Coherent Diffraction Imaging

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Outline

- Imaging with X-rays
- Coherence based imaging
- Nanocrystal structures
- Extension to phase objects
- Exploration of crystal strain
- Biological imaging by CXD

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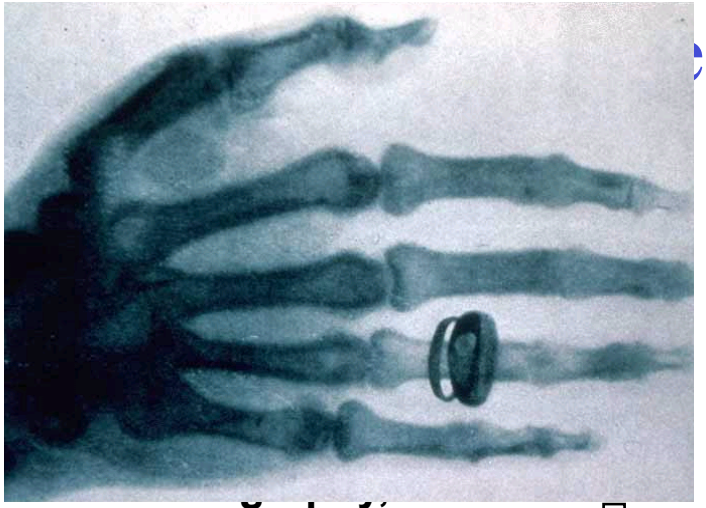
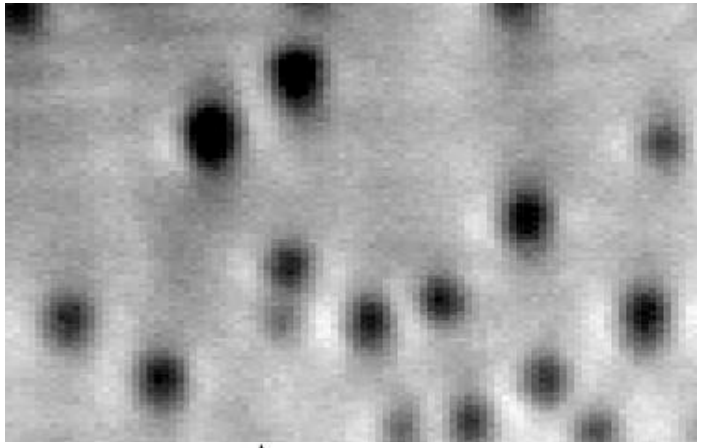
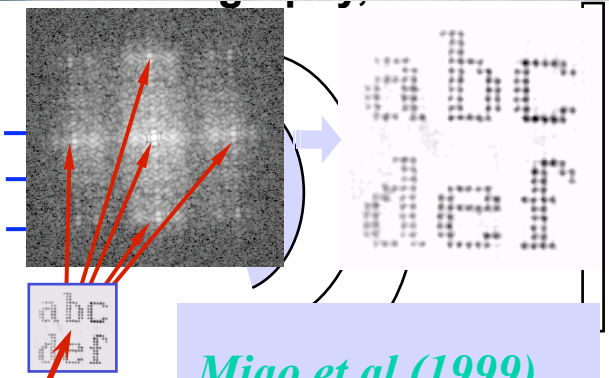
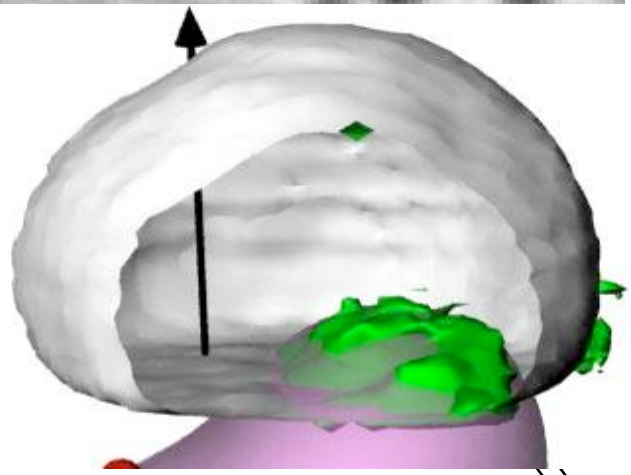
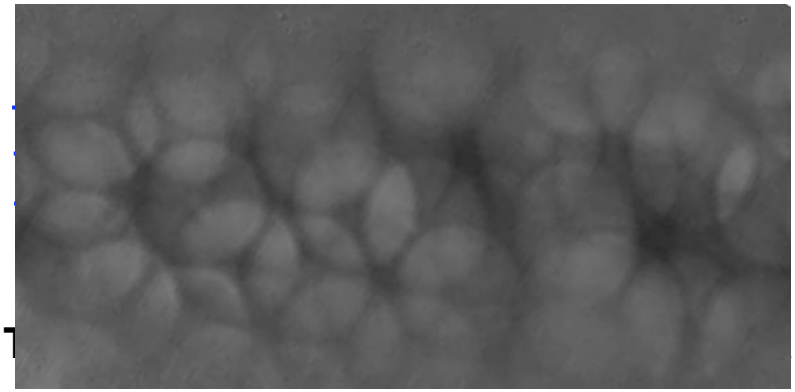






Miao et al (1999)

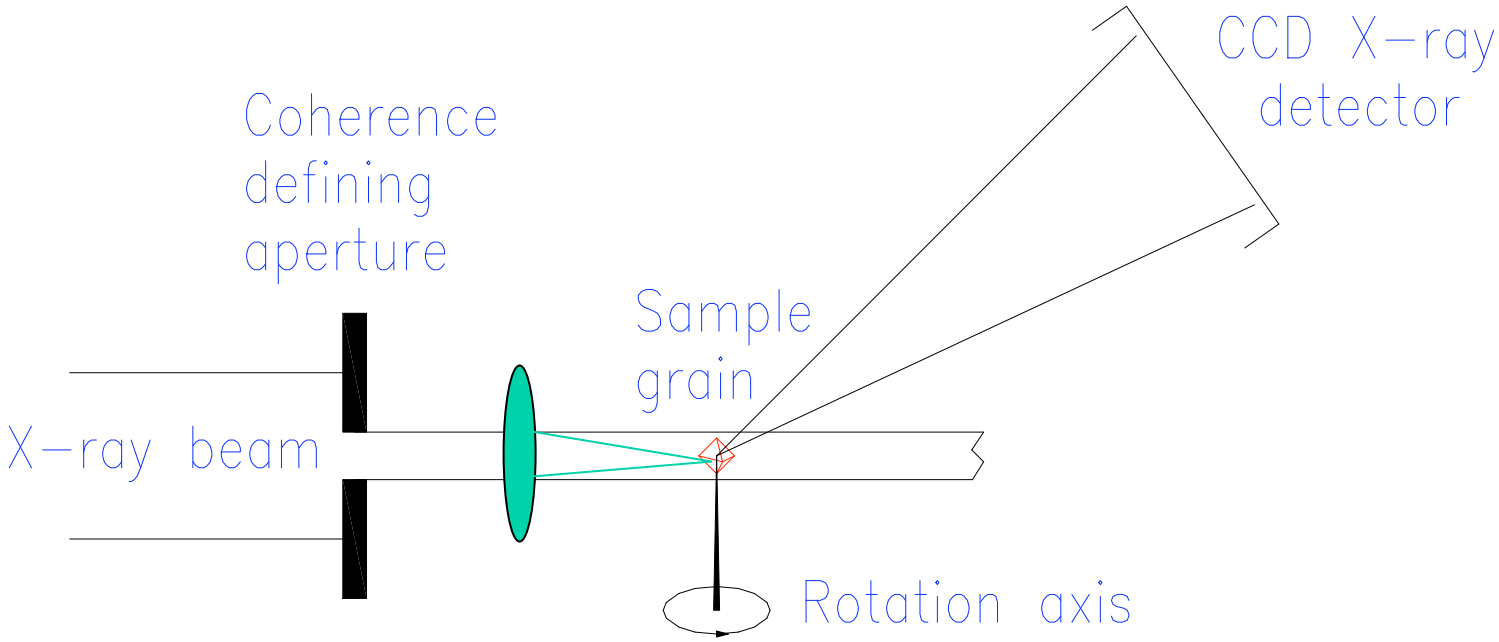




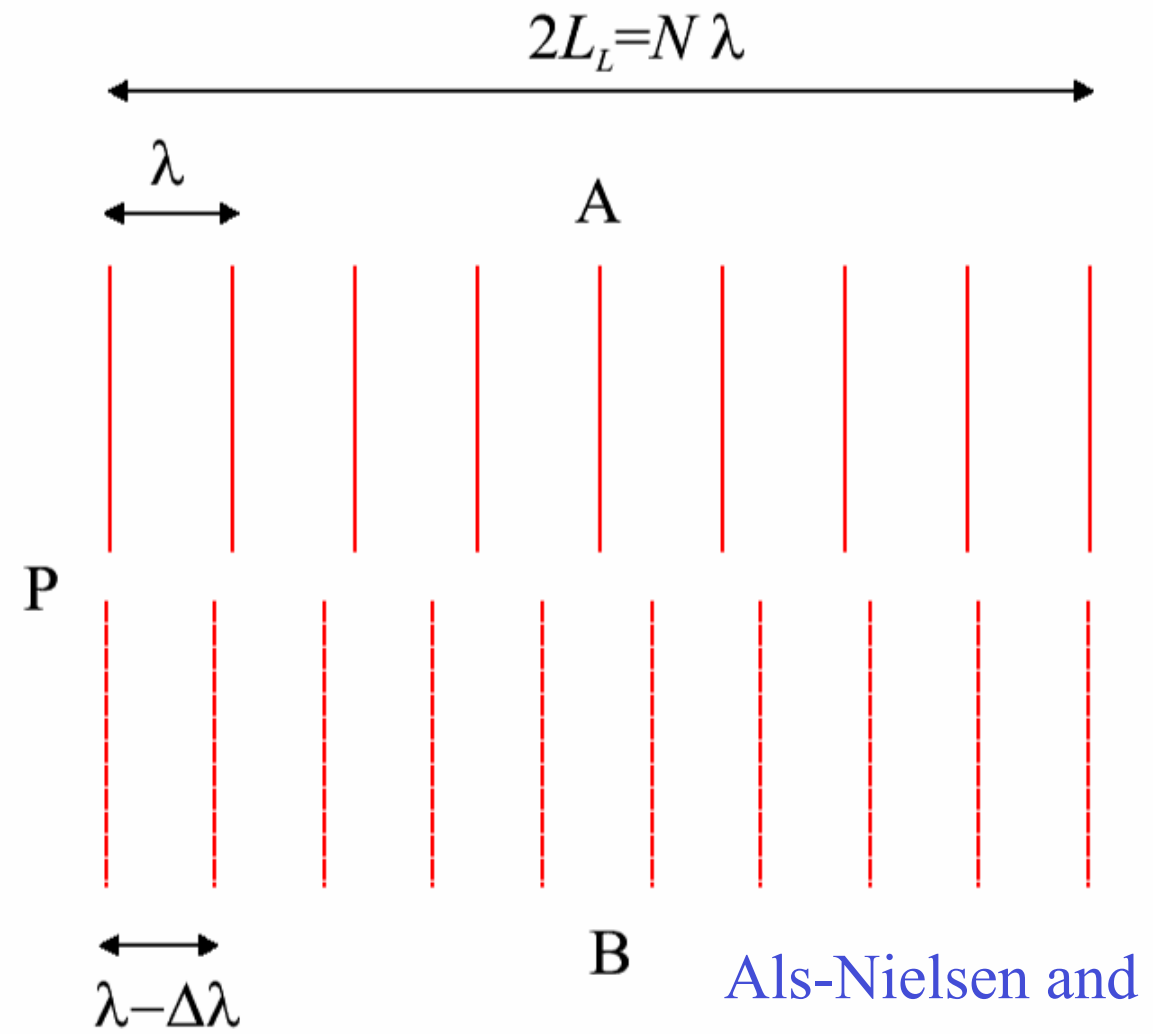
Lensless X-ray "Microscope"

APS ξ_{HOR}= 20μm, focus to 1μm

NSLS-II ξ_{HOR}= 500μm, focus to 0.05μm



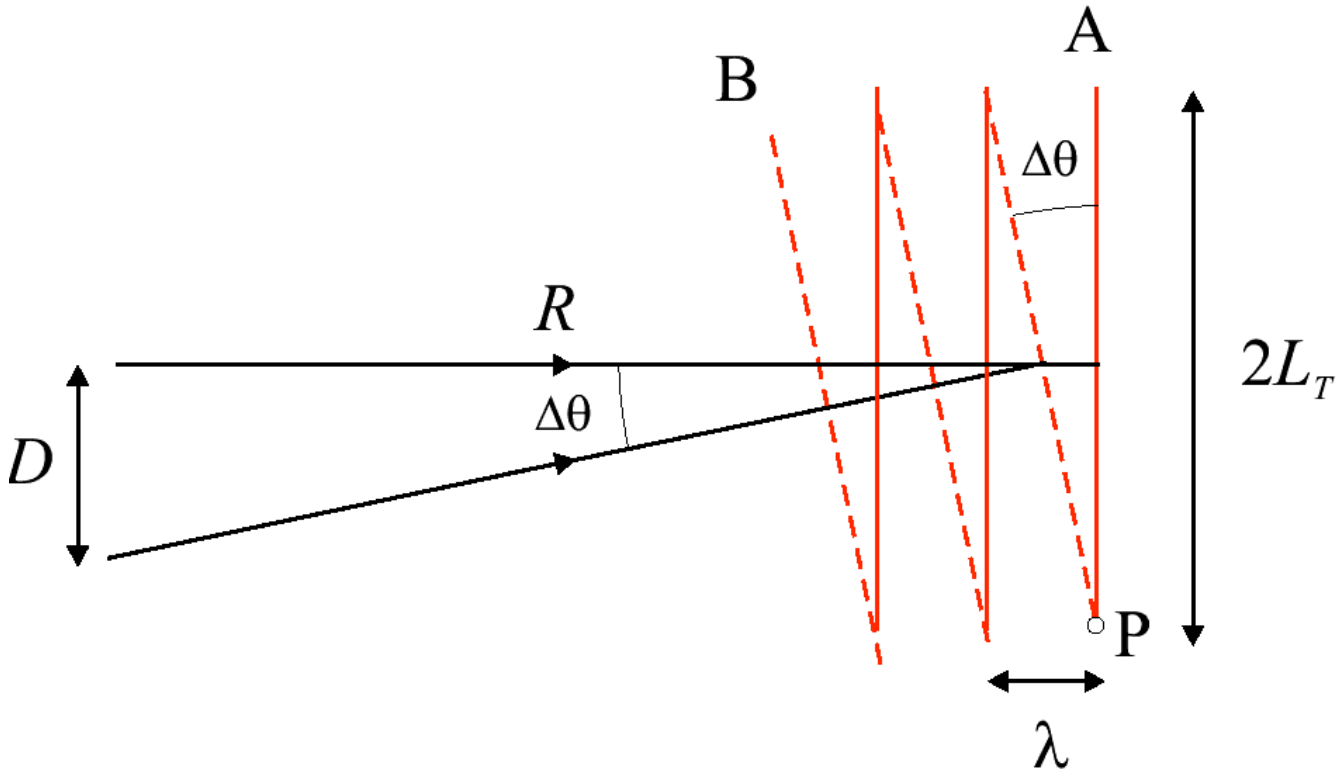
Longitudinal Coherence



$$L_L = \frac{1}{2}\frac{\lambda^2}{\Delta\lambda}$$

Als-Nielsen and McMorrow (2001)

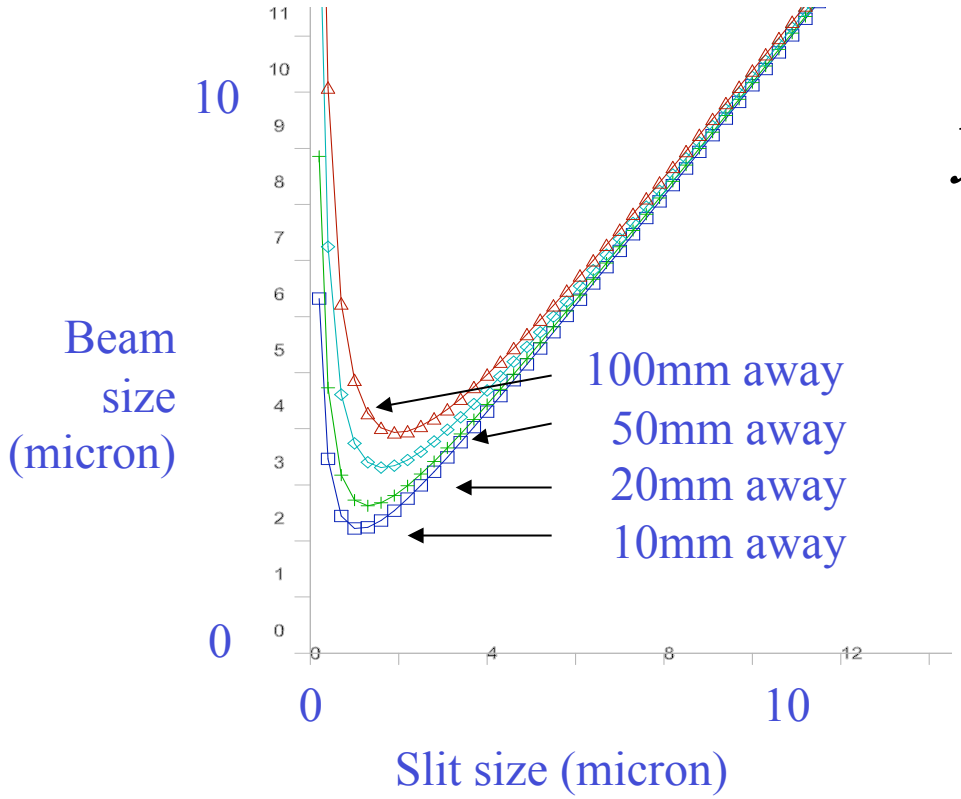
Lateral (Transverse) Coherence



$$L_T = \frac{\lambda}{2}\frac{R}{D}$$

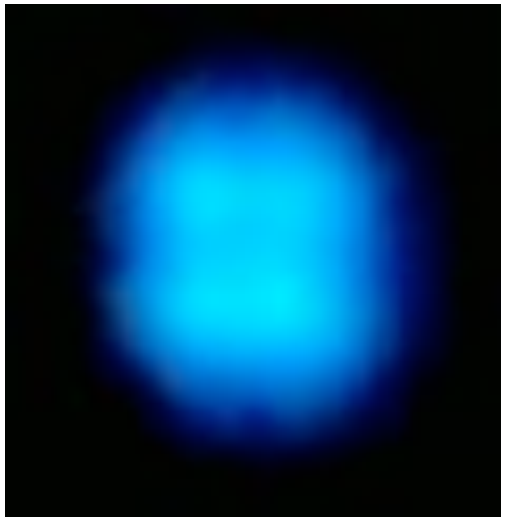
Als-Nielsen and McMorrow (2001)

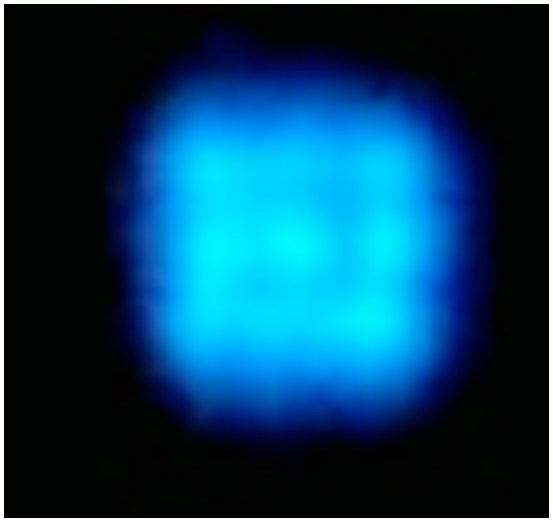
Smallest Beam using Slits (9keV)



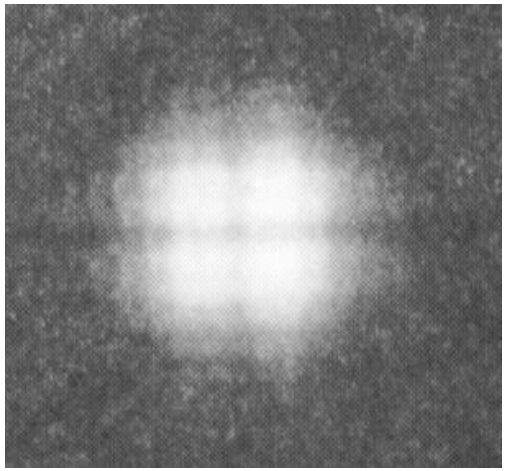
$$y(x) = x + \frac{\lambda d}{x}$$

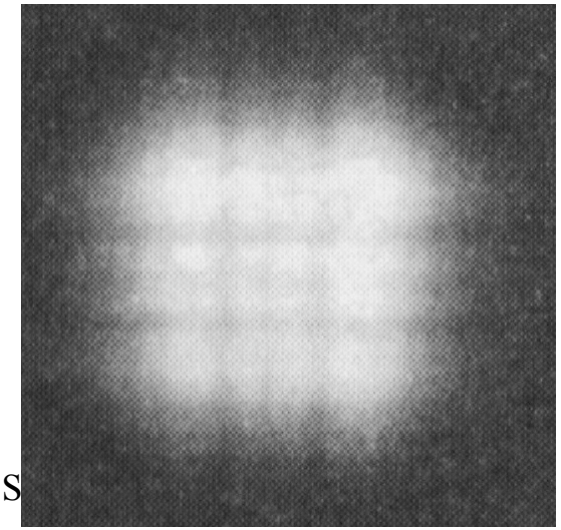
Fresnel Diffraction when $d^2 \sim \lambda D$





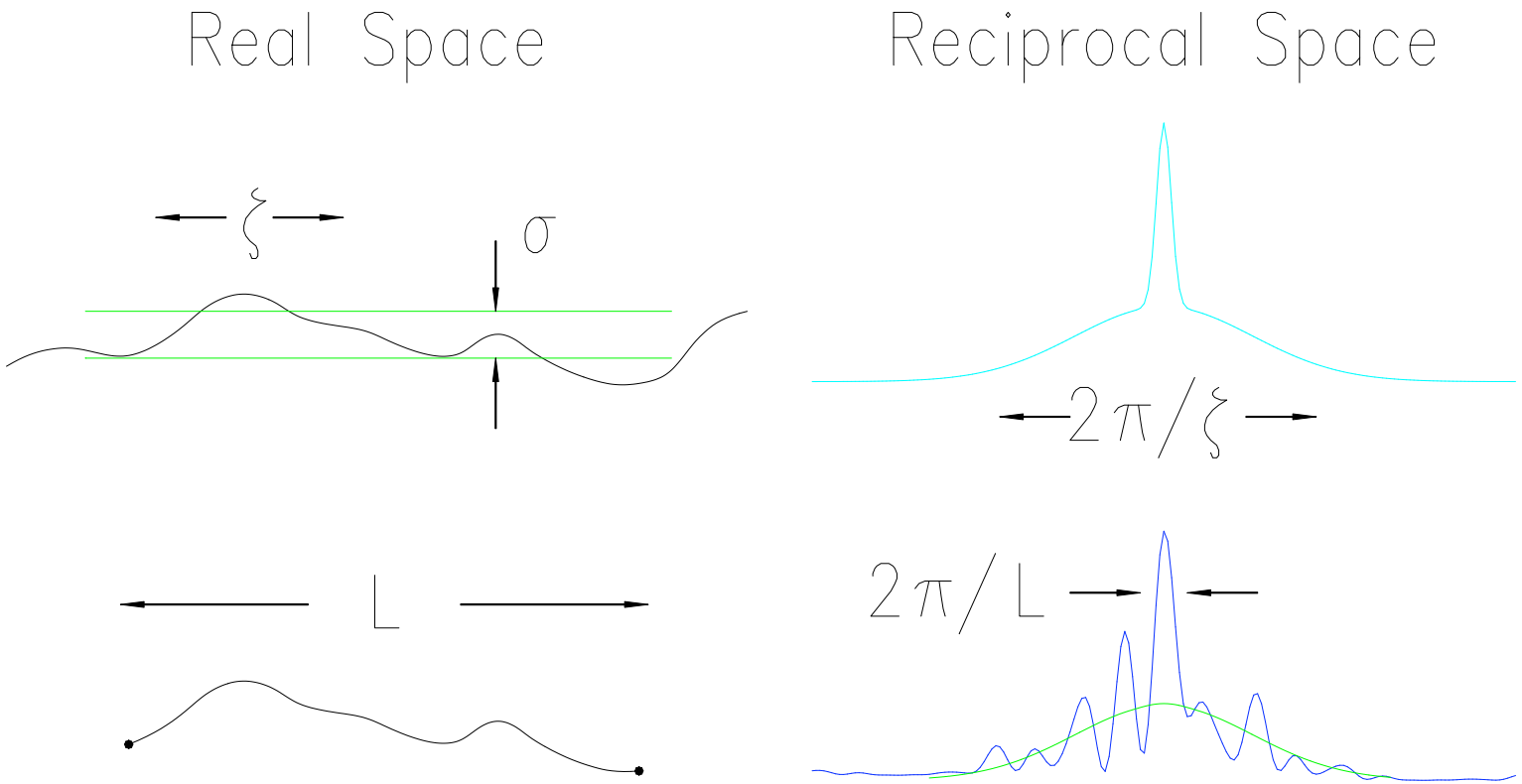
X-ray beam defined by RB slits



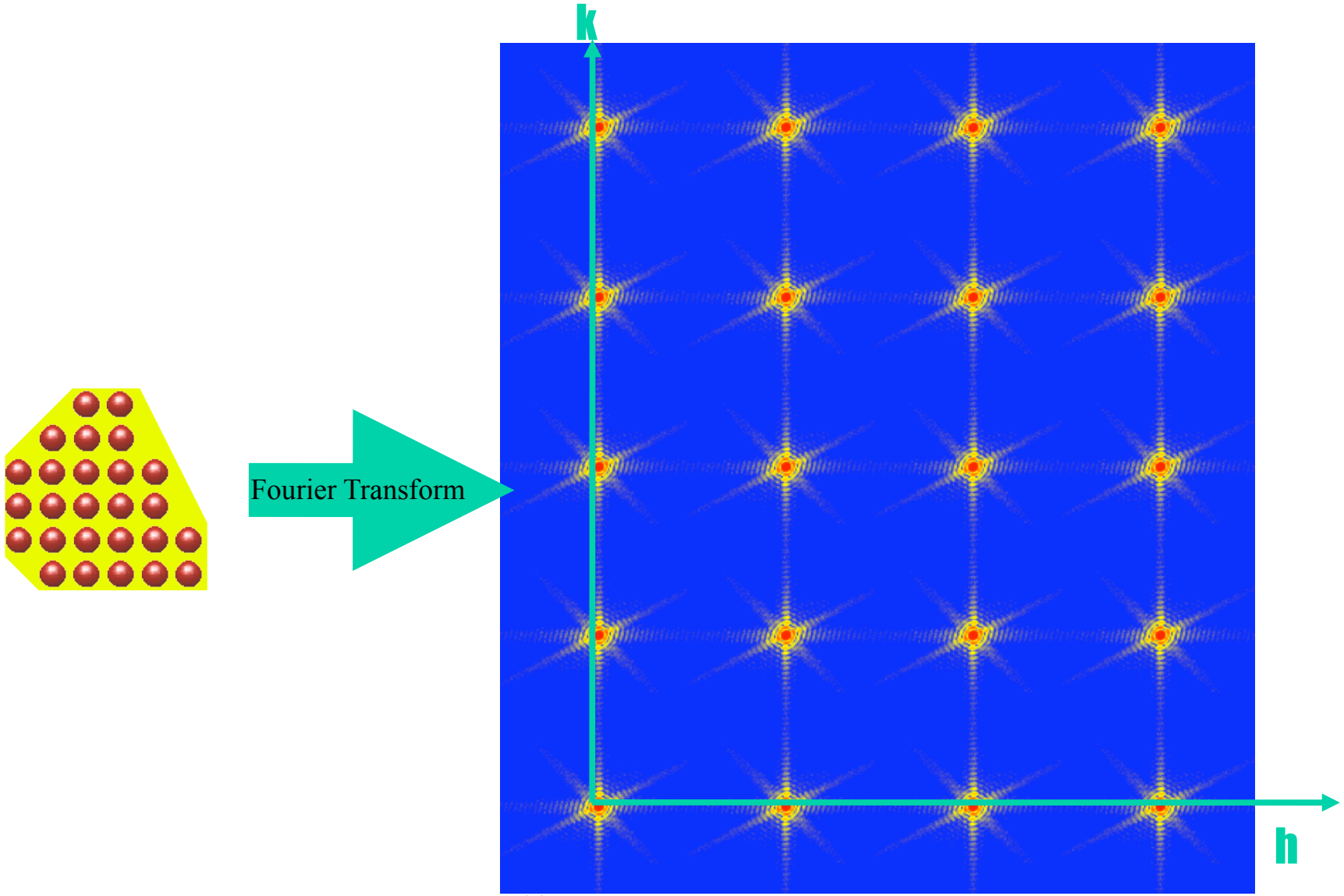


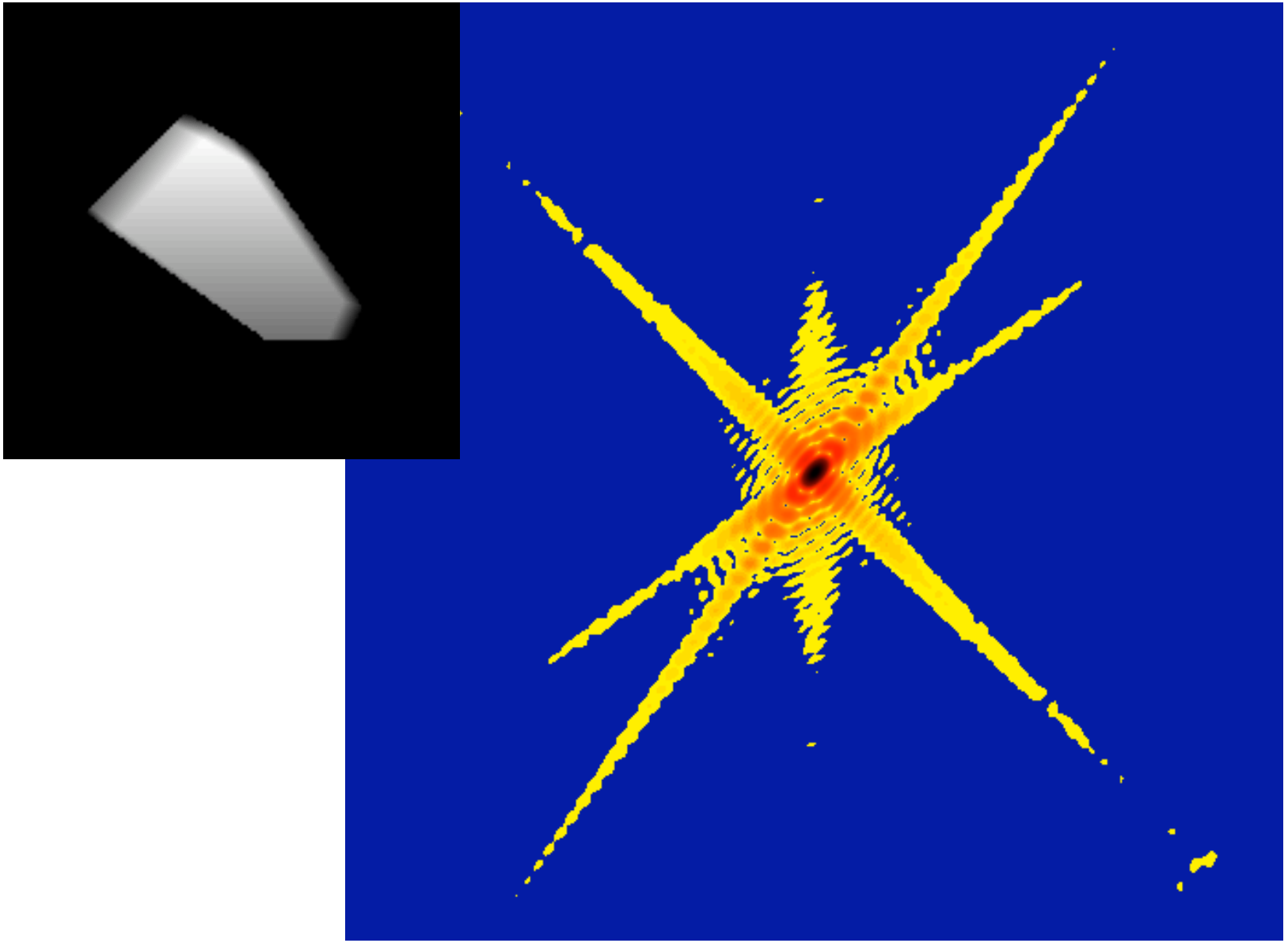
Visible Fresnel diffraction from Hecht "Optics"

Diffuse Scattering acquires fine structure with a Coherent Beam

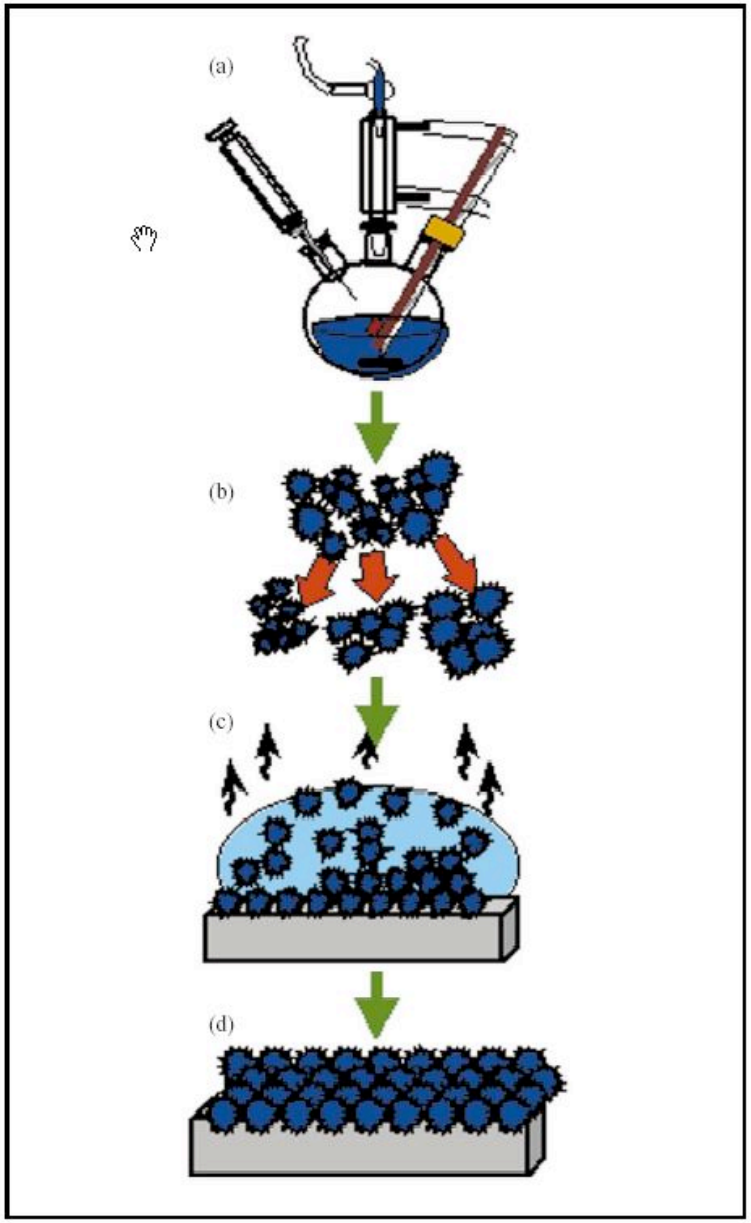


Coherent Diffraction from Crystals



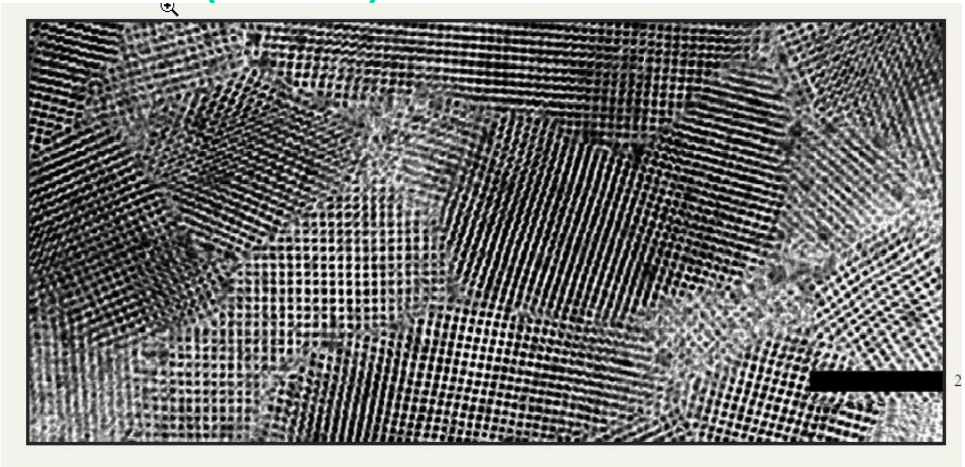


Chemical Synthesis of Nanocrystals

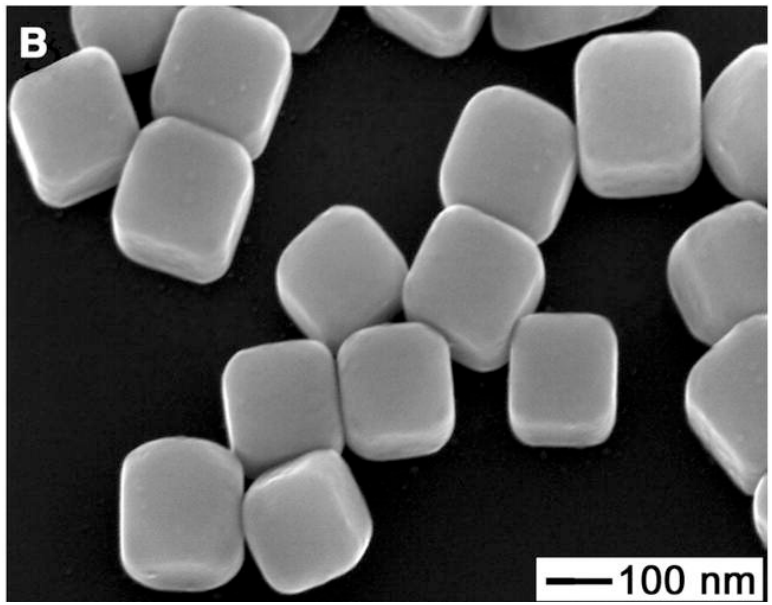


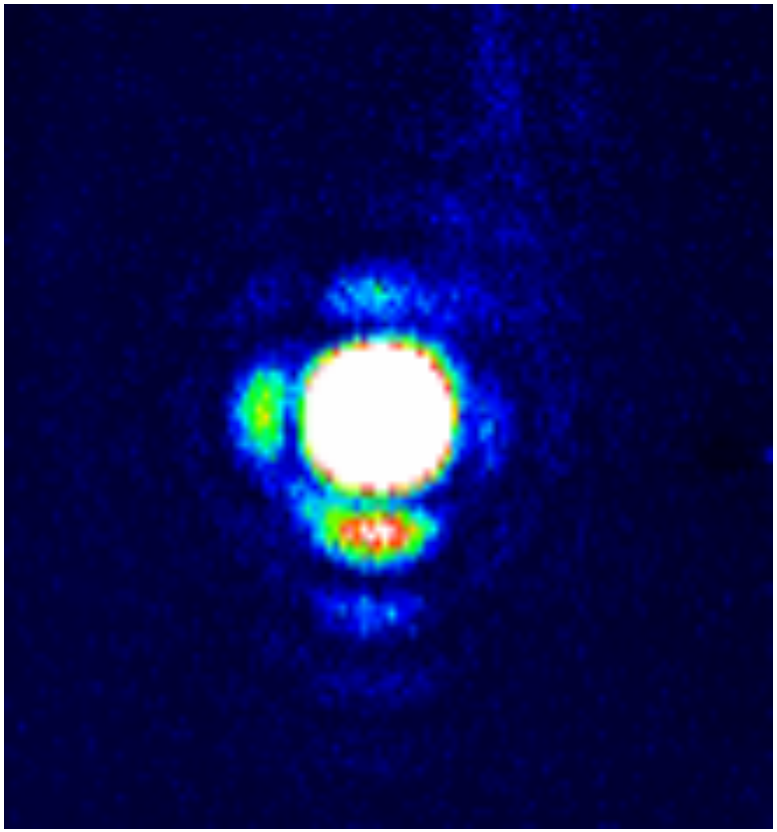
- Reactants introduced rapidly
- High temperature solvent
- Surfactant/organic capping agent
- Square superlattice (200nm scale)

C. B. Murray, IBM J. Res. & Dev. **45** 47 (2001)



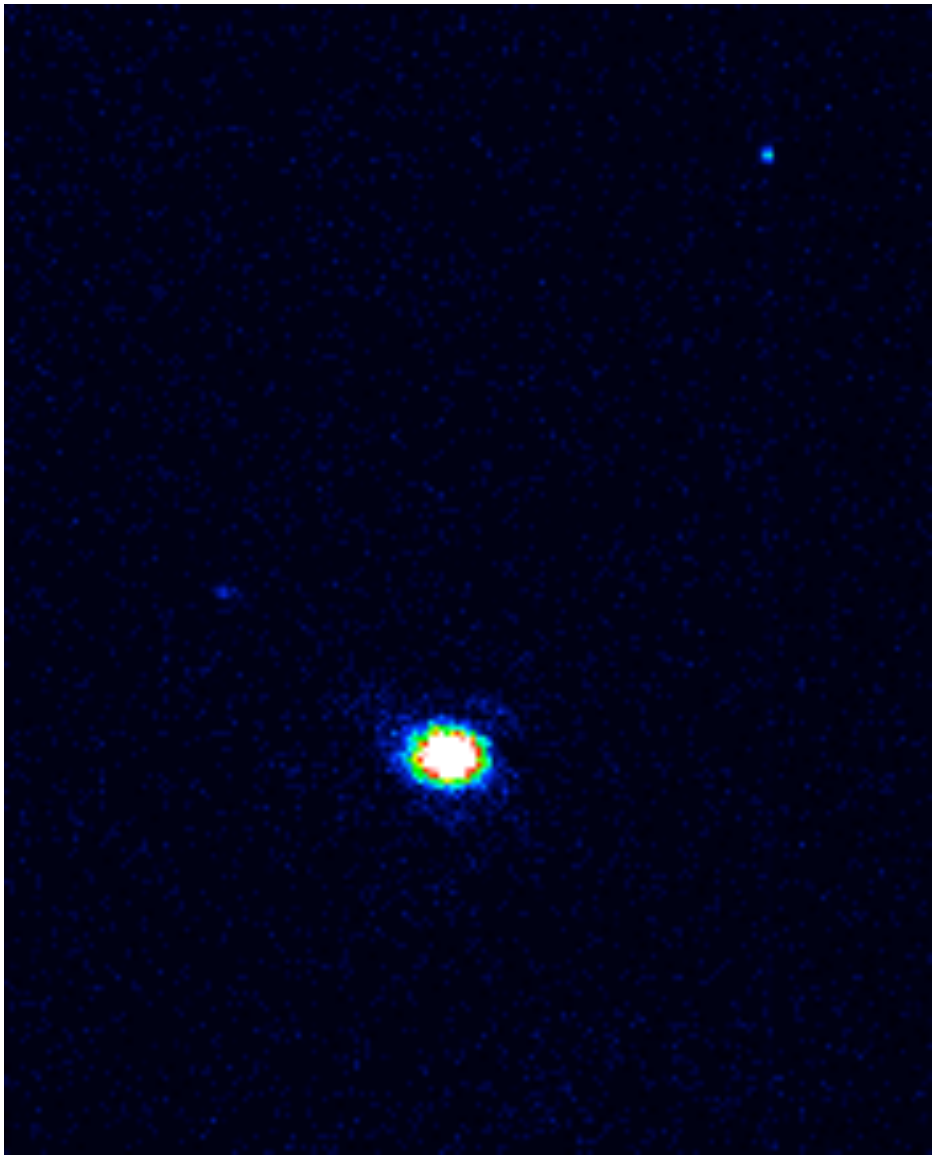
Chemically Synthesized Silver Nanocubes

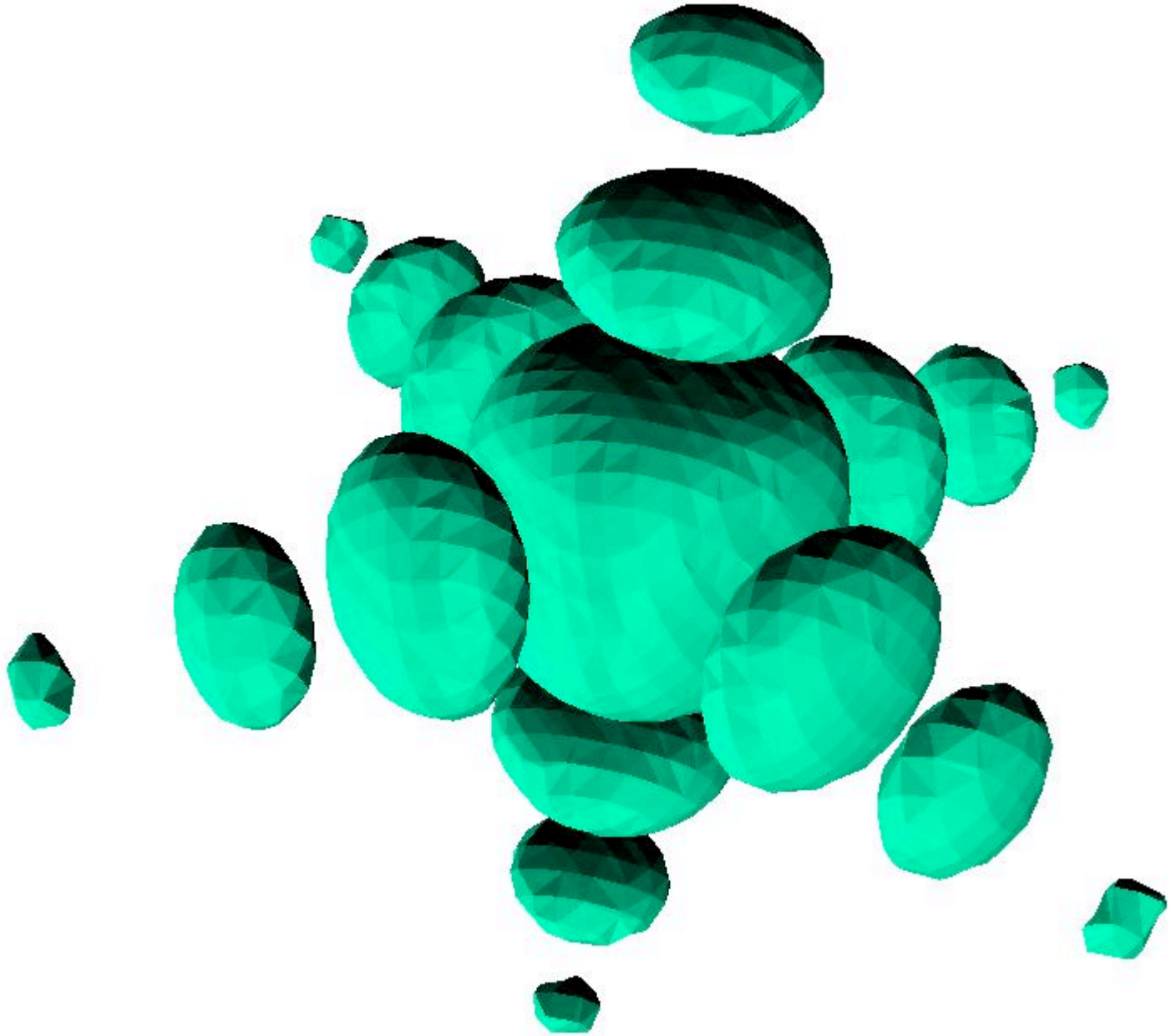




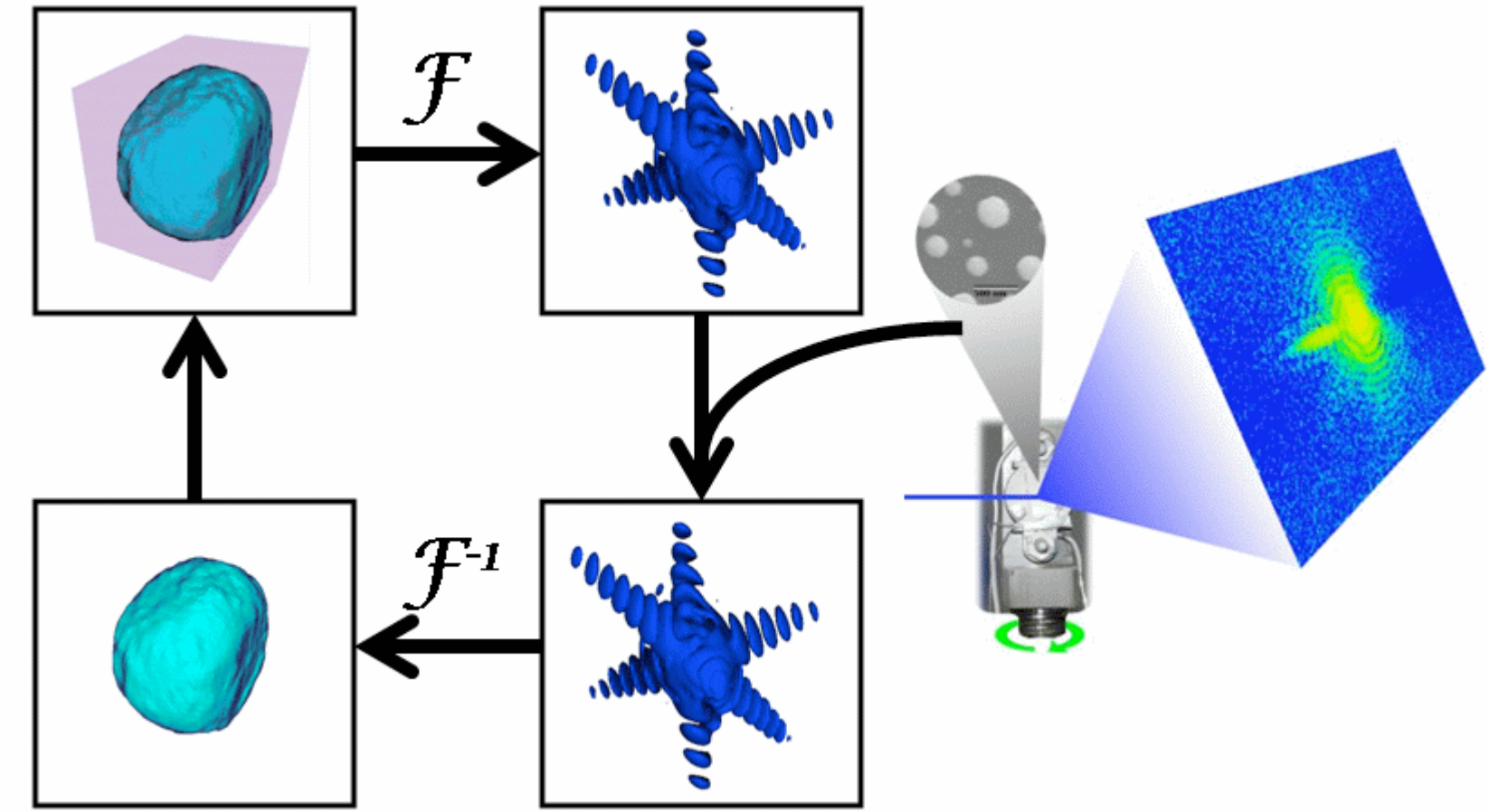
Yugang Sun and Younan Xia,
Science 298 2177 (2003)

Rocking scan of Ag cubes with 0.01° steps

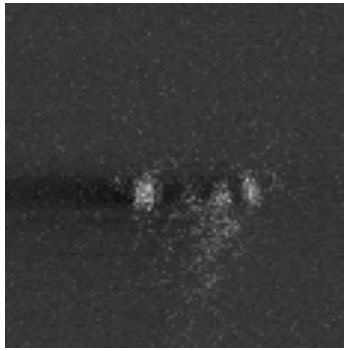


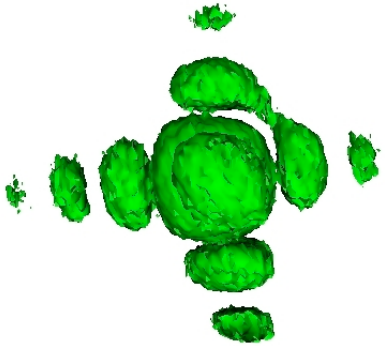


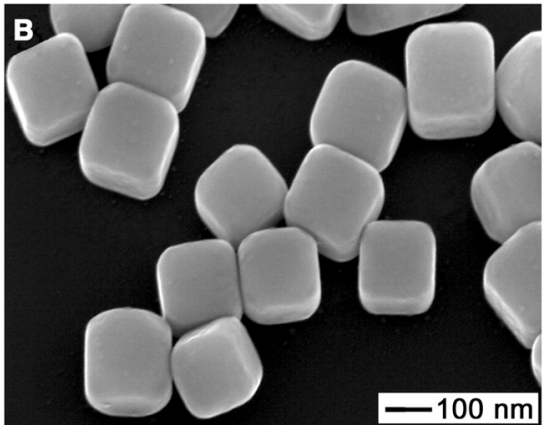
Generic "Error Reduction" method

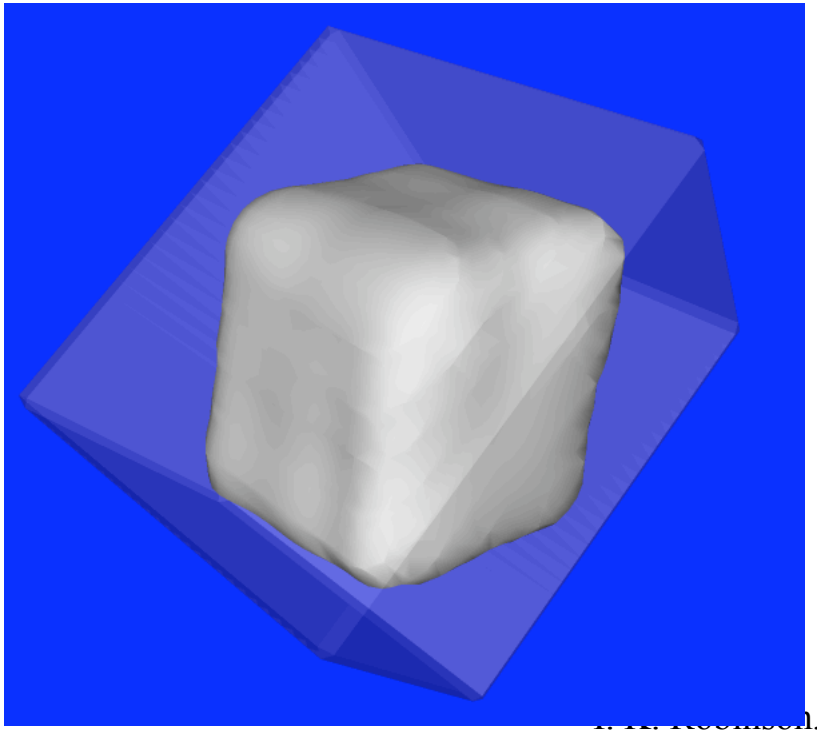


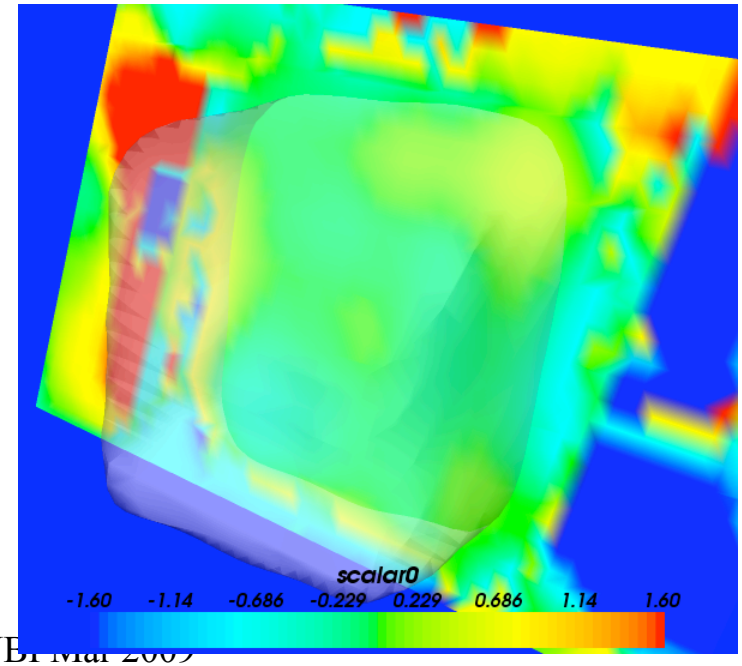
J. R. Fienup Appl. Opt. 21 2758 (1982)
R. W. Gerchberg and W. O. Saxton Optik 35 237 (1972)



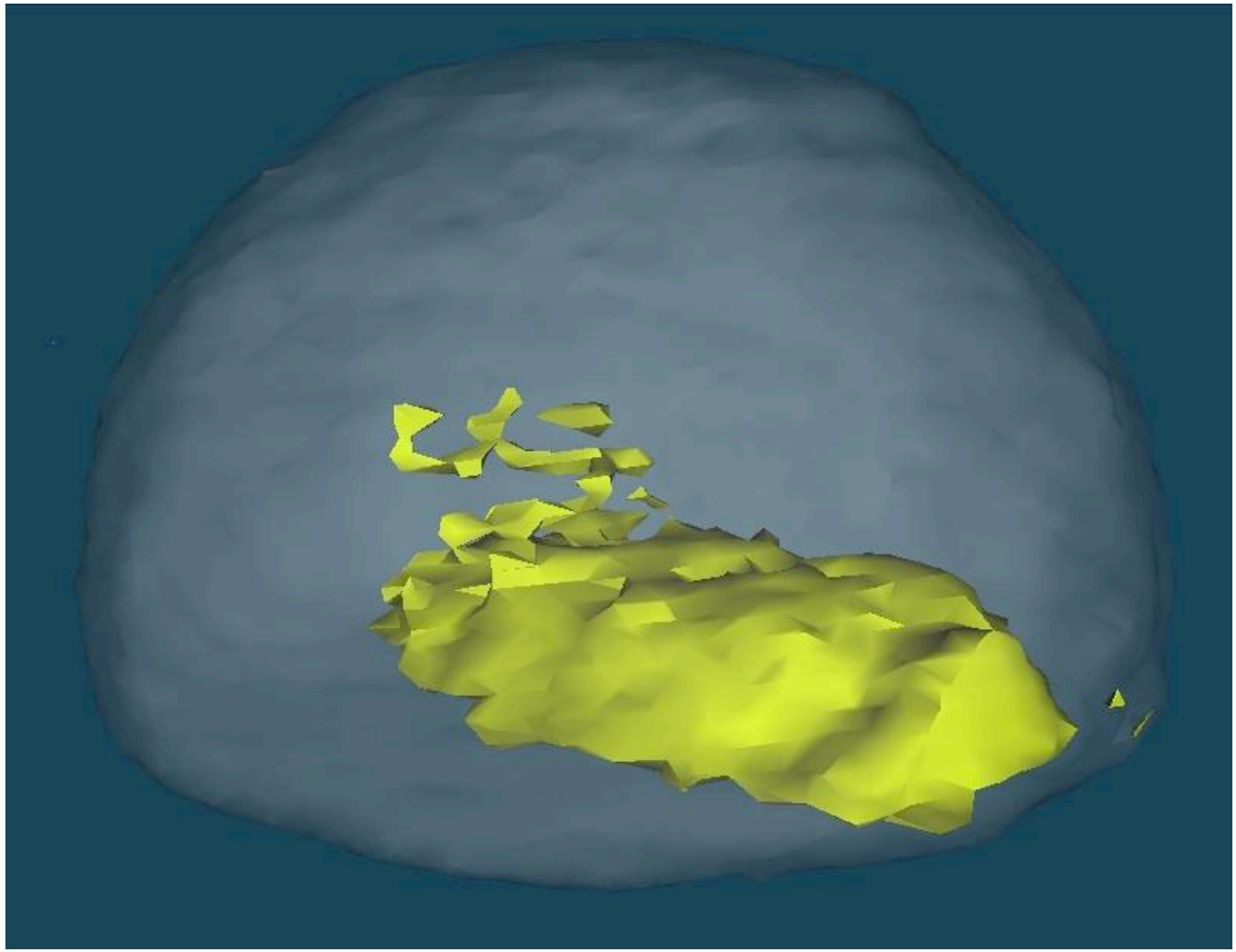



B
100 nm

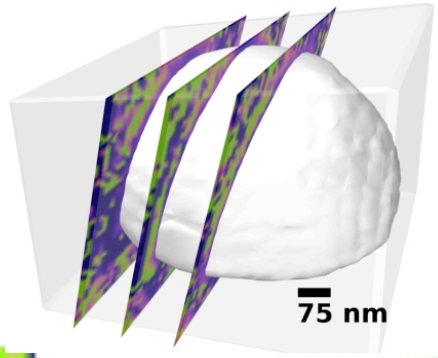


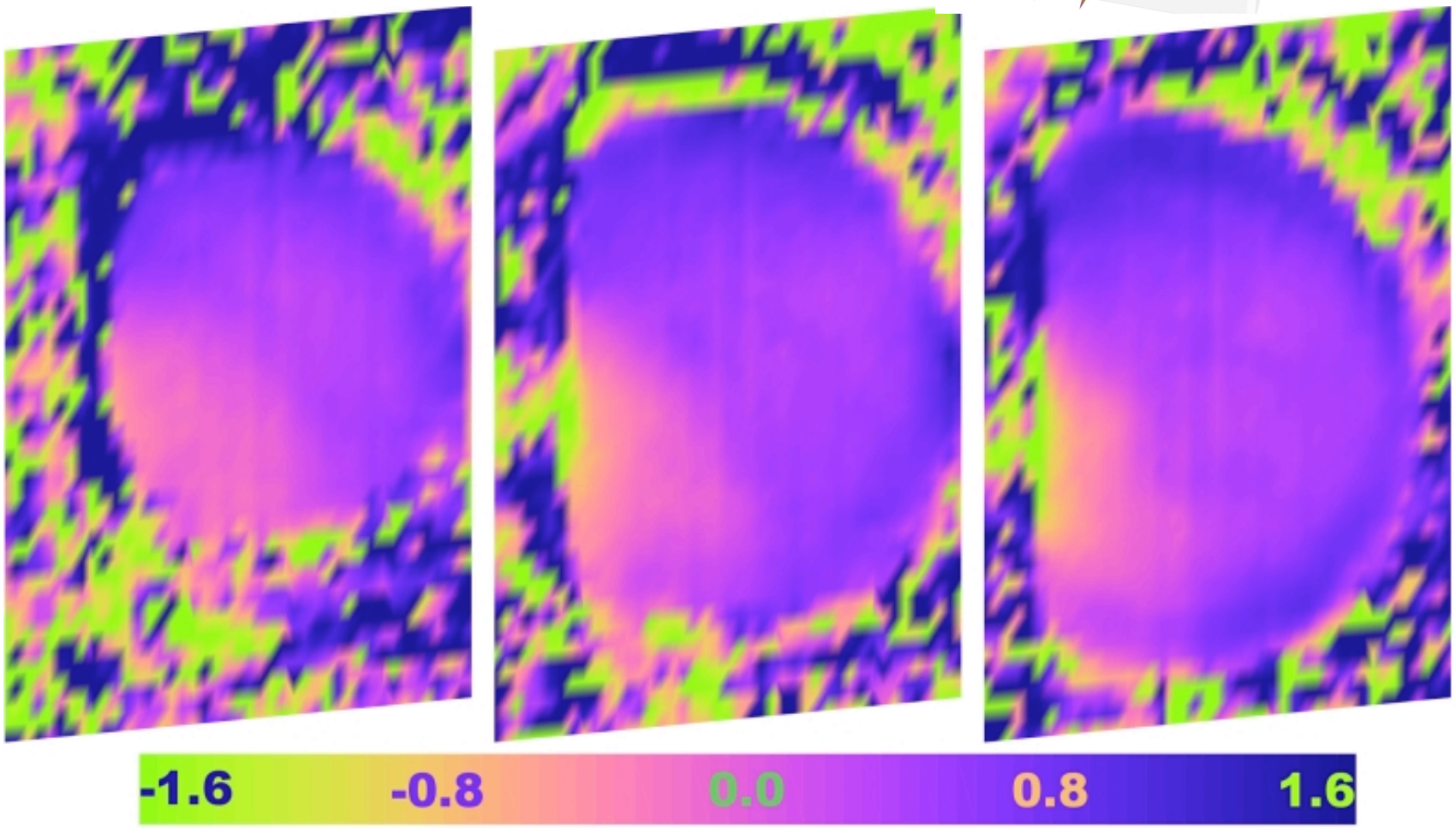

scalar0
-1.60 -1.14 -0.686 -0.229 0.229 0.686 1.14 1.60

Isosurface of 3D Phase Bump



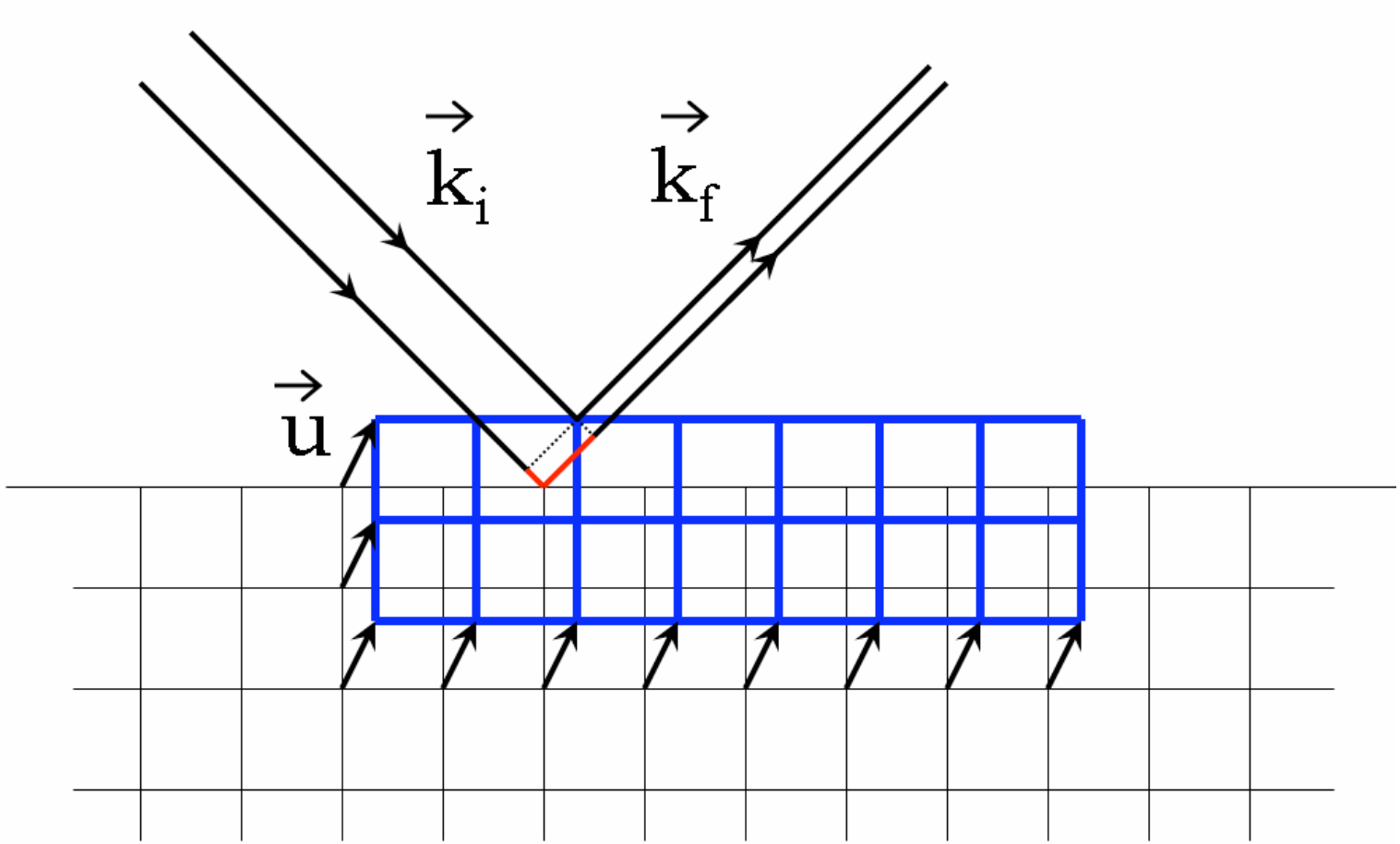
3D phase map sections

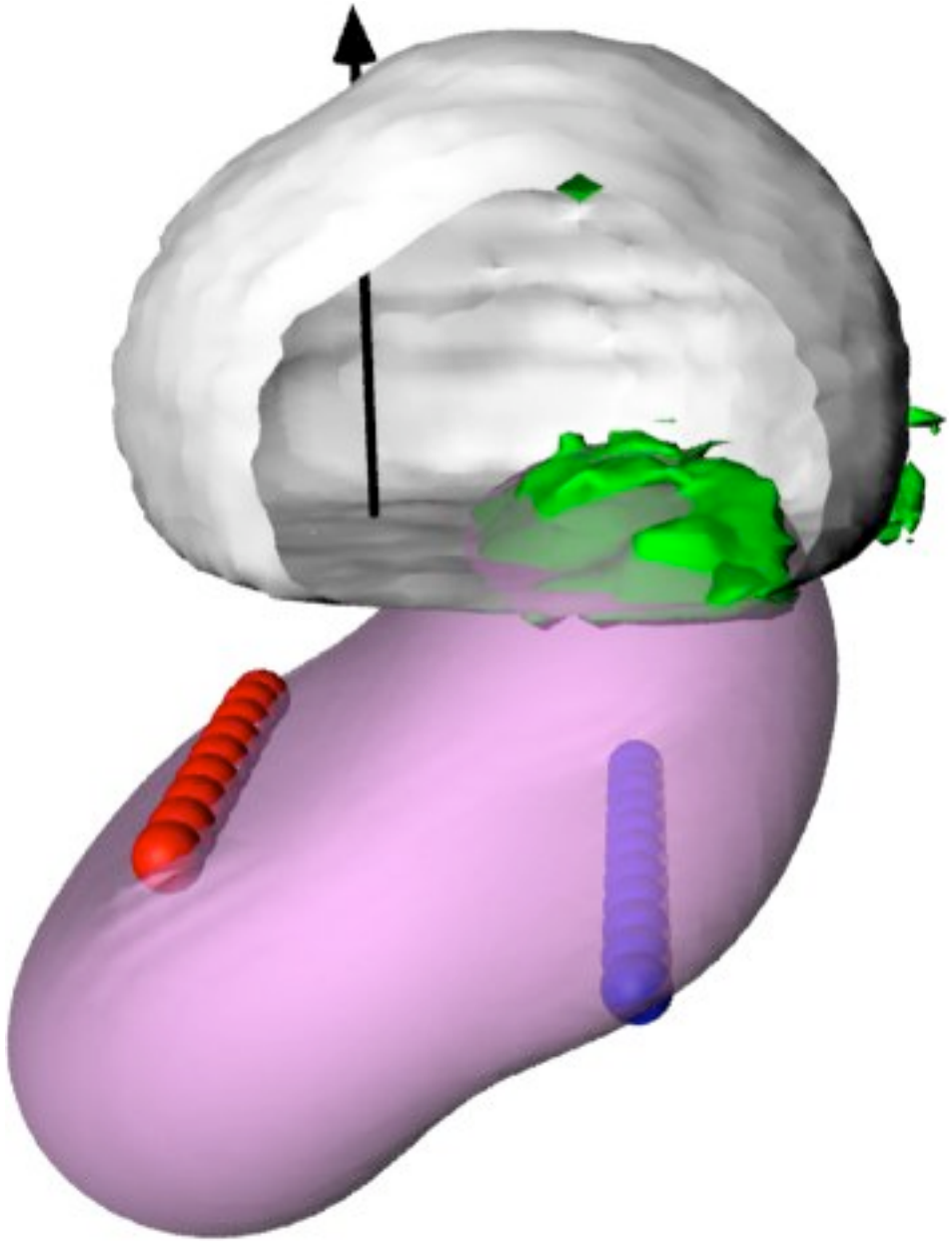




Sensitivity to strain

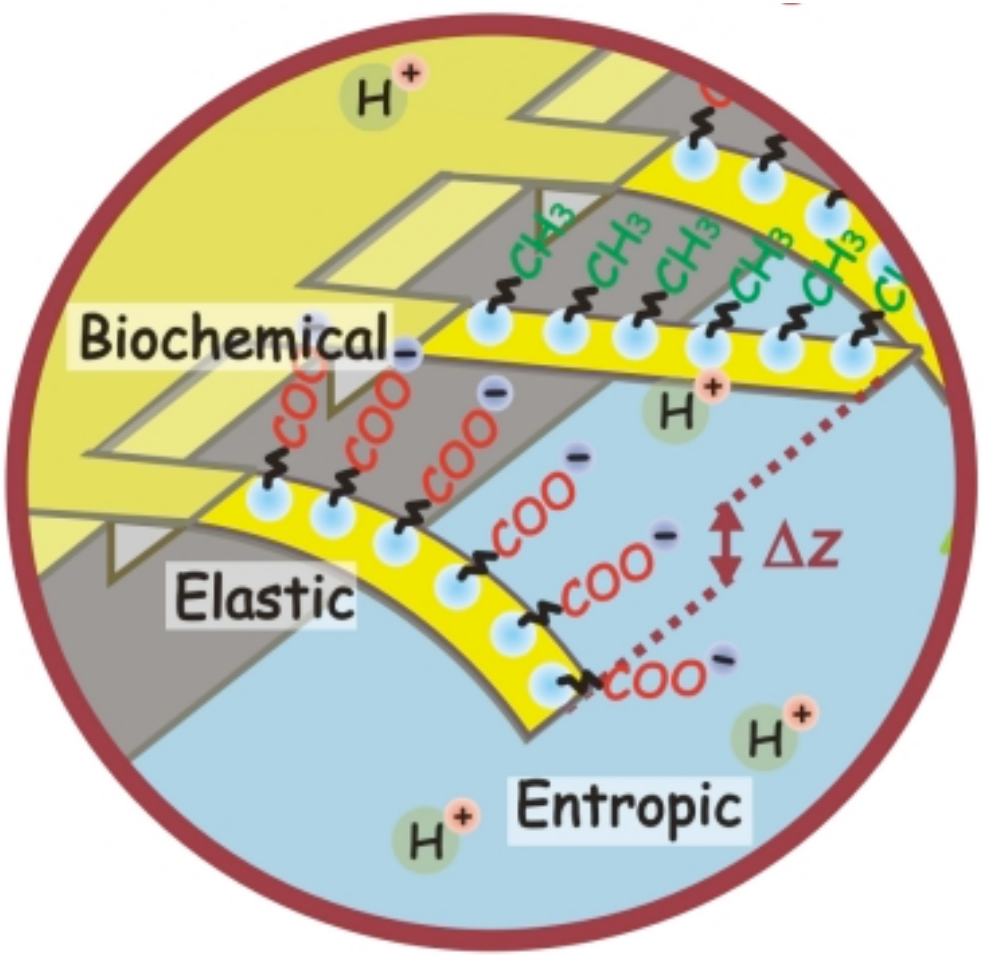
$$\Delta\varphi = \mathbf{k}_f \cdot \mathbf{u} - \mathbf{k}_i \cdot \mathbf{u} = \mathbf{Q} \cdot \mathbf{u}$$





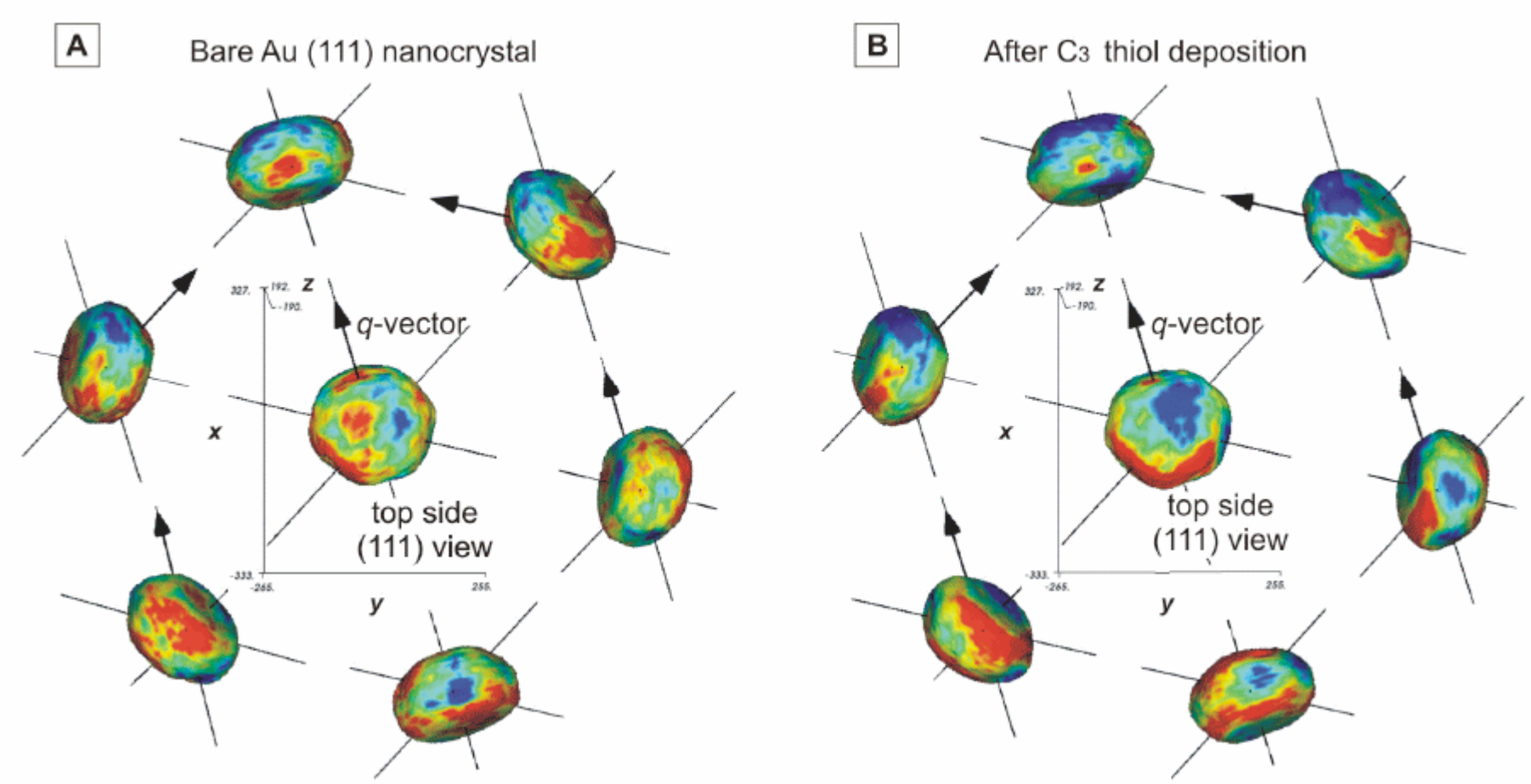
Nanocantilevers

Dr Rachel McKendrie



Strain induced by thiol binding

Moyu Watari, UCL, Oct 2008



CXD applied to collagen

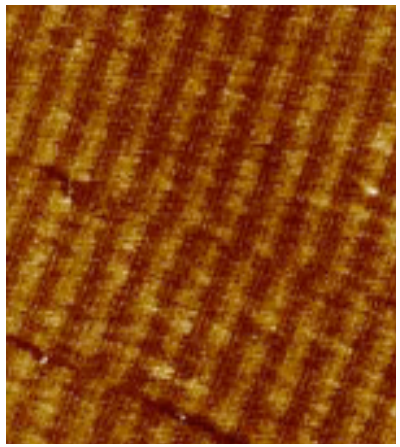
Felisa Berenguer, LCN

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

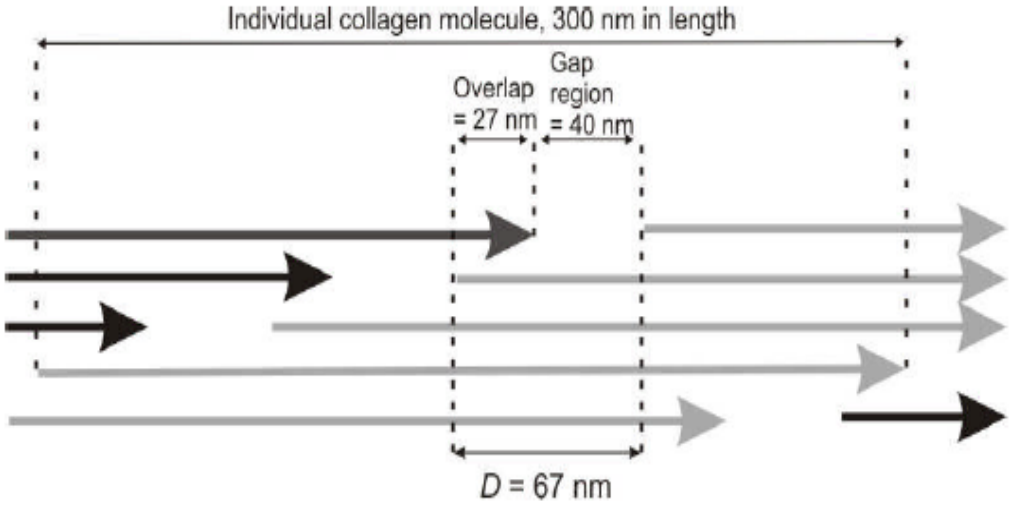
- Potential applications in medicine (artificial bone, skin diseases)

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

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

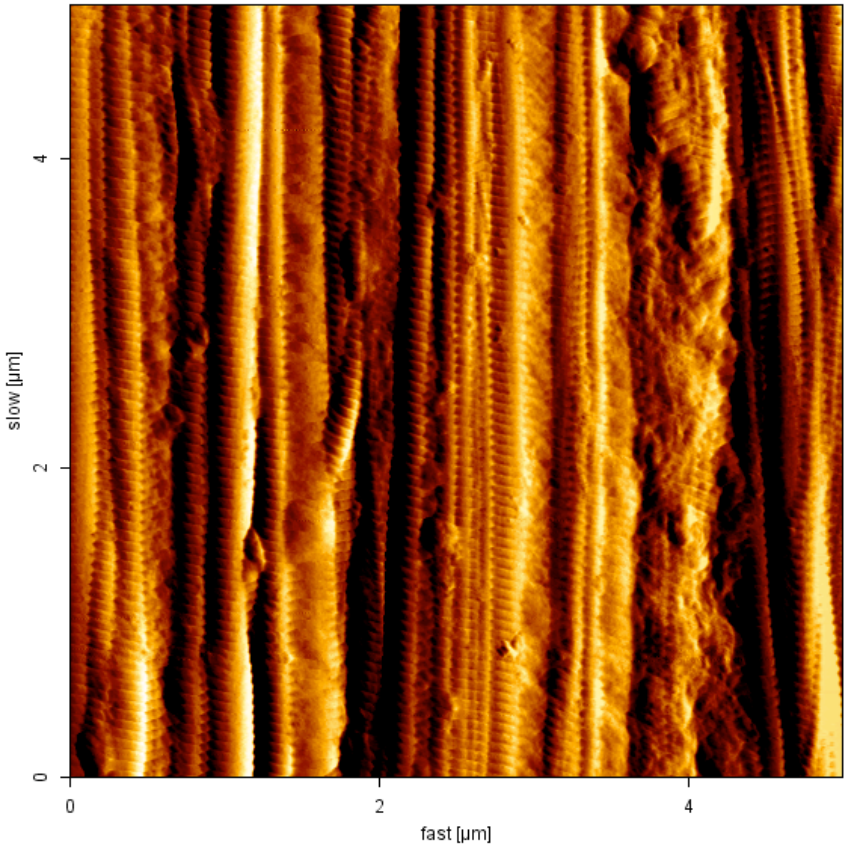


SEM [Cisneros, 2006]

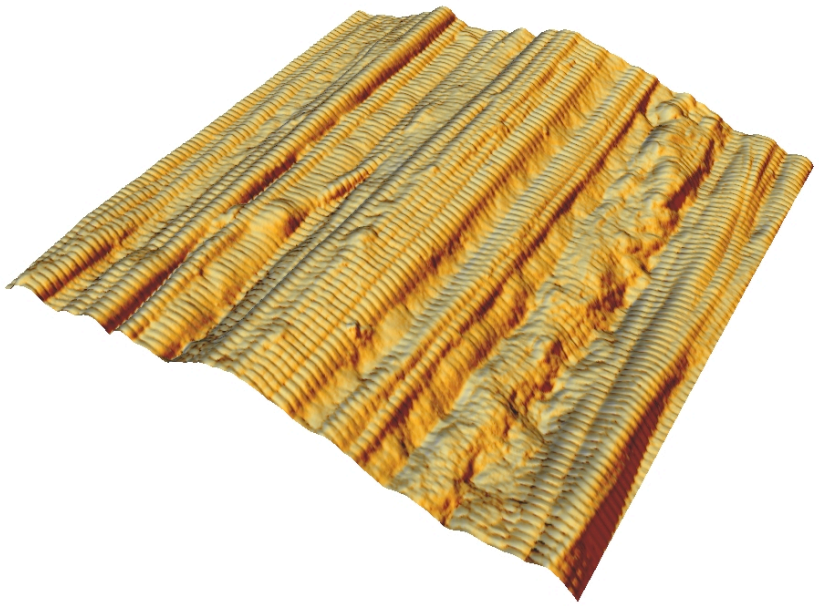


[Hodge and Petruska, 1976]

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, STRUBI Mar 2009

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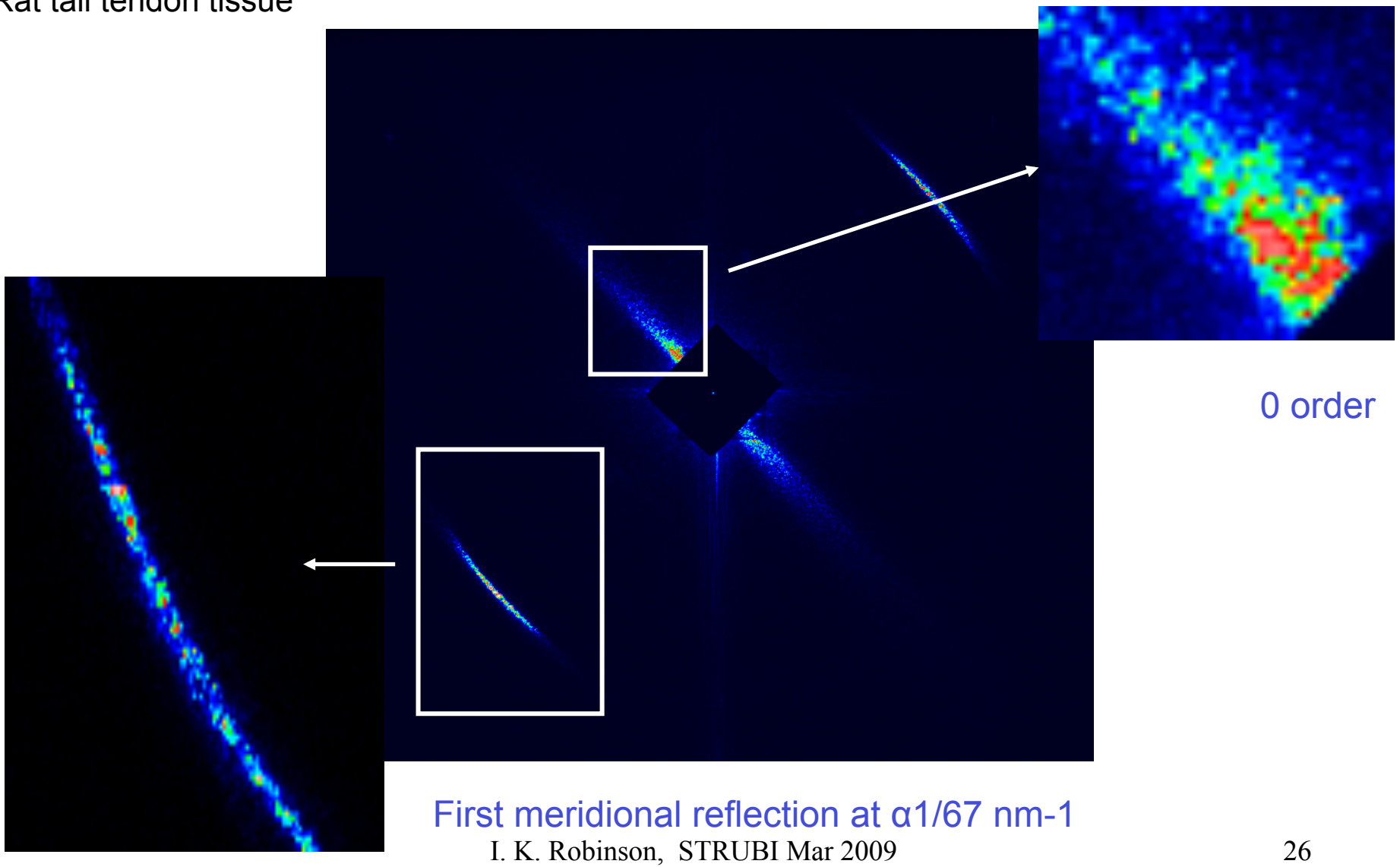
First experimental results on collagen

Rat tail tendon tissue

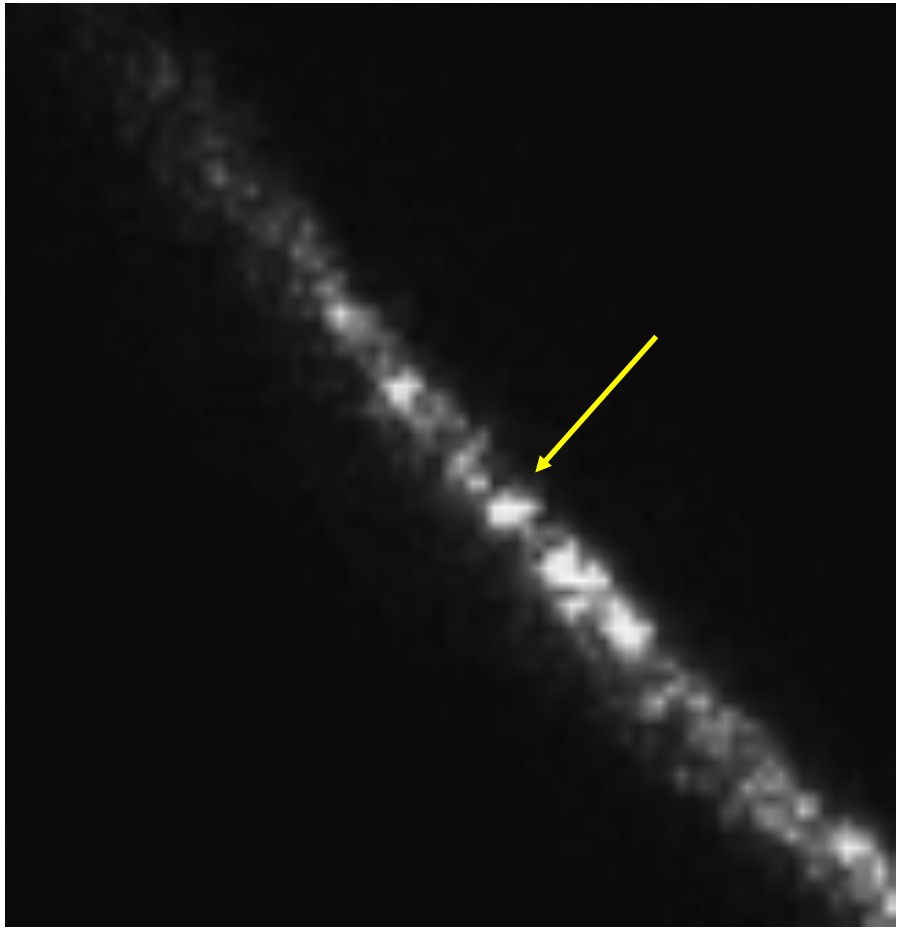


0 order

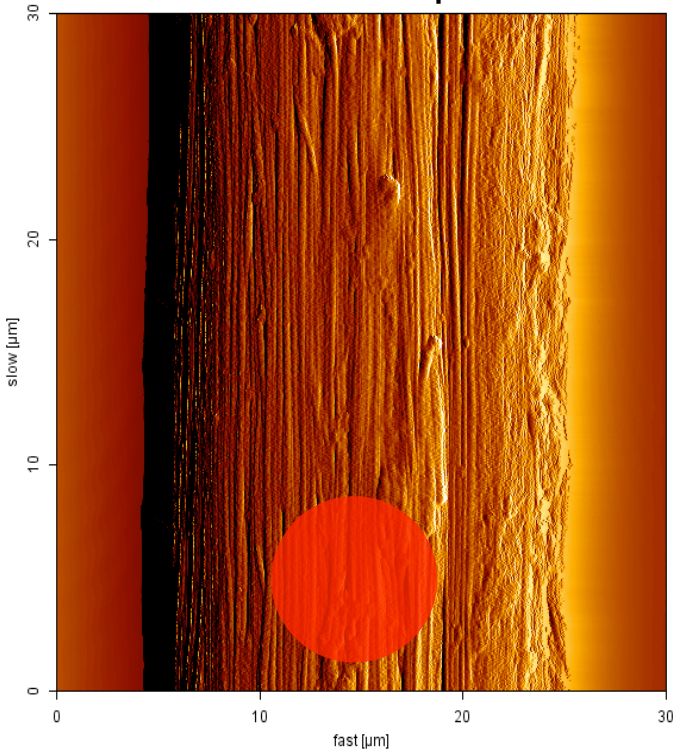
First meridional reflection at α1/67 nm-1

X-ray Ptychography

First meridional reflection

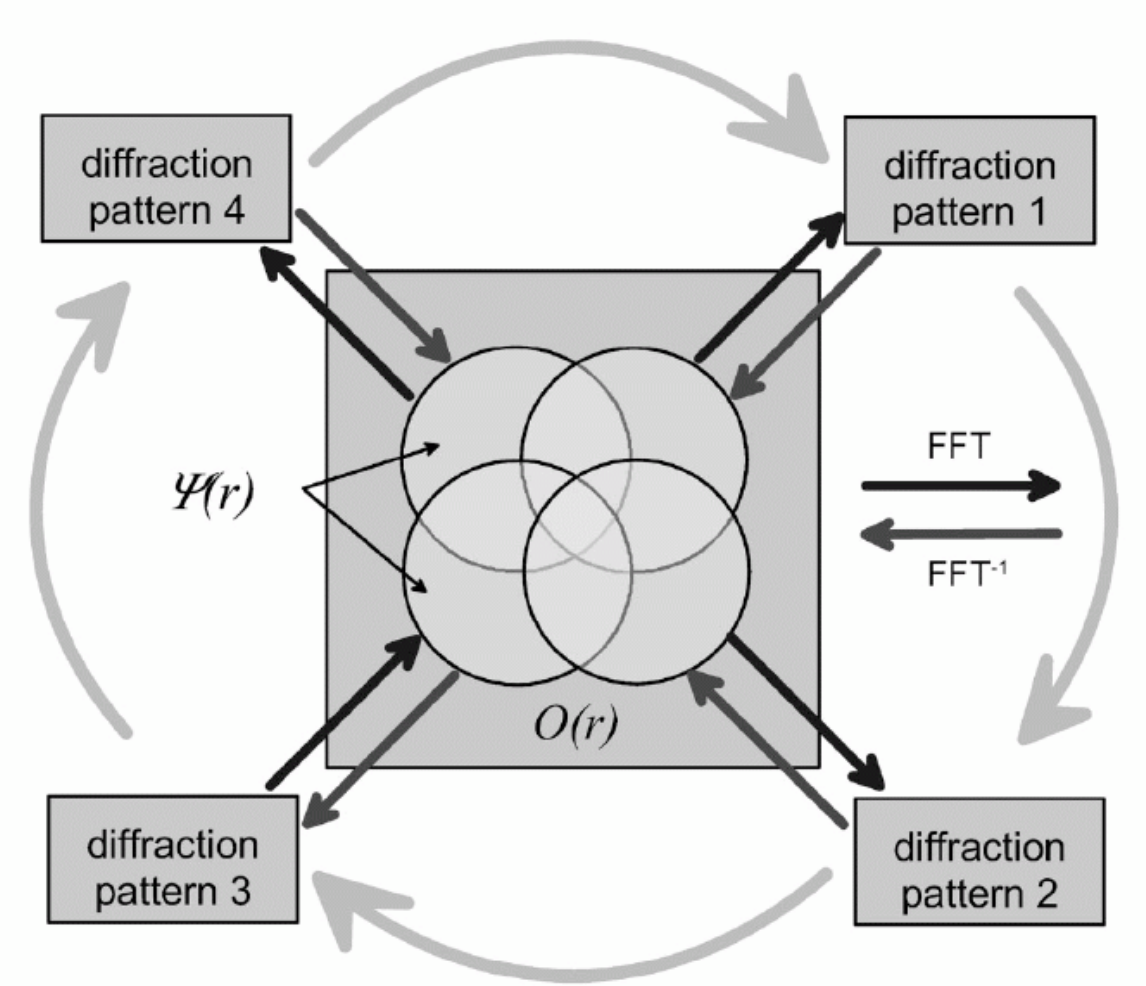


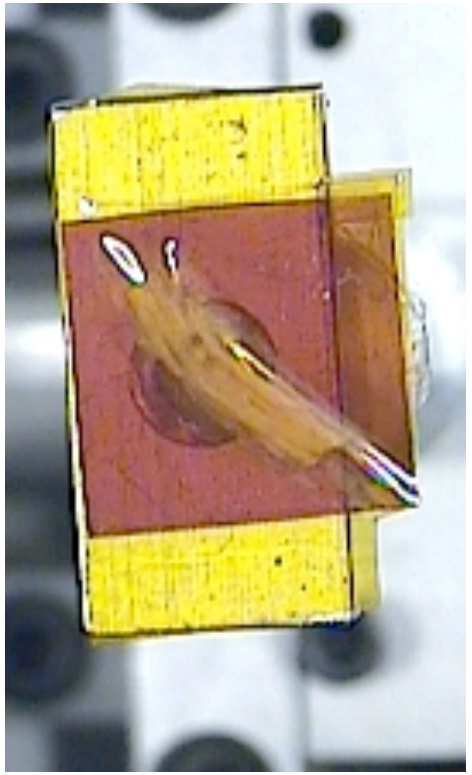
10 μm beam



Dark field imaging:
collagen distribution in different tissues

X-ray Ptychography

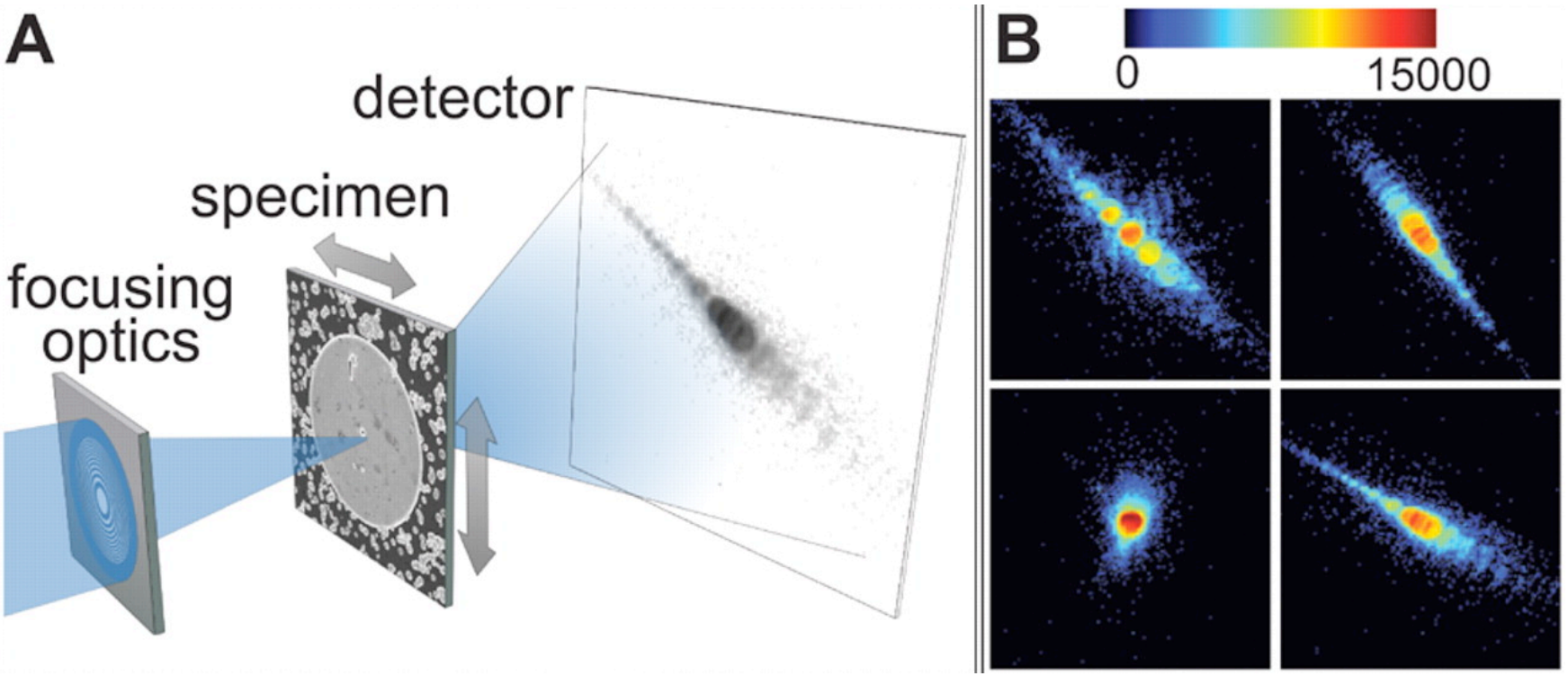




J. M. Rodenburg et al, Phys. Rev. Lett. 98 034801 (2007)

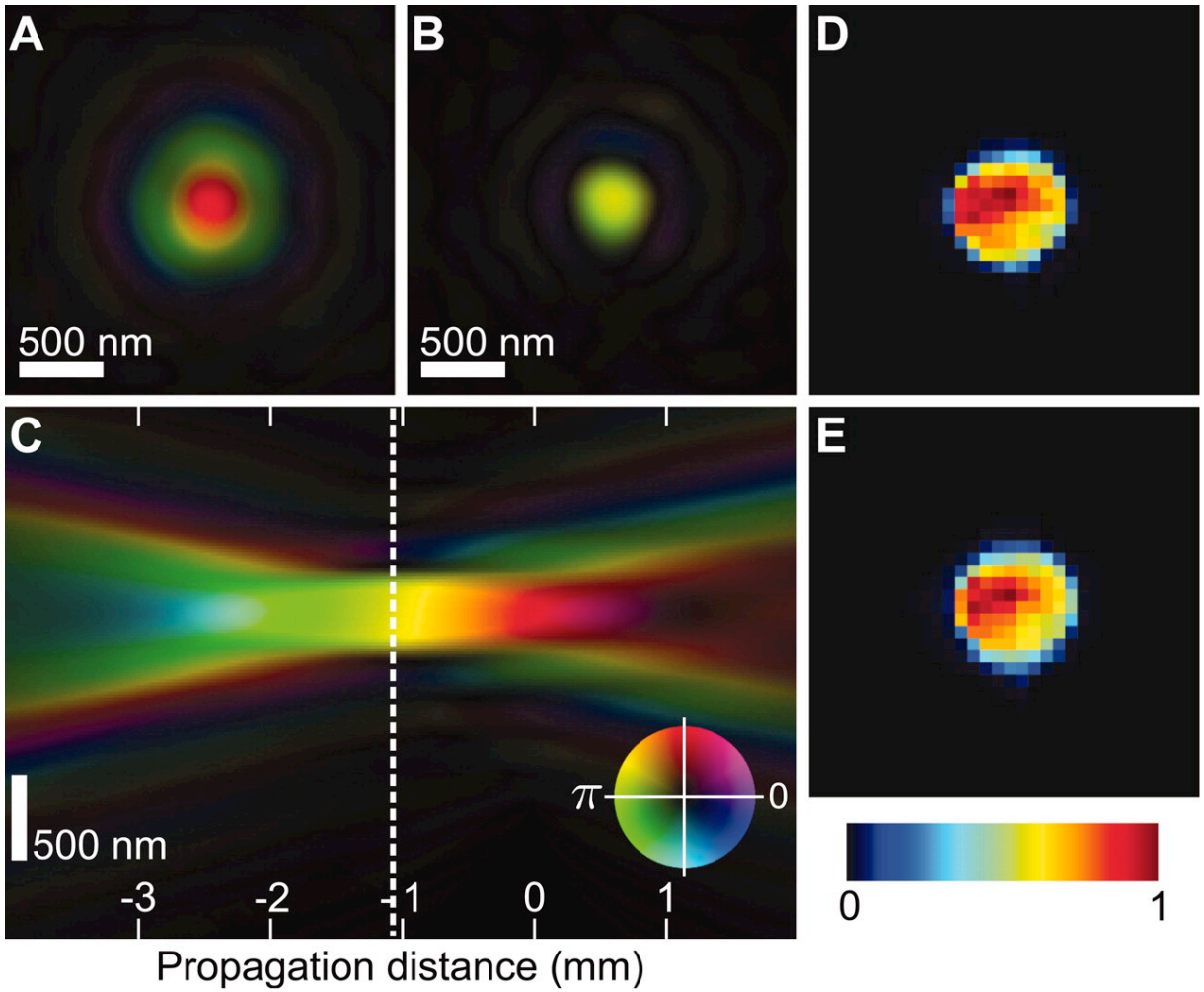
X-ray Ptychography

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



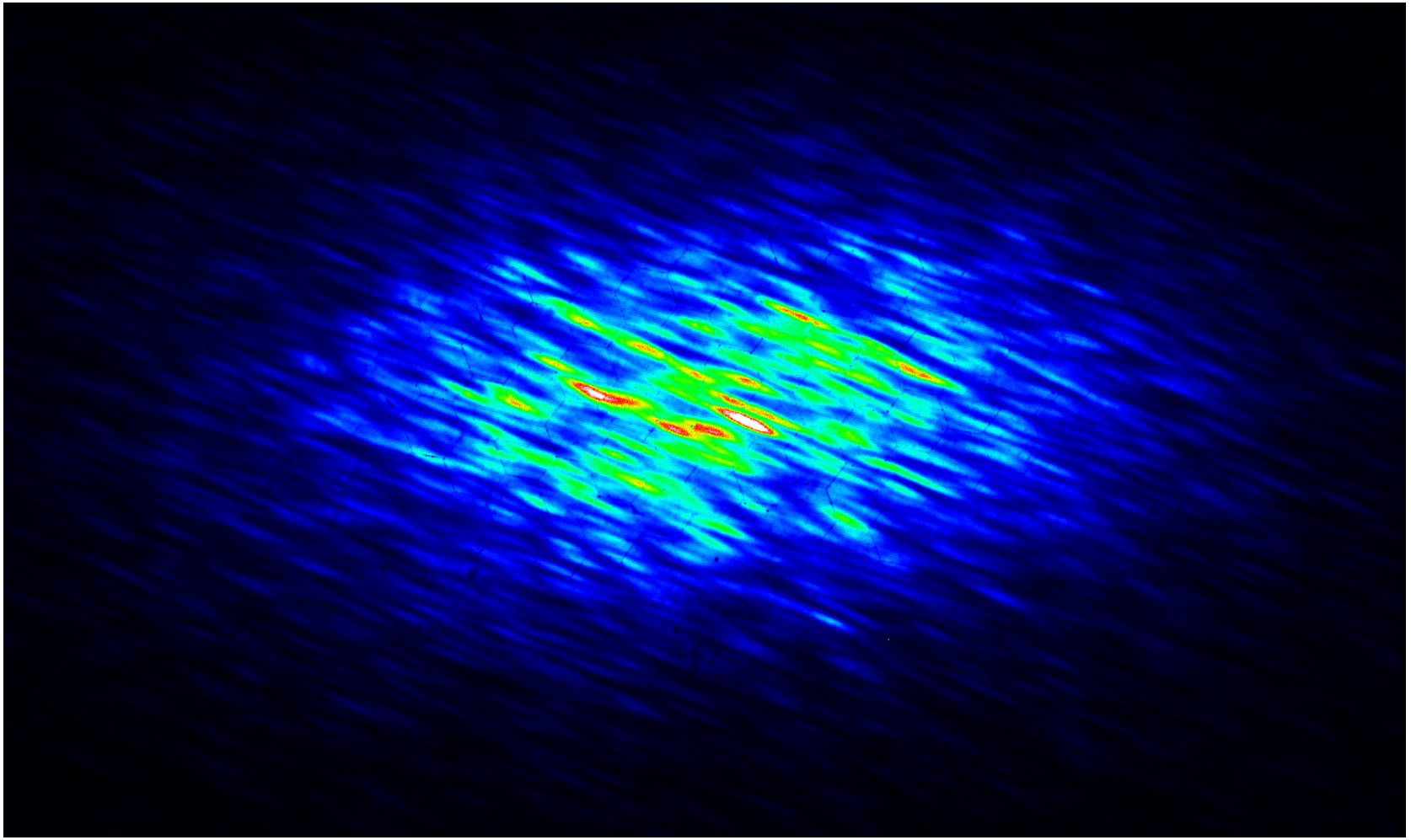
Reconstruction of Probe

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



Niobium (110) Thin Film Grains

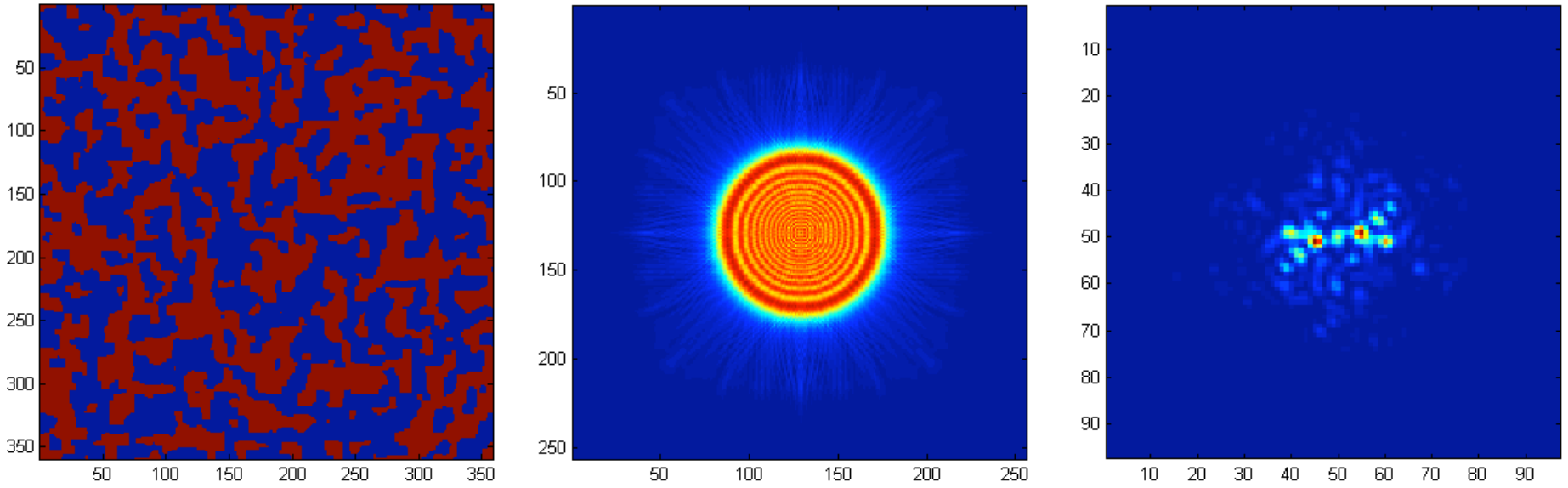
Richard Bean, I-16, Nb110-35 Jan 2009



Ptychography phasing tests

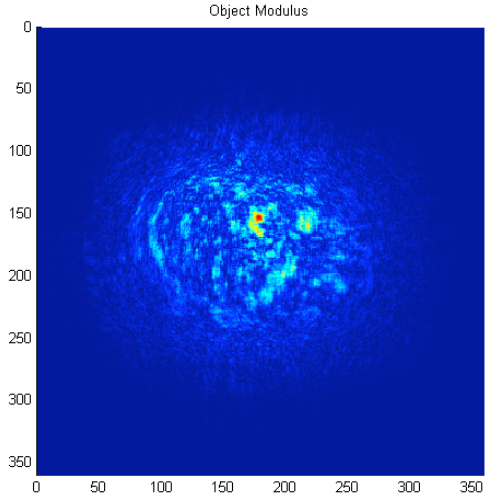
Diffraction patterns computed from i) simulated domain array ii) propagated pinhole function with an overlap of ~80% between adjacent positions.

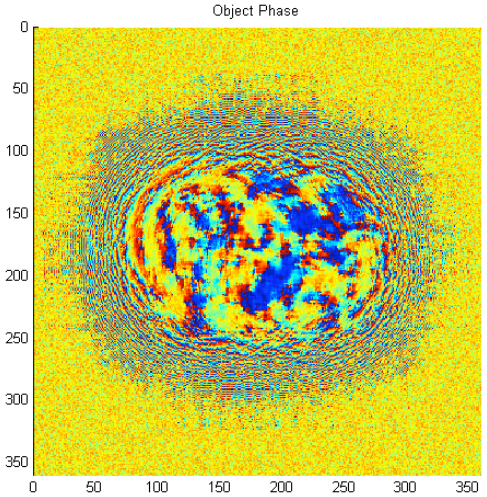
Richard Bean, UCL, Jan 2009



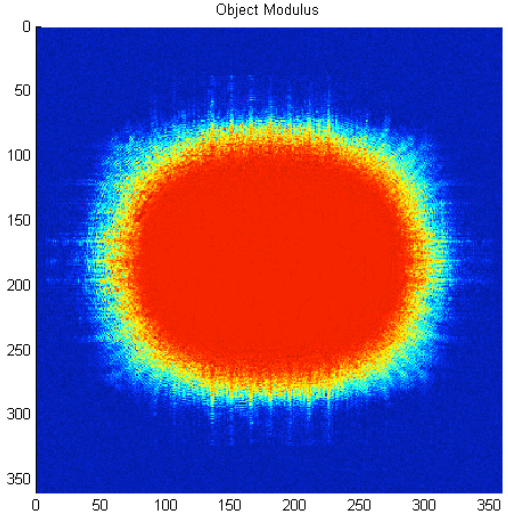
Ptychography phasing tests

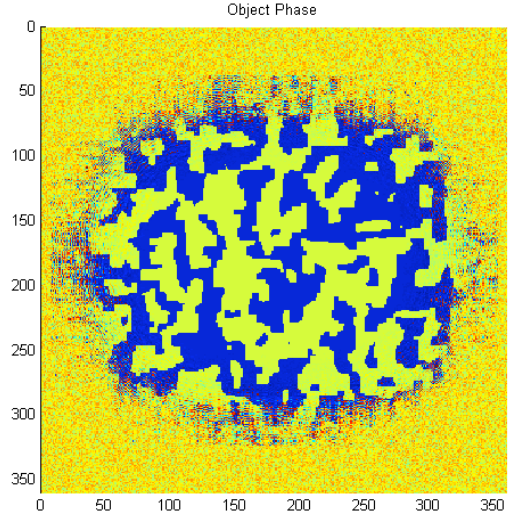
Sheffield Ptychography algorithm starting with an array of random numbers in both amplitude and phase. 7x3 array. Richard Bean, Jan 2009





Amplitude and phase after 1 iteration.

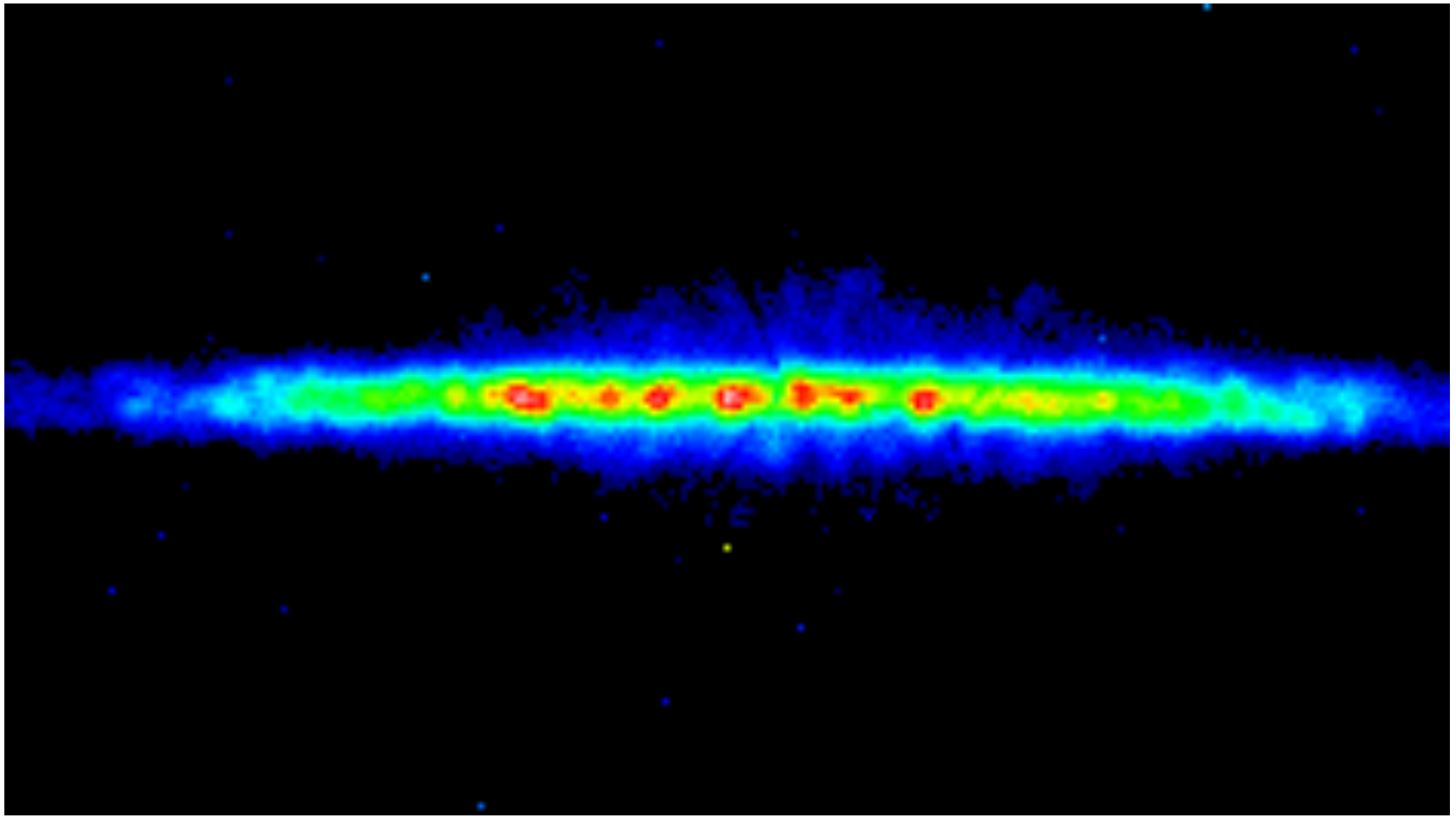




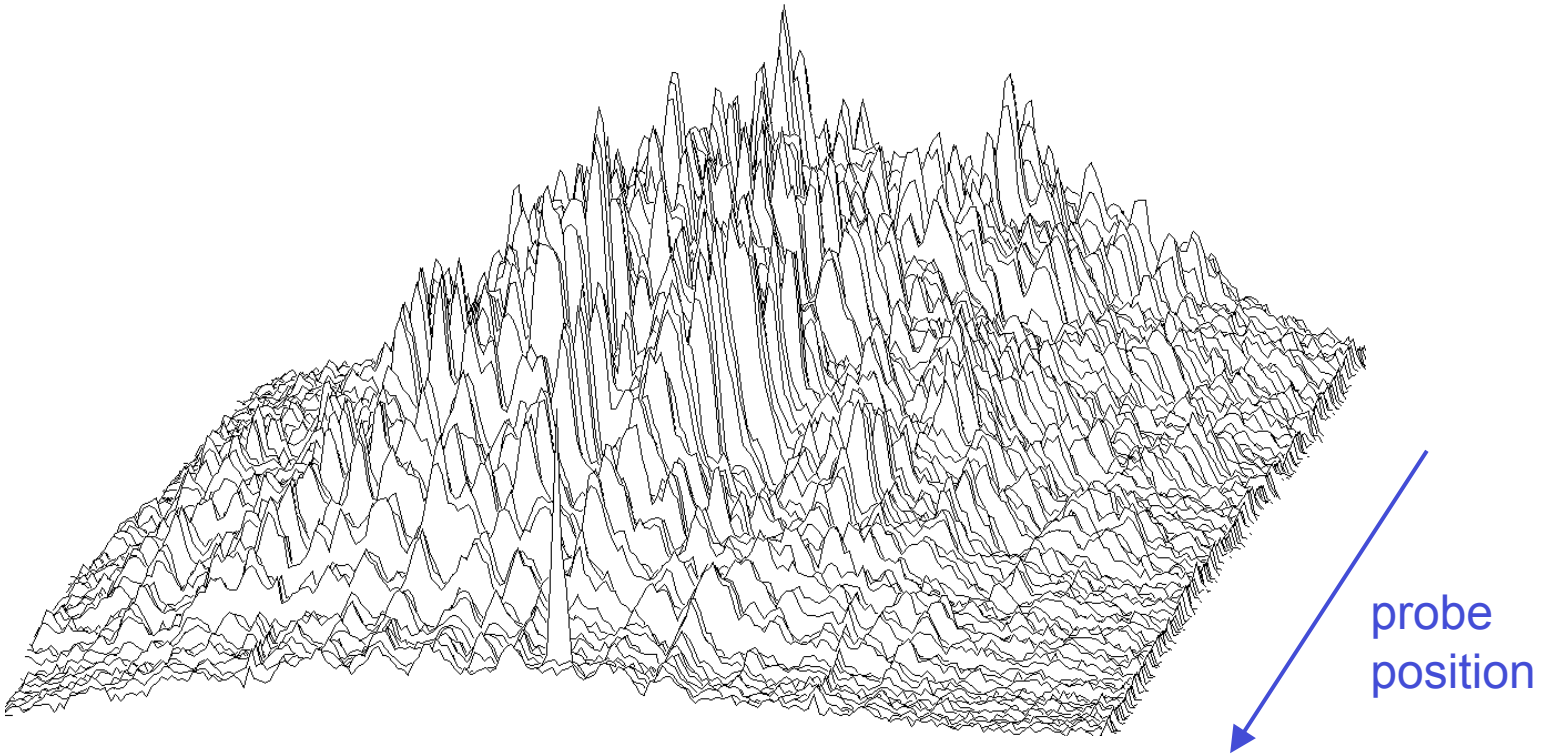
Amplitude and phase after 20 iterations.

Improved collagen sample prep

Diamond I-22, Nov 2008

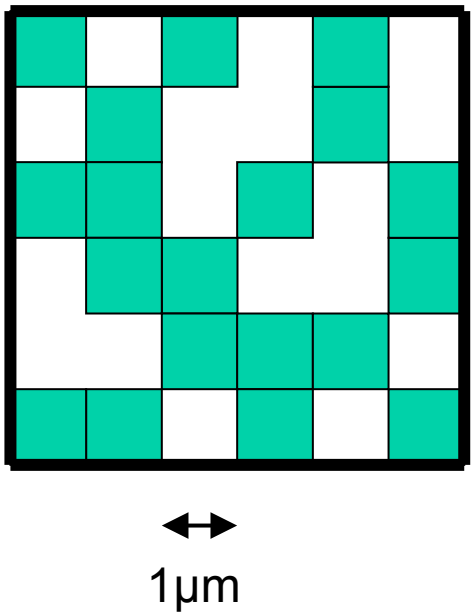


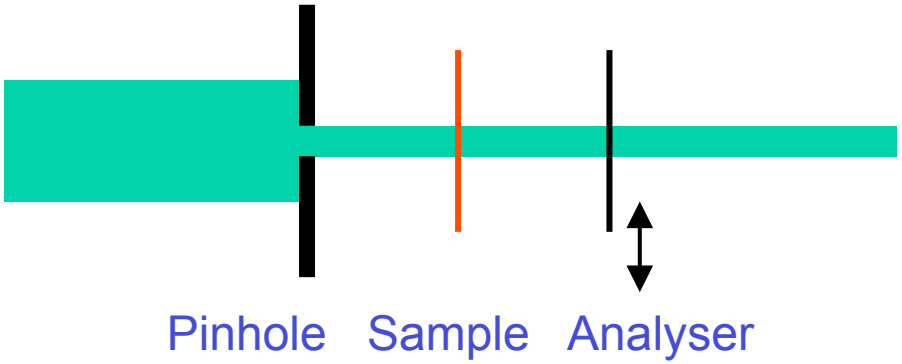
Evolution of Collagen Speckles



‘Random’ phase plate analyser

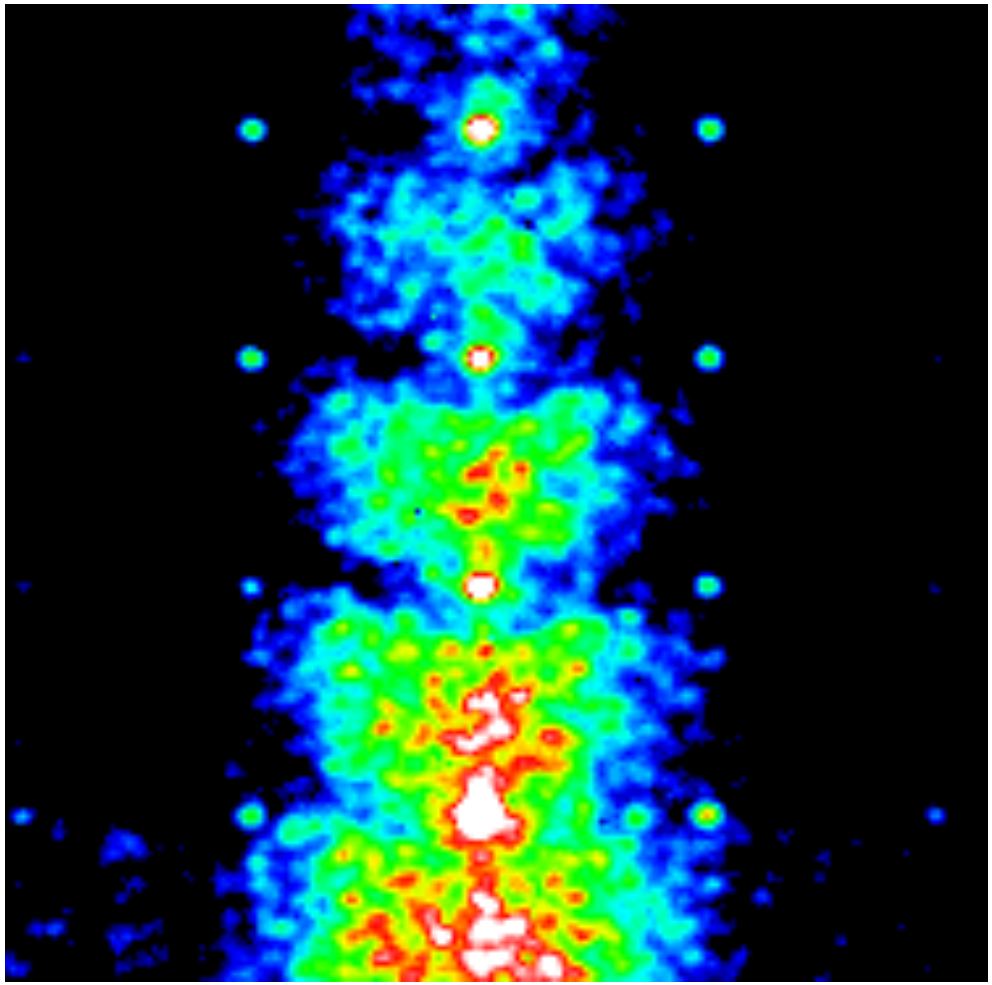
Joan Vila (PSI), Fucai Zhang (Sheffield)

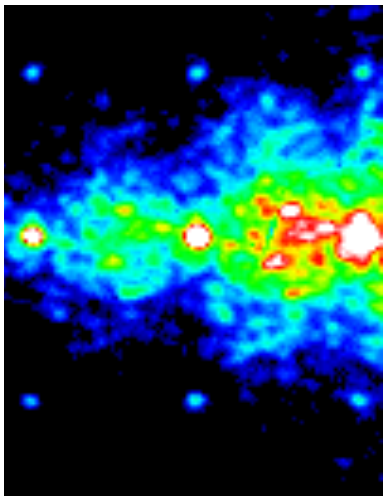


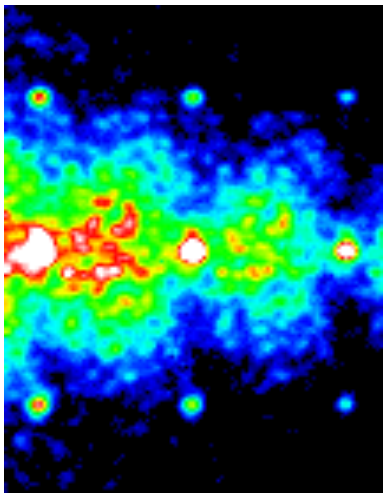


Phase plate scan near forward direction

1μm step per frame

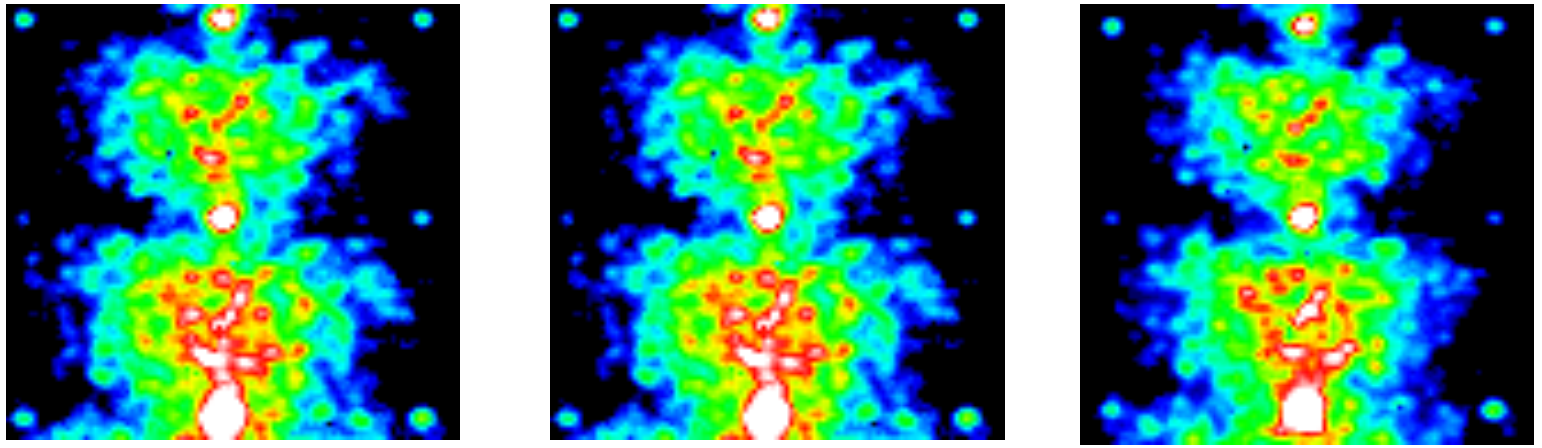






Collagen, buffer and empty cell

phplateFZP-236, -246 and -249



Conclusions

- X-ray allow 3D imaging on the nanoscale
- Internal structure of Ag and Pb Nanocrystals
- Phasing by computation instead of lens
- Strain fields imaged from asymmetric patterns
- Contact Forces and Surface Strain
- Nanowire domain structures in InP, GaAs
- Biological tissue accessible by ptychography