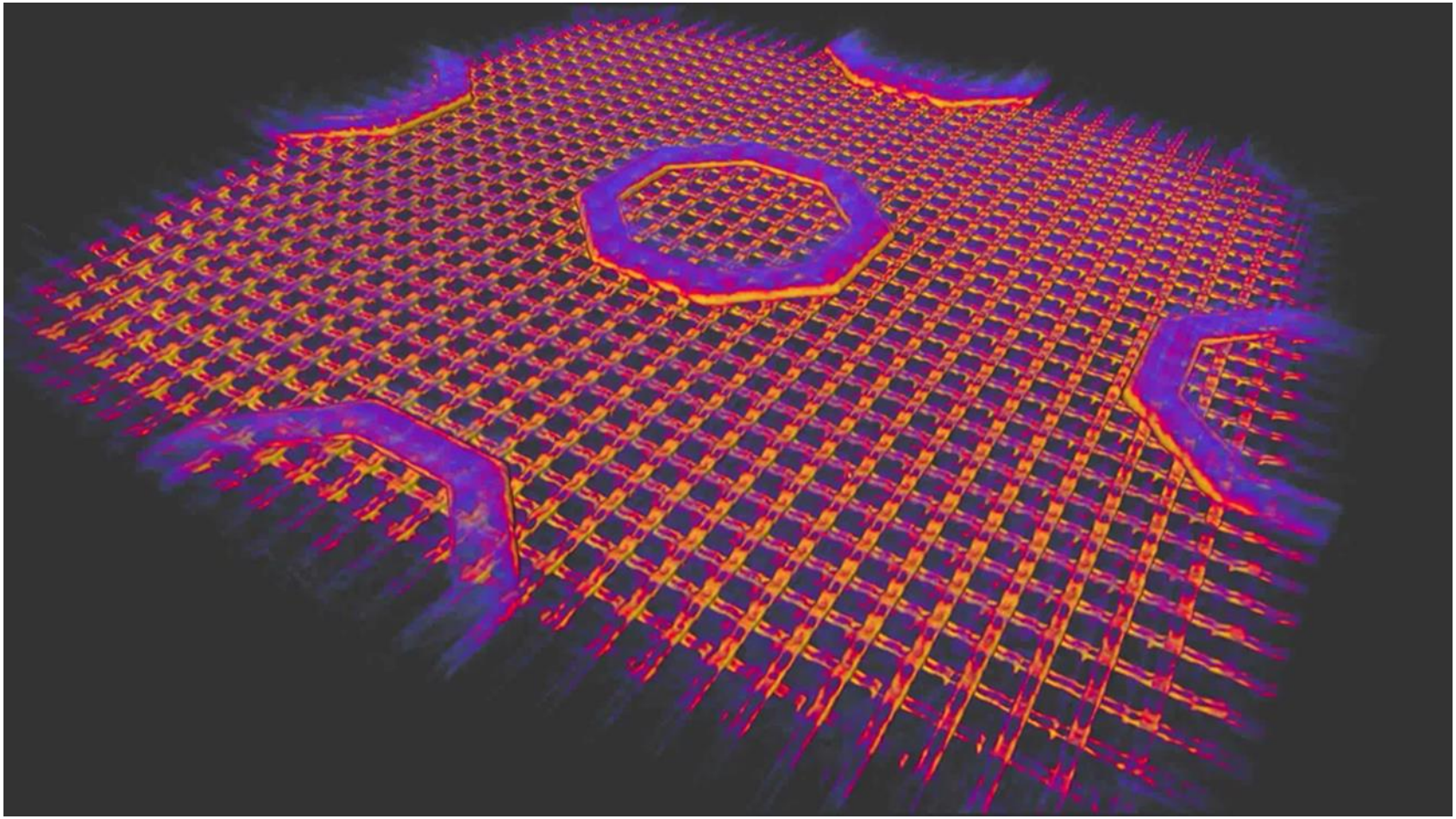


Ptychographic X-ray laminography (PyXL)

Holler *et al.*, "Three-dimensional imaging of integrated circuits with macro- to nanoscale zoom," Nat. Electron. **2**, 464 (2019)

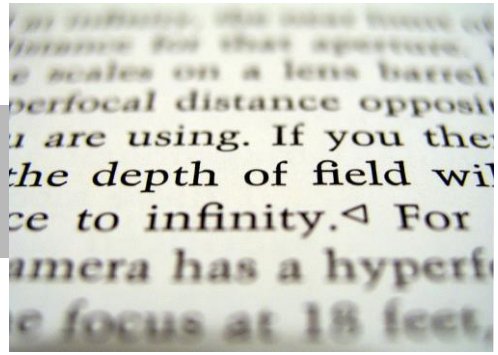
Nanoscale 3D imaging

Example ptychographic laminography imaging metal layers and interconnections in an integrated circuit at 20 nm resolution. Measurement in SLS, cSAXS beamline.



Holler et al, "Three-dimensional imaging of integrated circuits with macro- to nanoscale zoom," Nat. Electron. **2**, 464 (2019)

Beyond the depth of field limitation



https://commons.wikimedia.org/wiki/File:DOF-ShallowDepthofField.jpg
GNU Free Documentation License, Version 1.2

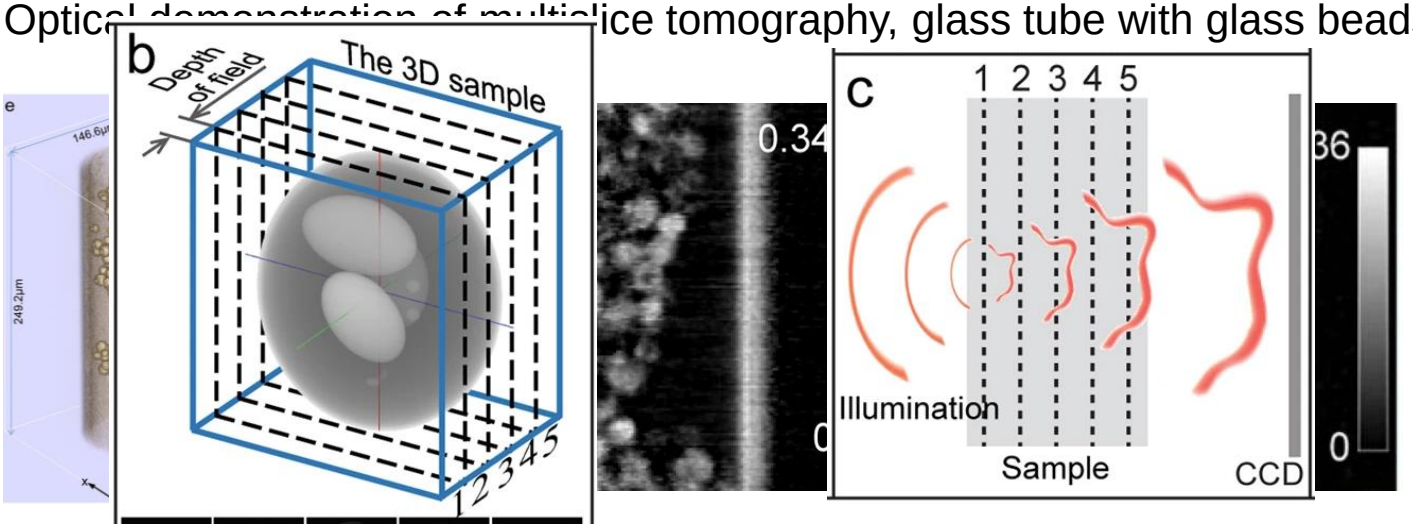
Depth of field (DOF) arises due to diffraction. Affects lens-based imaging, holography, etc.

Higher resolution results in smaller distance remaining in focus. Limiting the volumes we can measure with very high resolution.

Multislice ptychography overcomes this limitation. Represents the object by several slices and taking into account propagation through the object.

Maiden *et al.,* "Ptychographic transmission microscopy in three dimensions using a multi-slice approach," JOSA A **29**, 1606 (2012). https://doi.org/10.1364/JOSAA.29.001606

Optical demonstration of multislice tomography, glass tube with glass beads



Images from Li & Maiden, Sci. Rep. **8**, 2049 (2018). Under Creative Commons Attribution 4.0 International License.

3D chemical-state mapping

Combining X-ray spectroscopy (XANES) with 3D ptychography

Measurements with sampling the incident photon energy across an absorption edge

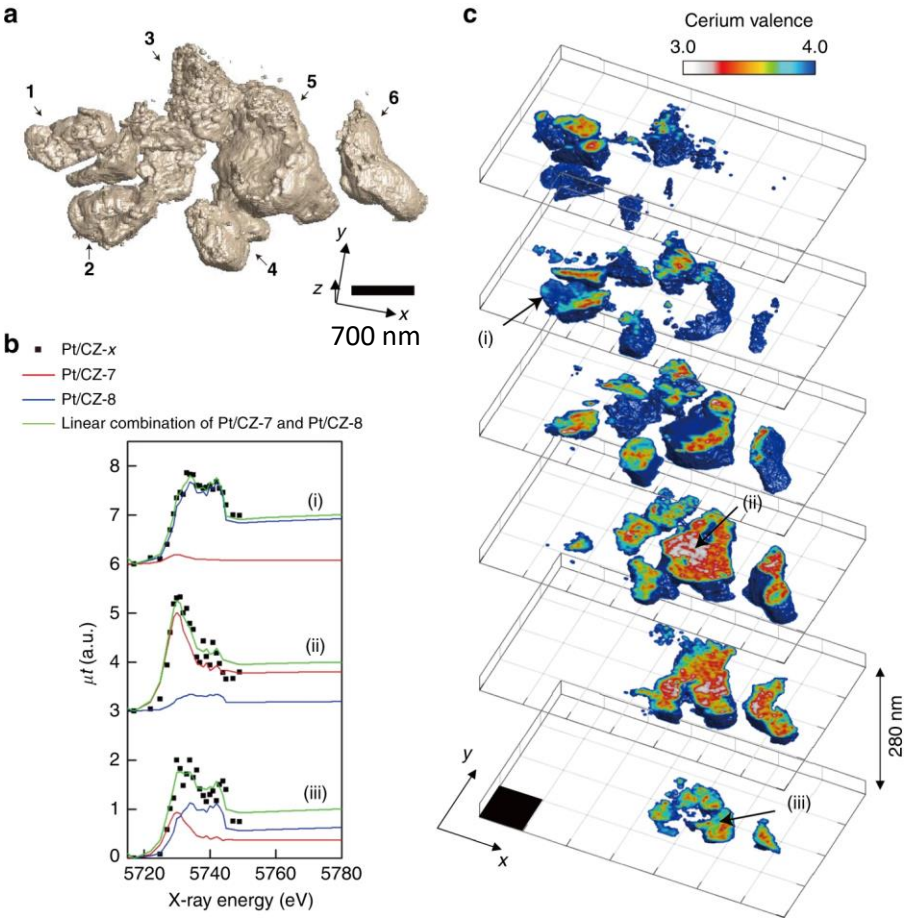
Additional to measuring the structure one obtains the valence or **chemical state – functional and structural imaging**

Pt/CZ-x solid solution particles during the oxygen storage process, measured at Spring-8

3D nanoscale imaging of Ce valence state. 28 energies (5.727 – 5.744 keV).

Three-way exhaust catalysis is a key reaction in automobiles

Challenge – How to scale up to larger samples and more X-ray energies?



Images from Hirose *et al.,* Commun. Chem **2**, 50 (2019). Under Creative Commons Attribution 4.0 International License.

Further reading

F. Pfeiffer, “X-ray ptychography,” Nature Photon. **12**, 9–17 (2018)
Review article
https://doi.org/10.1038/s41566-017-0072-5

C. Jacobsen, “X-ray Microscopy,” Cambridge University Press (2019)
Covers many concepts and techniques for X-ray microscopy in 2D and 3D
https://doi.org/10.1017/9781139924542

J. Rodenburg and A. Maiden “Ptychography” chapter in Springer Handbook of Microscopy pp 819-904 (2019)
https://doi.org/10.1007/978-3-030-00069-1_17

M. Guizar-Sicairos and P. Thibault, “Ptychography: A solution for the “phase problem” finds countless applications,” Phys. Today (2021)

IF YOU WANT TO KNOW MORE

Download slides

Publications

Webinar: Fast-Scanning Ptychography

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and manuel.guizar-sicairos@psi.ch

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For more webinars, please visit our dedicated webpage

Thank you and see you soon!

