

# Coherent Diffraction Imaging

Ian Robinson

Felisa Berenguer

Ross Harder

Richard Bean

Moyu Watari

London Centre for Nanotechnology

Diamond Light Source

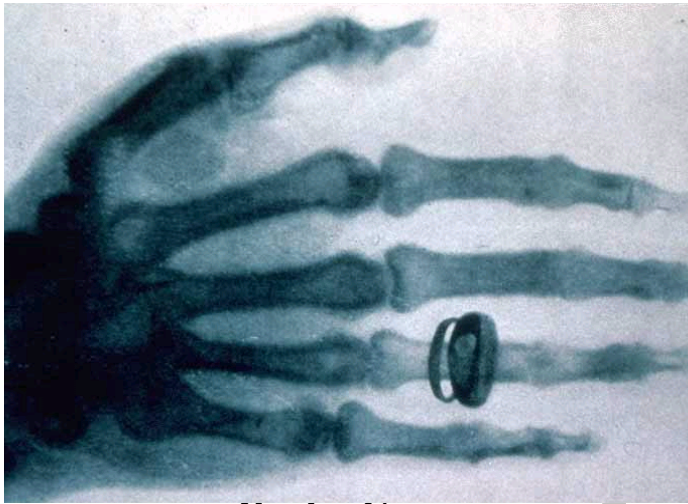
School of Optometry & Vision Sciences

Cardiff University

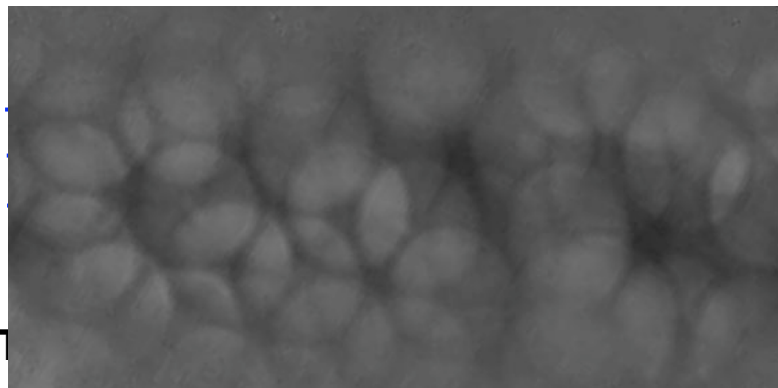
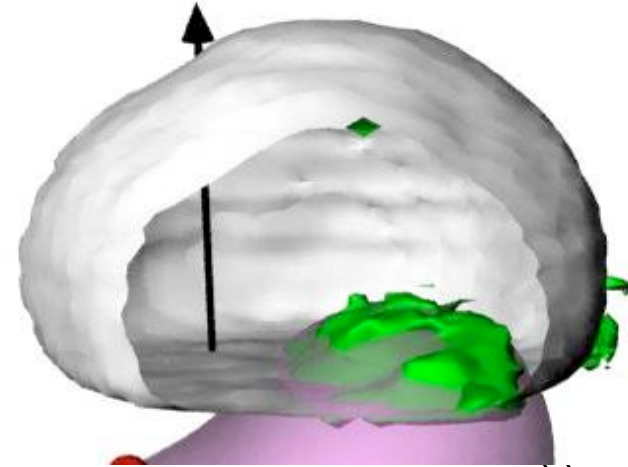
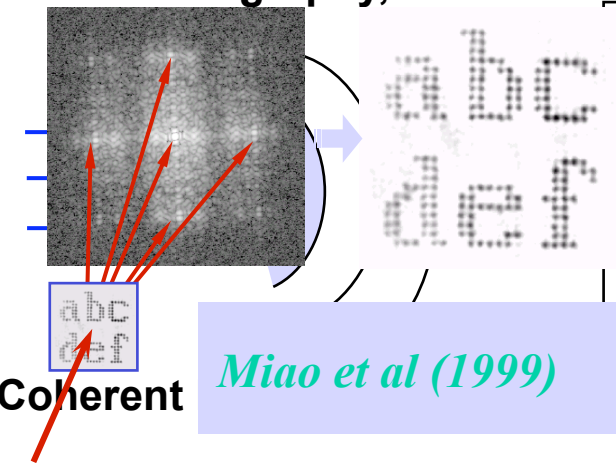
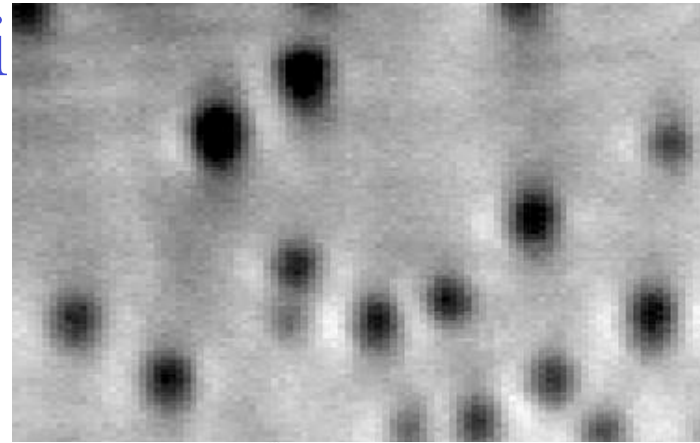
March 2009

# Outline

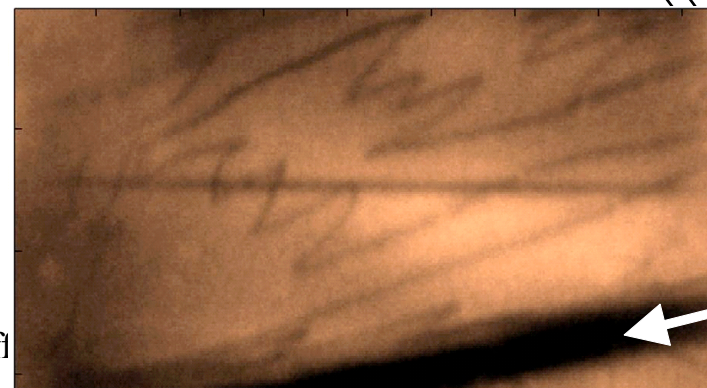
- Imaging with X-rays
- Coherence based imaging
- Nanocrystal structures
- Extension to **phase** objects
- Exploration of crystal strain
- Biological imaging by CXD



old Mi



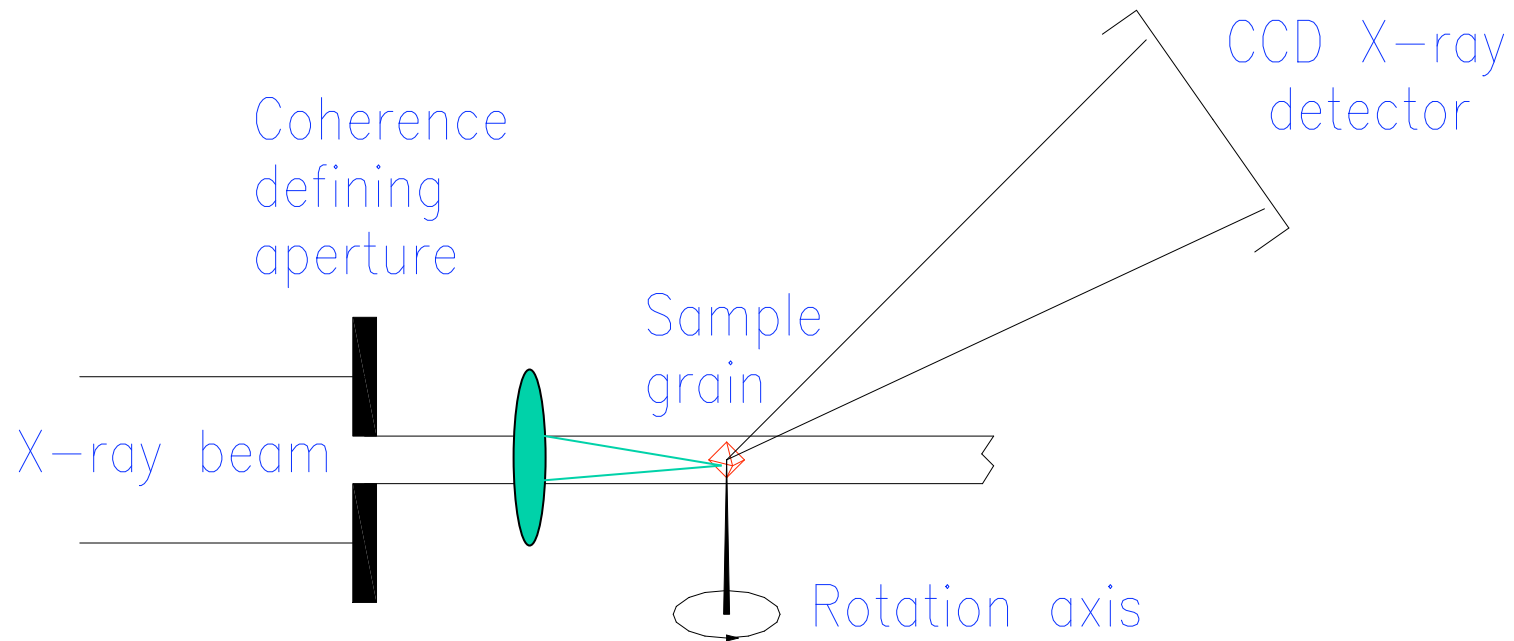
, Cardiff



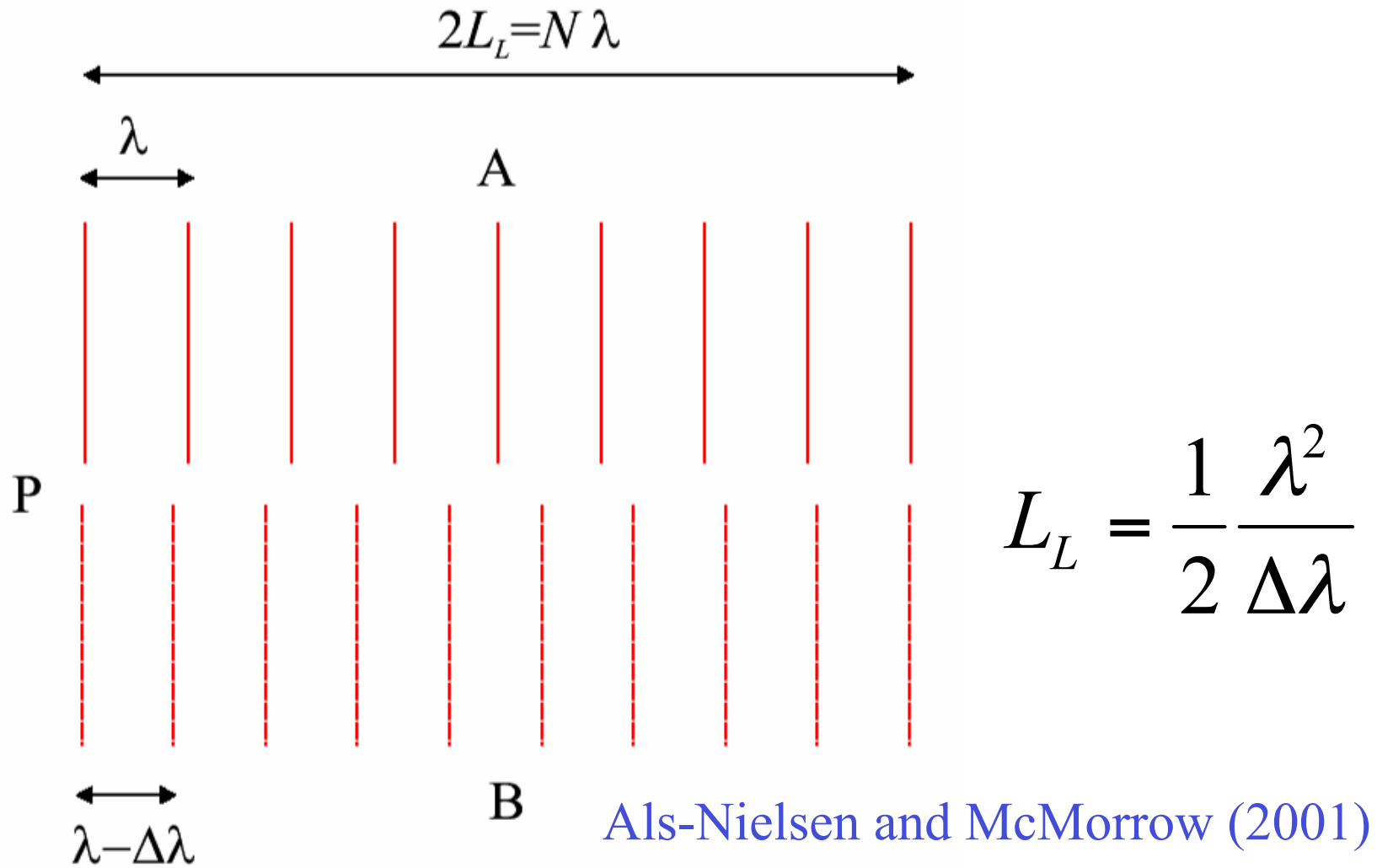
# Lensless X-ray “Microscope”

APS  $\xi_{\text{HOR}} = 20\mu\text{m}$ , focus to  $1\mu\text{m}$

NSLS-II  $\xi_{\text{HOR}} = 500\mu\text{m}$ , focus to  $0.05\mu\text{m}$

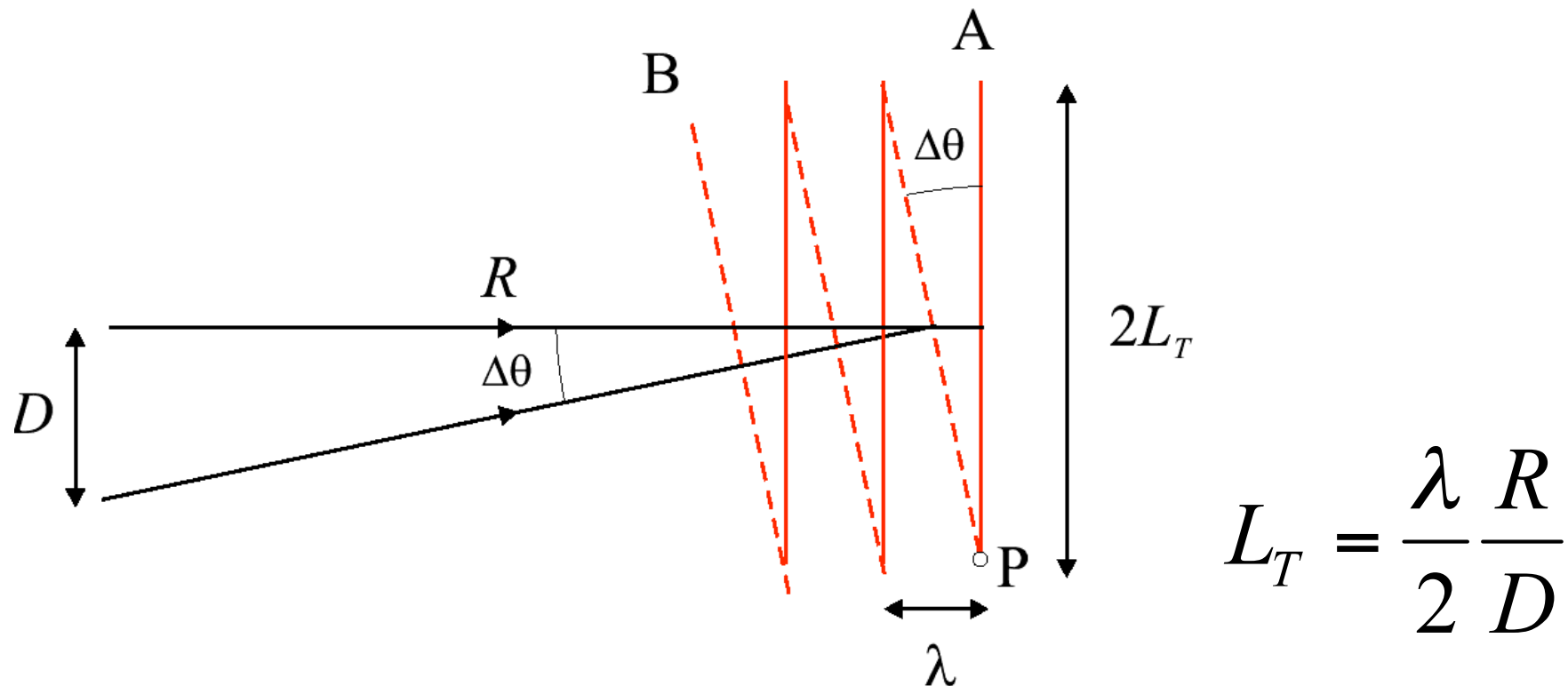


# Longitudinal Coherence



Als-Nielsen and McMorrow (2001)

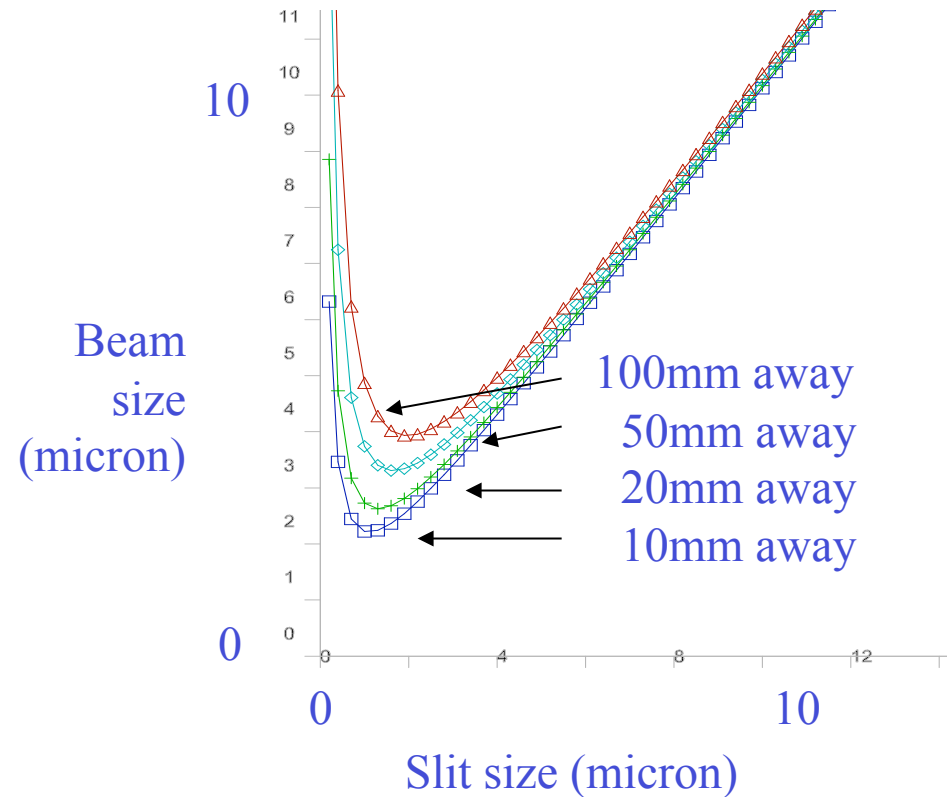
# Lateral (Transverse) Coherence



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

Als-Nielsen and McMorrow (2001)

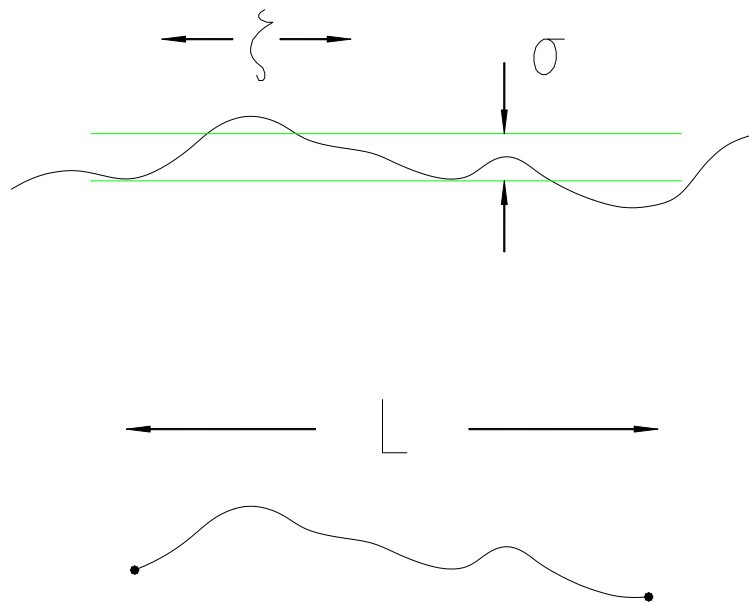
# Smallest Beam using Slits (9keV)



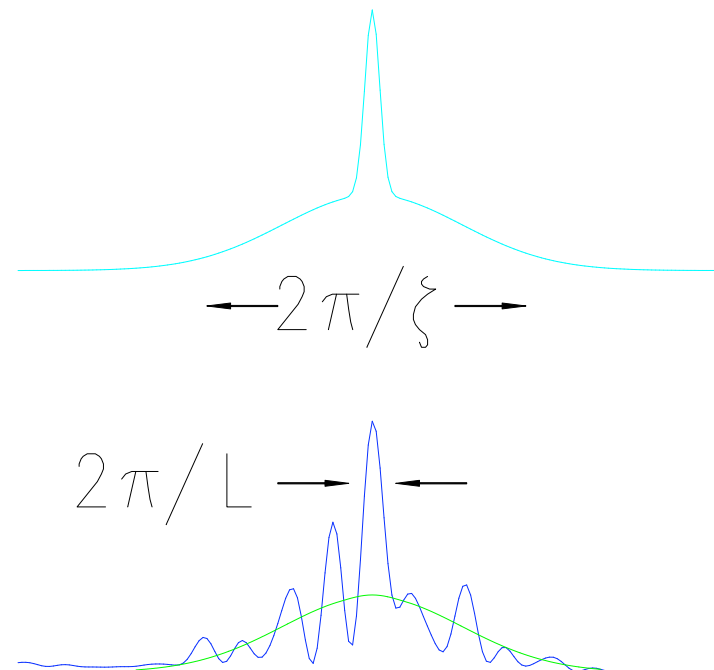
$$y(x) = x + \frac{\lambda d}{x}$$

# Diffuse Scattering acquires fine structure with a Coherent Beam

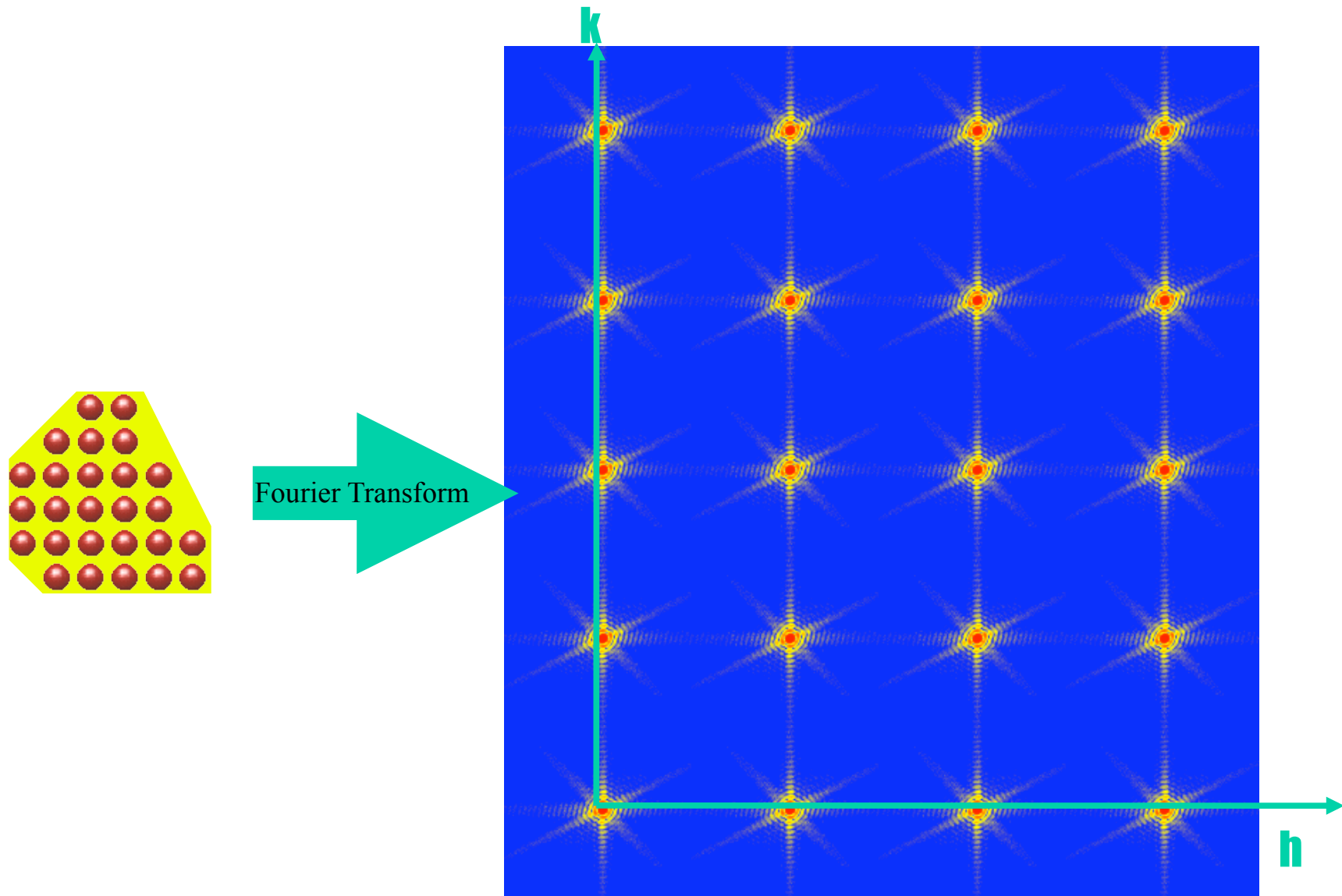
Real Space

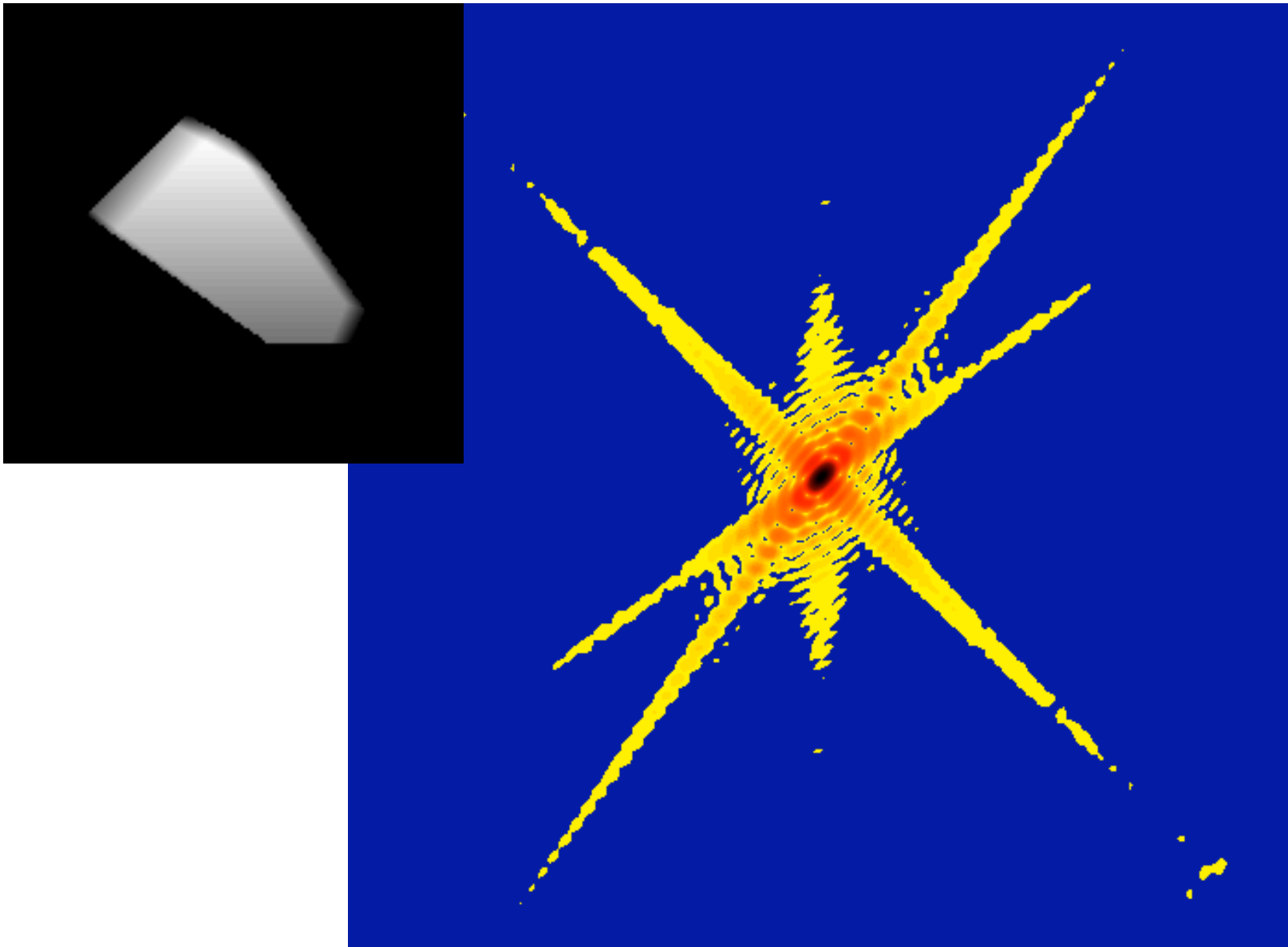


Reciprocal Space

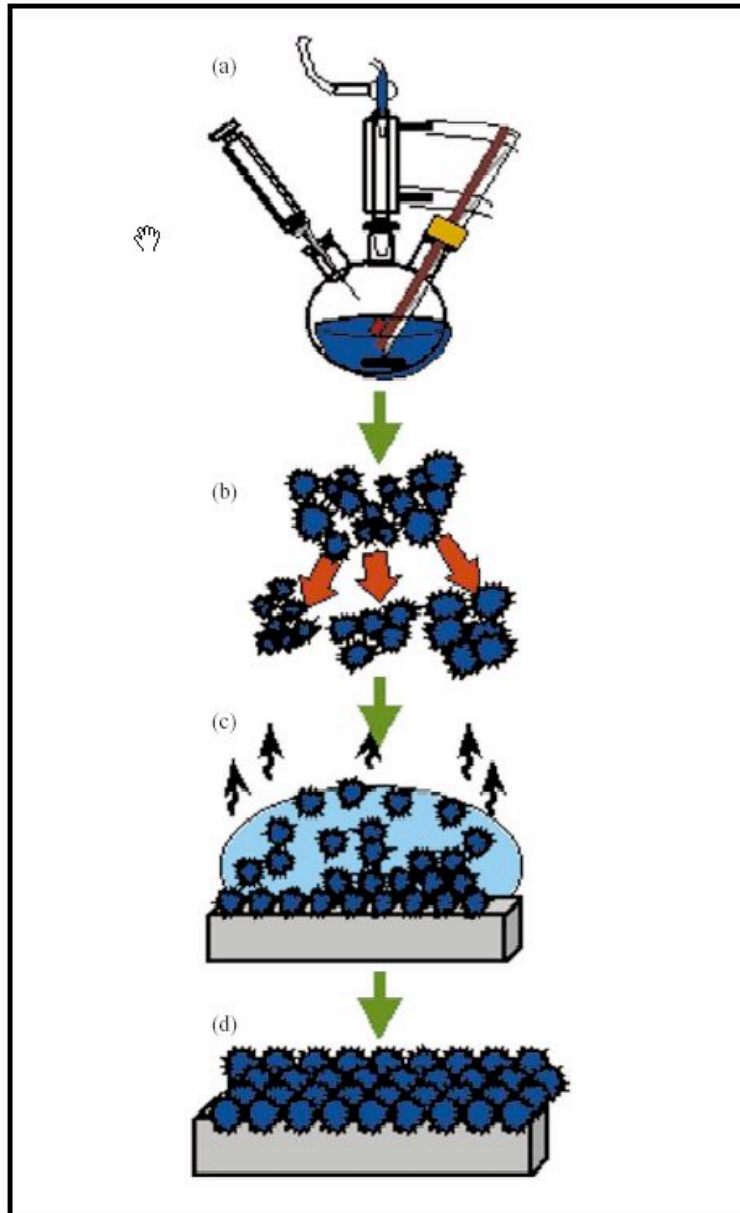


# Coherent Diffraction from Crystals



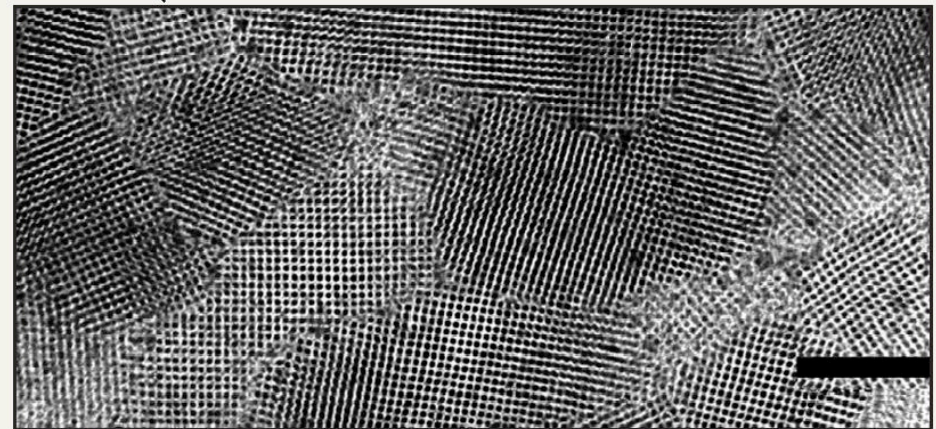


# Chemical Synthesis of Nanocrystals

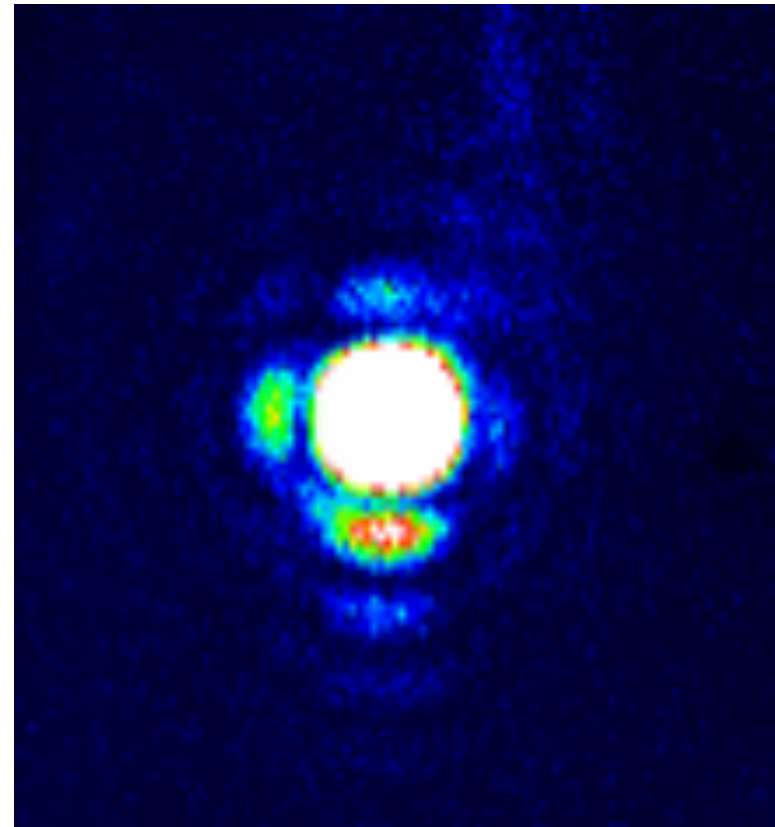
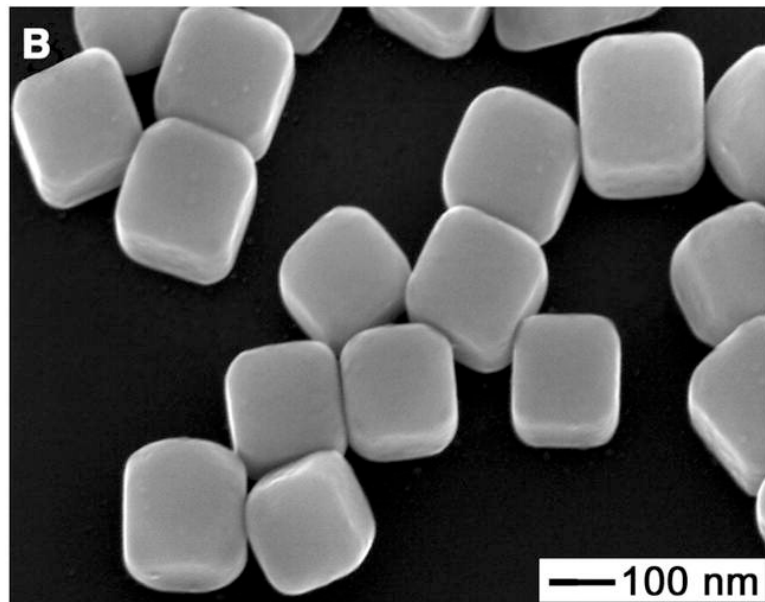


- Reactants introduced rapidly
- High temperature solvent
- Surfactant/organic capping agent
- Square superlattice (200nm scale)

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

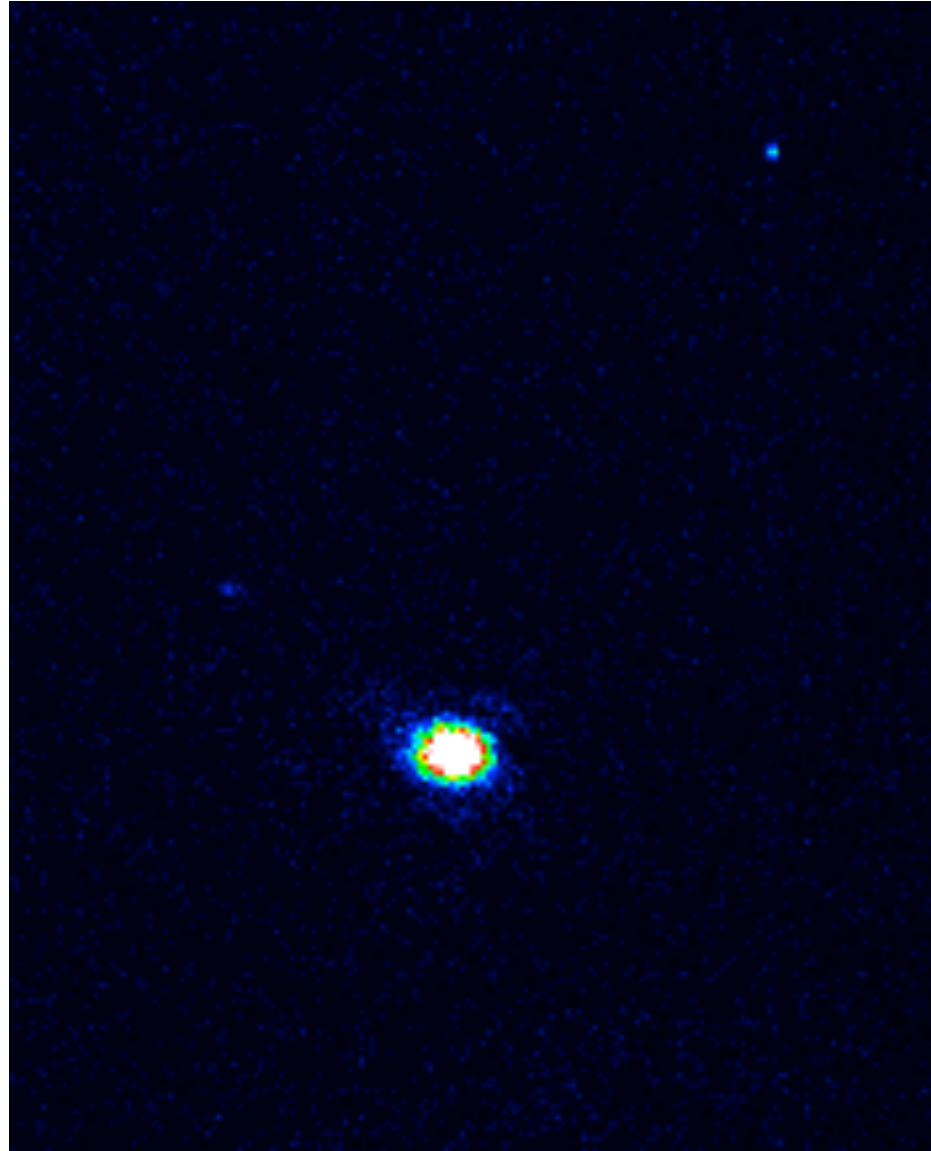


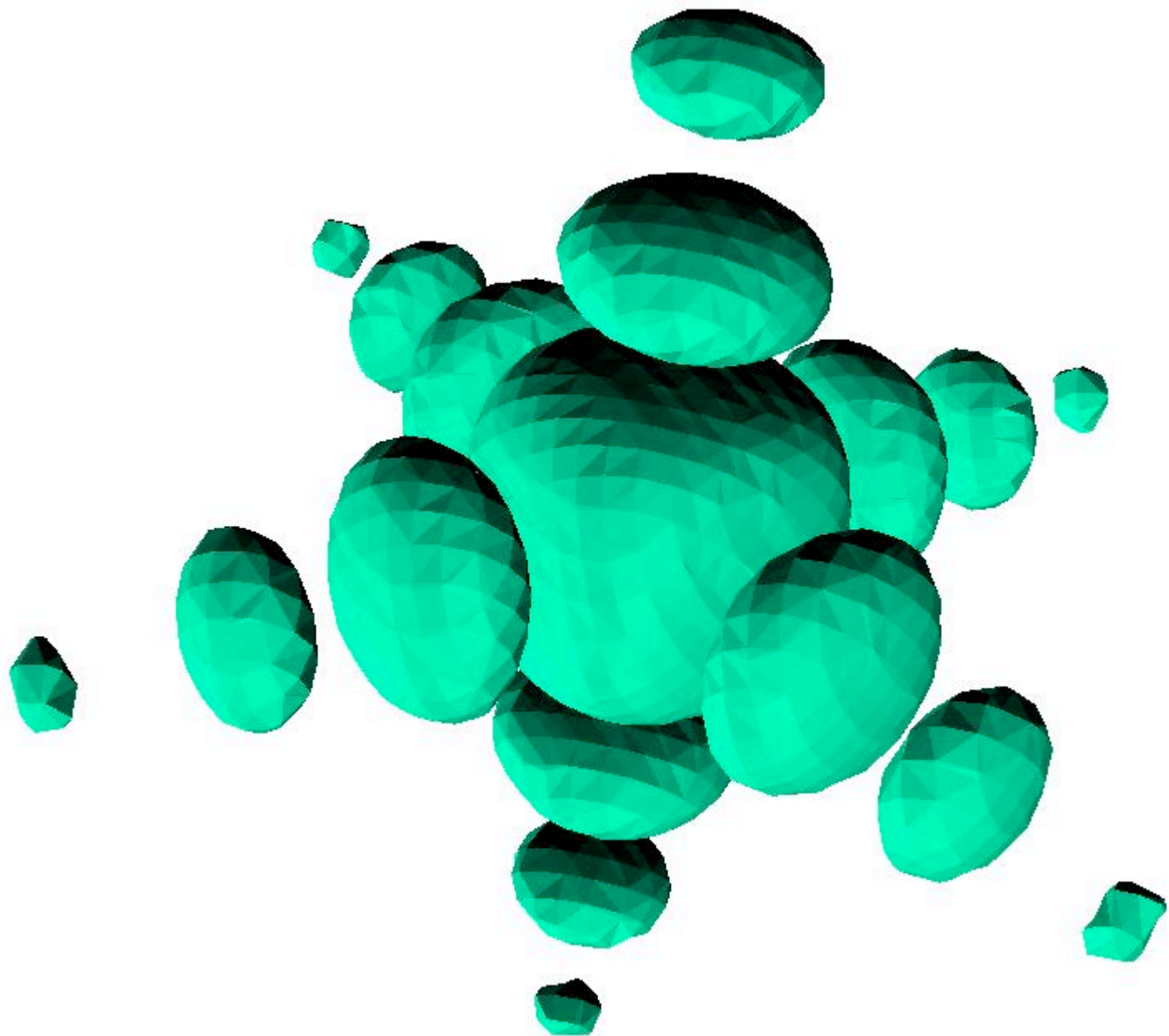
# Chemically Synthesized Silver Nanocubes



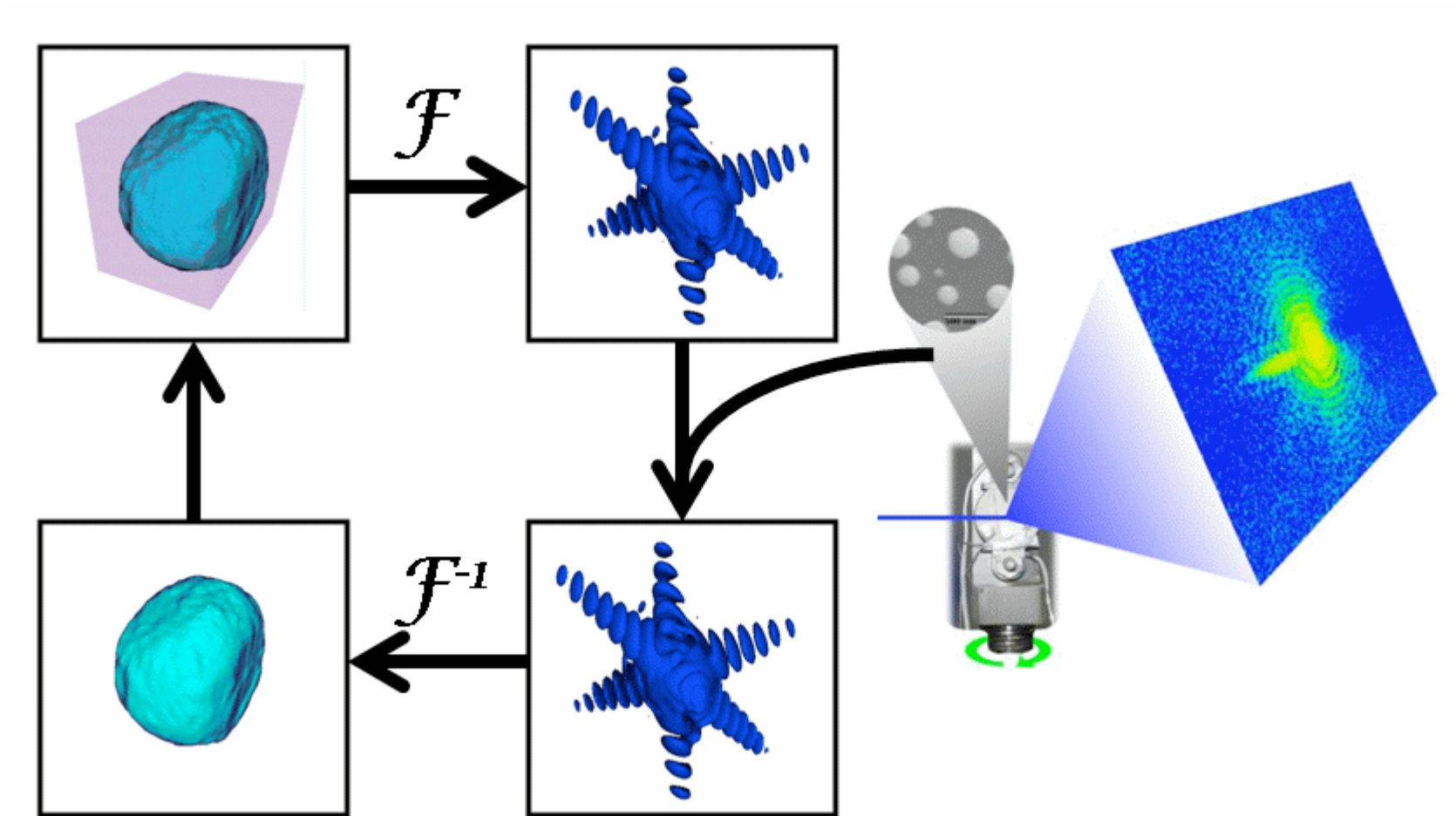
Yugang Sun and Younan Xia,  
*Science* 298 2177 (2003)

Rocking  
scan of Ag  
cubes with  
 $0.01^\circ$  steps





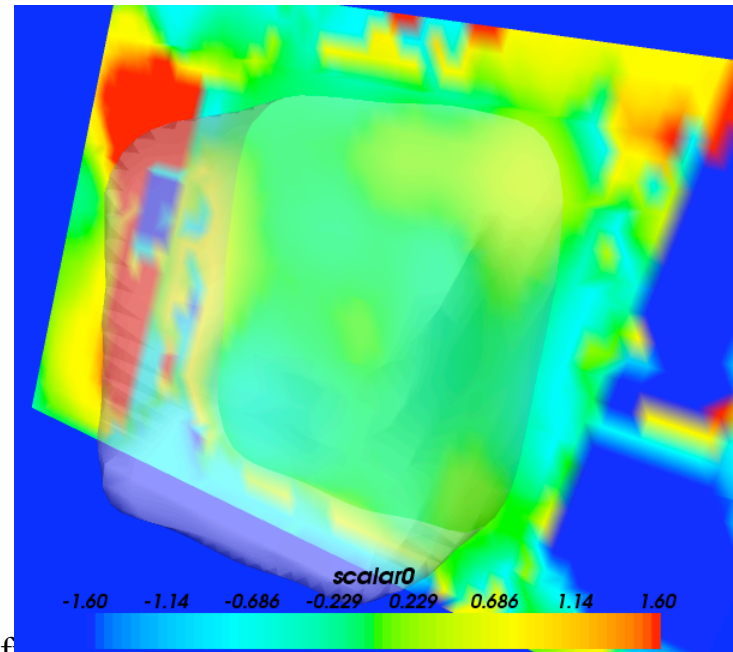
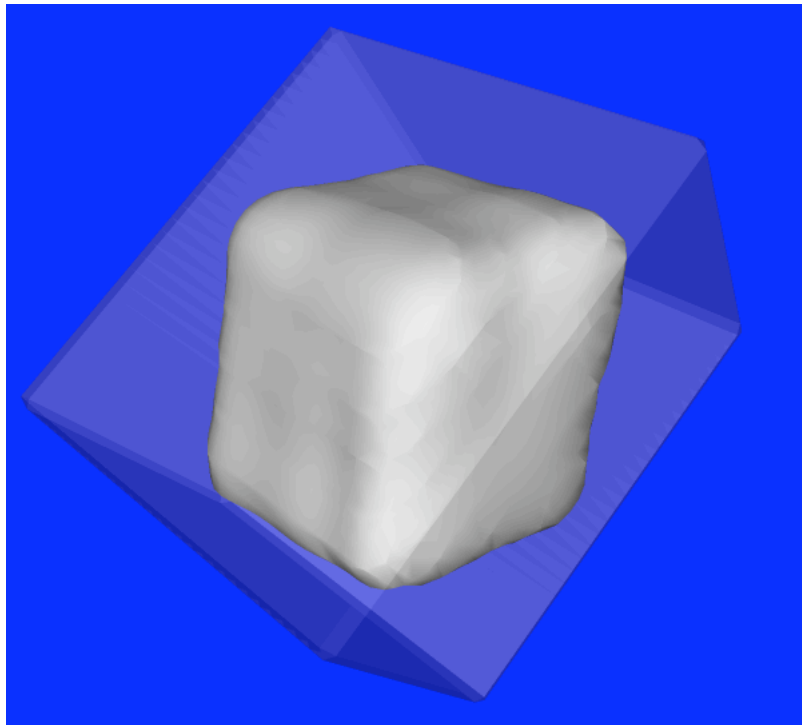
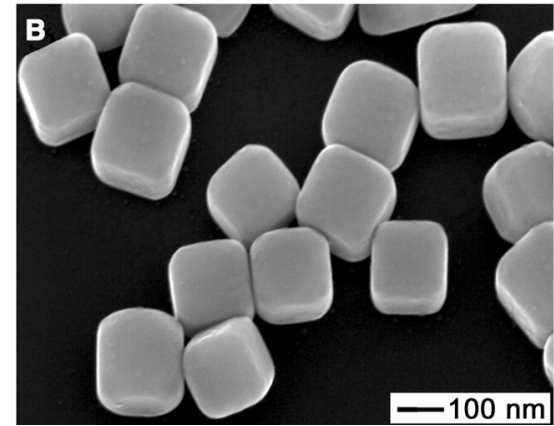
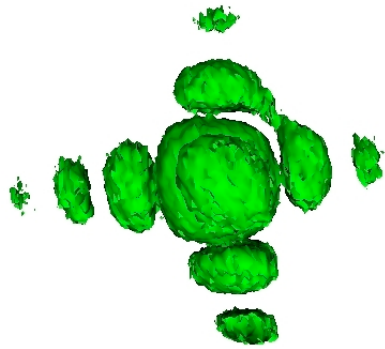
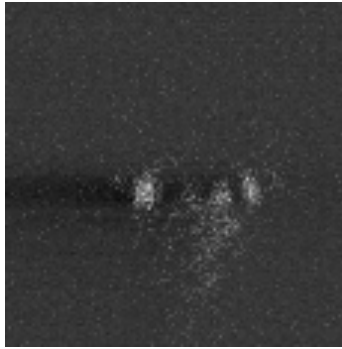
# Generic “Error Reduction” method



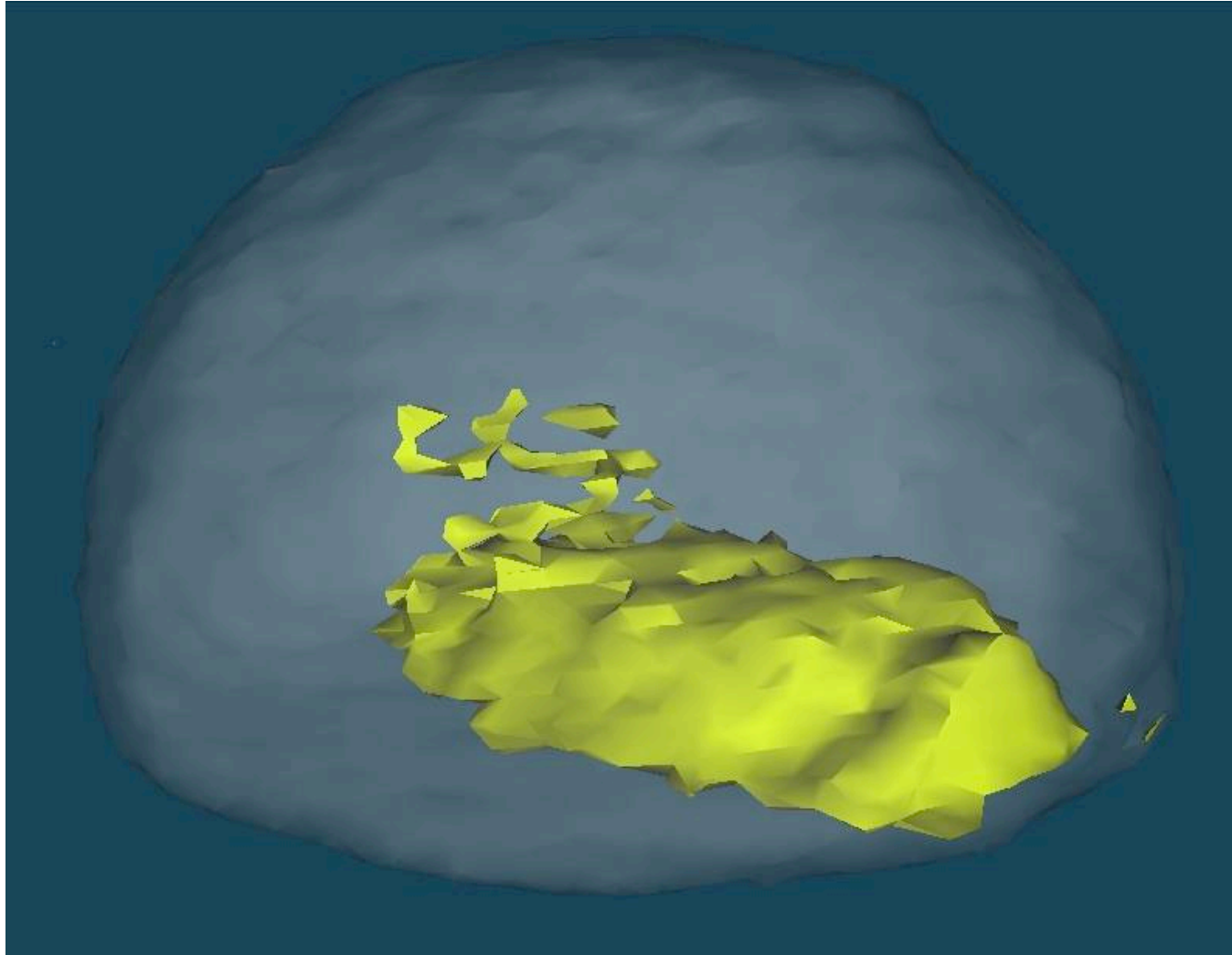
J. R. Fienup *Appl. Opt.* 21 2758 (1982)

R. W. Gerchberg and W. O. Saxton *Optik* 35 237 (1972)

I. K. Robinson, Cardiff Mar 2009

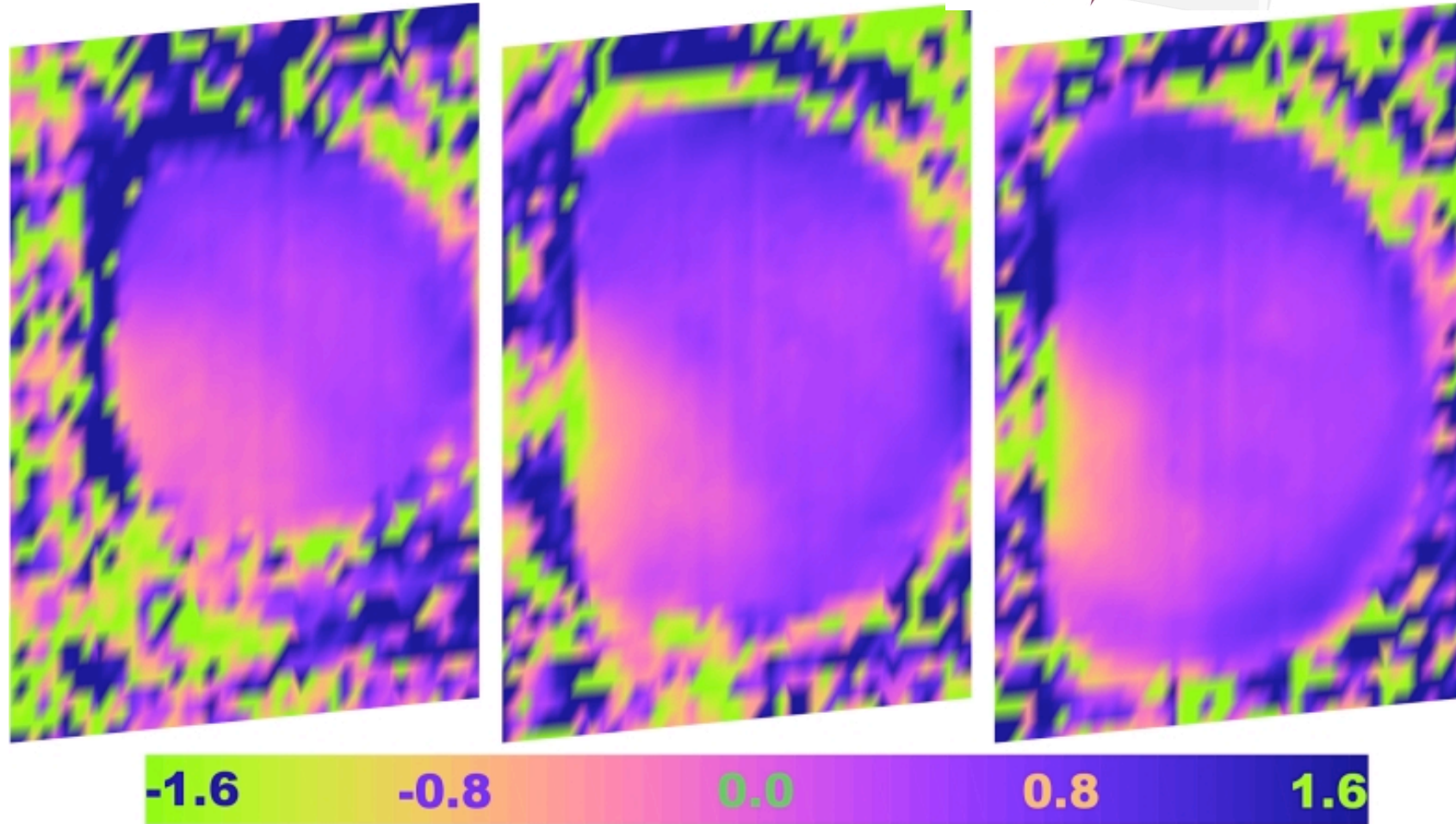
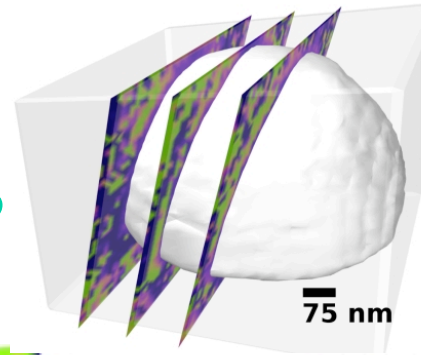


# Isosurface of 3D Phase Bump



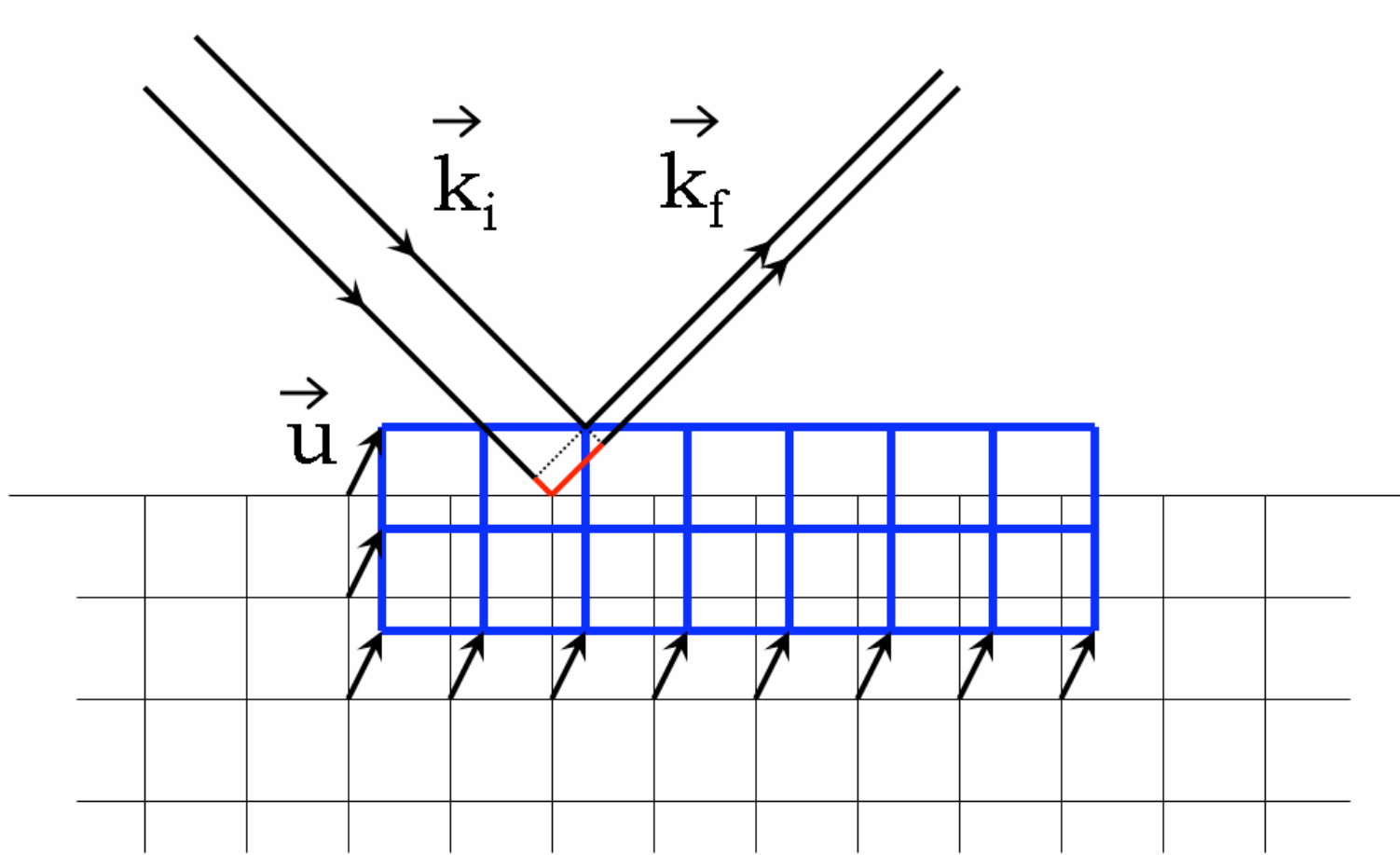
I. K. Robinson, Cardiff Mar 2009

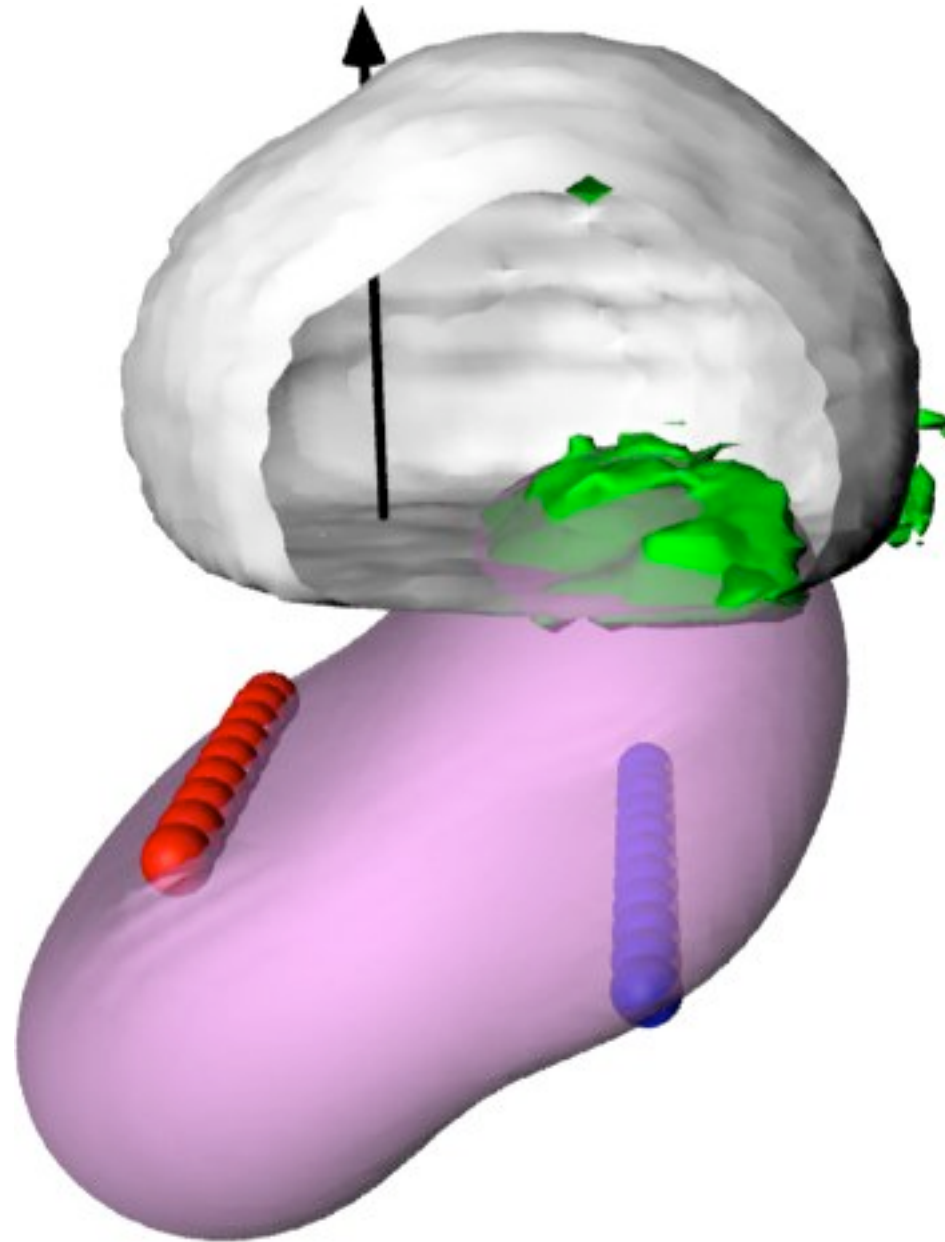
# 3D phase map sections



# Sensitivity to strain

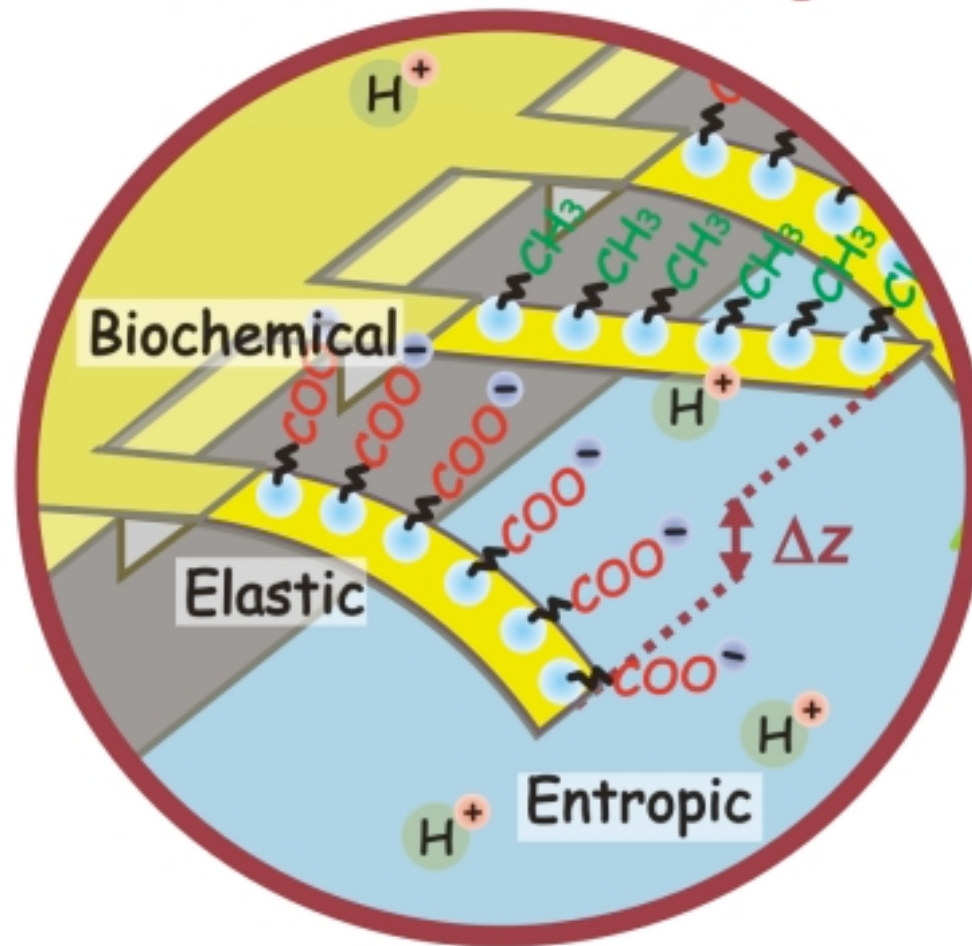
$$\Delta\varphi = \mathbf{k}_f \cdot \mathbf{u} - \mathbf{k}_i \cdot \mathbf{u} = \mathbf{Q} \cdot \mathbf{u}$$





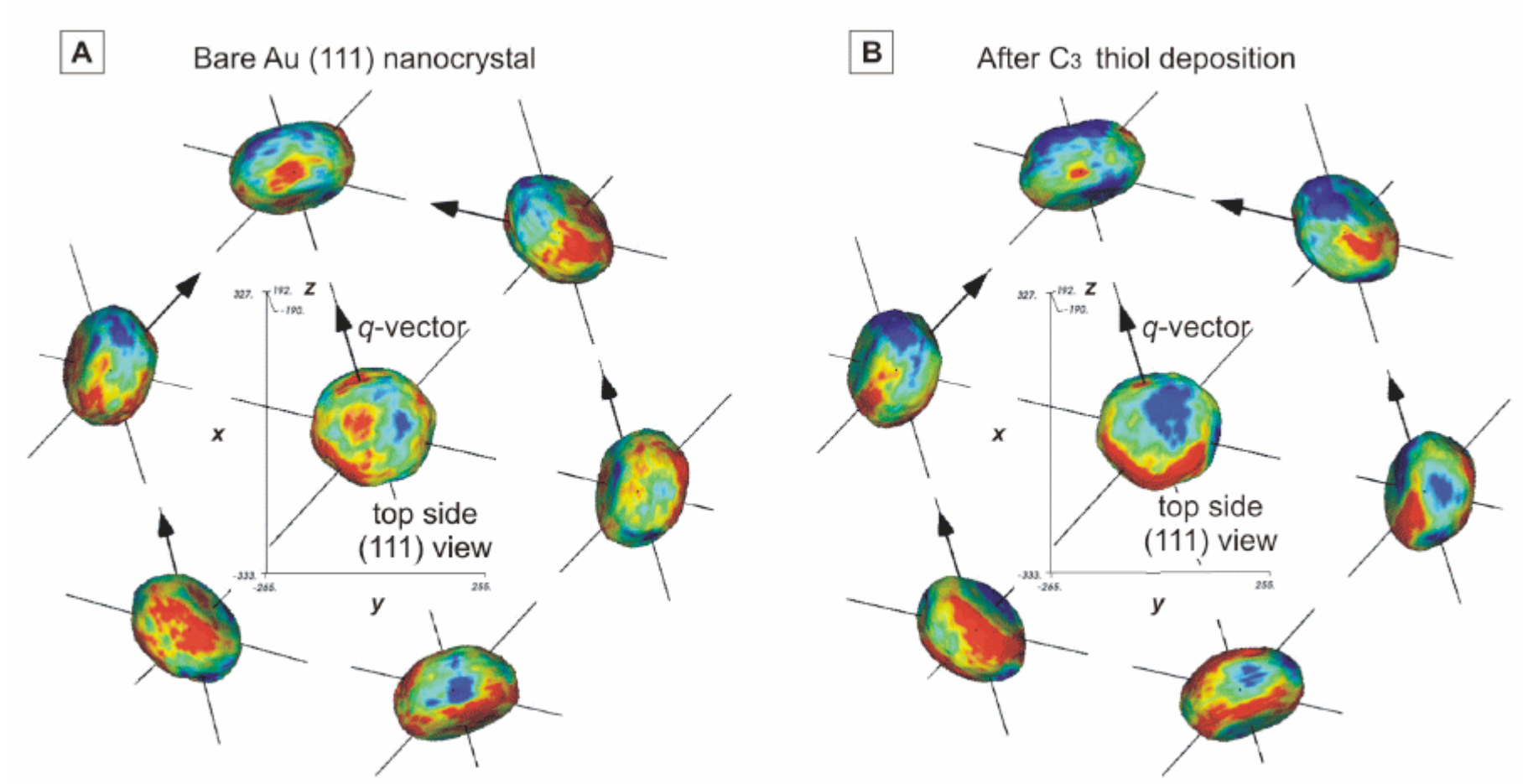
# Nanocantilevers

Dr Rachel McKendrie

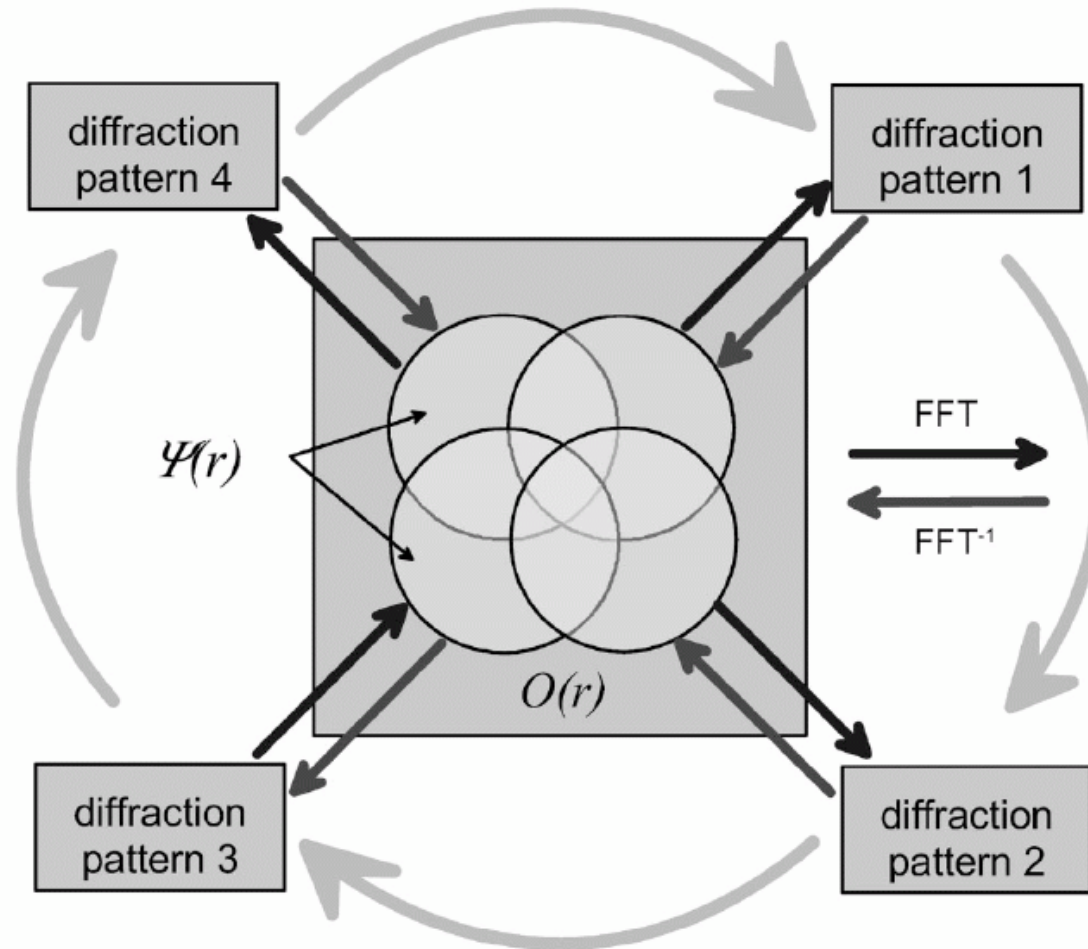


# Strain induced by thiol binding

Moyu Watari, UCL, Oct 2008



# X-ray Ptychography

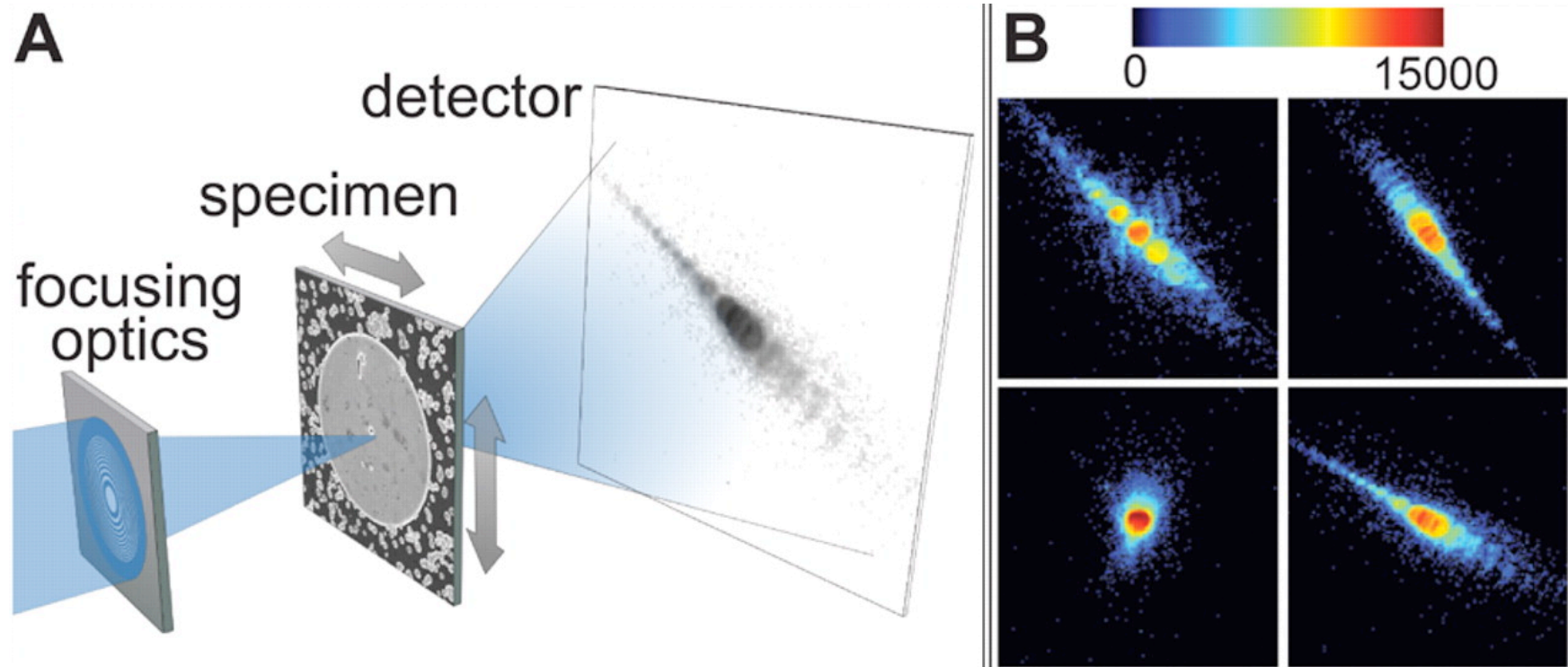


J. M. Rodenburg et al, Phys. Rev. Lett. 98 034801 (2007)

I. K. Robinson, Cardiff Mar 2009

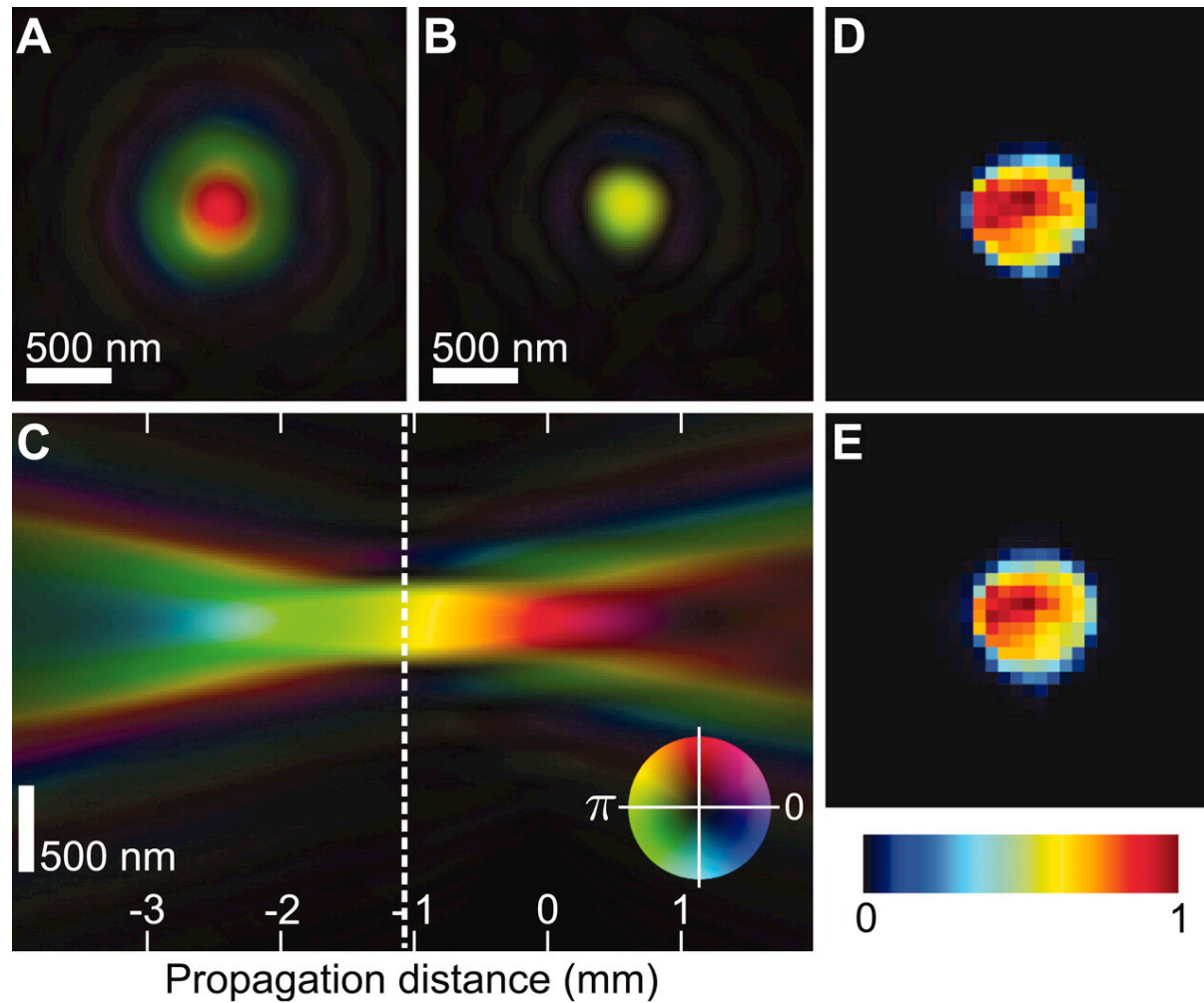
# X-ray Ptychography

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



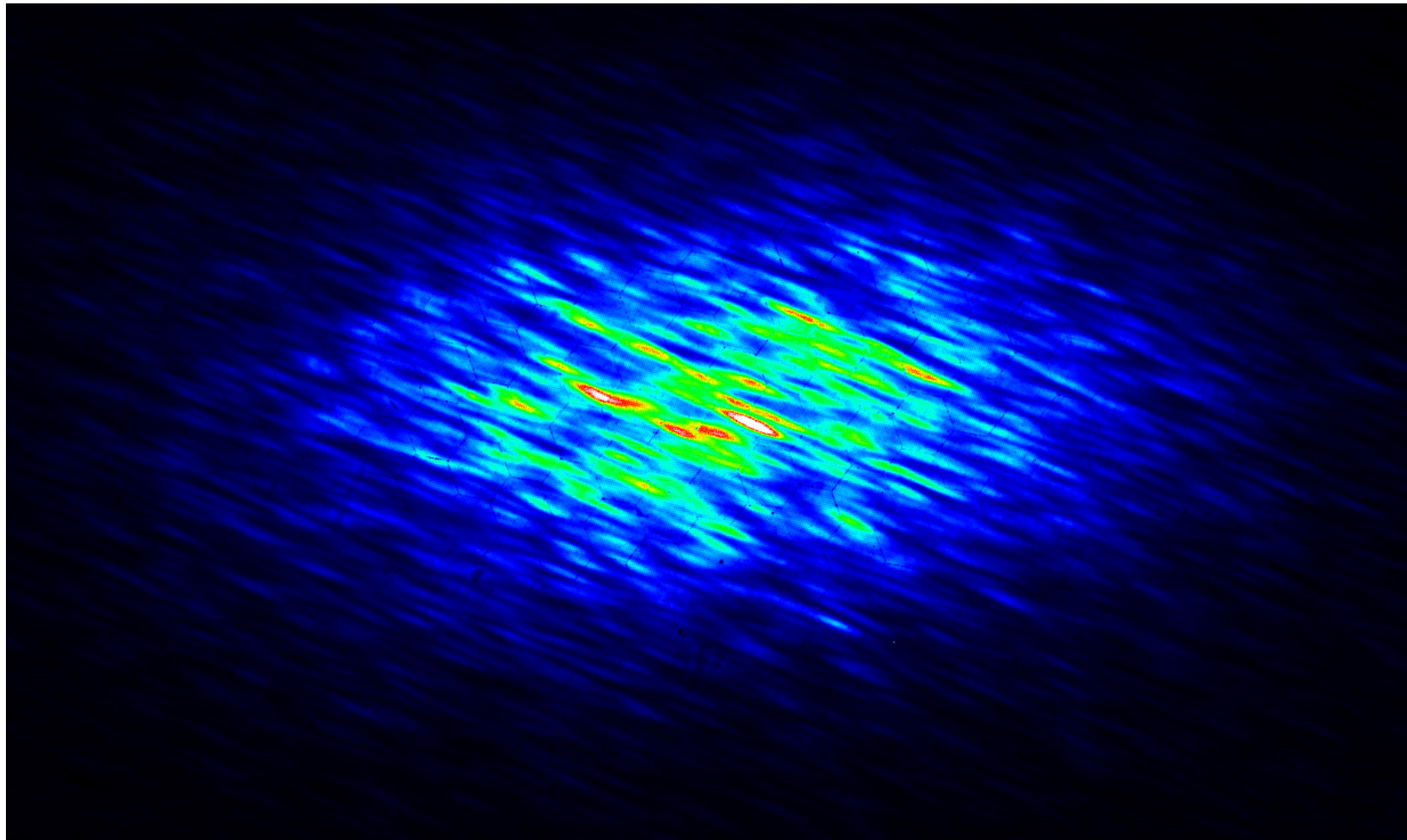
# Reconstruction of Probe

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



# Niobium (110) Thin Film Grains

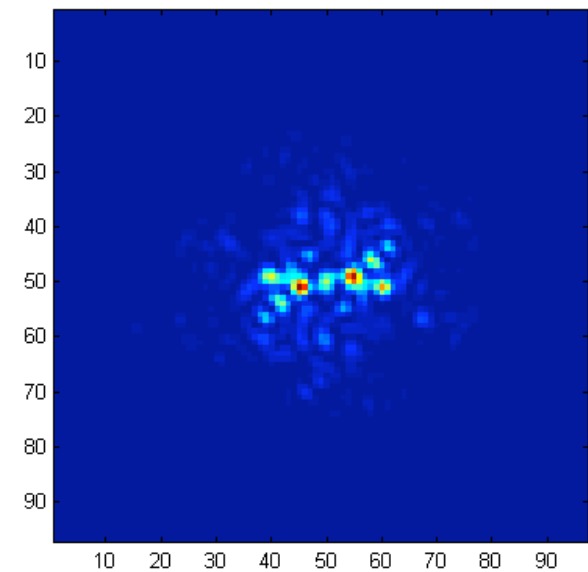
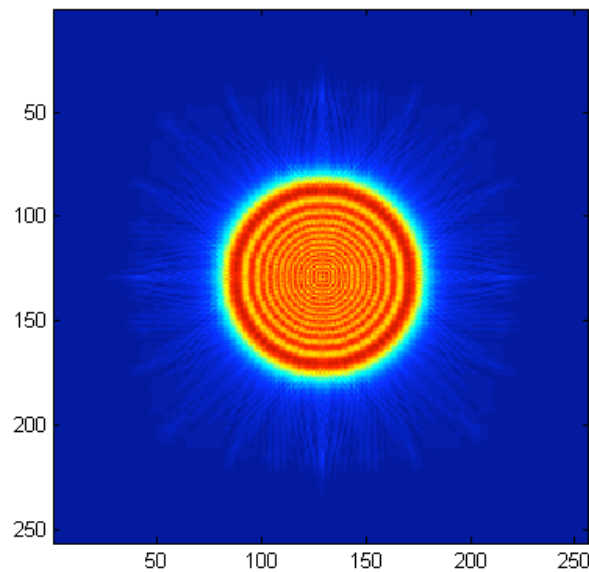
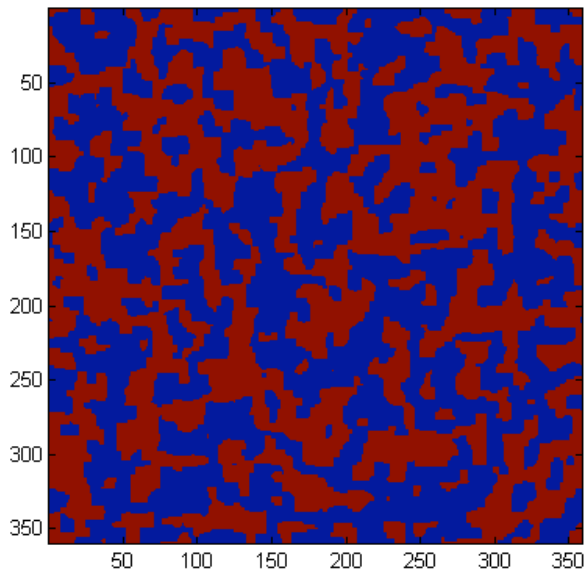
Richard Bean, I-16, Nb110-35 Jan 2009



# Ptychography phasing tests

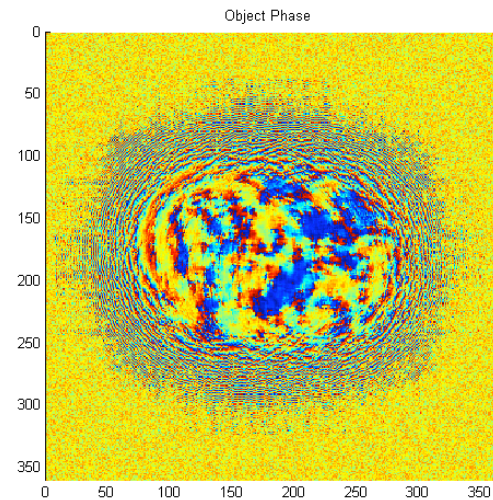
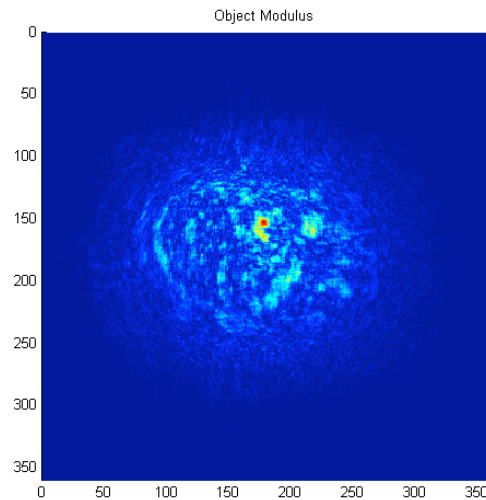
Diffraction patterns computed from i) simulated domain array ii) propagated pinhole function with an overlap of  $\sim 80\%$  between adjacent positions.

Richard Bean, UCL, Jan 2009

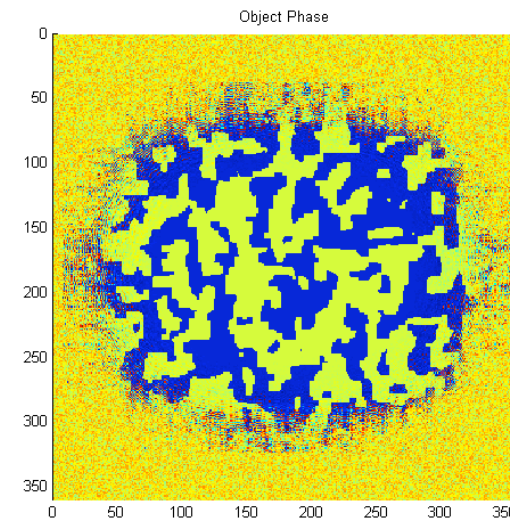
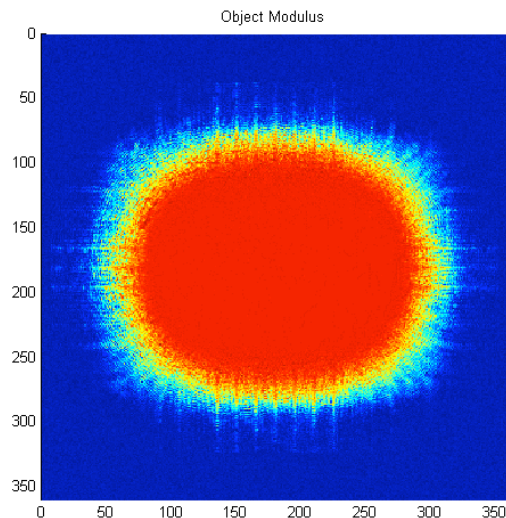


# Ptychography phasing tests

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



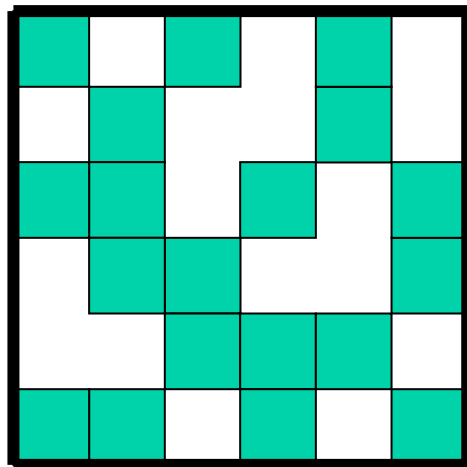
*Amplitude and phase after 1 iteration.*



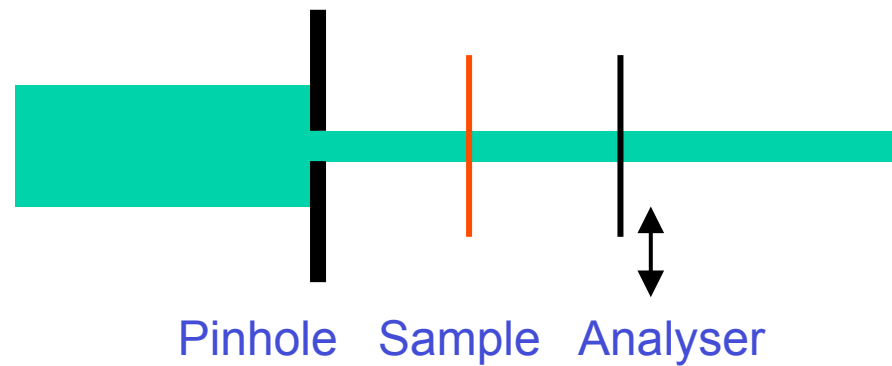
*Amplitude and phase after 20 iterations.*

# 'Random' phase plate analyser

Joan Vila (PSI), Fucai Zhang (Sheffield)

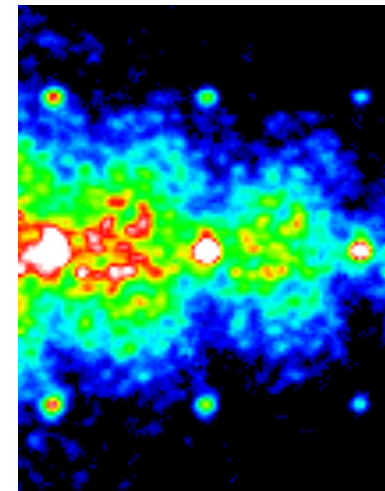
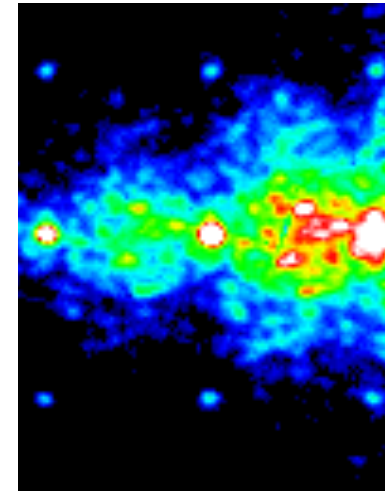
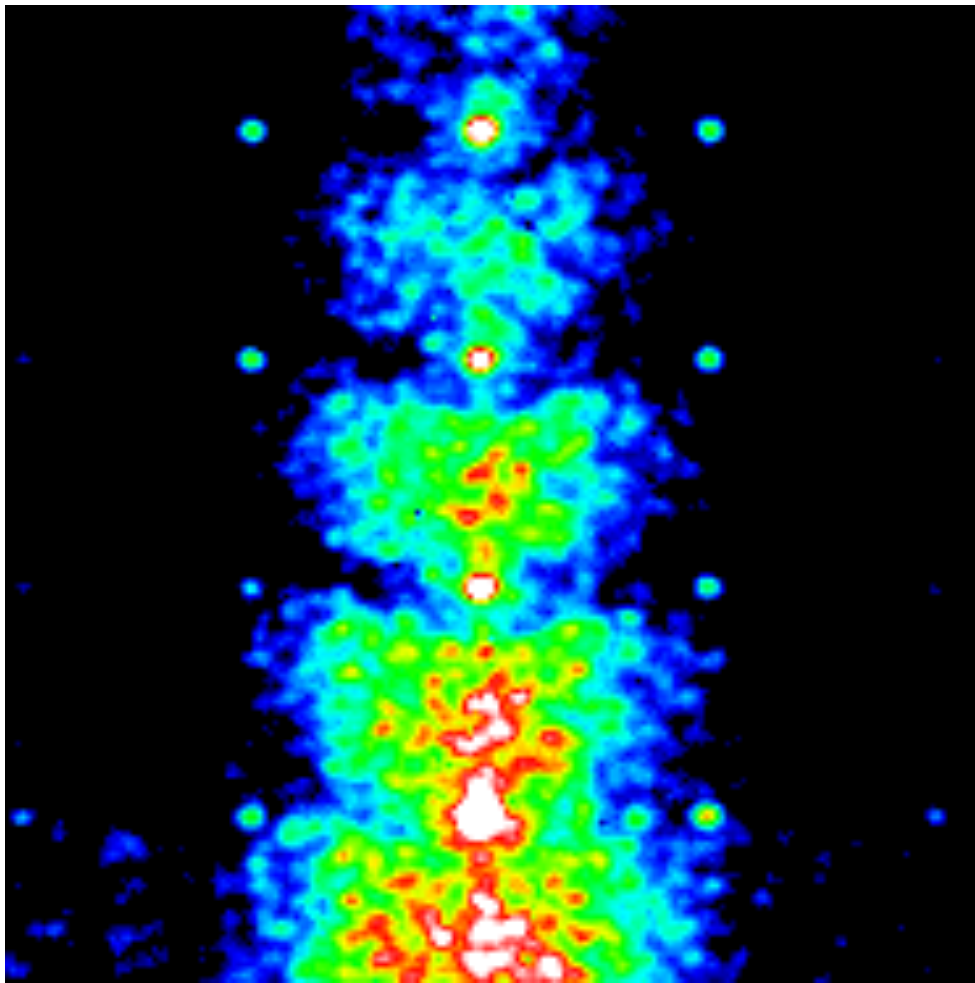


↔  
1  $\mu$ m



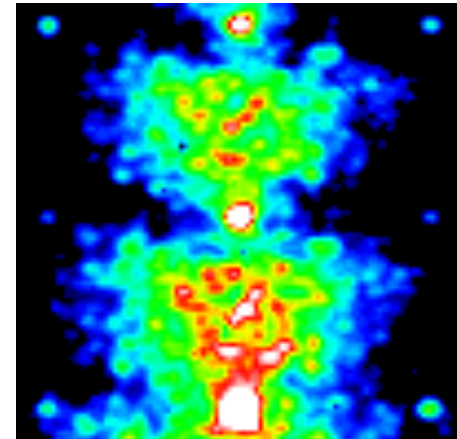
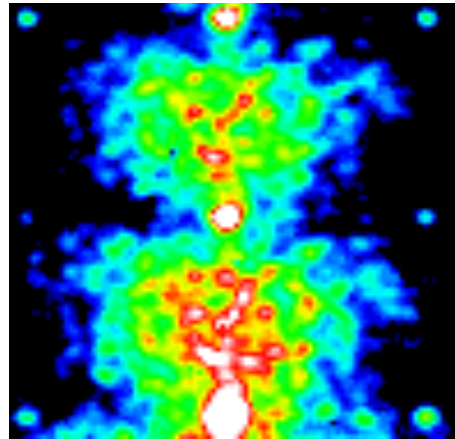
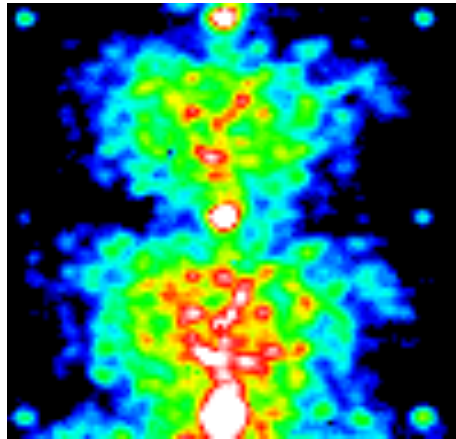
# Phase plate scan near forward direction

1  $\mu\text{m}$  step per frame



# Collagen, buffer and empty cell

phplateFZP-236, -246 and -249



# Coherent X-ray Diffraction

- Allows 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
- Biological tissue accessible by ptychography