Imaging of Domain Structures by Coherent X-ray Diffraction

Ian Robinson — London Centre for Nanotechnology

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Frontiers in Optics

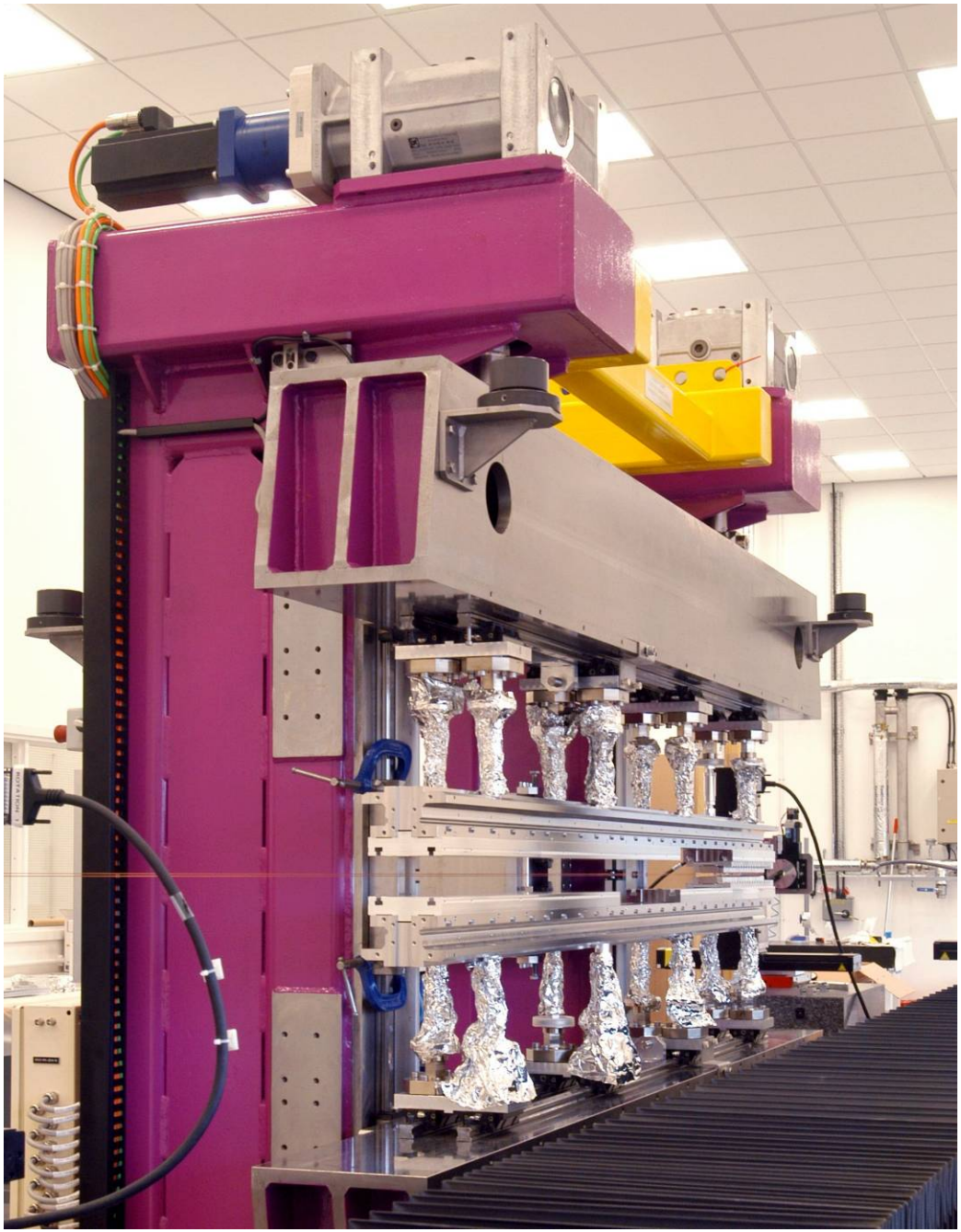
San Jose, CA

October 2009

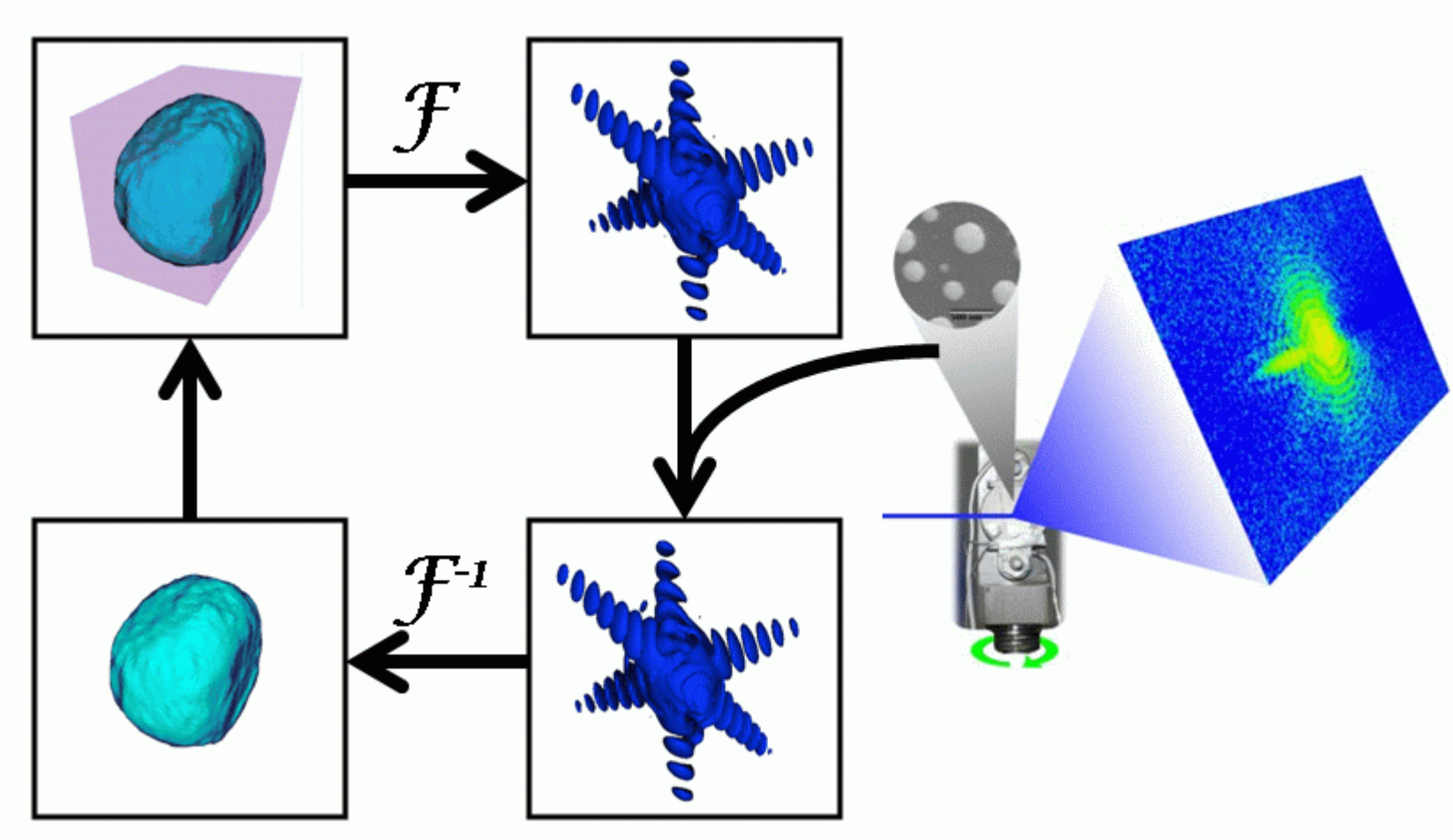
Outline

- Coherent X-ray Diffraction
- Domain speckle patterns
- Ptychography
- Phase-plate approach
- Phase domains in collagen
- Preparations for LCLS

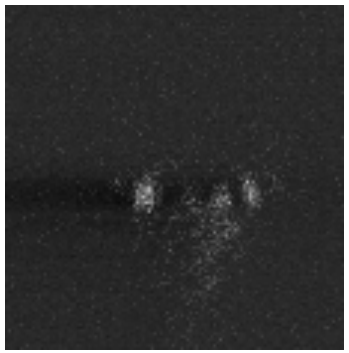
Diamond in-vacuum X-ray Undulator

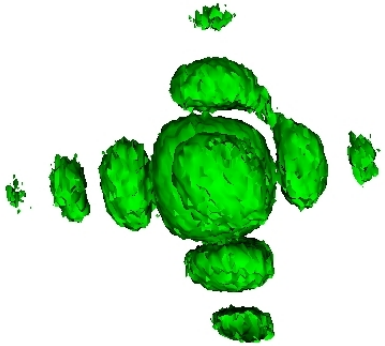


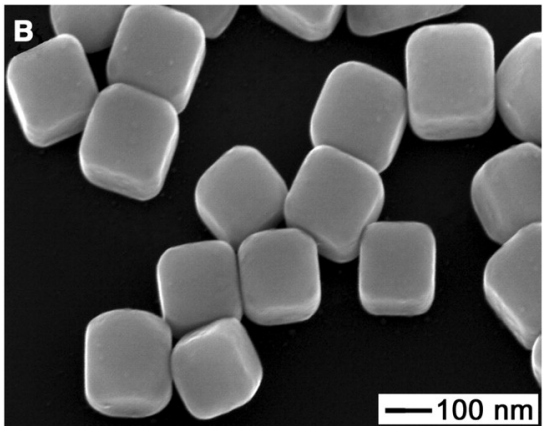
Generic "Error Reduction" method

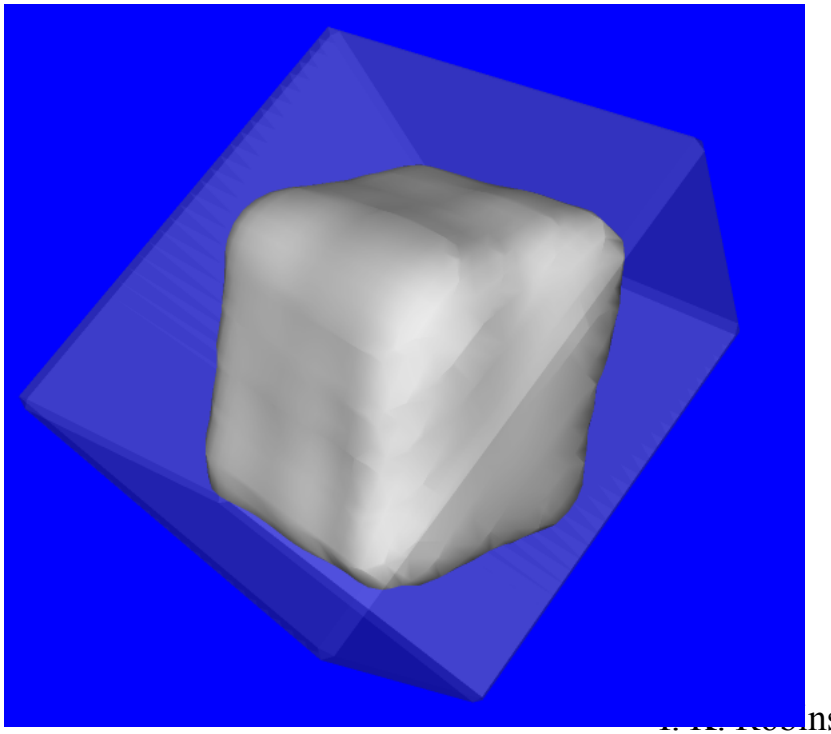


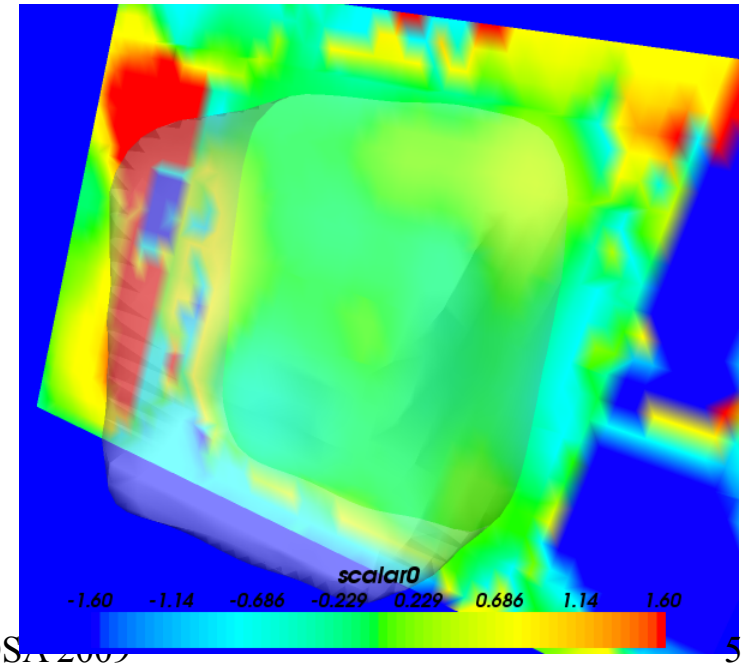
J. R. Fienup Appl. Opt. 21 2758 (1982)
R. W. Gerchberg and W. O. Saxton Optik 35 237 (1972)





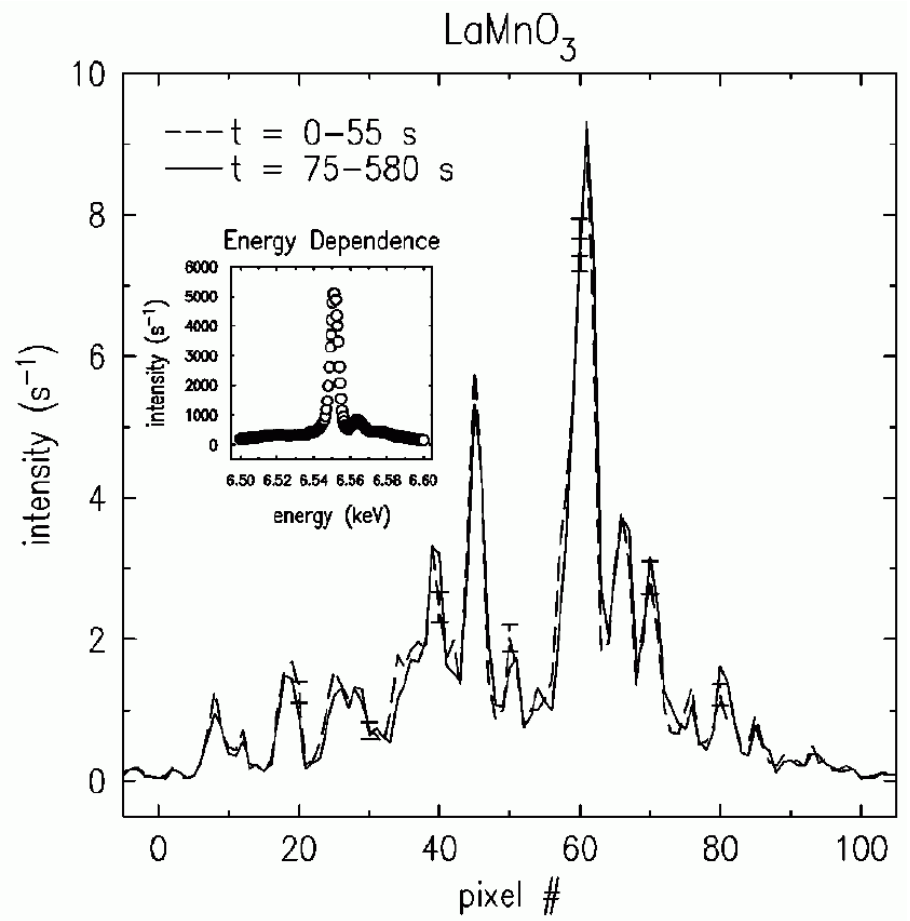

B
100 nm

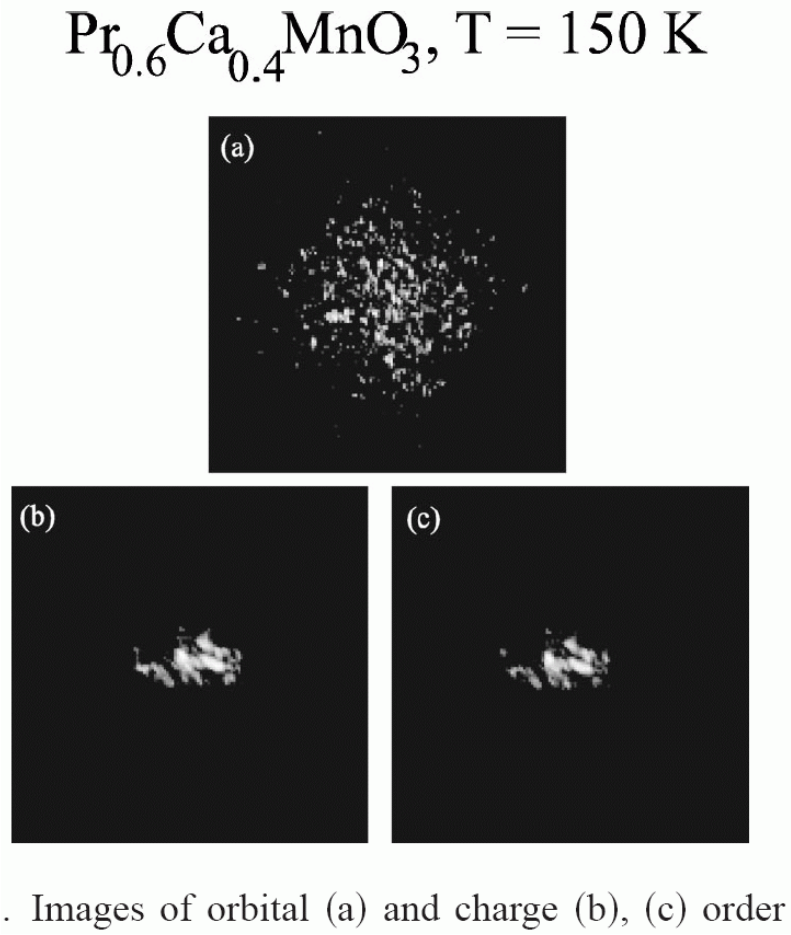



scalar0
-1.60 -1.14 -0.686 -0.229 0.229 0.686 1.14 1.60

$LaMnO_3$ and $Pr_{0.6}Ca_{0.4}MnO_3$ speckle

C. S. Nelson, J. P. Hill, Doon Gibbs, F. Yakhou, F. Livet, Y. Tomioka, T. Kimura and Y. Tokura, PRB 66 134412 (2002)

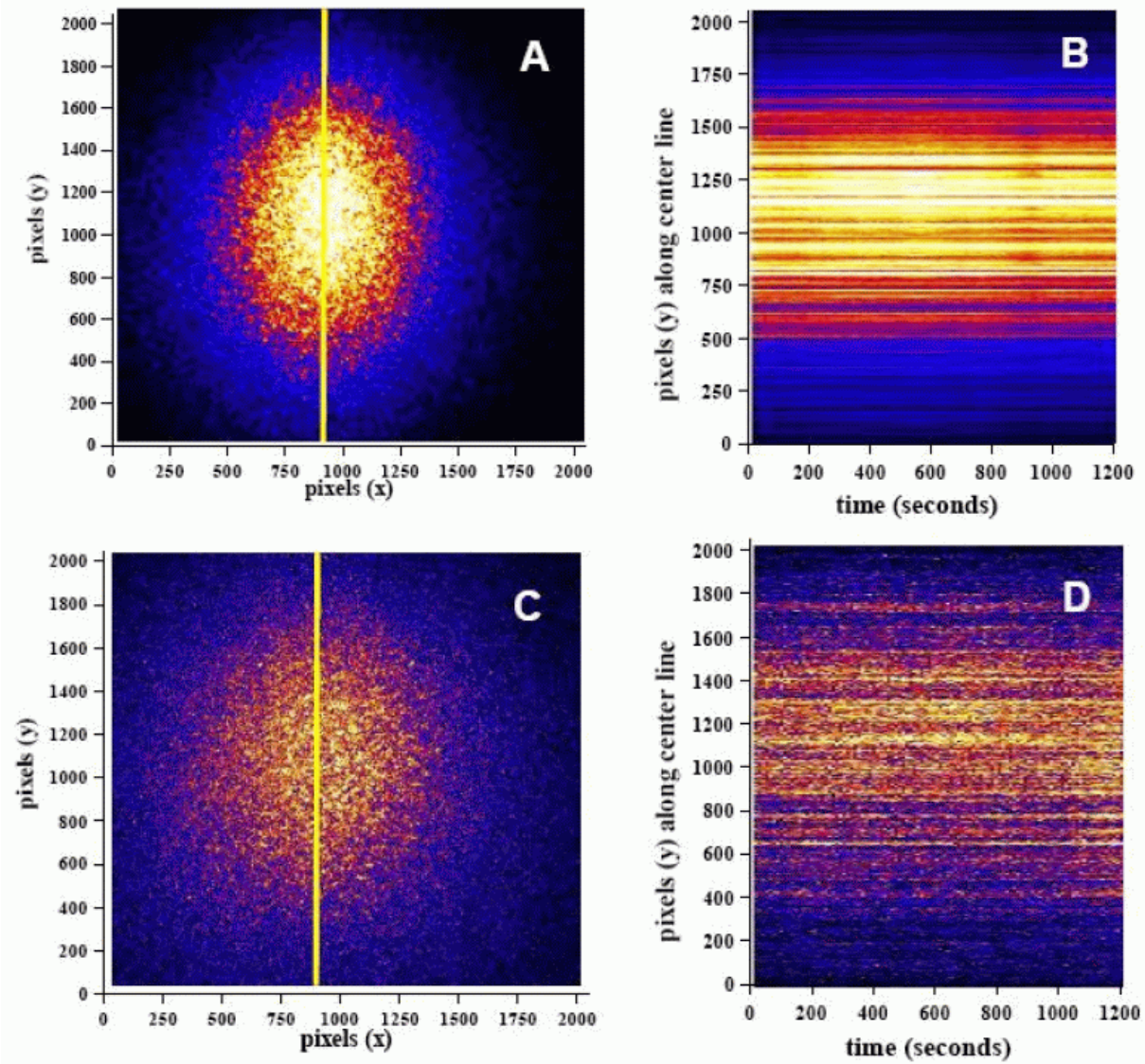




. Images of orbital (a) and charge (b), (c) order

$Pr_{0.5}Ca_{0.5}MnO_3$ at MnL_{III} edge (650 eV)

J. J. Turner et al, New Journal of Physics 10 053023 (2008)

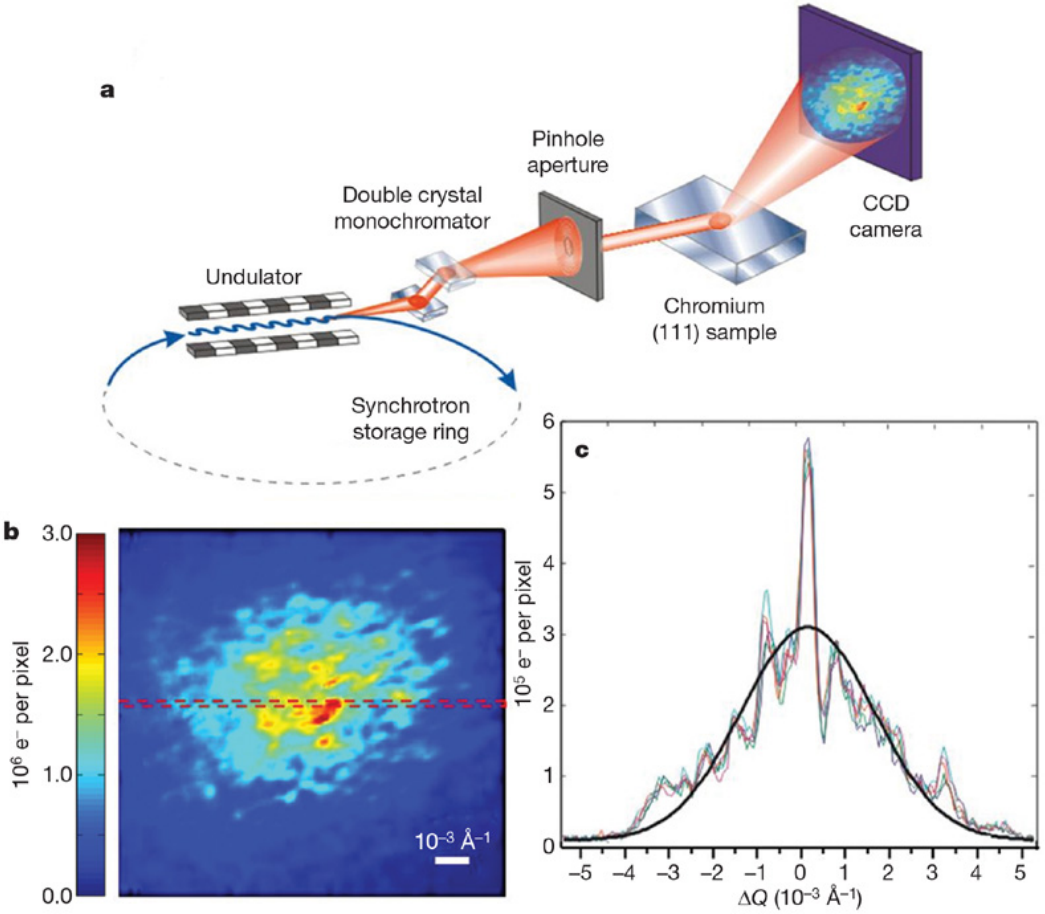


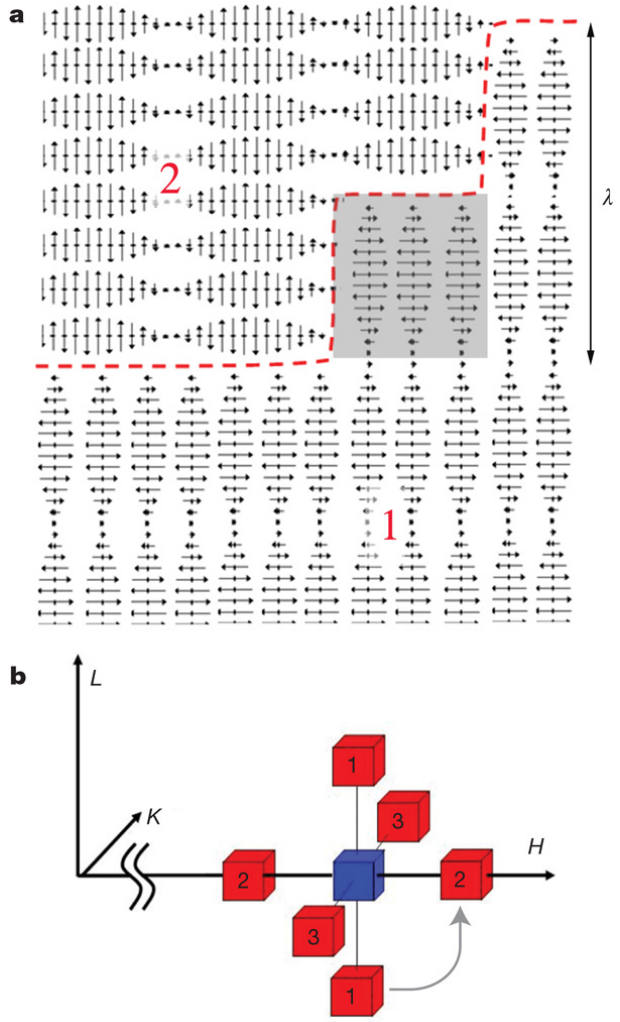
(0, ½ , 0)
Orbital ordered
T=205K

(0, ½ , 0)
Near phase transition
T=232K

Antiferromagnetic Domains in Cr

O. Shpyrko et al, Nature 447 68 (2007)





I. K. Robinson, OSA 2009

FeAl antiphase domains (001)

Lorenz Stadler, PhD dissertation, TU Wien (2005)

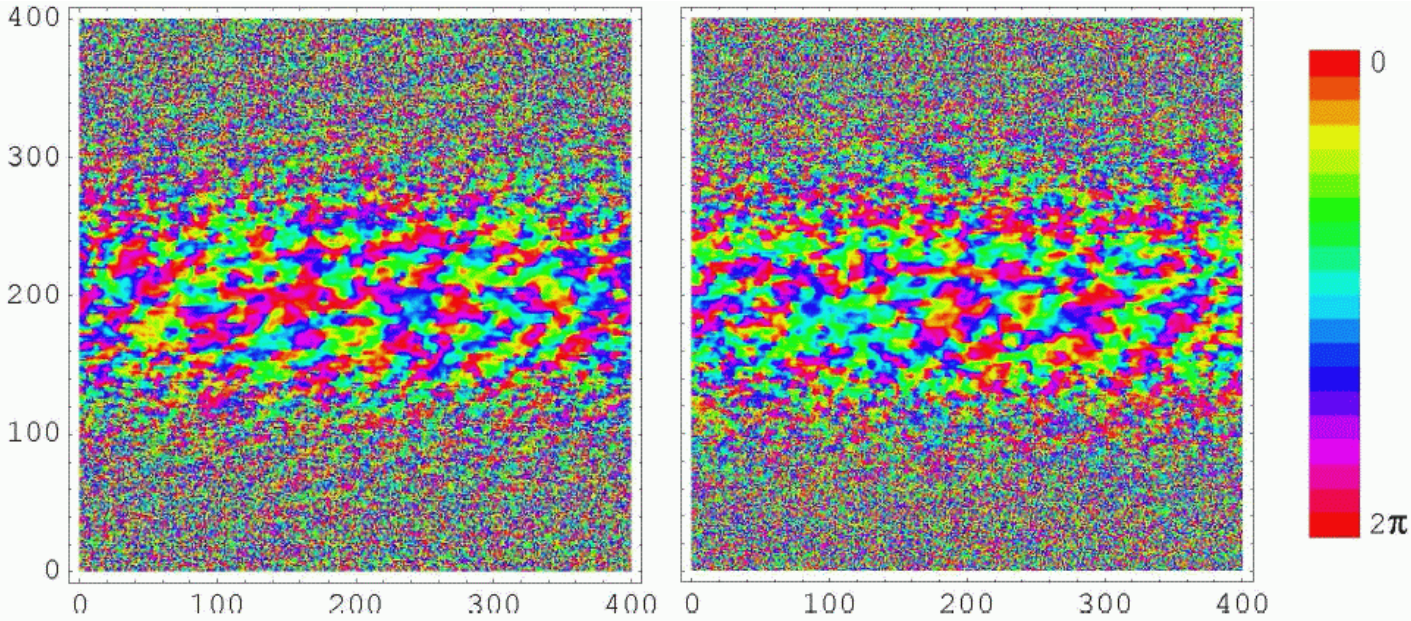
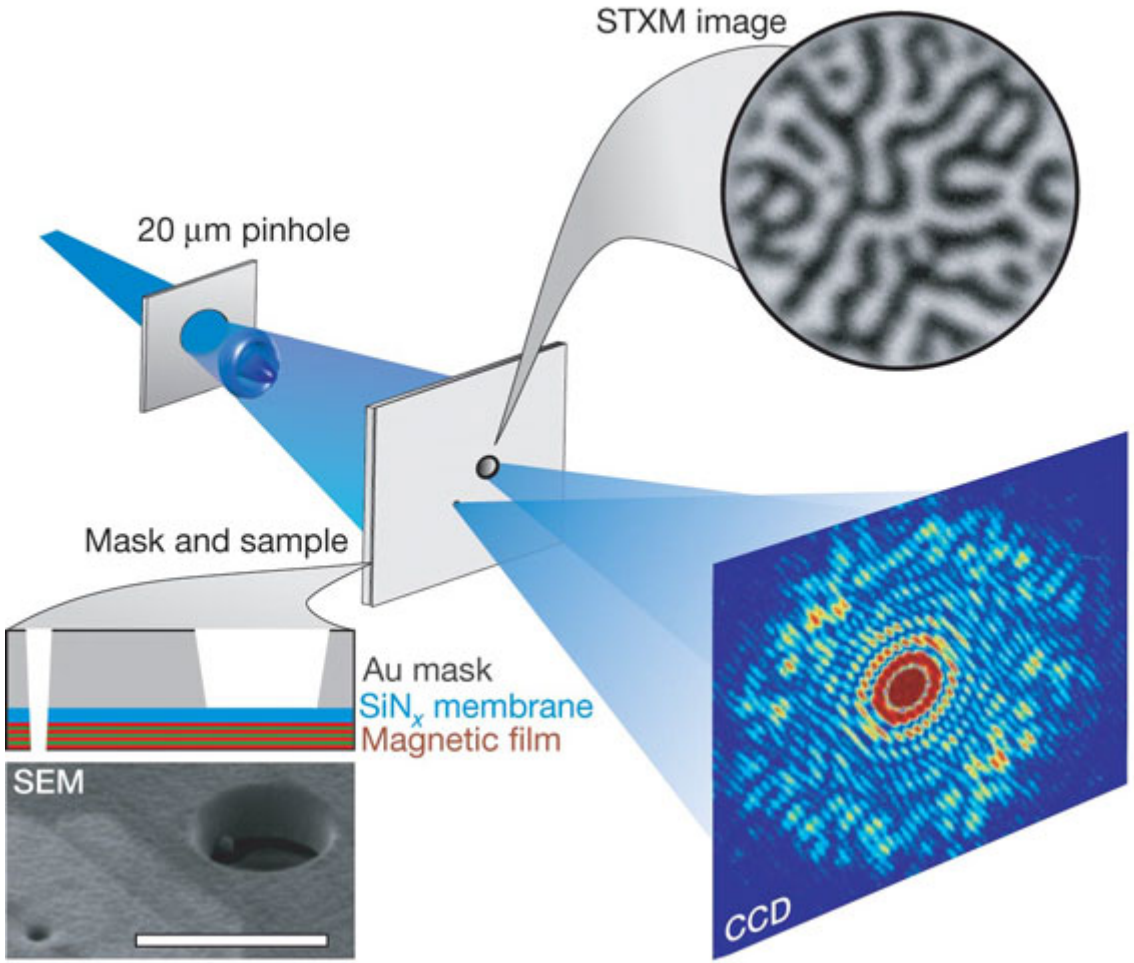


Figure 7.11: Typical reconstructed phases from runs with different combinations of algorithms and supports derived from the 2D Gaussian fit of the illumination function. Numbers in brackets denote how many iterations of the particular algorithm were done each cycle. Graphs on the left are from reconstruc-

X-ray Holography of Pt/CoML Domains

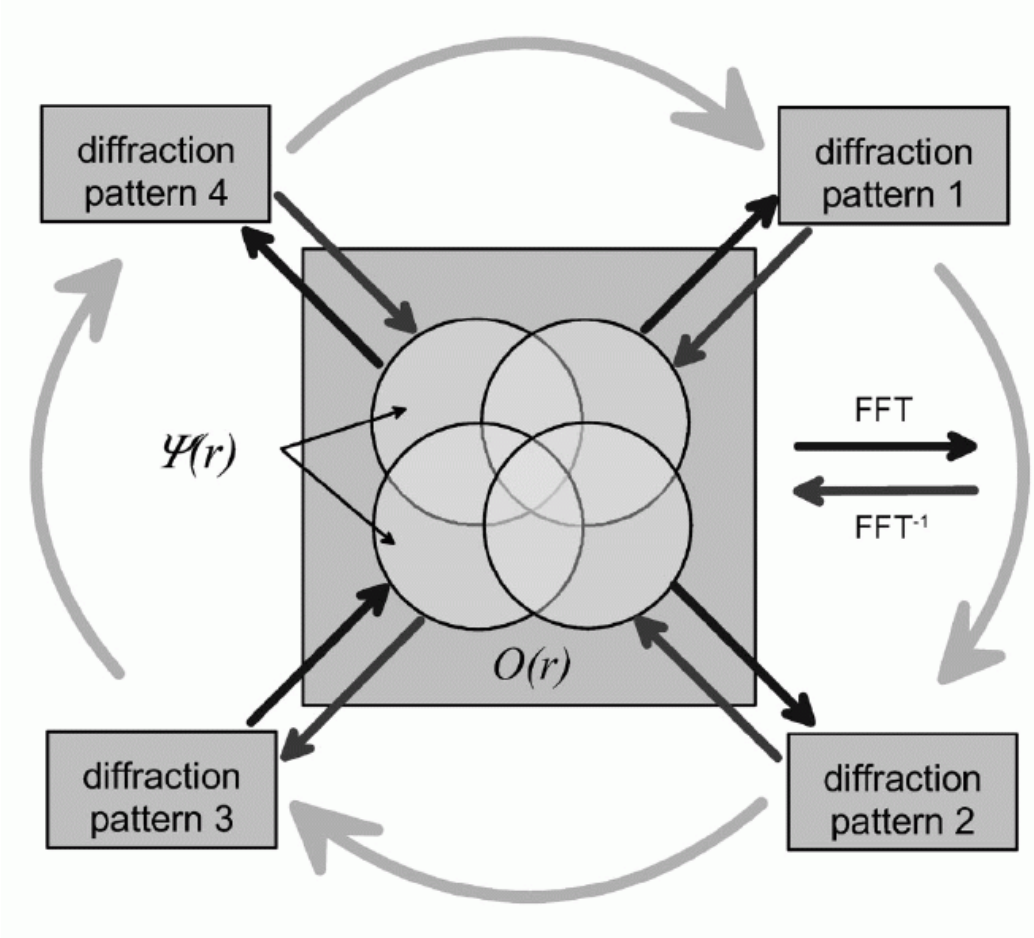
S. Eisebitt et al. Nature 432 885 (2004)



Field of view 1.5 µm

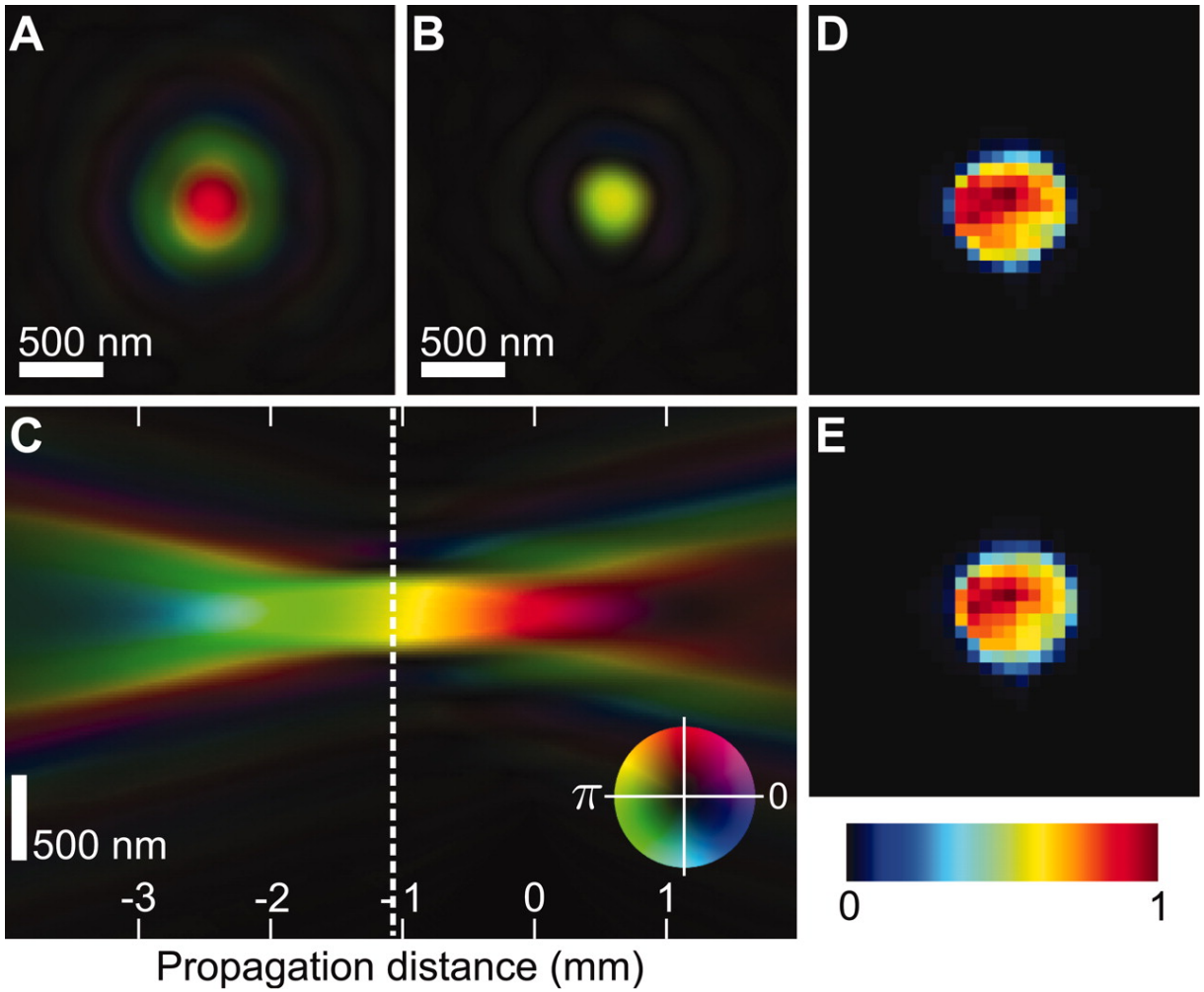
X-ray Ptychography

J. Rodenburg et al, PRL 98, 034801 (2007)



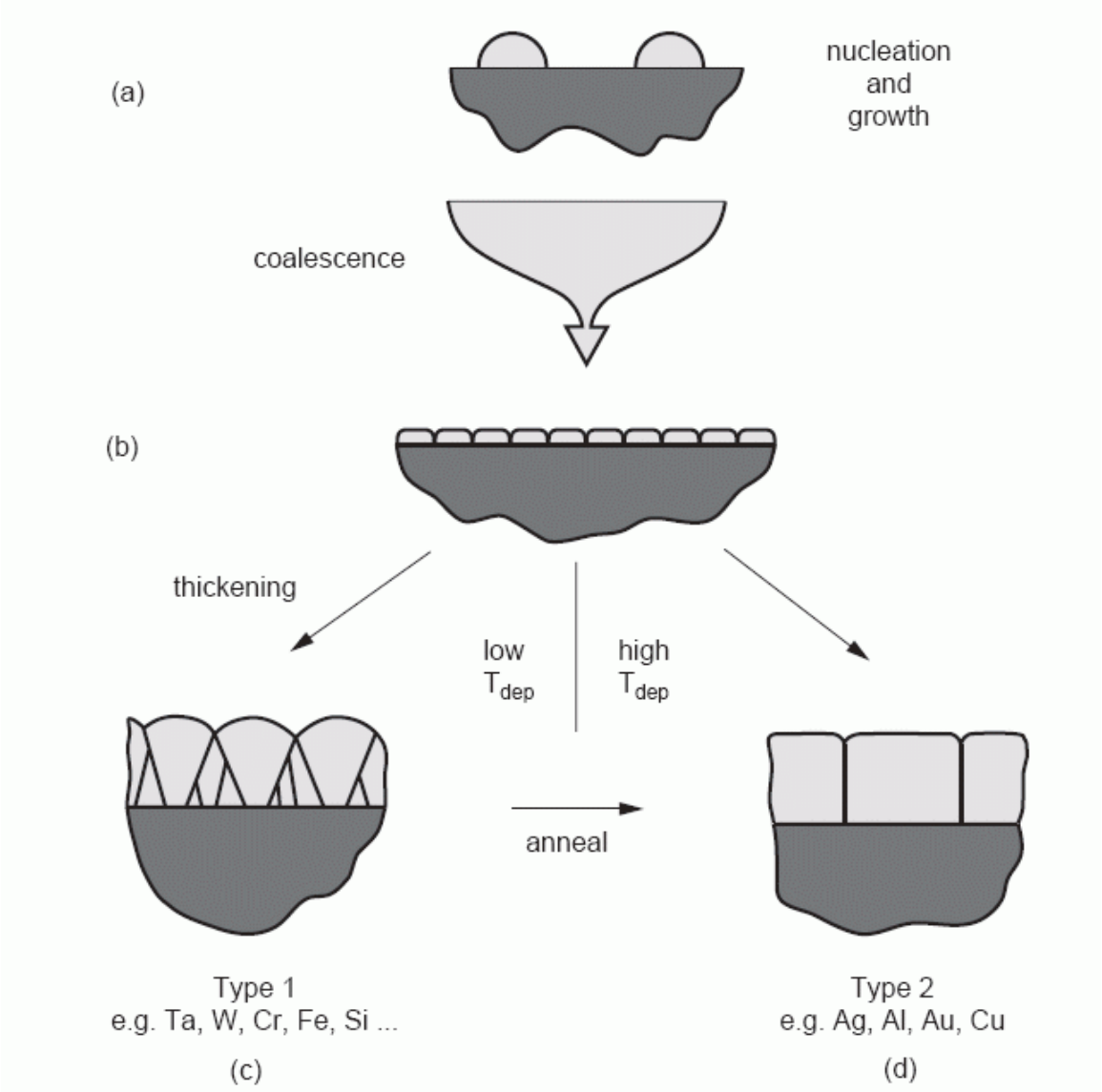
Reconstruction of Probe

P. Thibault et al, Science 321 379 (2008)

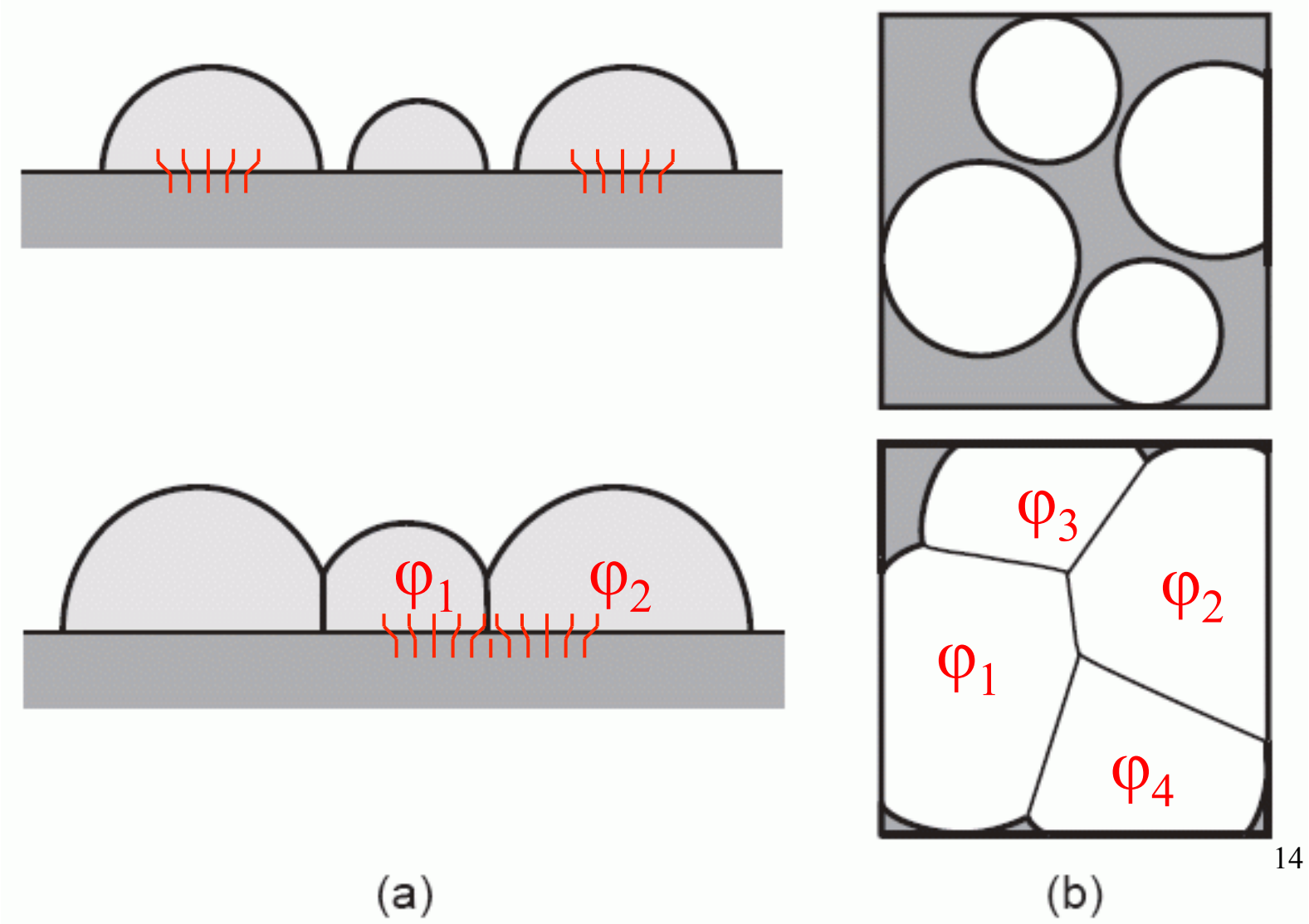


Thin film growth after deposition

C. V. Thompson, Annu. Rev. Mater. Sci. 2000. 30:159–90



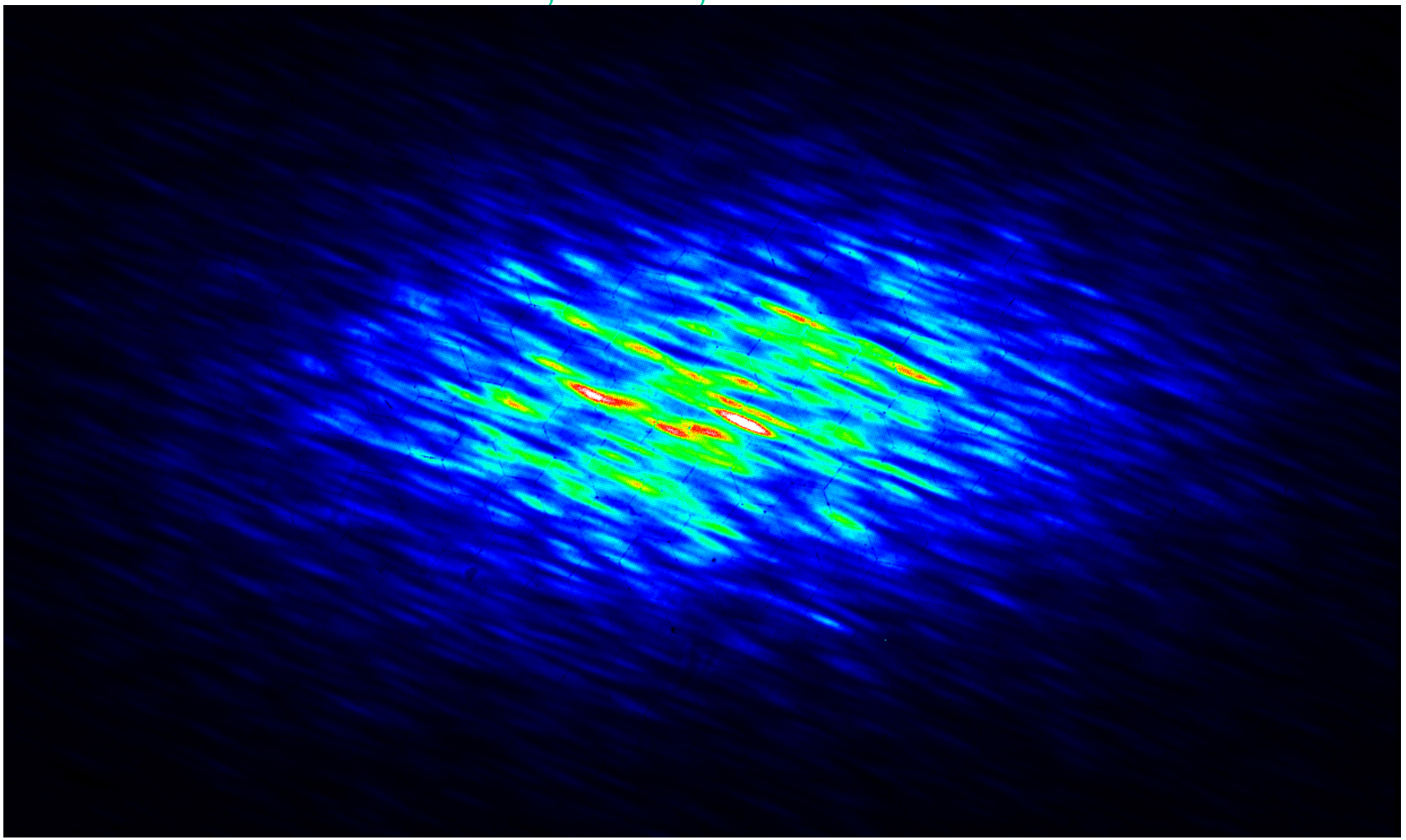
Epitaxial growth effects



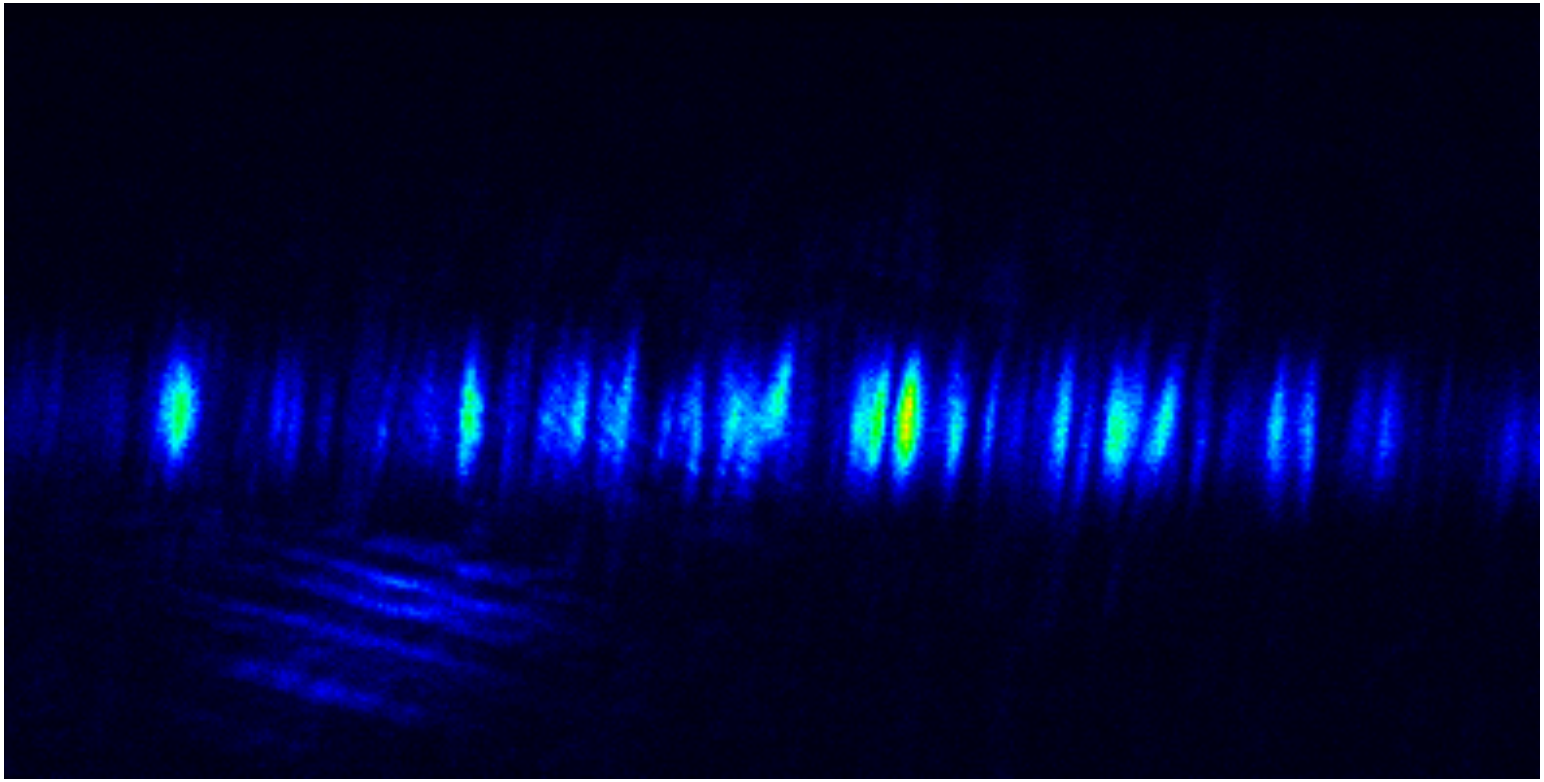
Niobium (110) Thin Film Grains

1μm steps across 3μm beam of KB mirror focus

Richard Bean, I-16, Nb110-35 Jan 2009

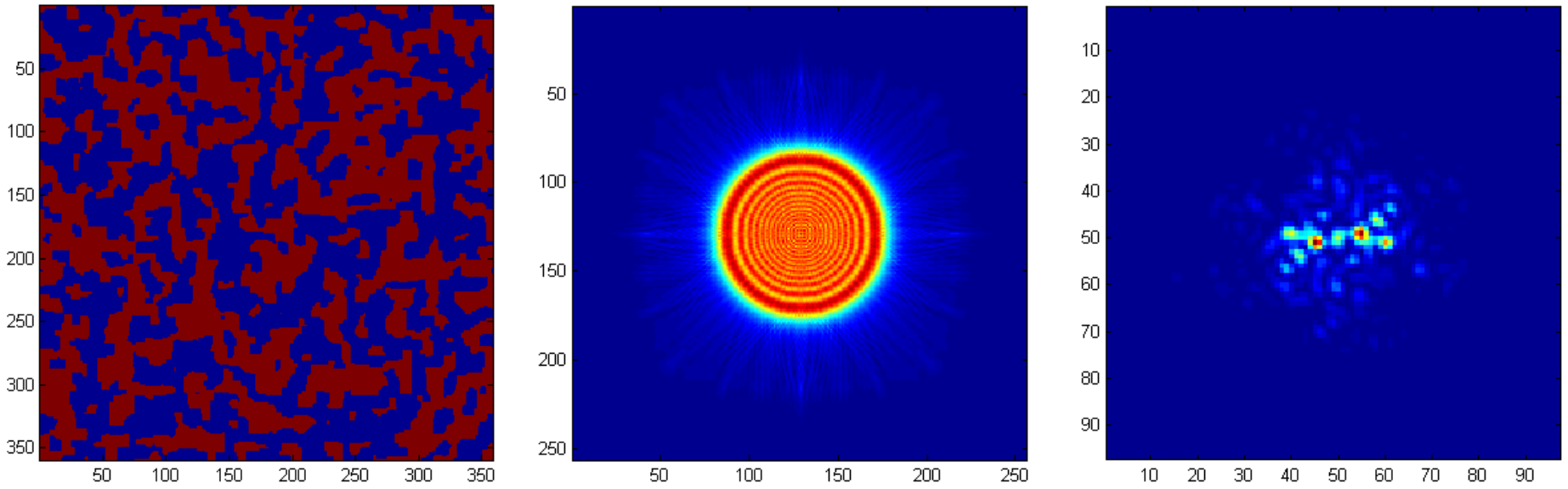


“Barcode” diffraction of GaAs nanowire



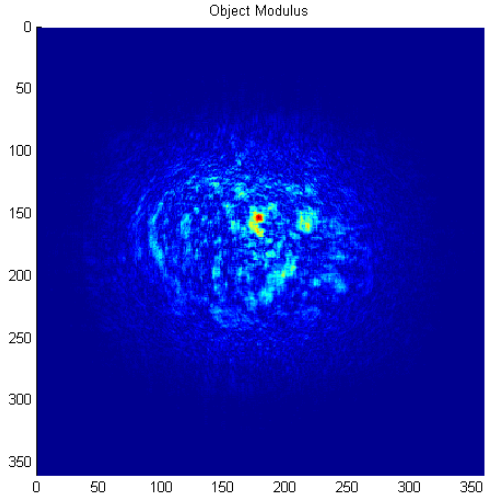
Ptychography phasing tests

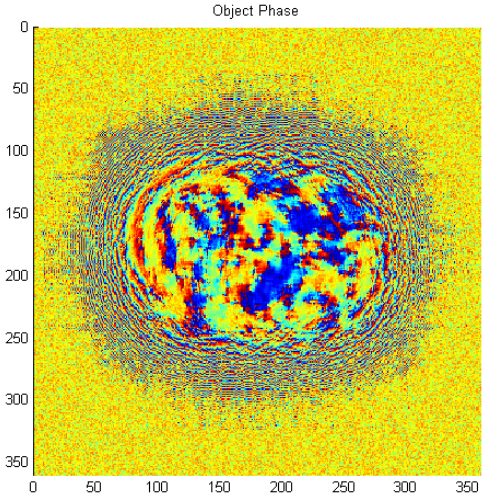
Diffraction patterns computed from i) simulated domain array ii) propagated pinhole function with an overlap of ~80% between adjacent positions.



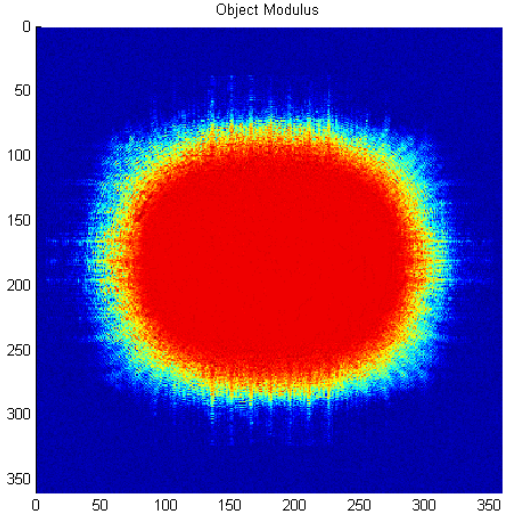
Ptychography phasing tests

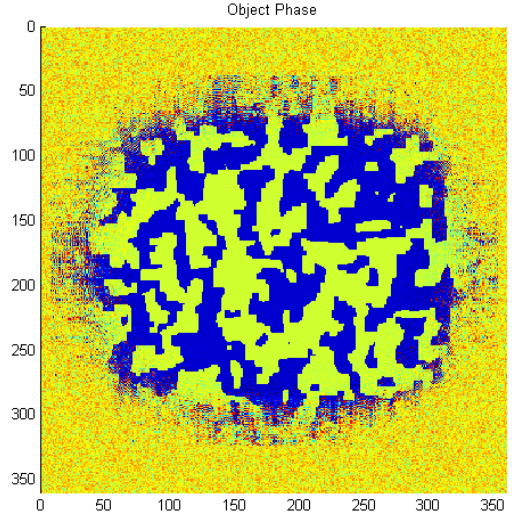
Sheffield Ptychography algorithm starting with an array of random numbers in both amplitude and phase. 7x3 pinhole array. Richard Bean, Jan 2009





Amplitude and phase after 1 iteration.



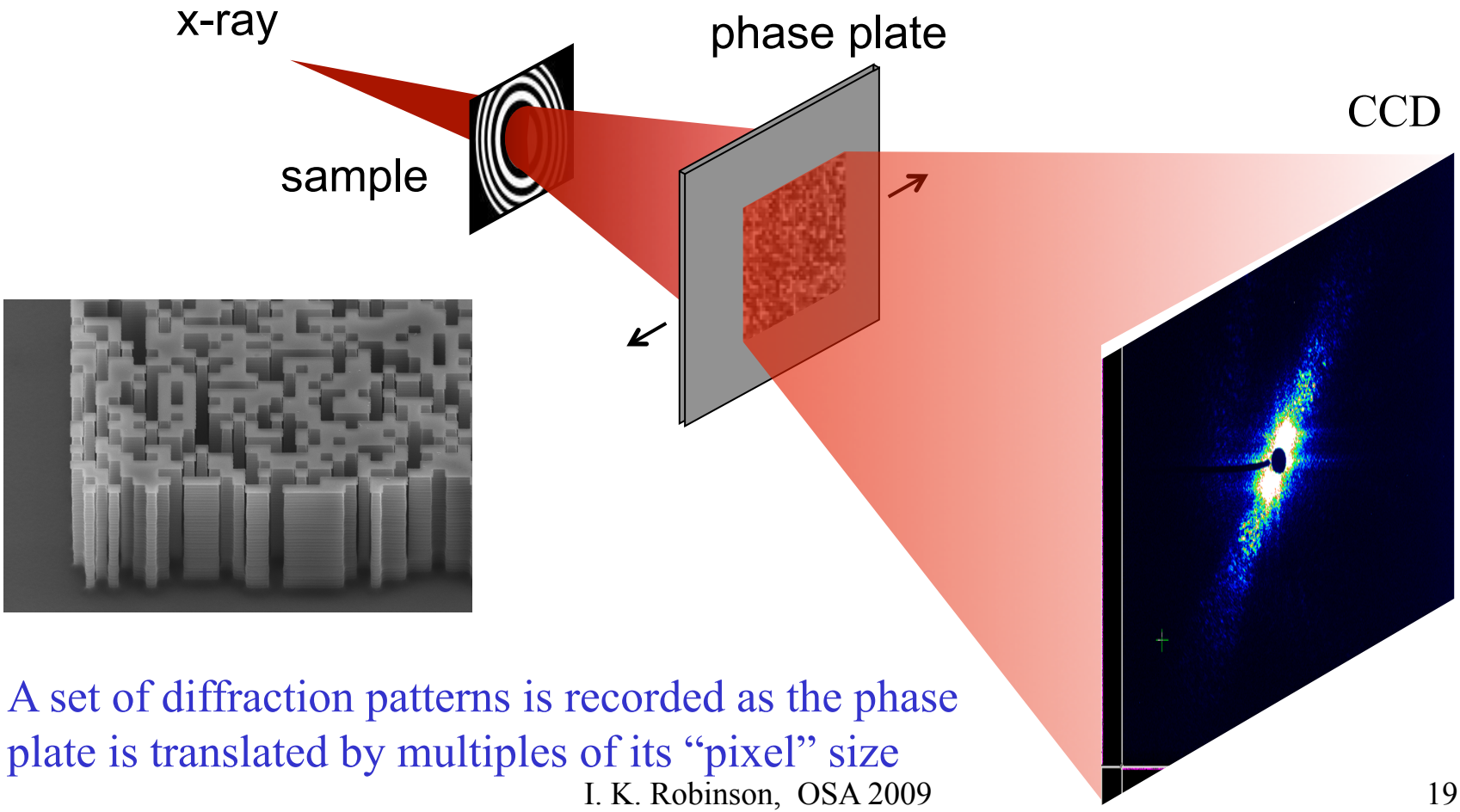


Amplitude and phase after 20 iterations.

Imaging by Wavefront Modification

F. Zhang et al., Phys Rev A 75 (2007)

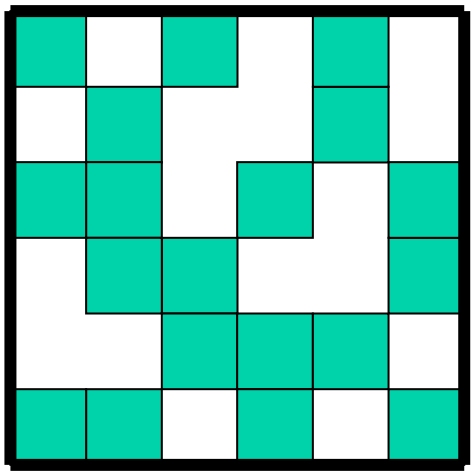
I. Johnson et al., Phys Rev Lett 100 (2008)



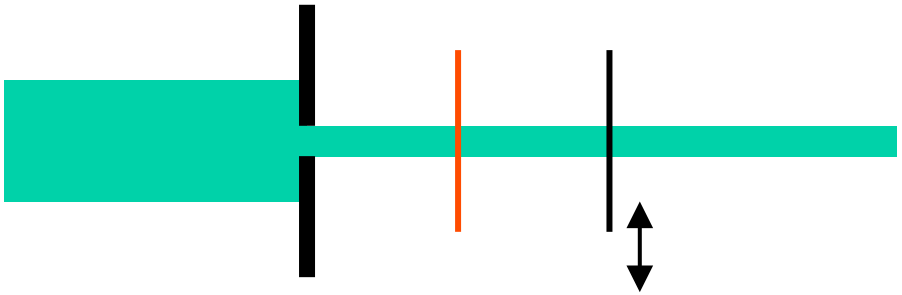
A set of diffraction patterns is recorded as the phase plate is translated by multiples of its "pixel" size

‘Random’ phase plate analyser

Joan Vila (PSI), Fucai Zhang (Sheffield)



1 μm



Pinhole Sample Analyser

CXD applied to collagen

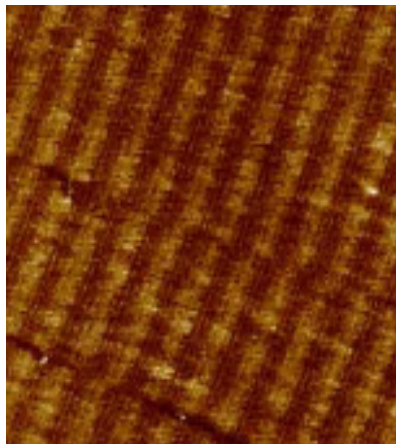
Felisa Berenguer, LCN

• Collagen is the most common protein in animal tissue (bones, teeth, tendon, cartilage, connective tissue)

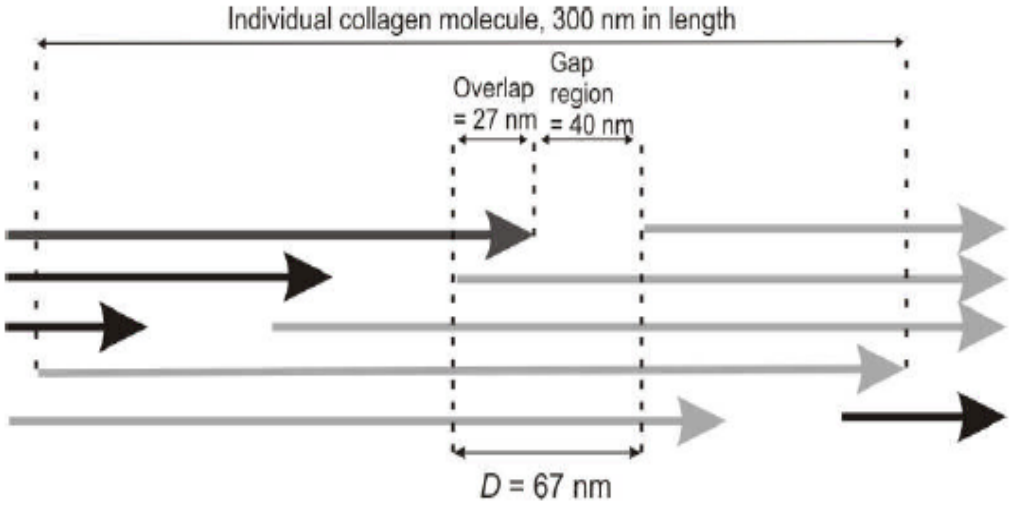
• Potential applications in medicine (artificial bone, skin diseases)

• Collagen packing to built-up fibres is not completely understood

Different proposed models by Orgel 2007, Wess 2006, Bozec 2007 …

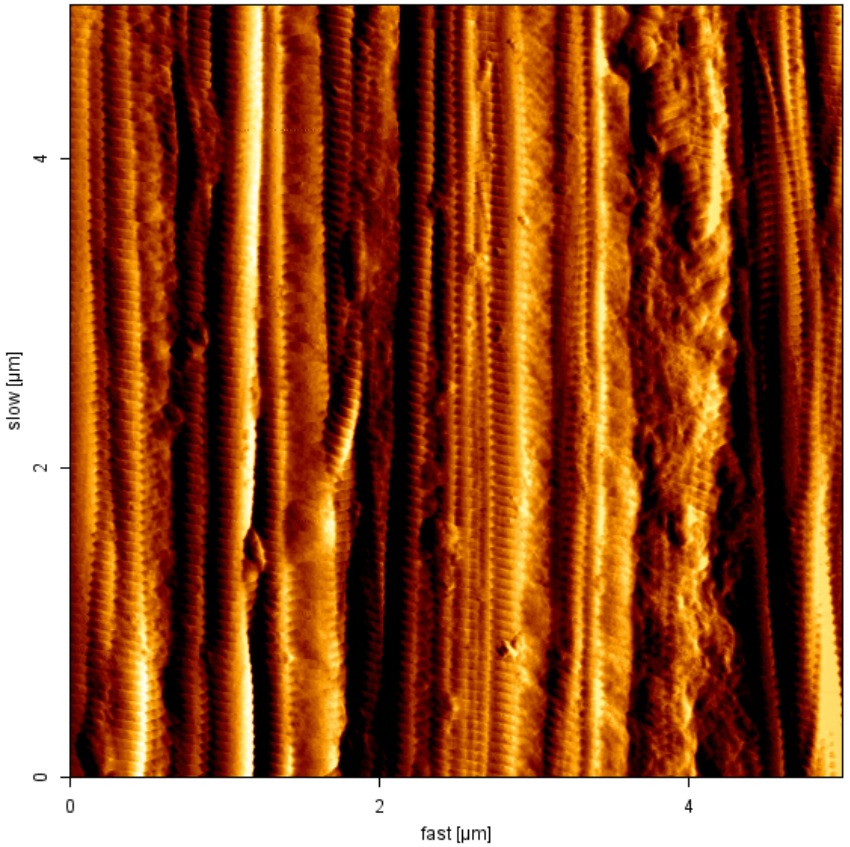


SEM [Cisneros, 2006]

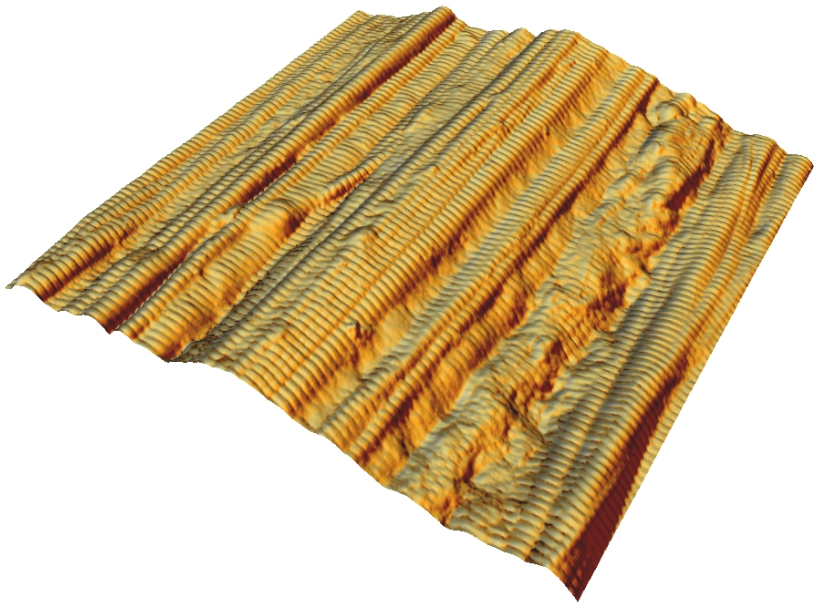


[Hodge and Petruska, 1976]

AFM imaging of rat-tail collagen



Dehydrated rat tail tendon tissue



Strong D-banding with 67 nm periodicity:

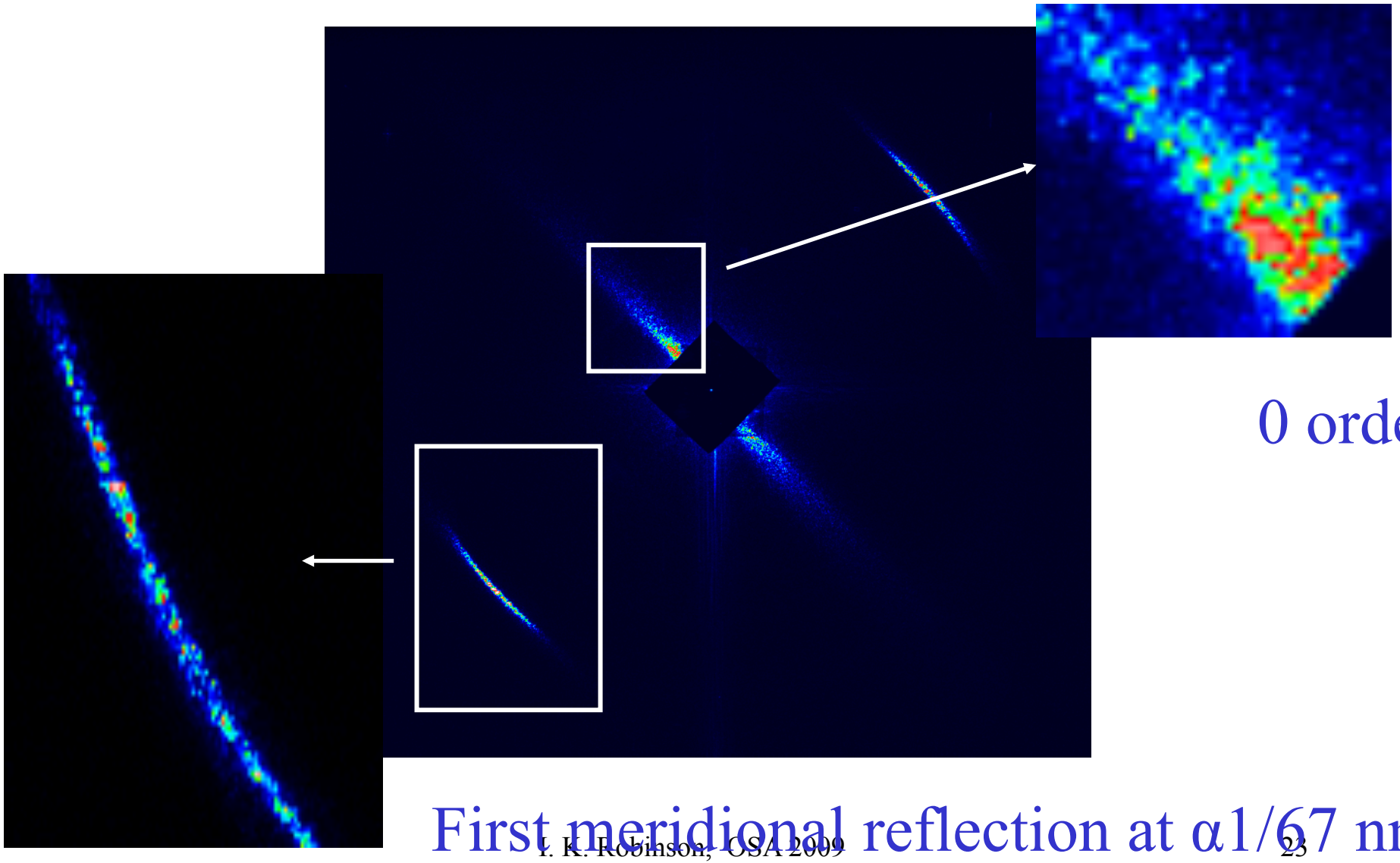
→Diffraction pattern with strong meridional maxima at multiples of 1/67 nm^{-1}

I. K. Robinson, OSA 2009

LCN
LONDON CENTRE
FOR NANOTECHNOLOGY

First experimental results on collagen

Rat tail tendon tissue

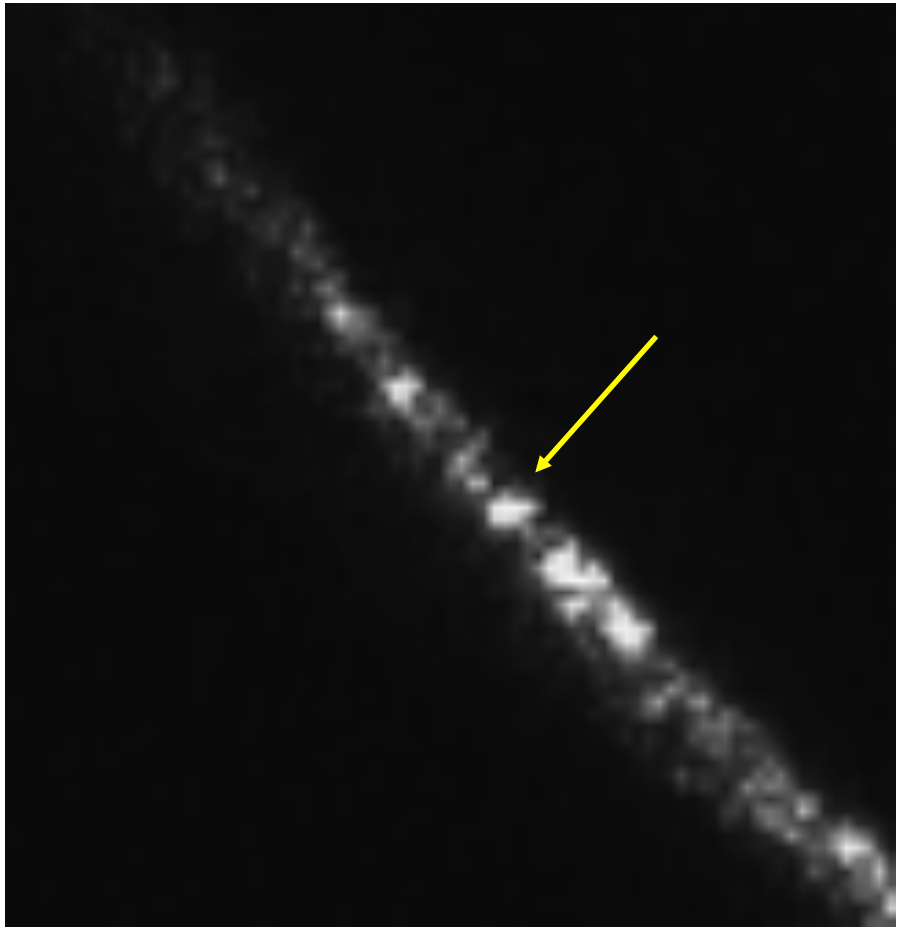


0 order

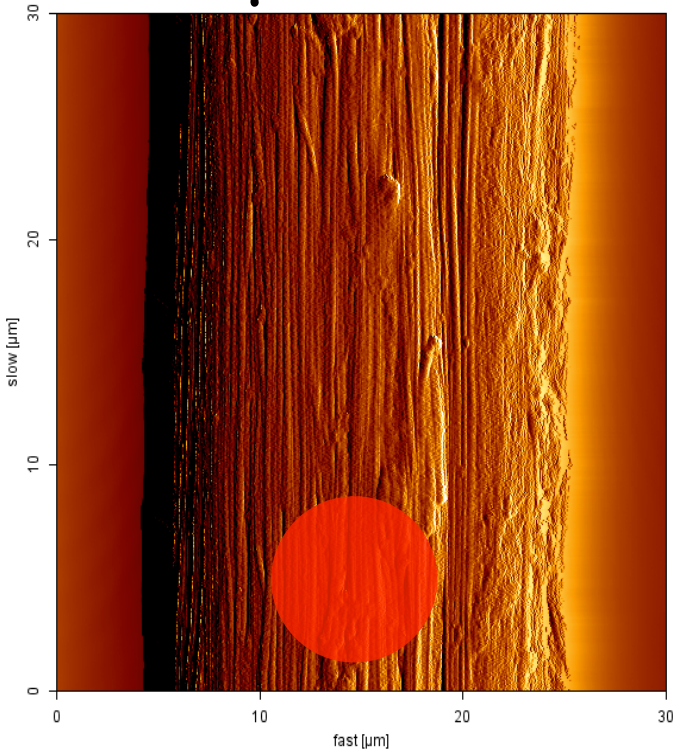
First meridional reflection at α1/67 nm-1

X-ray Ptychography

First meridional reflection



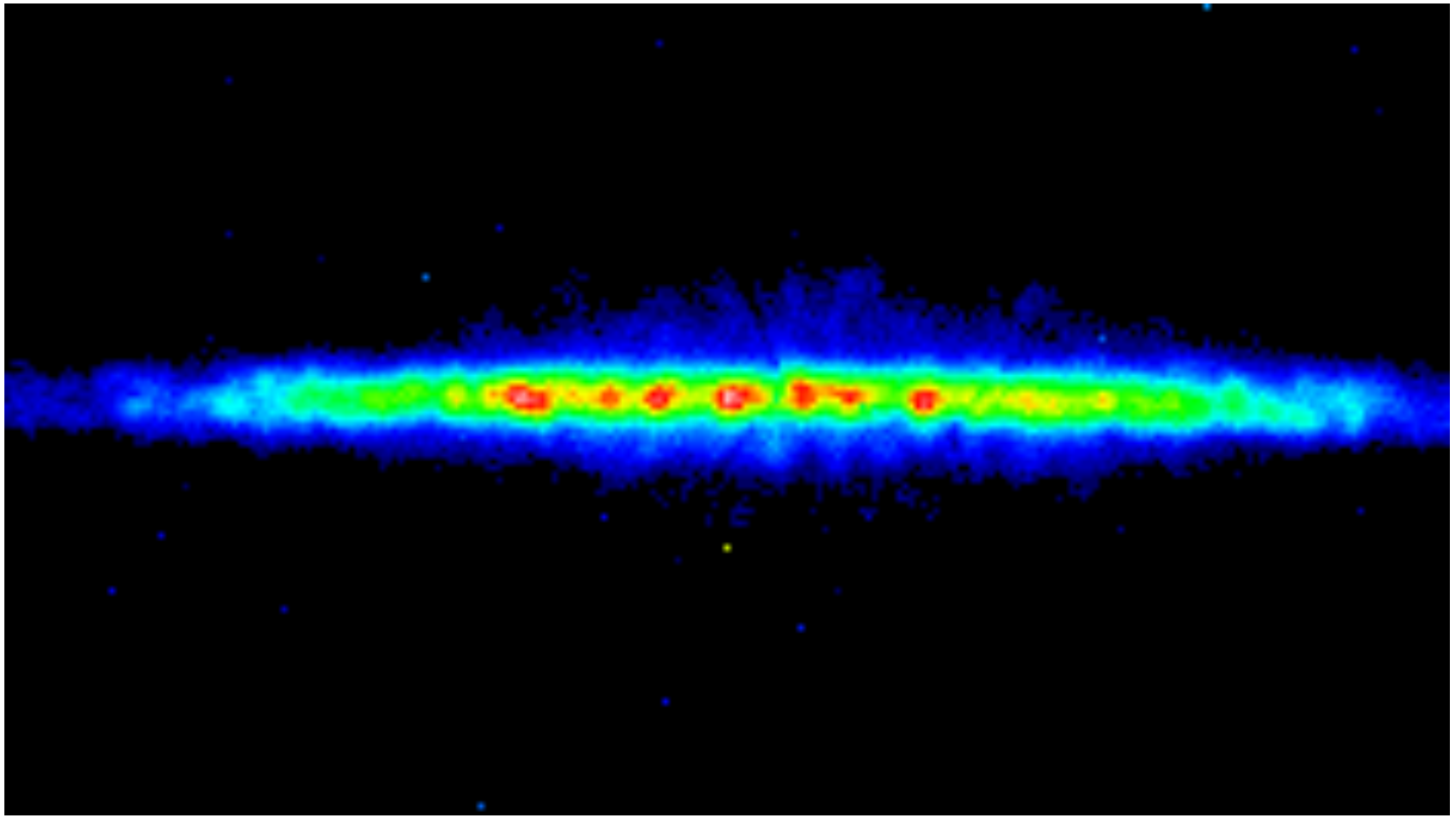
10 μm beam



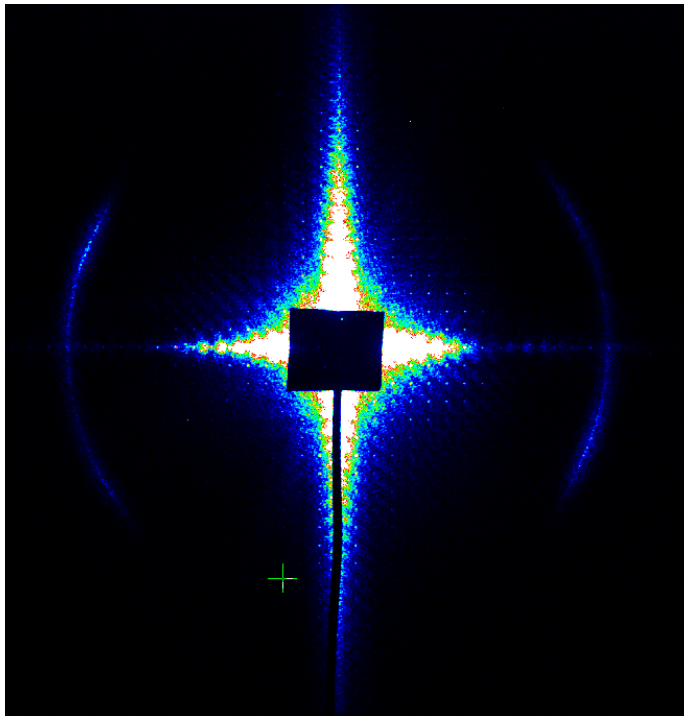
Dark field imaging:
collagen distribution in different tissues

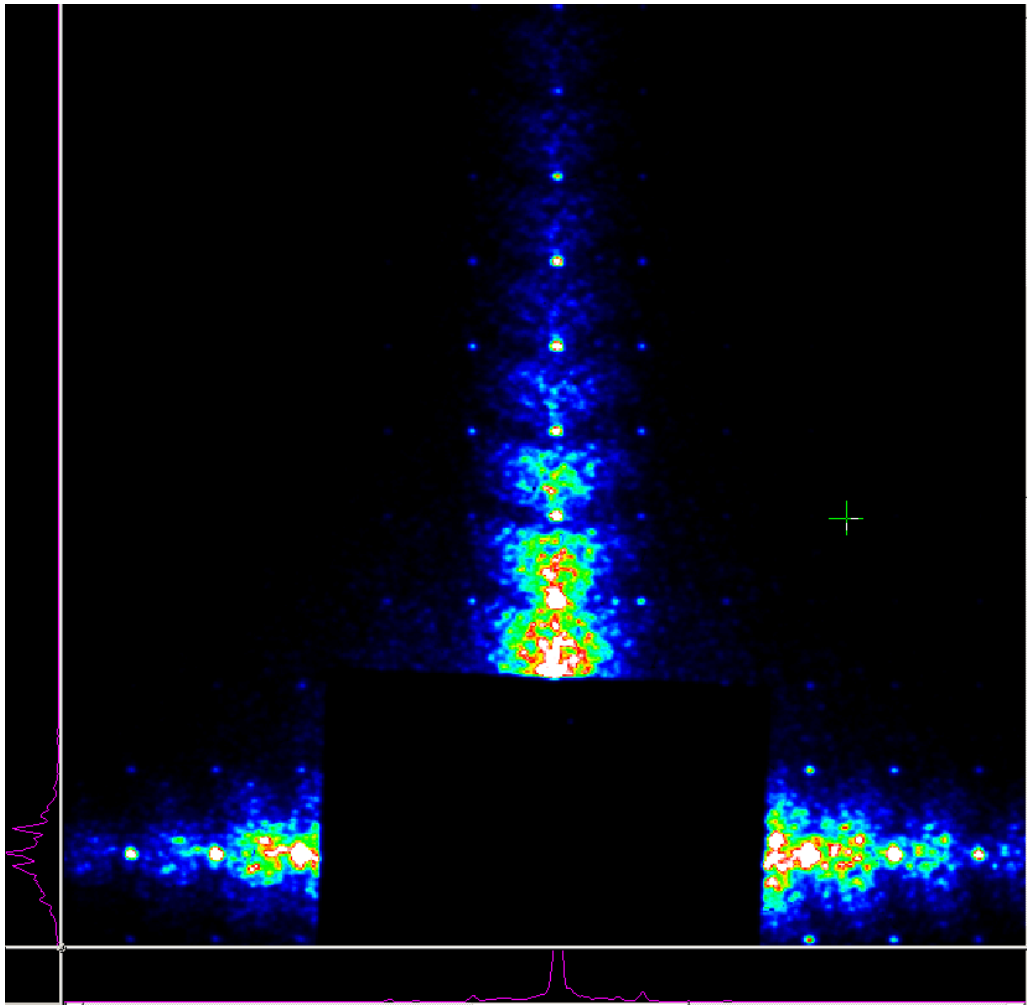
Improved collagen sample prep

Diamond I-22, Nov 2008



Collagen rat tail tendon + phaseplate

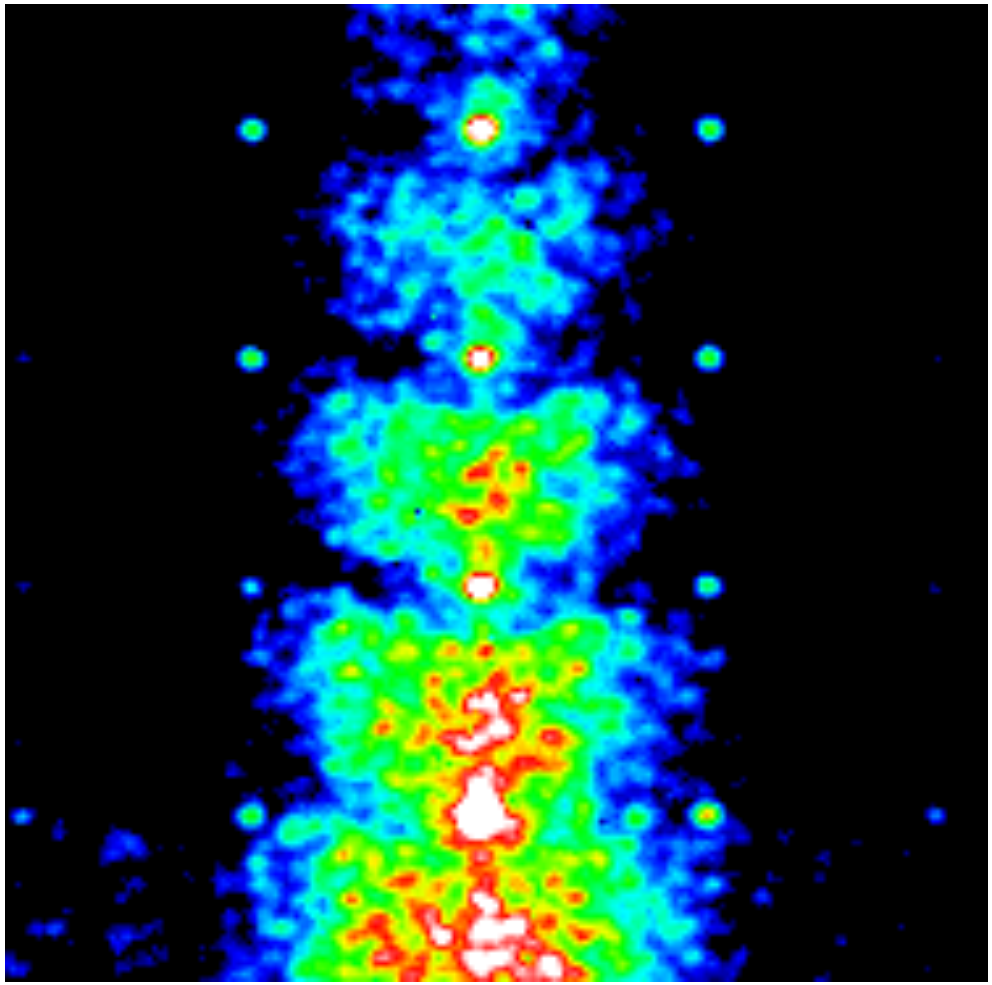


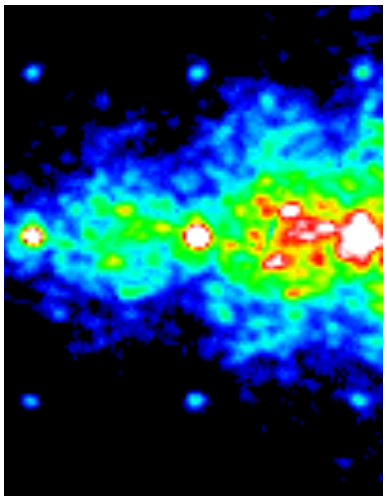


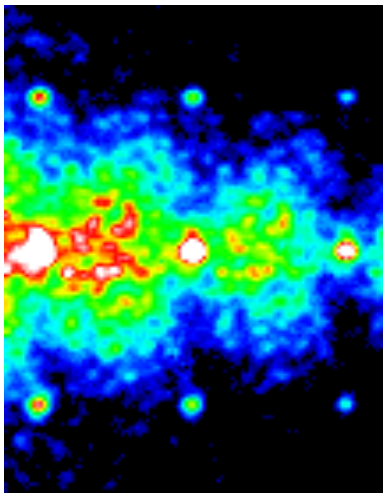
*** 0th order "repeated" in the meridian and equator**
*** Strong phase modification due to phase plate!**
*** No successful reconstruction**

Phase plate scan near forward direction

1μm step per frame

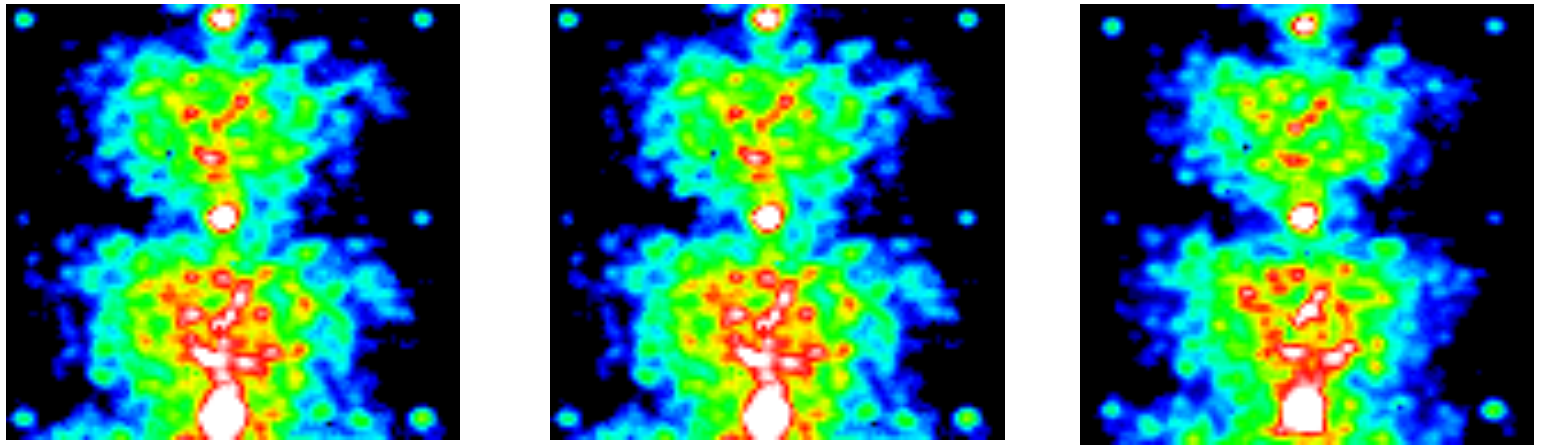






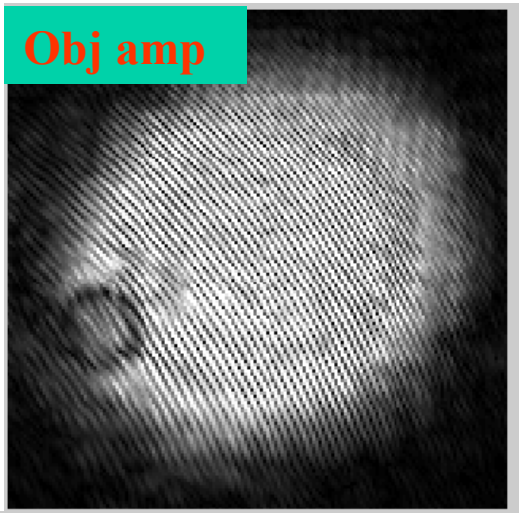
Collagen, buffer and empty cell

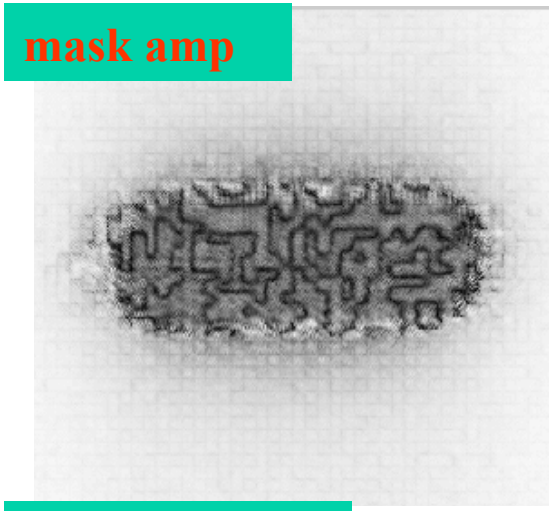
phplateFZP-236, -246 and -249

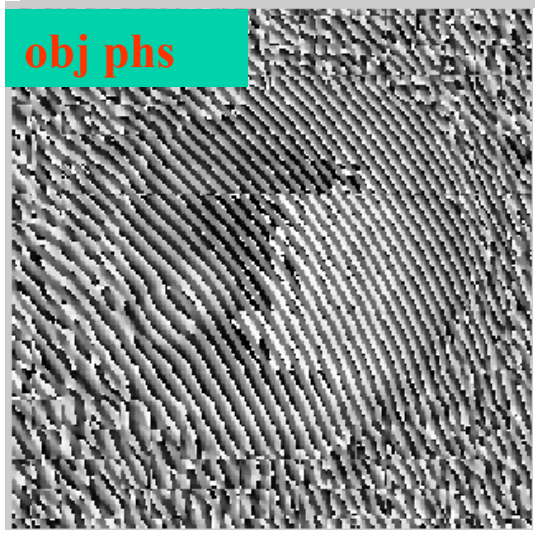


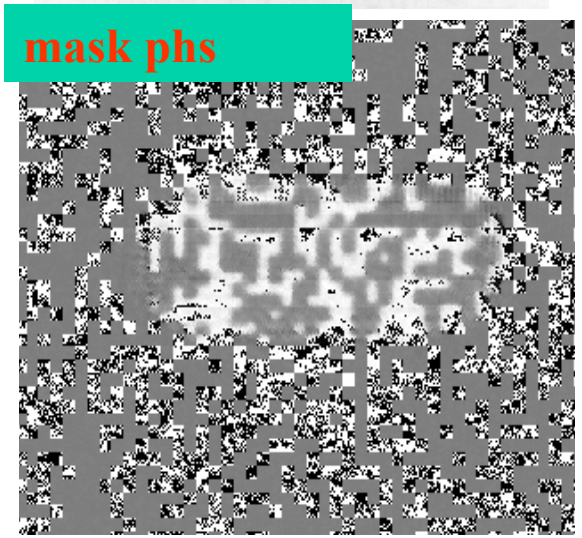
Reconstruction of Phase plate scan

1μm step per frame (512x512)



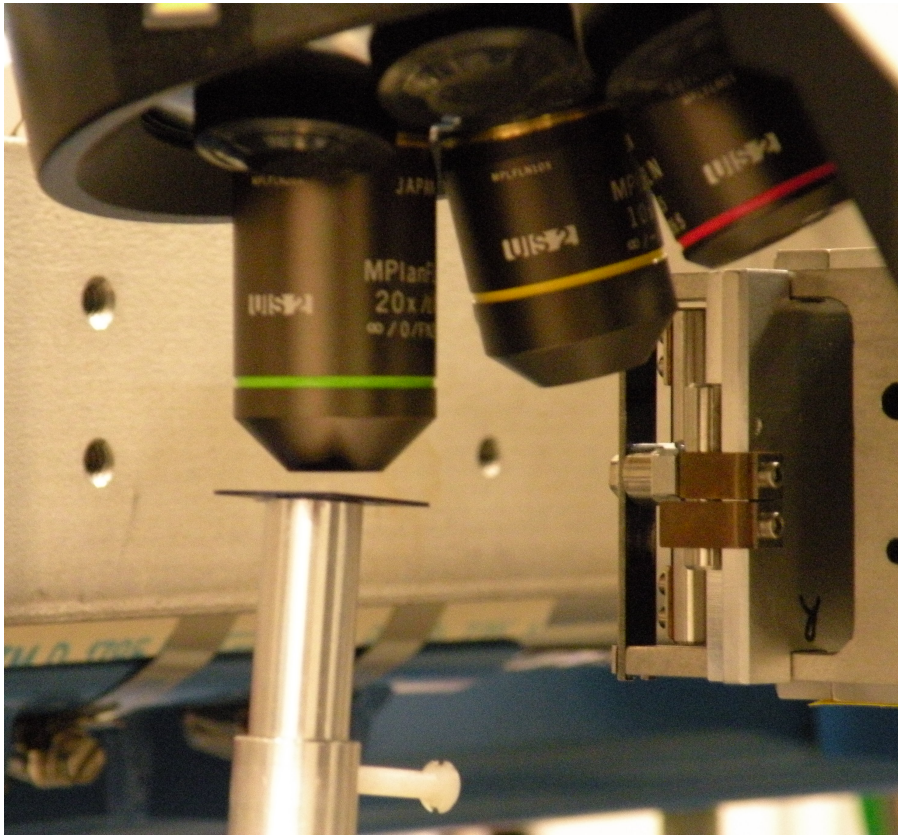


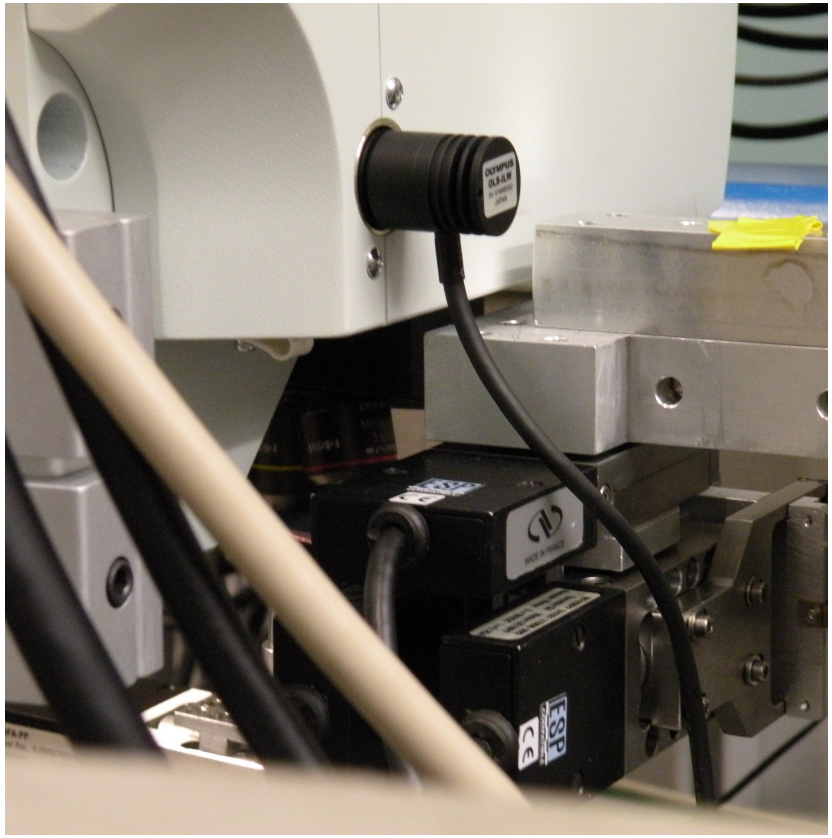




Reconstruction by F. Zhang (paper in preparation)

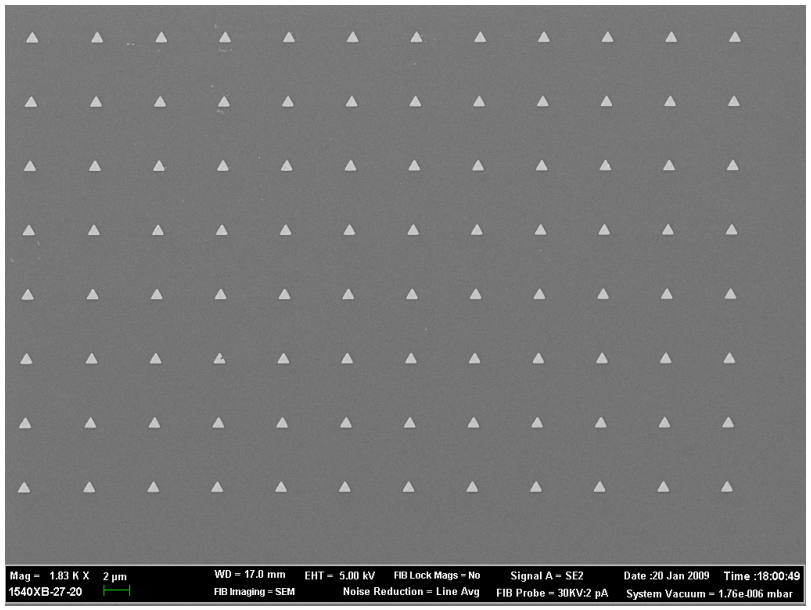
Confocal Alignment Microscope

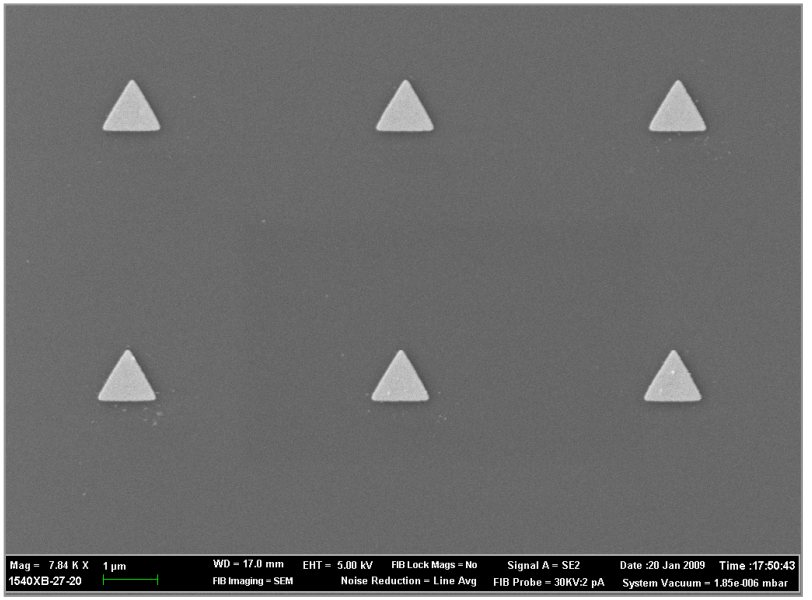


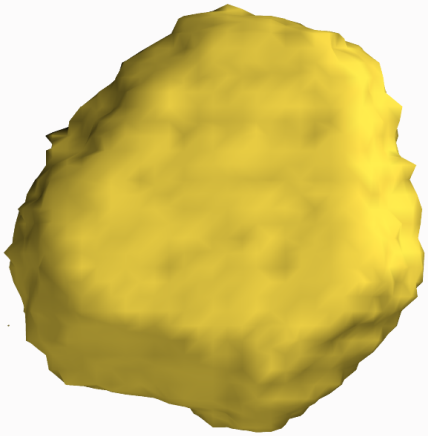


Patterned Au nanocrystal samples

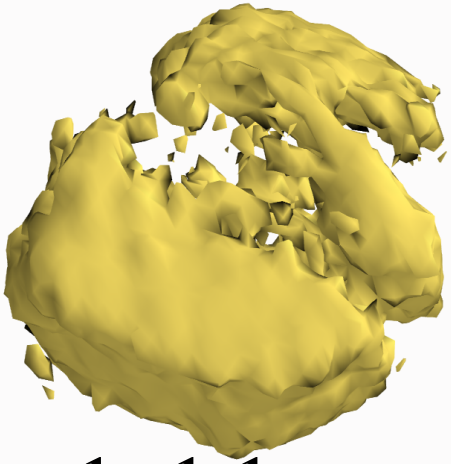
N. Shimamoto, Waseda University, Japan







1,1,-1



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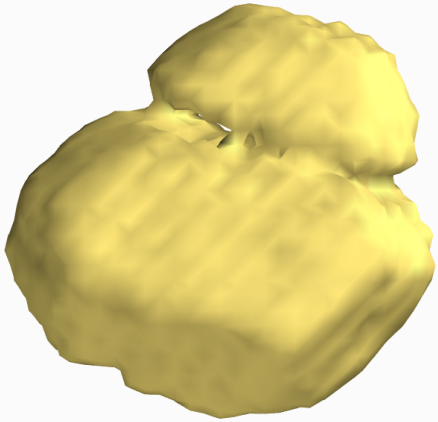
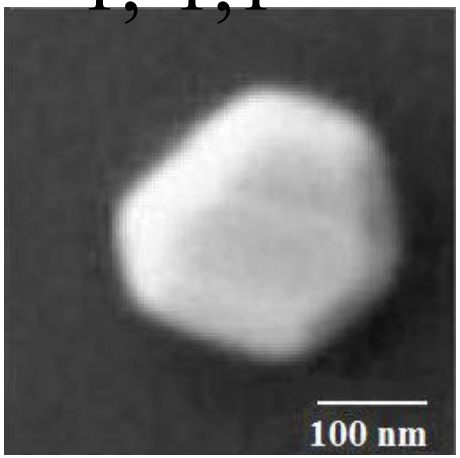
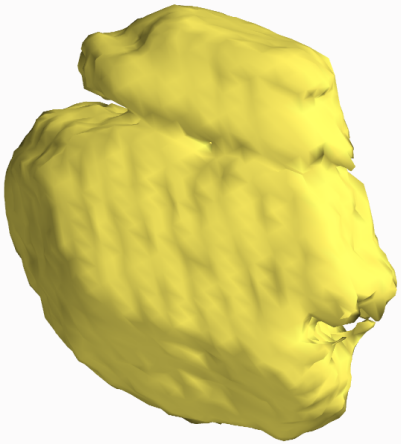
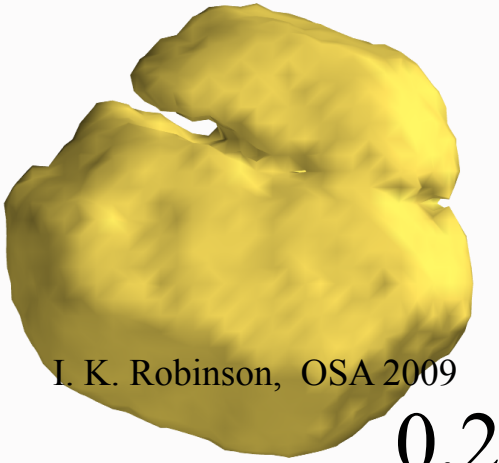


-1,1,1



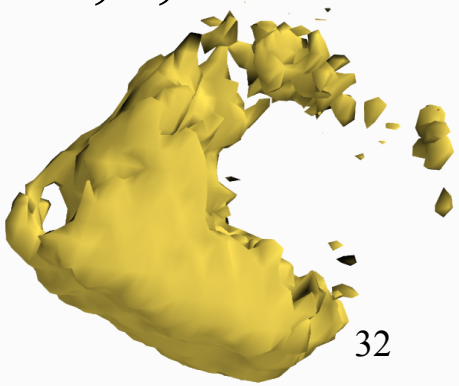
2,0,0





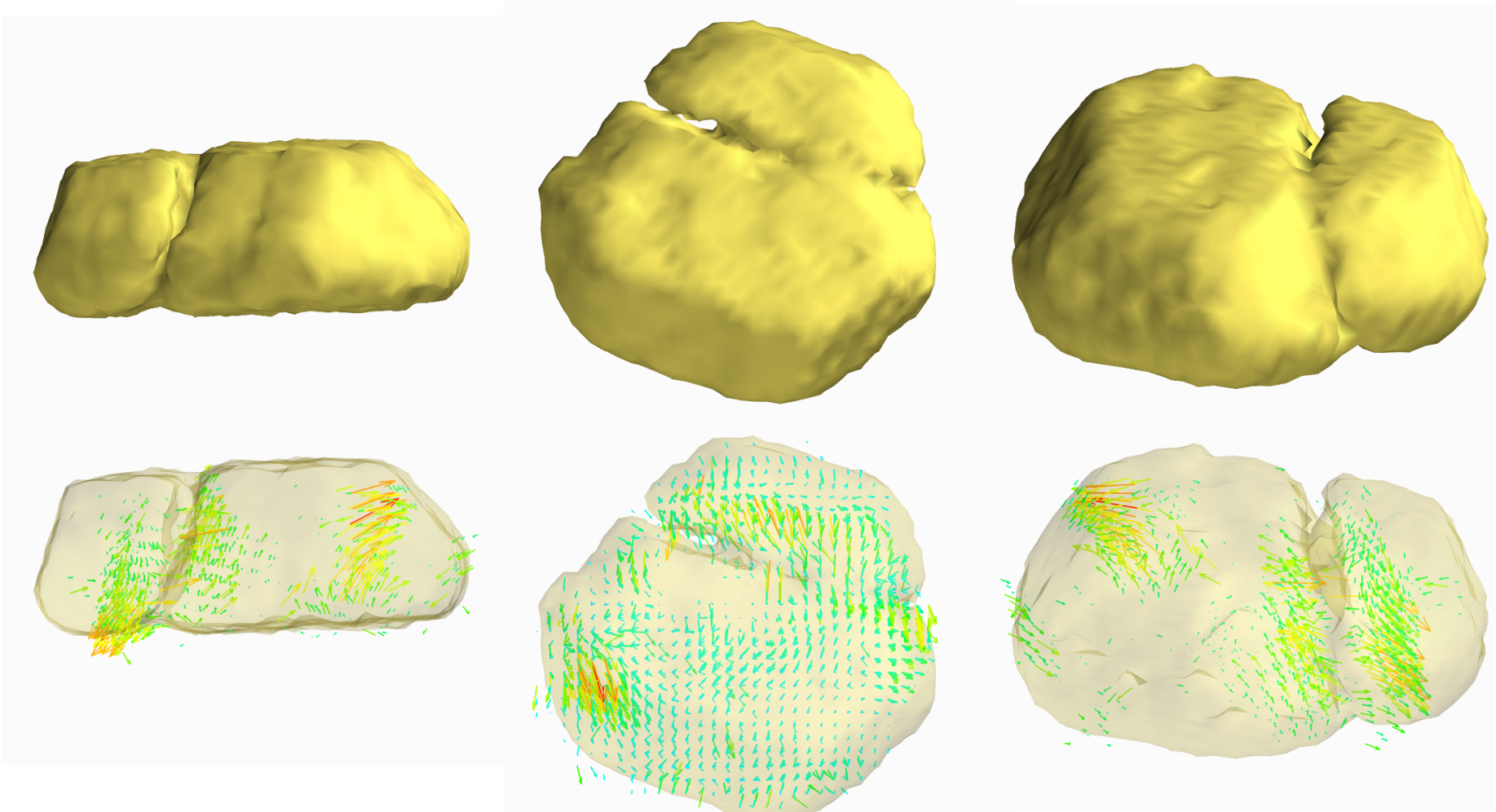
0,2,0

0,0,2



Vector displacement field

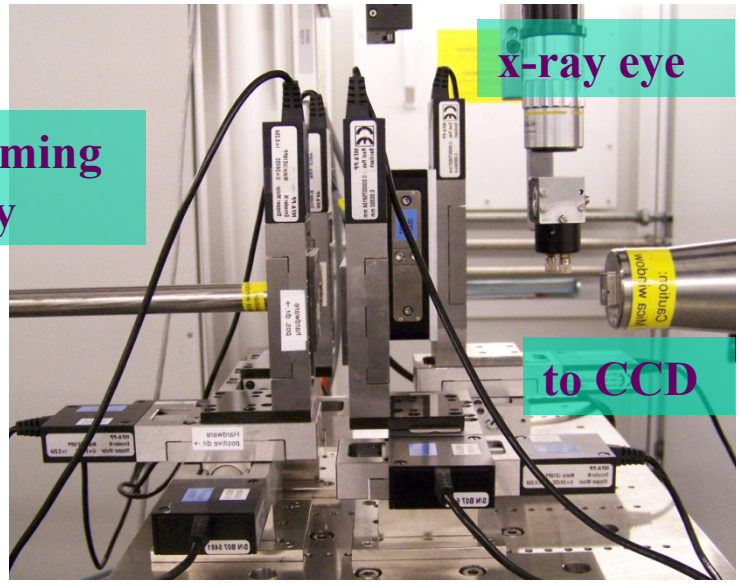
Merged reconstructions from (11-1) (020) and (-111)



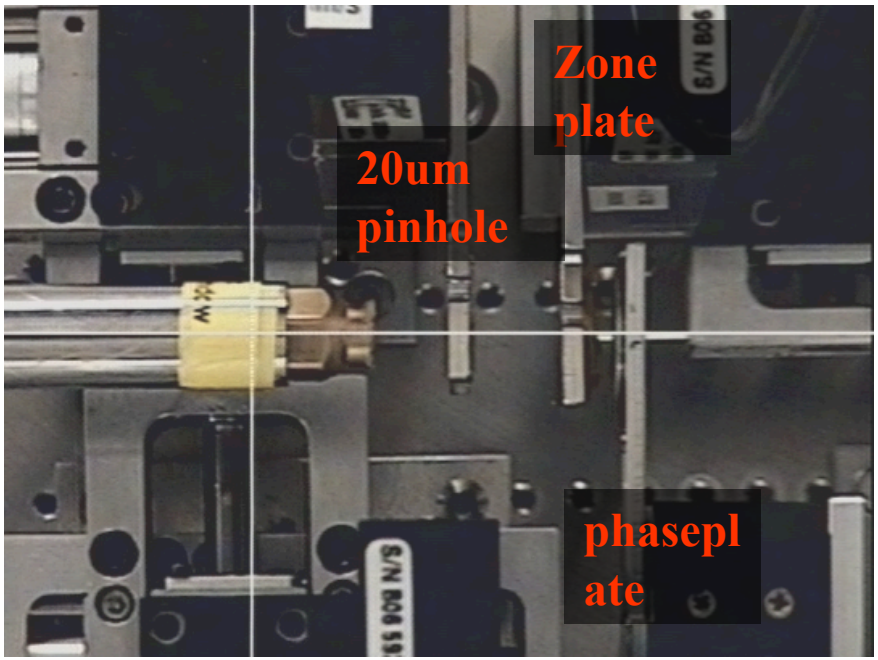
Conclusions

- Small crystal imaging
- Ptychography reveals probe structure also
- Phase plate demonstrated
- New custom phase plates
- Preparations under way for LCLS

Experimental setup cSAXS (SLS)



Side view



Top view (zoomed in)