PAUL SCHERRER INSTITUT

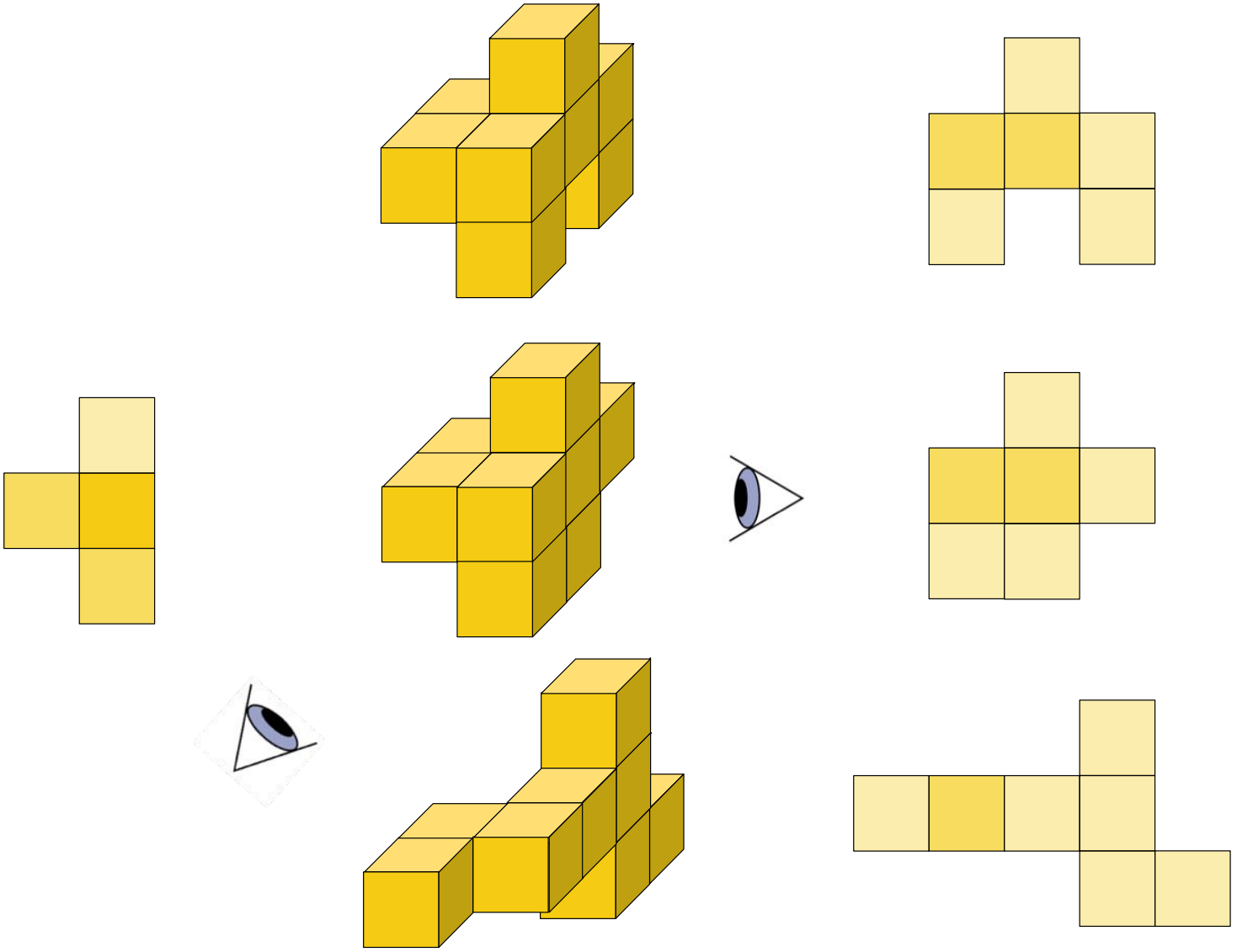
PSI

Rasmus Ischebeck

Imaging with Synchrotron Radiation: Tomography and Ptychography

Joint Universities Accelerator School

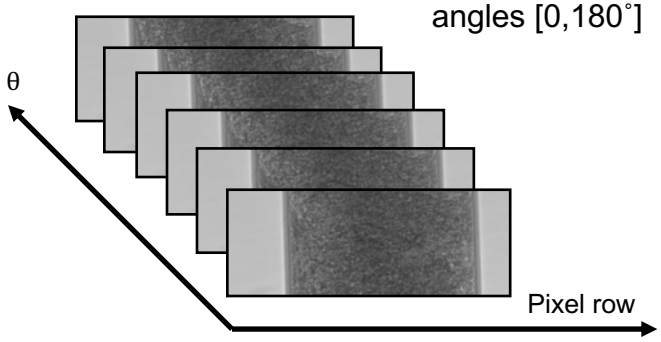
Micro-Tomography



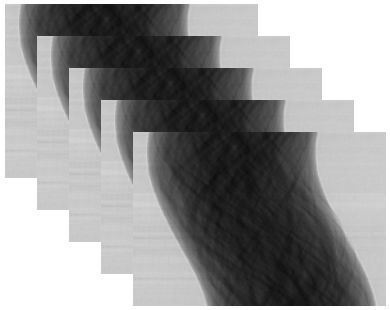
Microtomography principle

Data acquisition

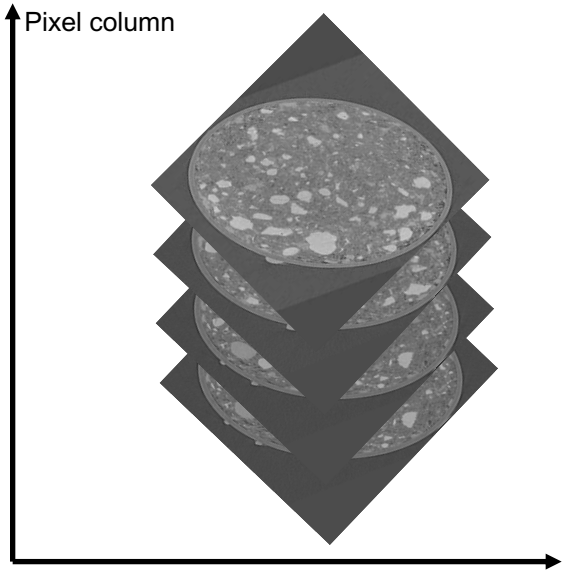
Raw projections at different rotation angles [0,180˚]

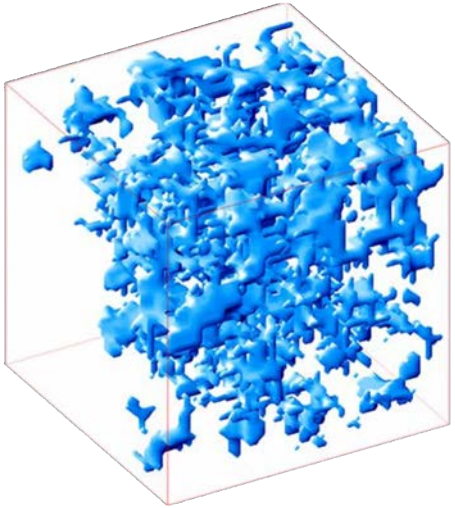


Rearrange data into sinograms

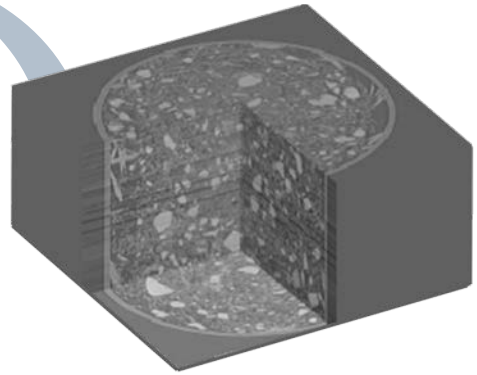


Computer Reconstruction (Filtered back-projection)



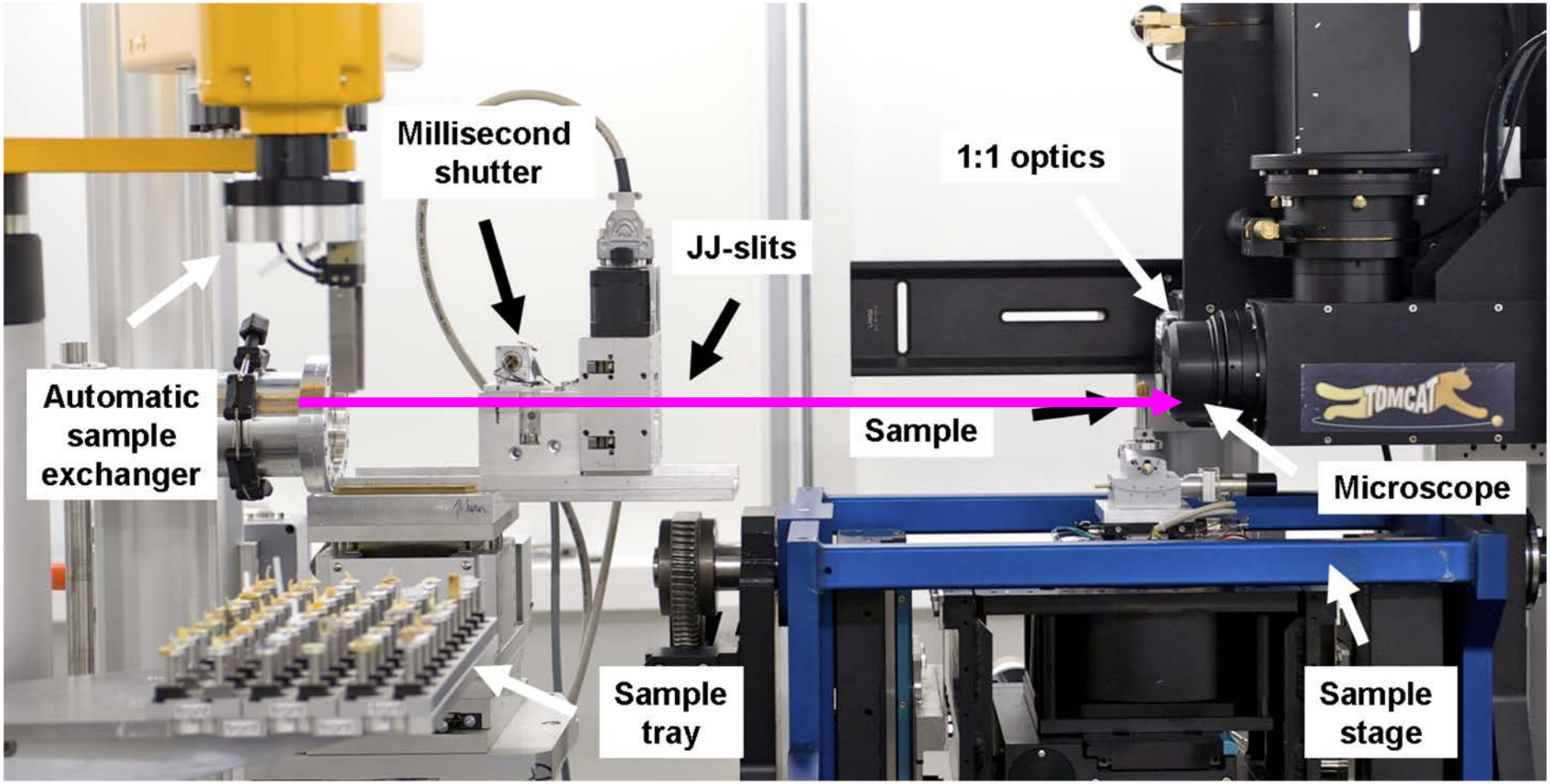


Further processing:
- **3D visualization**
- **quantitative analysis**



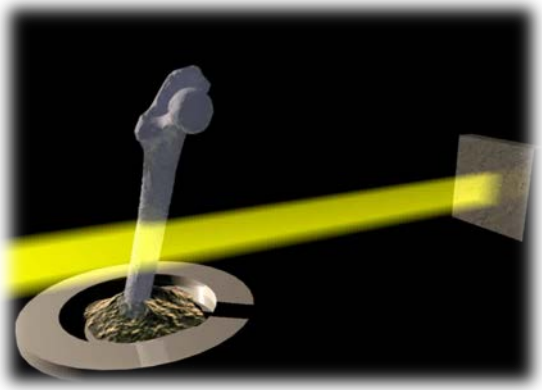
State-of-the-art SRXTM (1-50 um)

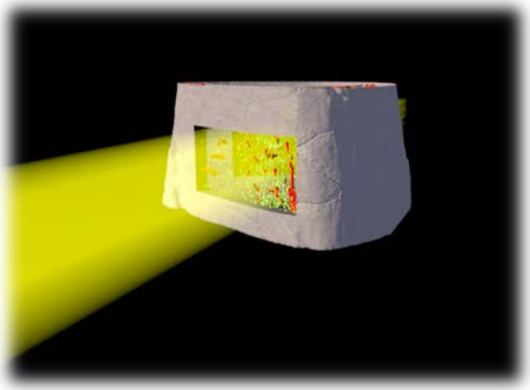
State-of-the-art SRXTM (1-50 um)

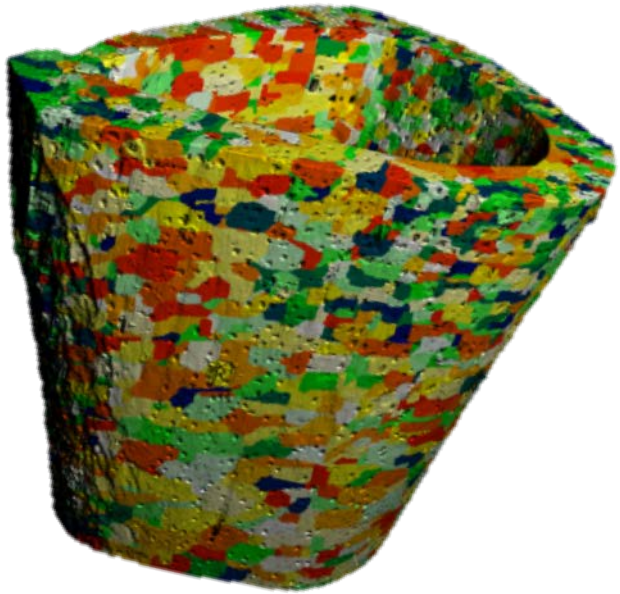


1 micron resolution routinely achieved at 10% MTF

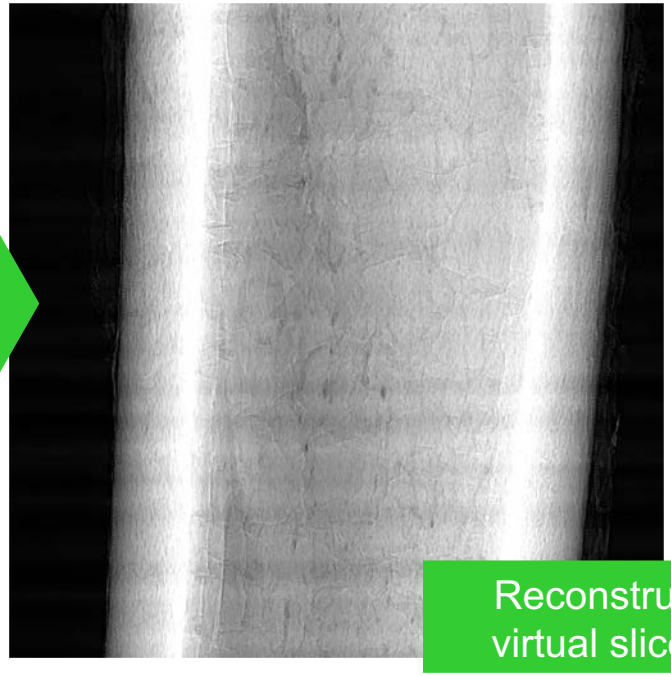
Gathering complex information



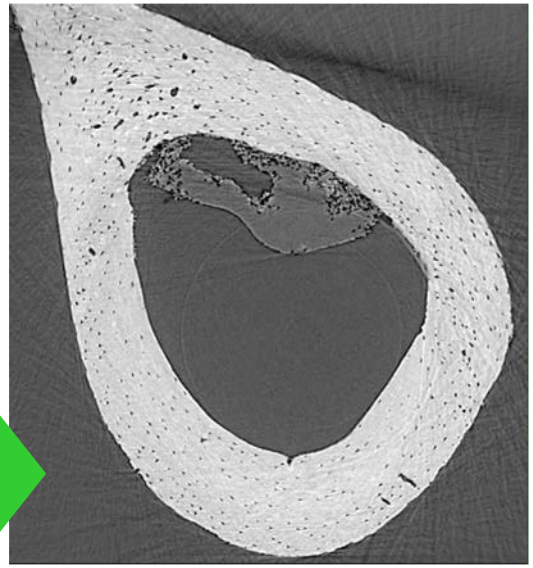




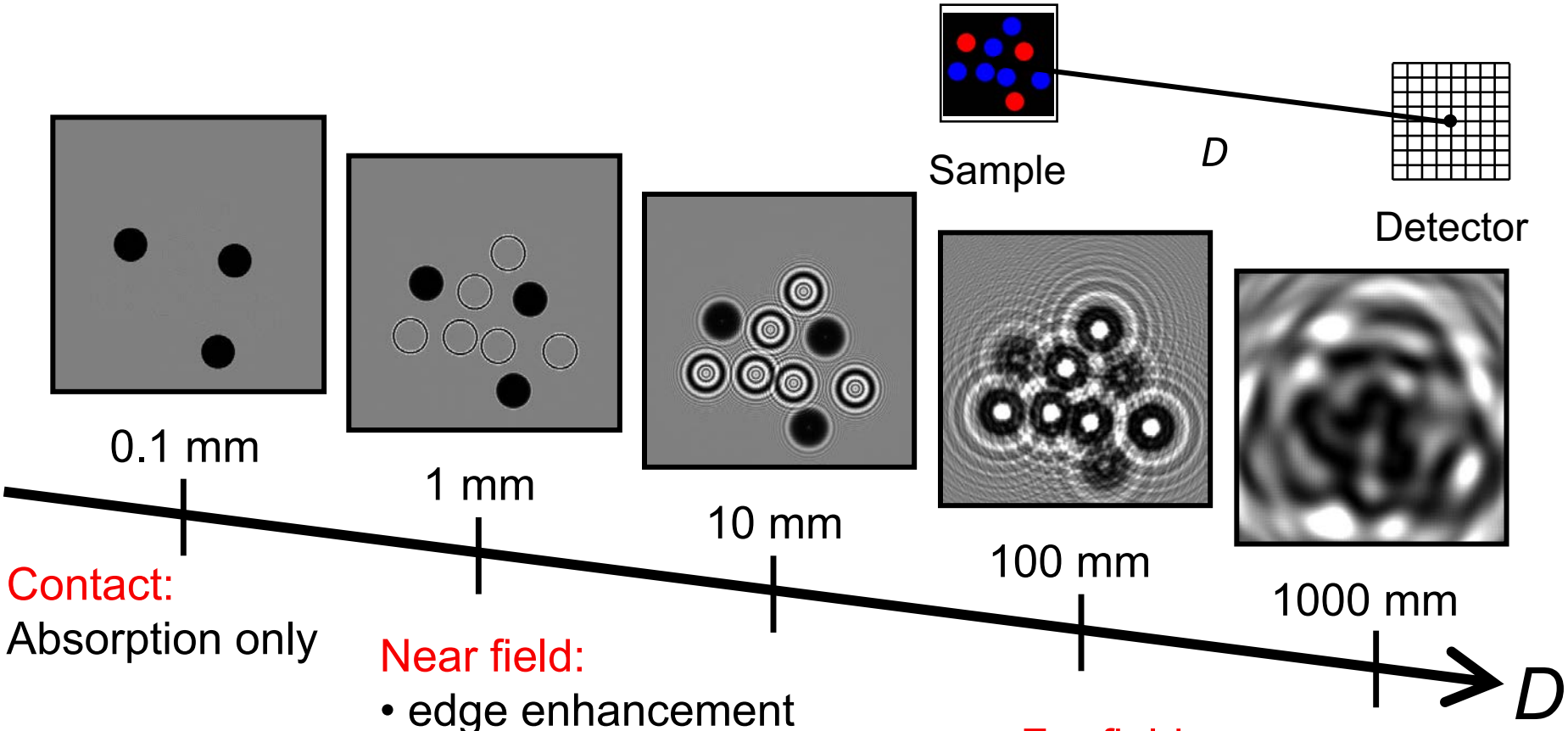
Measure
X-ray projections



Reconstruct
virtual slices



Propagation-based image formation



Contact:
Absorption only

Near field:
- edge enhancement
- phase objects detectable

SINGLE STEP PC-IMAGING (e.g. Paganin)
HOLOTOMOGRAPHY

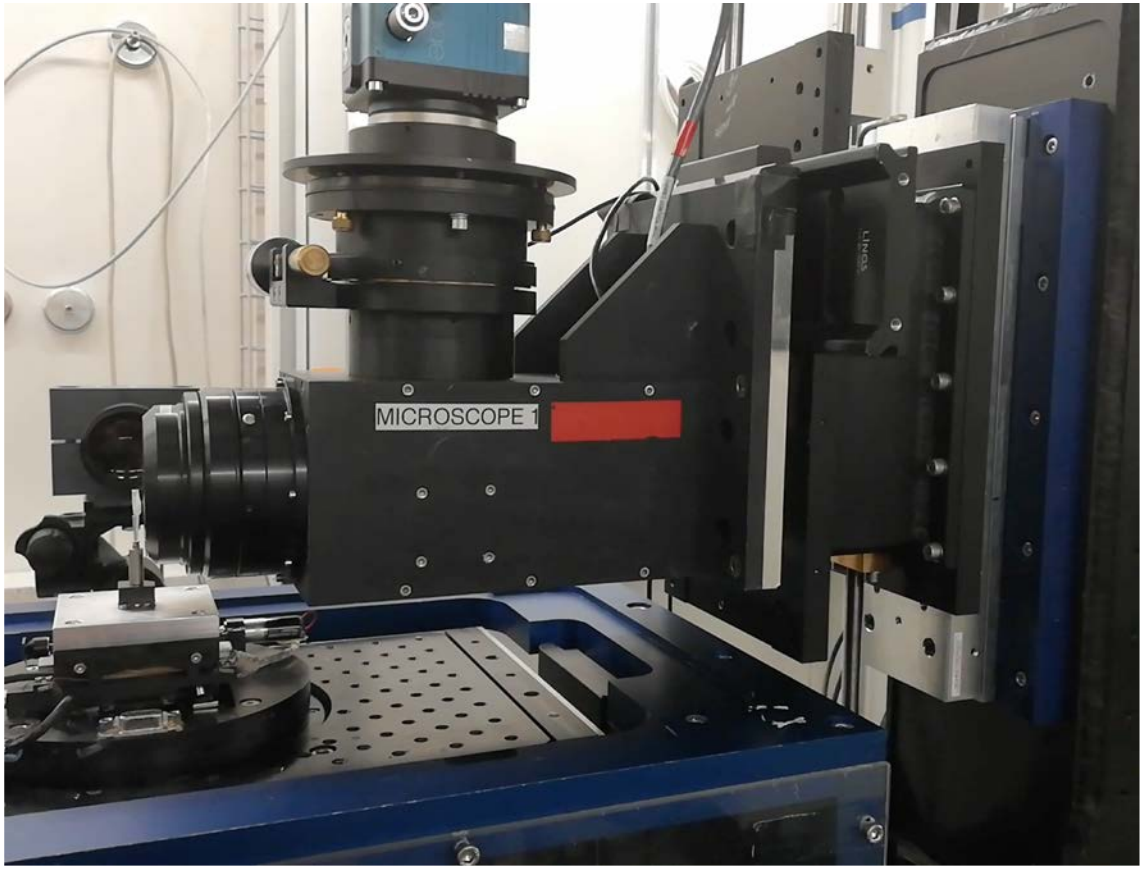
Far field:
- Coherent Diffraction Img.

Ptychography…

Cartoon courtesy: T. Weitkamp, SOLEIL

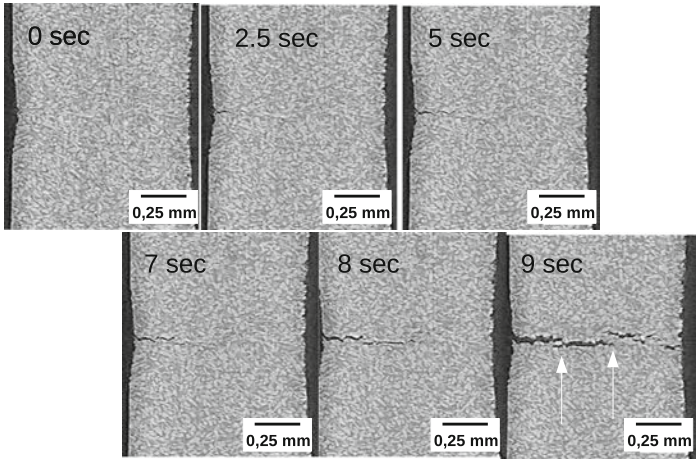
The effect of propagation distance

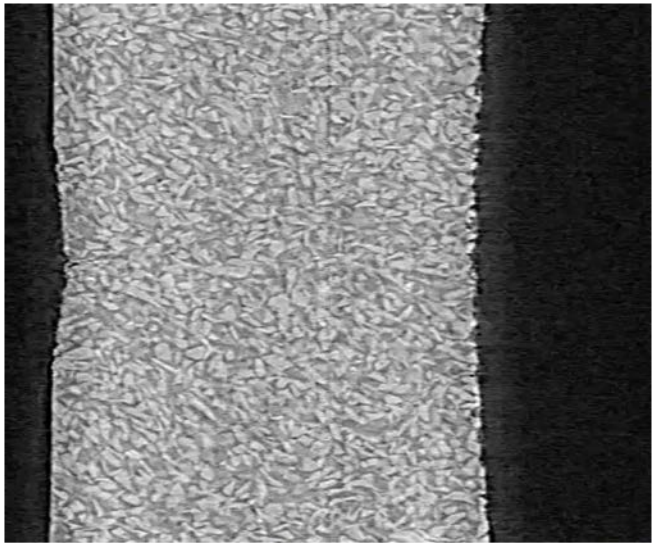
- Continuous data acquisition during camera motion
- Flat field corrected, shaking reduced



Sample courtesy of E. Cörek, J. Huwyler, University of Basel

In-situ 20 Hz tomographic imaging





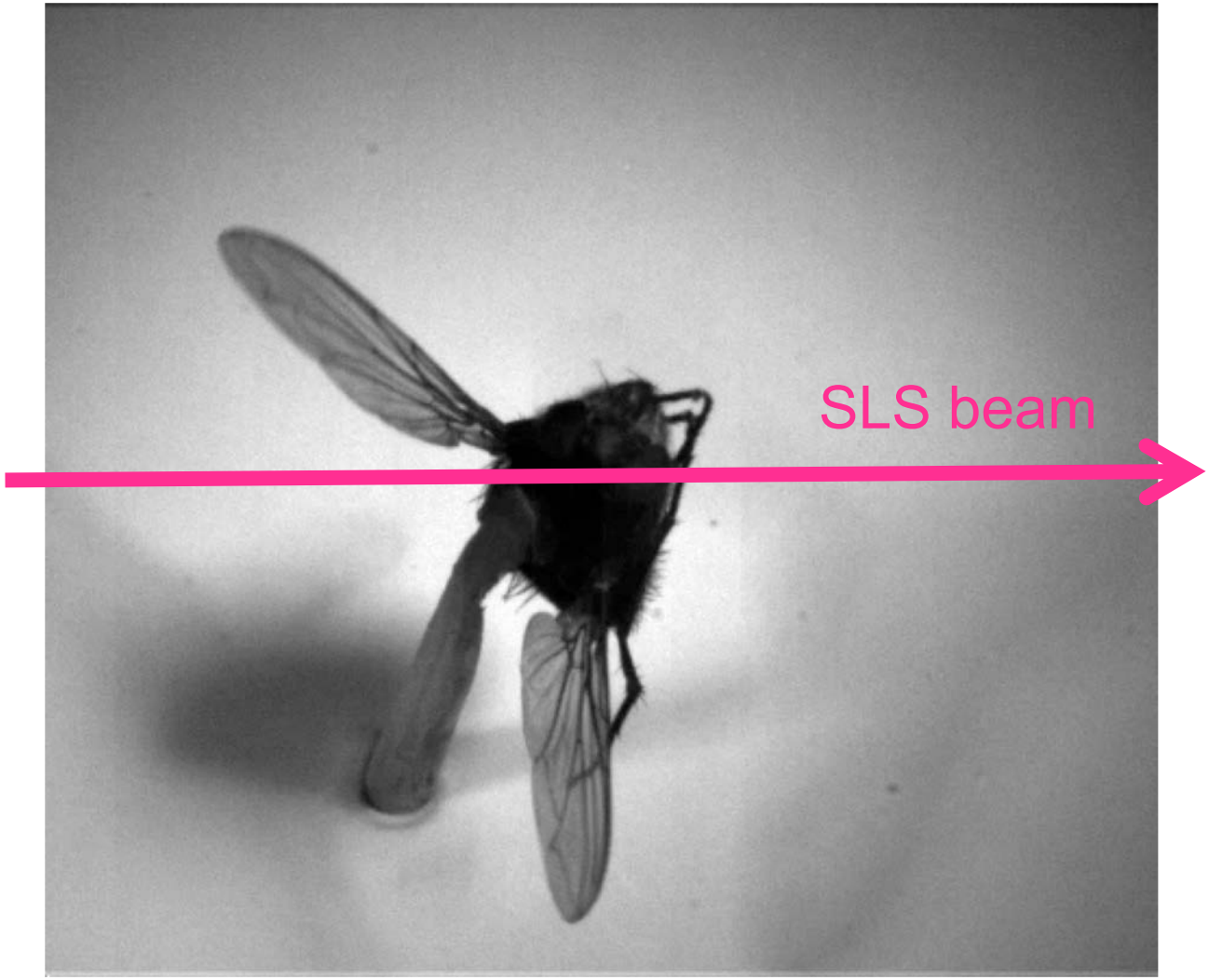
- Crack propagation dynamics under tensile load
- 20 (!) 3D volumes per second

Movie playing in real time (9 seconds, 180 frames)

Maire et. al., Int J Fract (2016)

How does a fly really fly?

Wings beat at 150 Hz !!



2500 X-ray images per second…

Muscles and tracheal network *during* flight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Surreal X-ray movie reveals how a fly beats its wings

21:00 25 March 2014 by Jacob Aron

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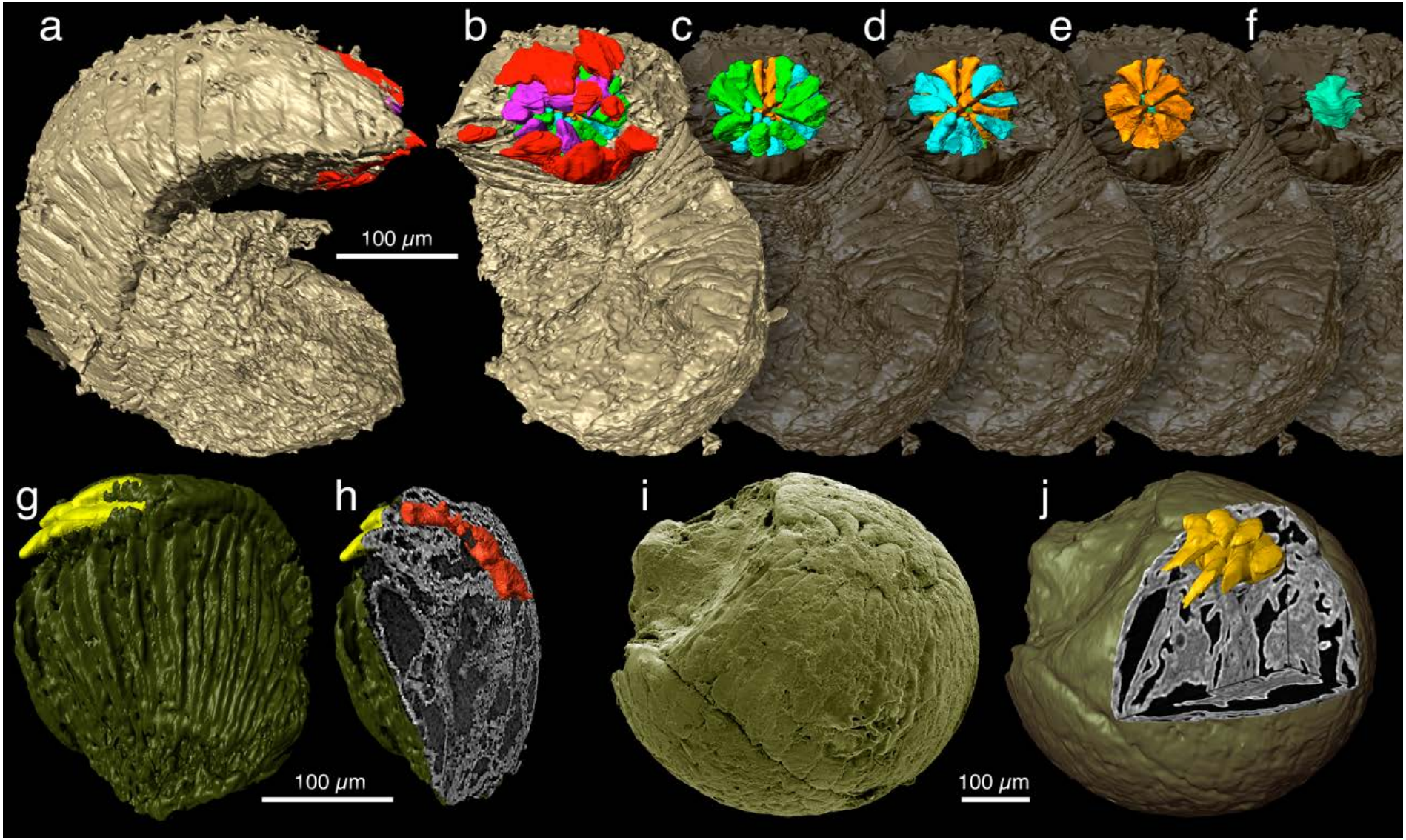
Scientists film inside a flying insect

By Victoria Gill
Science reporter, BBC News

26 March 2014 | Science & Environment

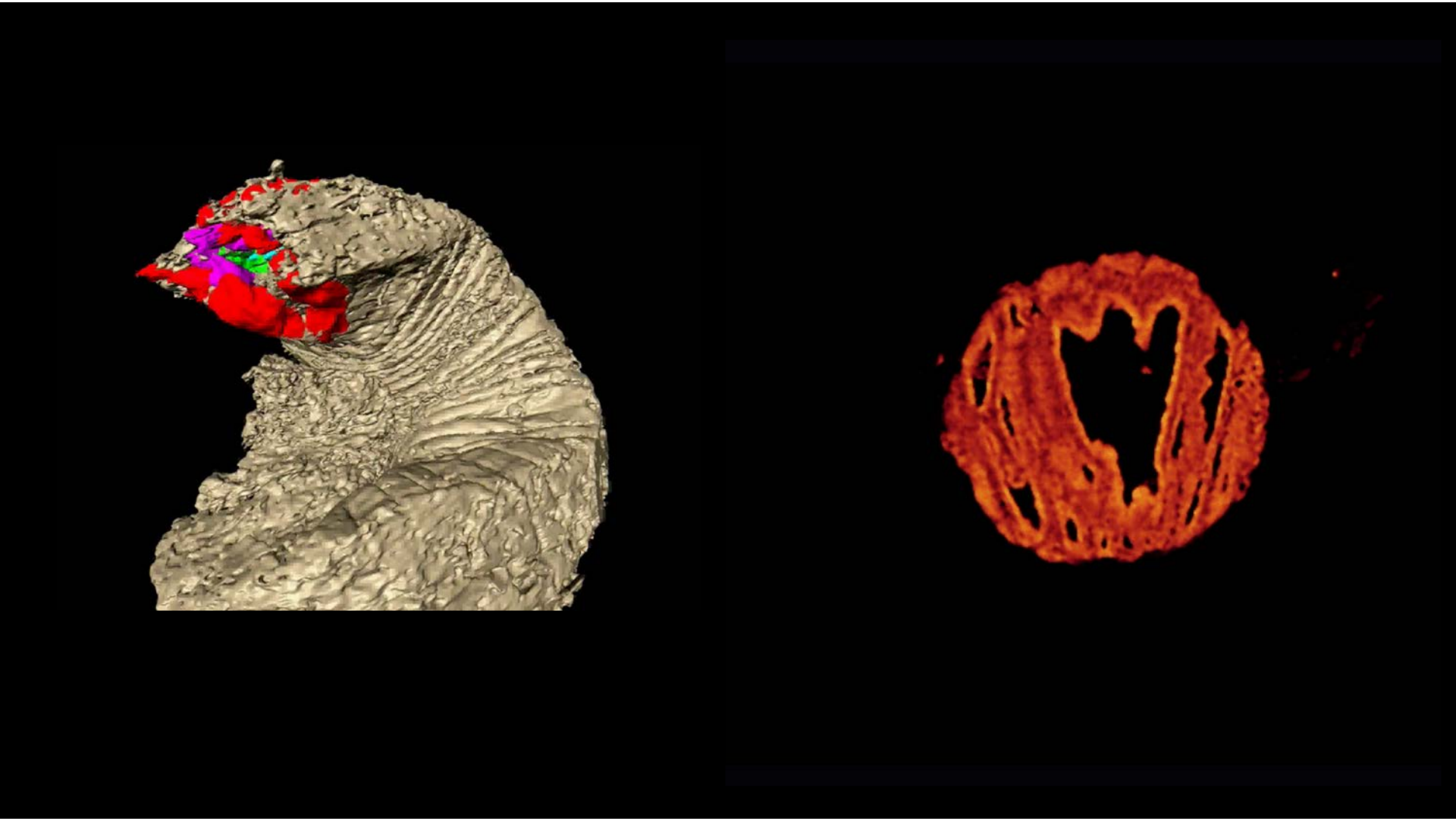
Walker et al., PloS Biology (2014); Mokso et al., Sci Rep (2015)

Complex image analysis and data interpretation



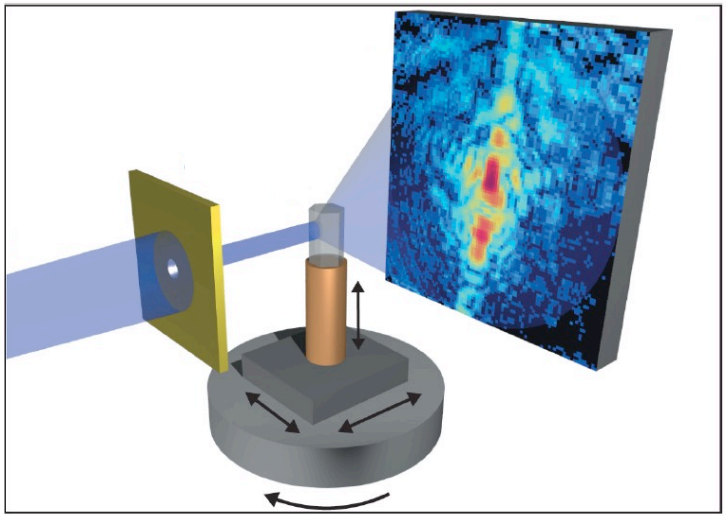
Donoghue et al (2006) Nature 442:680-3

Markuelia, the first "predator" on earth

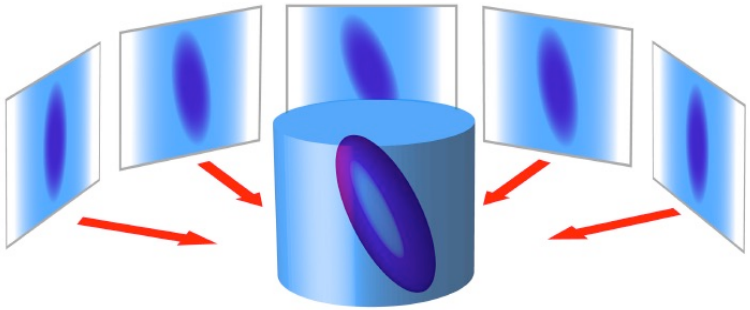


Donoghue et al (2006) Nature 442:680-3

Ptychographic X-ray tomography

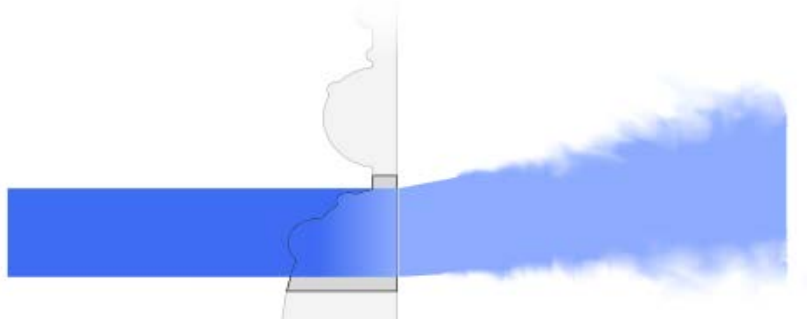


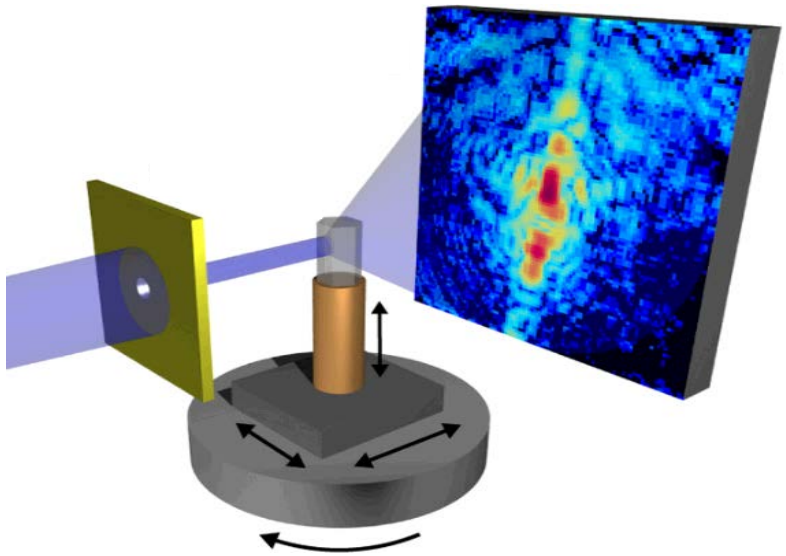
Access 3D information via computed tomography.
→ obtain many projections of the sample at different angle of incidence.



NATURE 467, 436 (2010)

Multi keV X-ray ptychography





+ Lens-less → high resolution
+ multi-keV X-rays → thick samples
  → 3D is important
+ Phase and absorption contrast
+ Quantitative

- Data analysis is involved
- Resolution depends on sample positioning accuracy → involved instrumentation

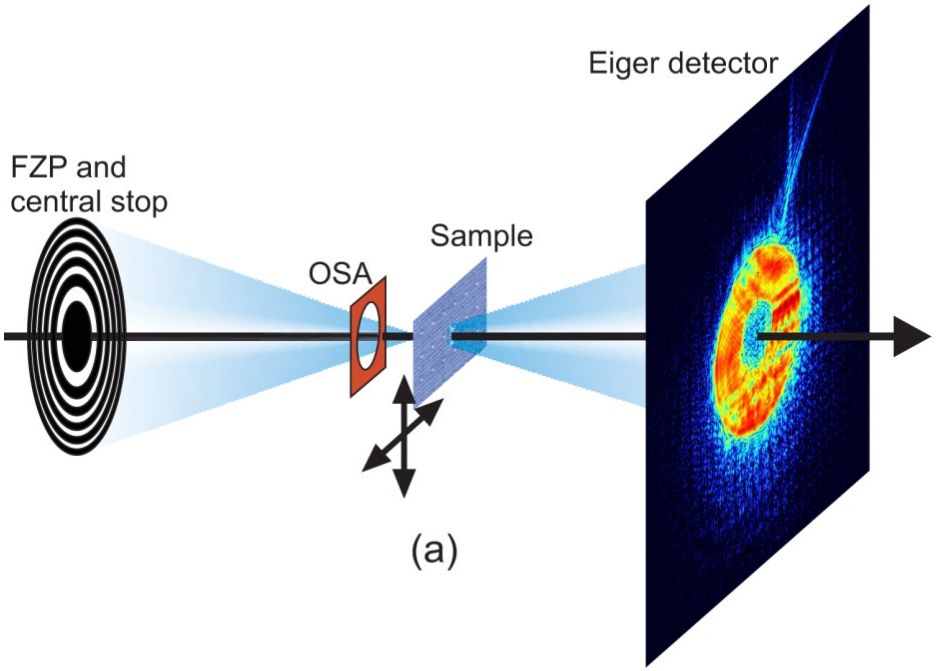
Chip imaging in 2D – The Eiger self portrait

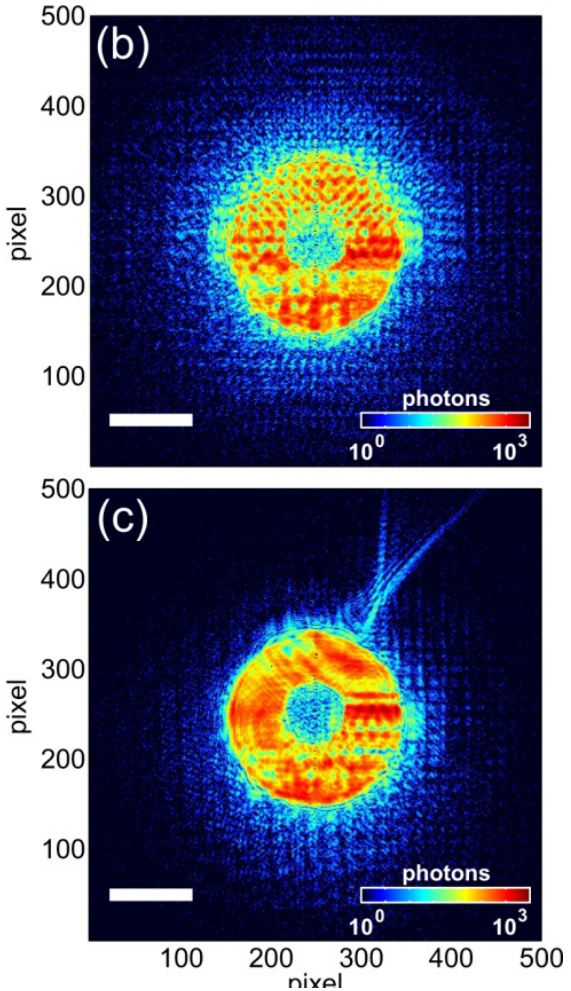
Sample 5 mm downstream of focus

Beam at sample ~ 10 microns

Scanning average step 3.5 microns

Eiger ASIC as sample and Eiger as detector



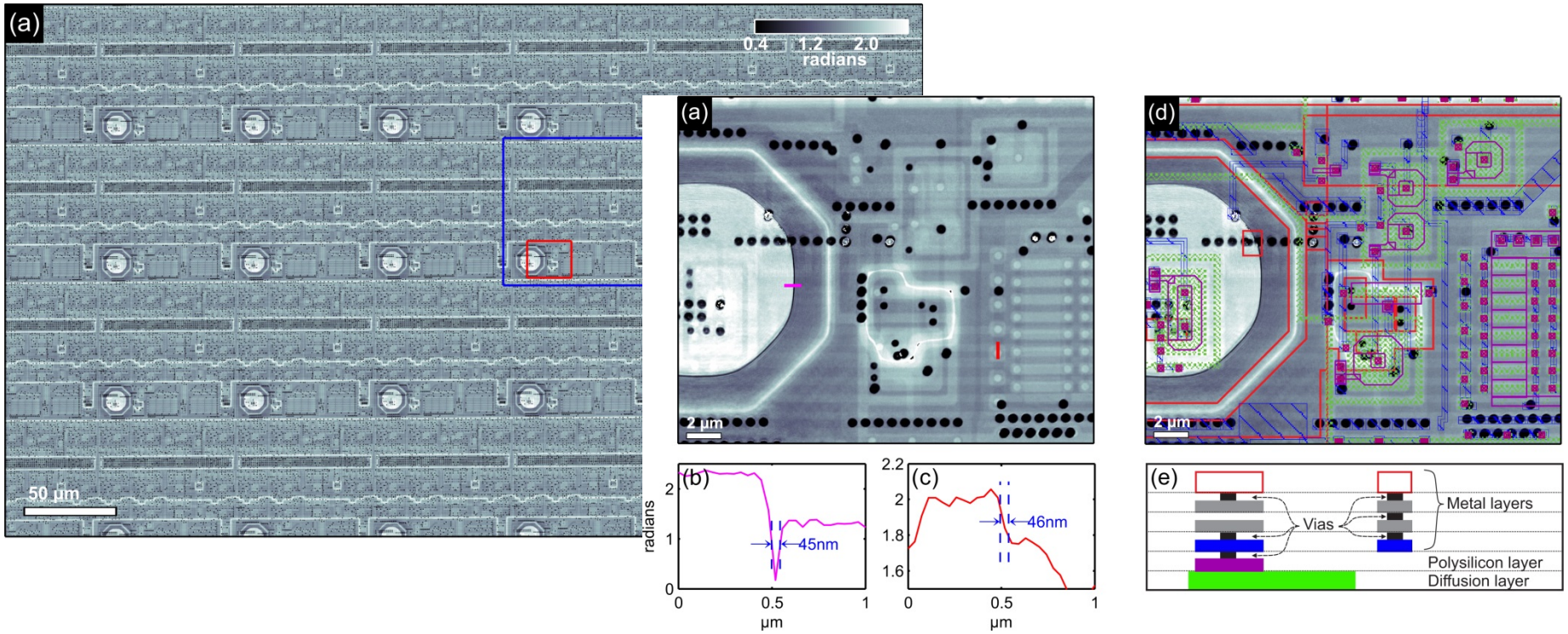


M. Guizar-Sicairos *et al.*, Opt. Express **22**, 14859 (2014)

Imaging throughput – The Eiger self portrait

98.4 Mpixel (13,028 x 7,556)

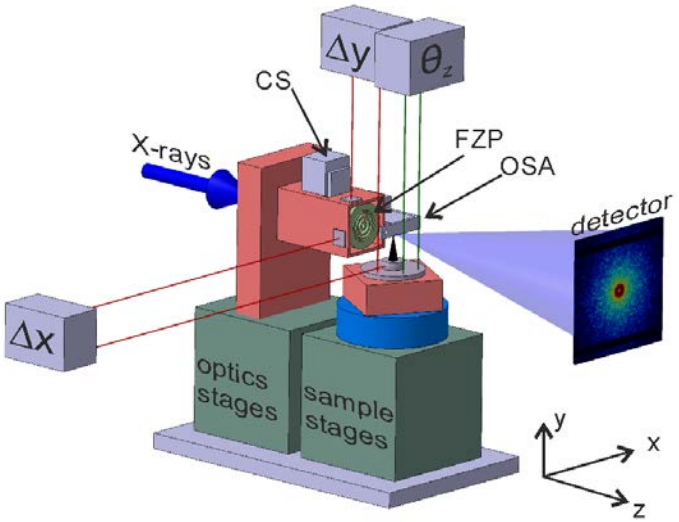
Resolution 41 nm, 38.4 nm pixel



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

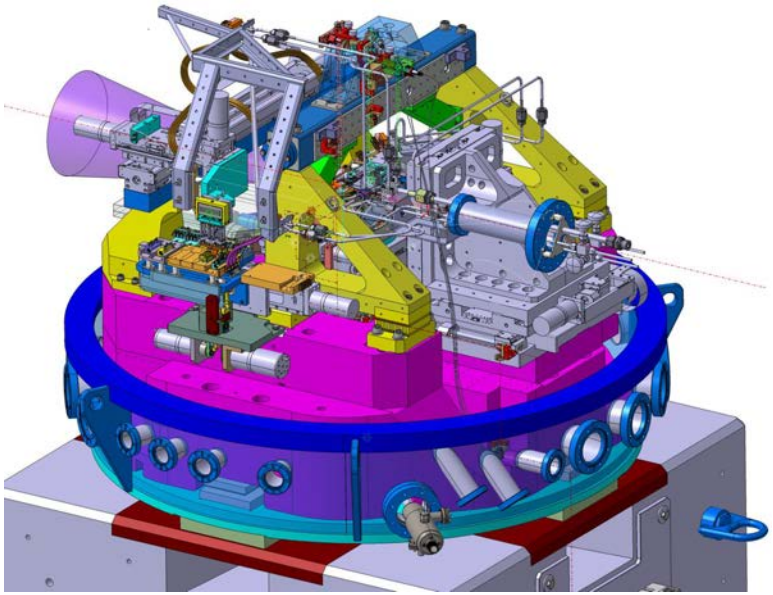
Two instruments with different sample environements

flOMNI (flexible tOMography Nano Imaging)
+ nano-positioning, tomography with interferometer
+ room-temperature
+ atmospheric pressure
+ test bench



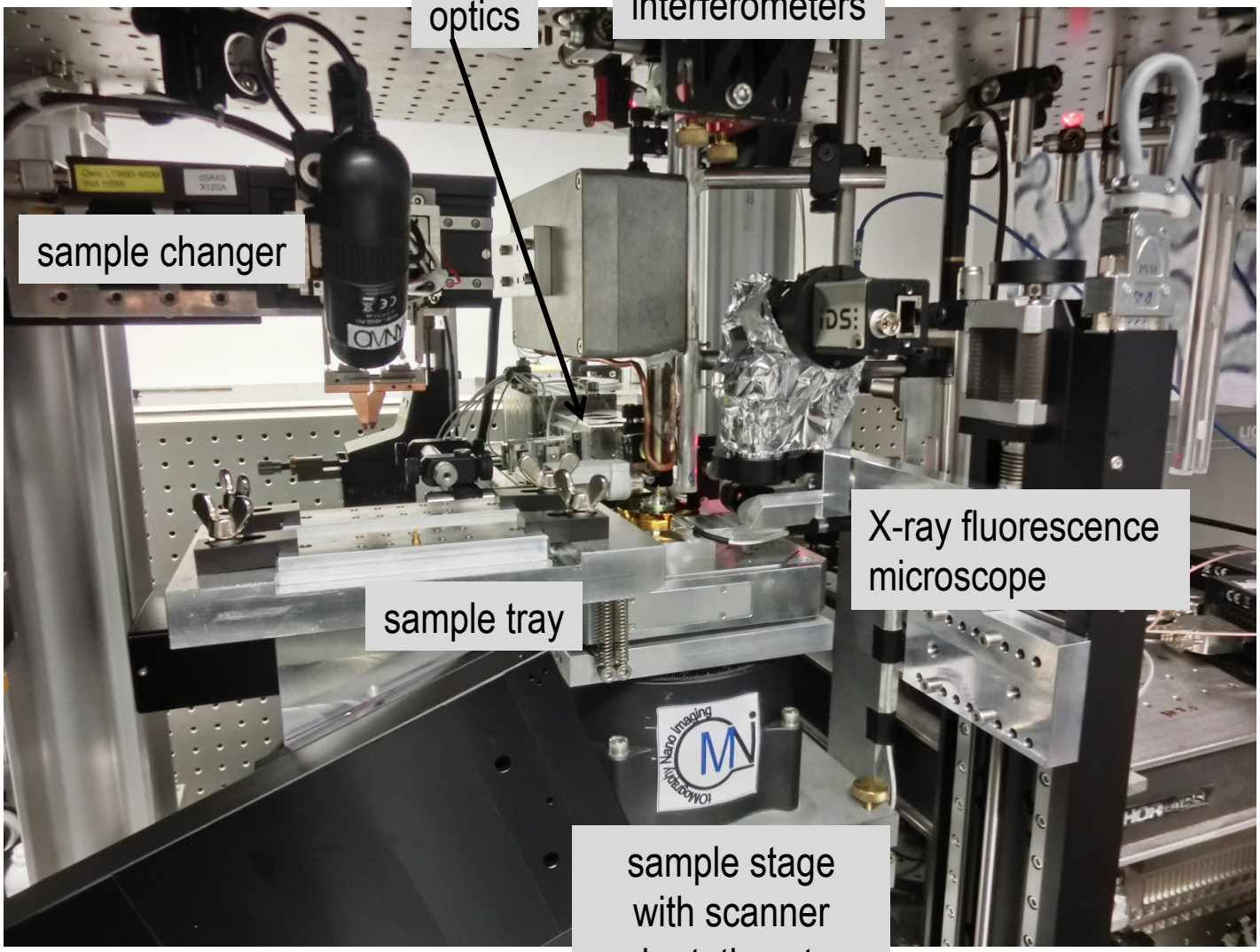
M. Holler, et al., Rev. Sci. Instrum. 83, 073703 (2012)
M. Holler and J. Raabe, Opt. Eng. 54(5) 054101 (2015)
Pat. publication no. WO 2012079875 A1

OMNY (tOMography Nano crYo)
+ optimized mechanical structures
+ cryogenic environment and UHV



M. Holler et al., Rev. Sci. Instrum. 89, 043706 (2018)

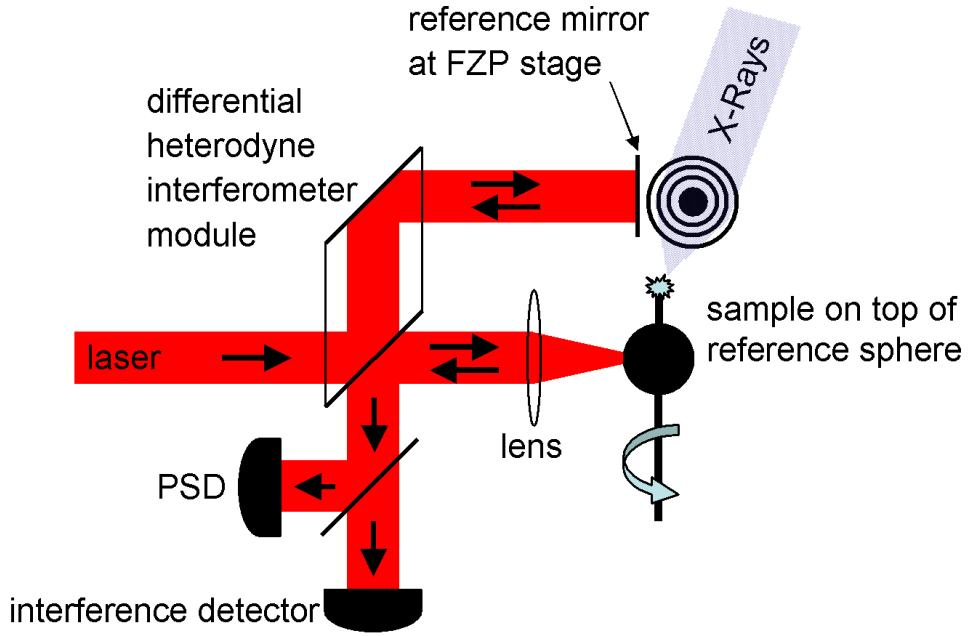
flOMNI (flexible tOMography Nano Imaging)

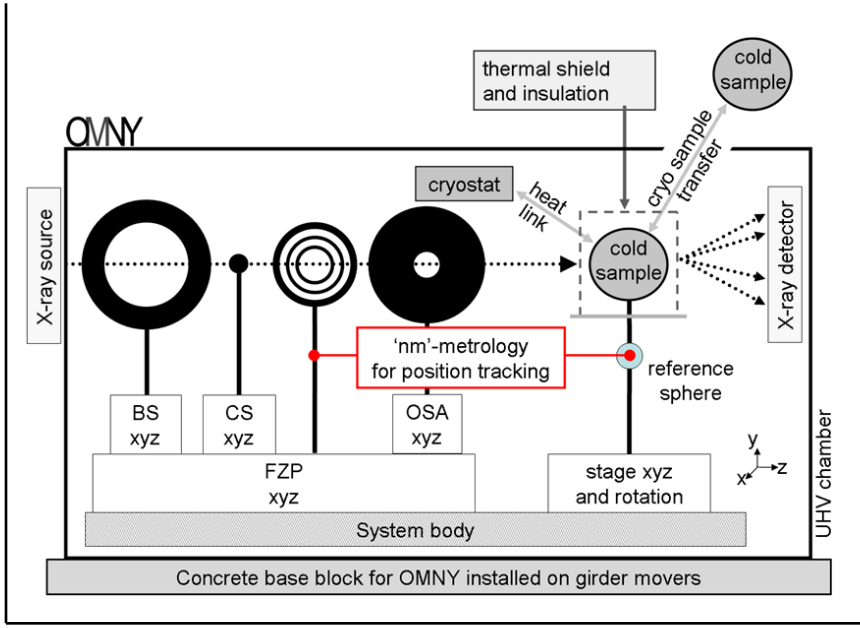


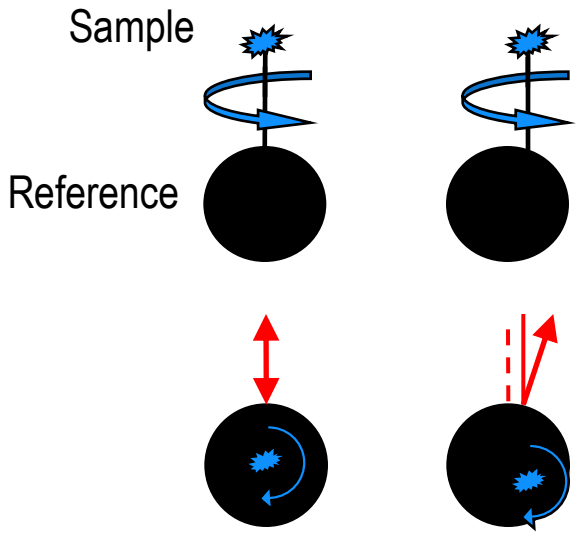
Metrology for OMNY: Tracking interferometer

Position sensitive detector measures sphere motion perpendicular to laser beam propagation.

Closed loop: interferometer tracks the reference sphere and keeps pointing at its center

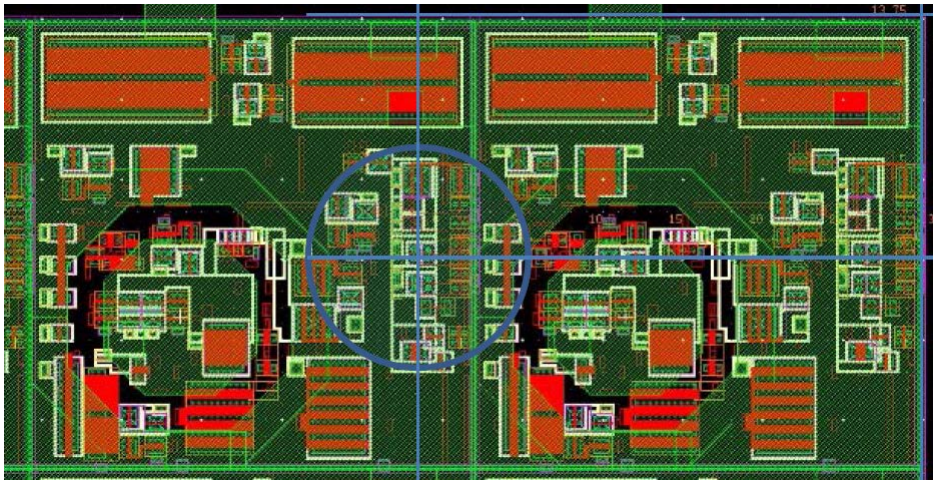




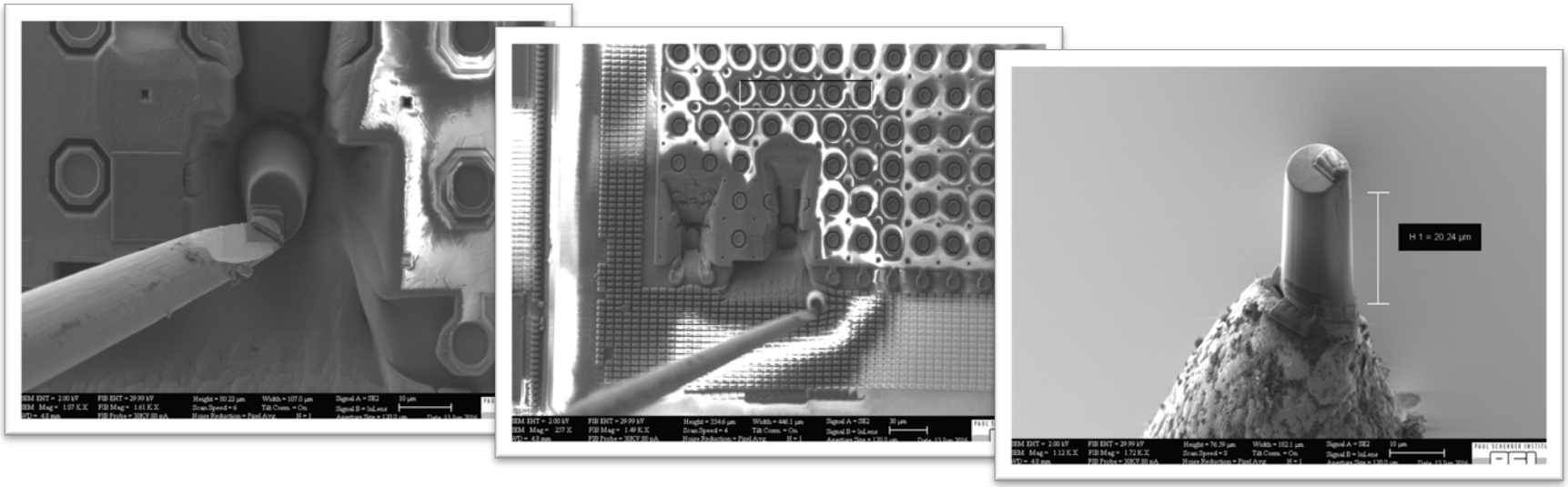


Compensation of mechanical tracking error motion needed – details in
M. Holler and J. Raabe, Opt. Eng. 54(5) 054101 (2015)
Pat. publication no. WO 2012079875 A1

IC imaging – typical sample preparation



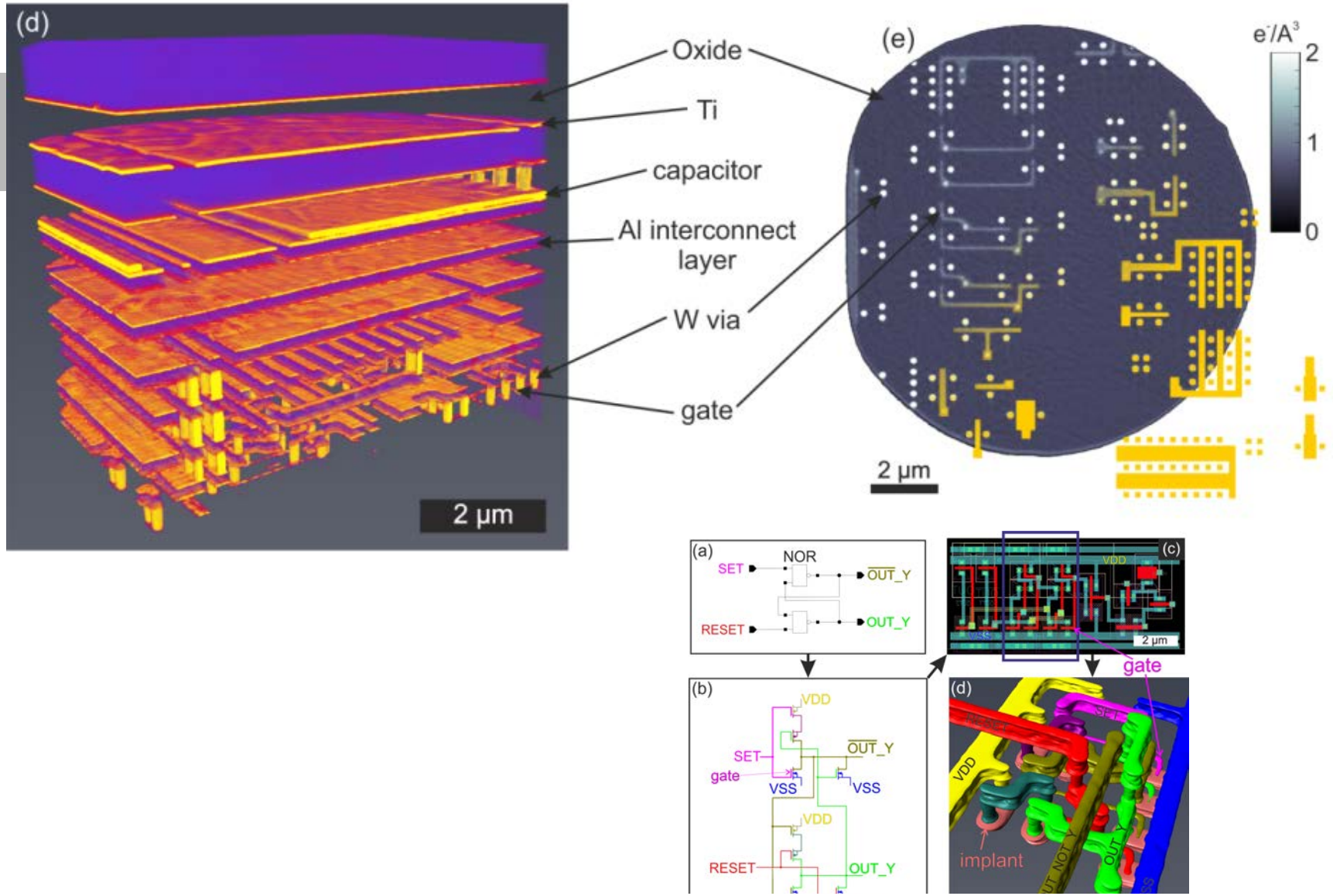
UMC 110 nm technology
hybrid silicon pixel detector
25 µm pixel pitch



- select region in sample preparation step
- volume limited by thickness, limited by transmission

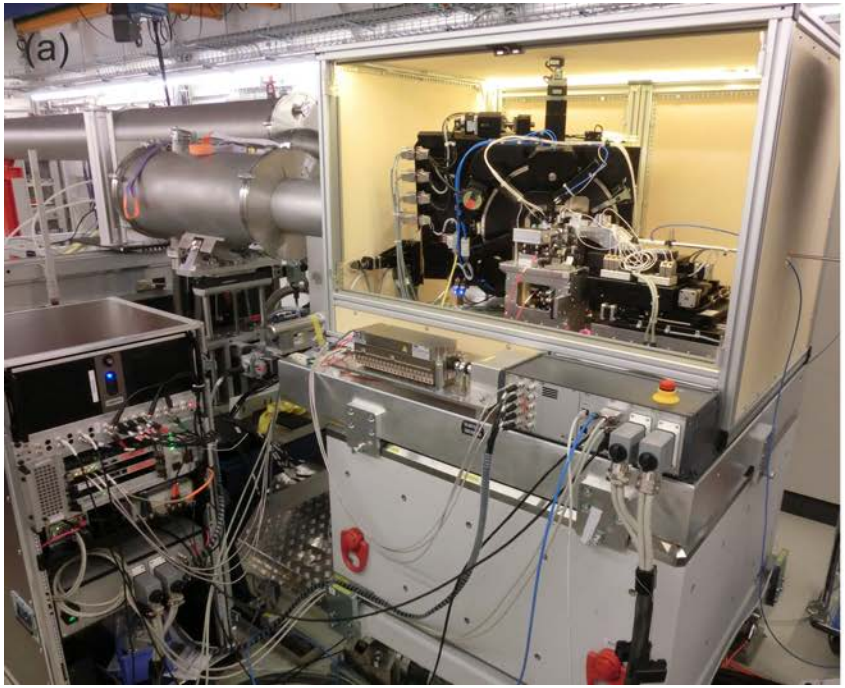
Holler *et al.,* Nature 543, 402–406 (16 March 2017)

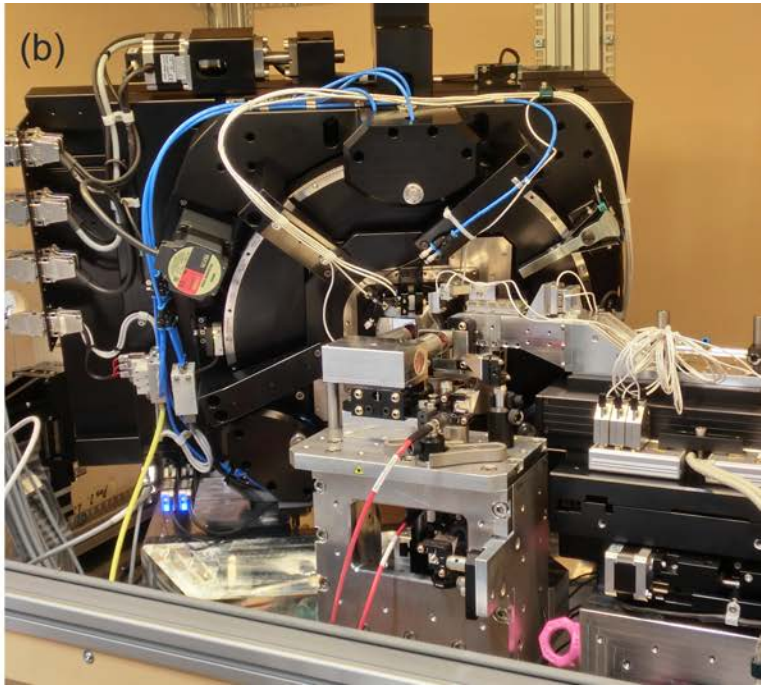
Detector ASIC - tomography result



Holler *et al.,* Nature 543, 402–406 (16 March 2017)

LamNI installed at the cSAXS beamline

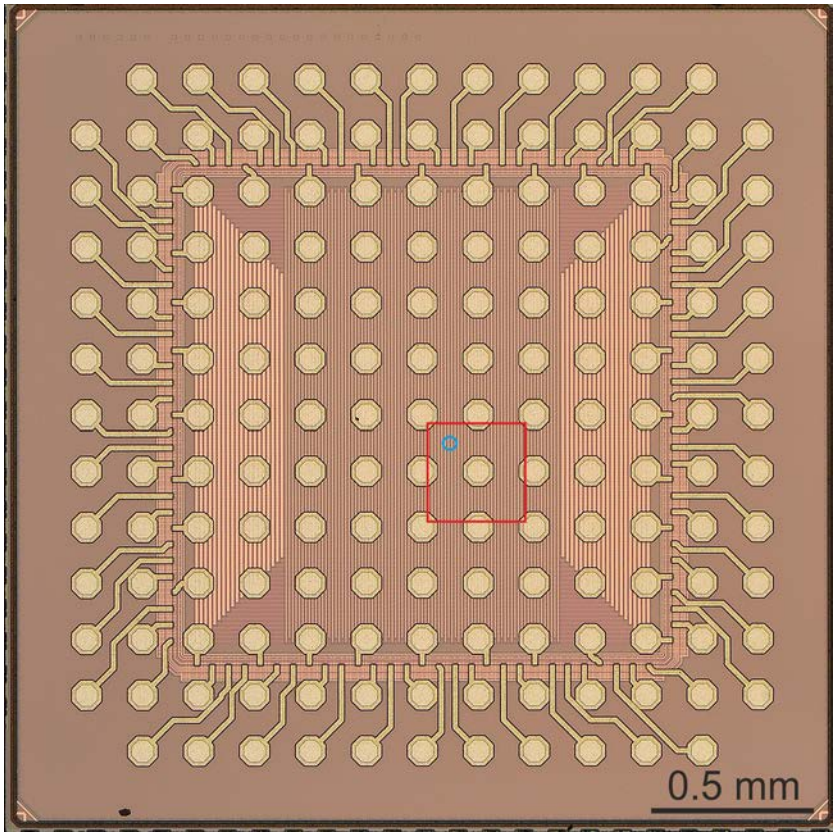




M. Holler et al., Nature Electronics 2, 464 (2019)
https://rdcu.be/bTudW

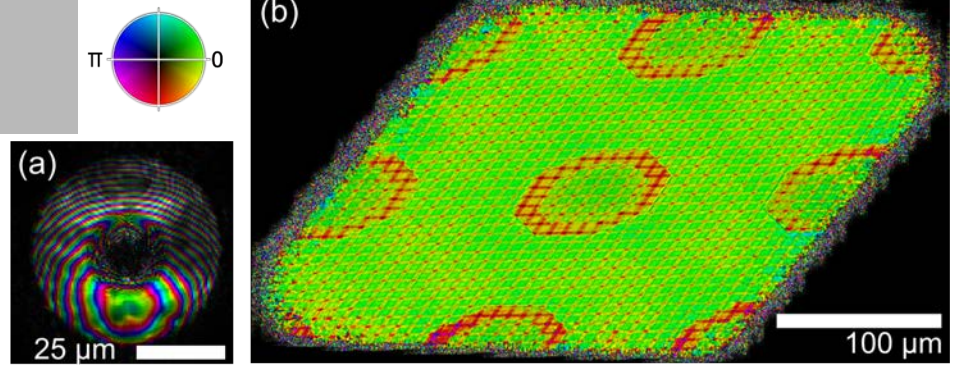
LamNI – measurement of an IC

Photograph of IC measured
16 nm FinFET technology
mechanically polished an entire chip of 2.5x2.5 mm^2 to a substrate thickness of about 20 µm
Mounted in LamNI and measured at 6.2 keV two laminograms with an Eiger detector module in air at 2.3 m distance.

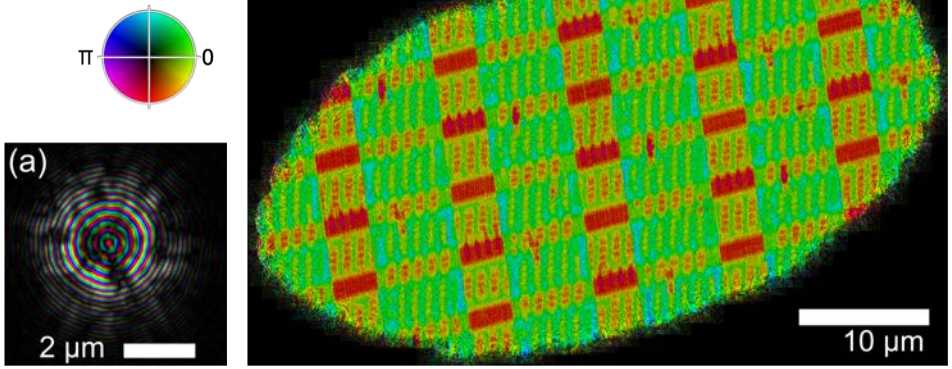


Holler *et al., in review at* Nature

LamNI – measurement of an IC



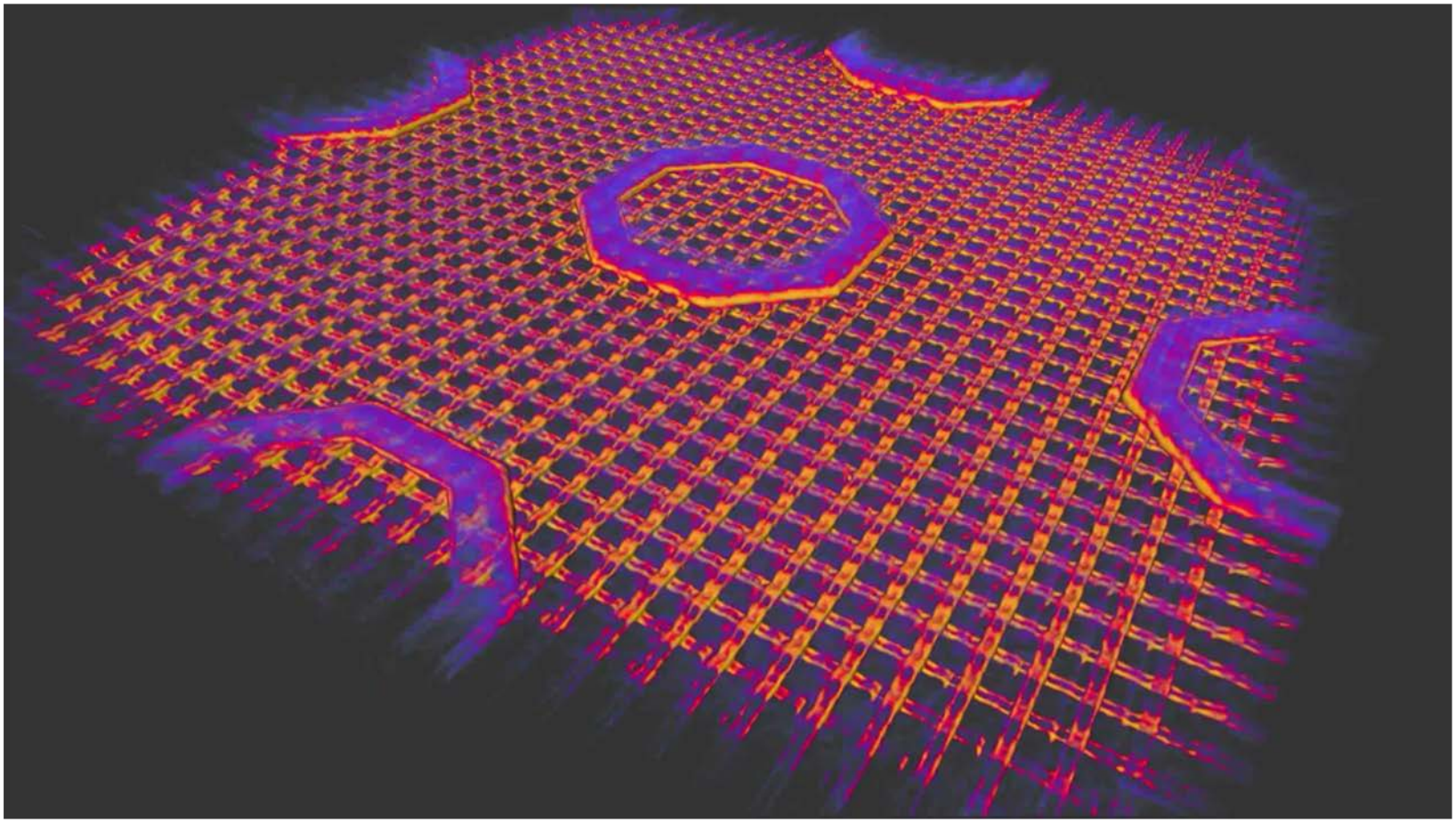
Low resolution overview scan
near-field ptychography,
300x300 µm^2 (square in sample plane)
by stitching 25 regions 70x70 µm^2
step size of 10 µm
14 sec per projection including all overhead
300 projections



High resolution ptychography scan
circular in sample plane, diameter 40 µm^2
485 scan points, 0.7 µm, 0.1 s
76 s per projection incl. all overhead
2872 projections

M. Holler et al., Nature Electronics 2, 464 (2019)
https://rdcu.be/bTudW

LamNI – measurement of an IC – 3D rendering



high-resolution voxel size was 13.0 nm and that volume covers 3800x3800x600 elements

M. Holler et al., Nature Electronics 2, 464 (2019)
https://youtu.be/GvyTiK9CNO0

Questions?