

Strained Nanocrystals

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Diamond Light Source

Physikalische Kolloquium,

Kiel University,

May 2010

Outline

- Coherent x-ray diffraction
- CXD can solve the **phase** problem
- Nanocrystal structures
- Crystal strain as complex density
- Nanowire structures
- Full strain tensor

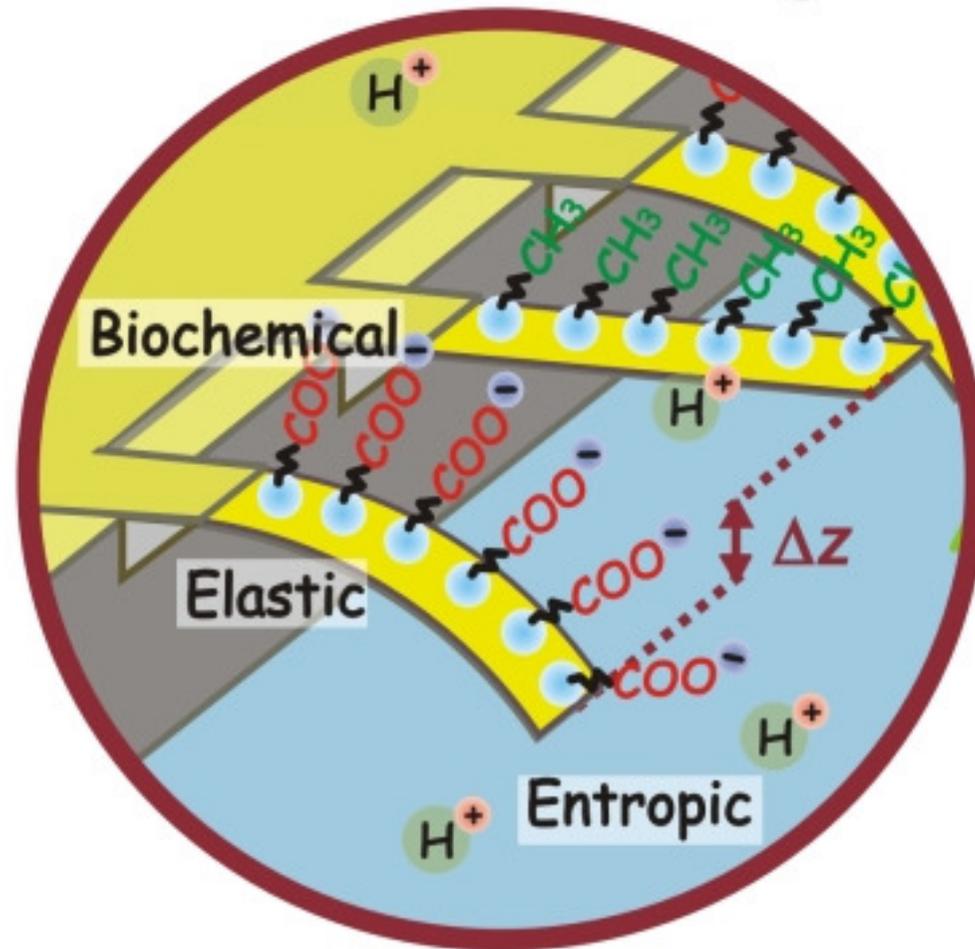
London Centre for Nanotechnology

- Clean Rooms
- Low-T STM
- Lithography
- 3-beam FIB
- Visualisation
- CLS?



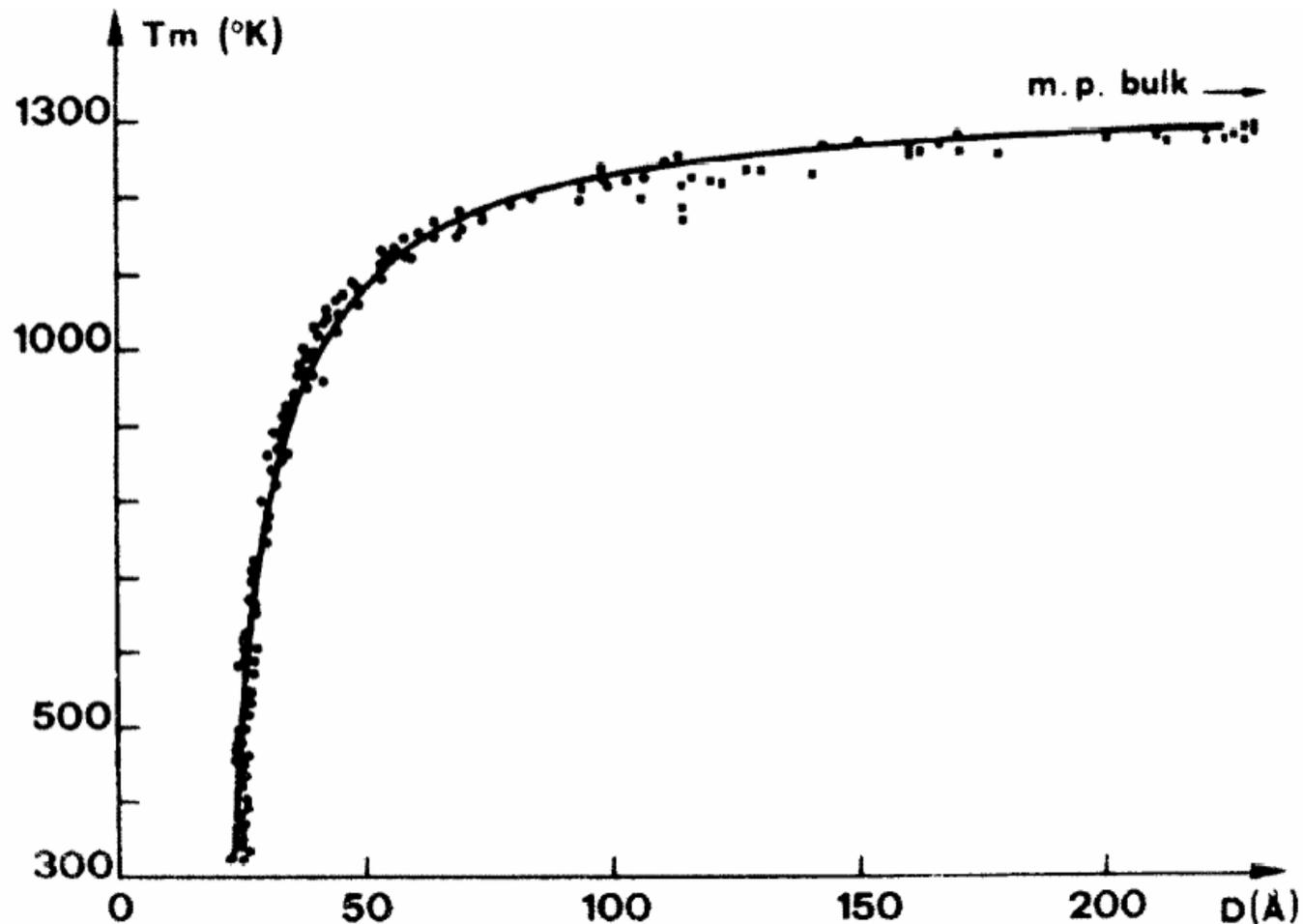
Nanocantilevers

Dr Rachel McKendrie

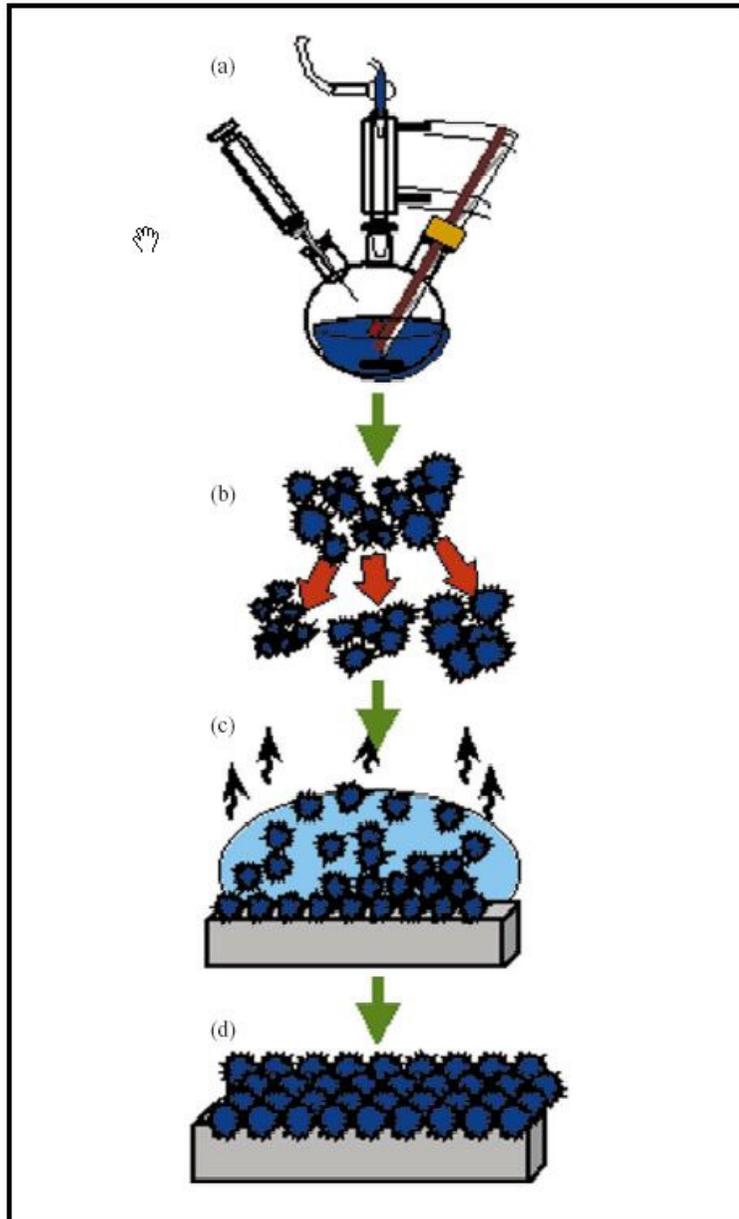


Size-dependent Melting of Au Particles

P. Buffat and J-P. Borel, Phys. Rev. A 2287-97 (1975)

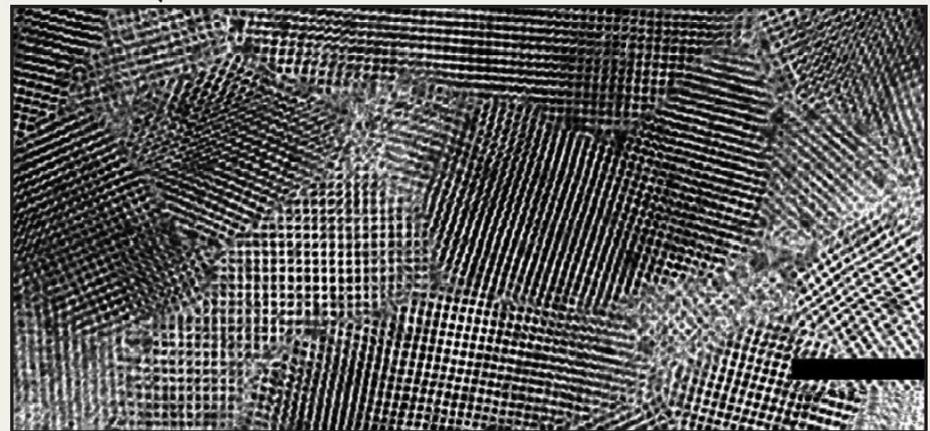


Chemical Synthesis of Nanocrystals



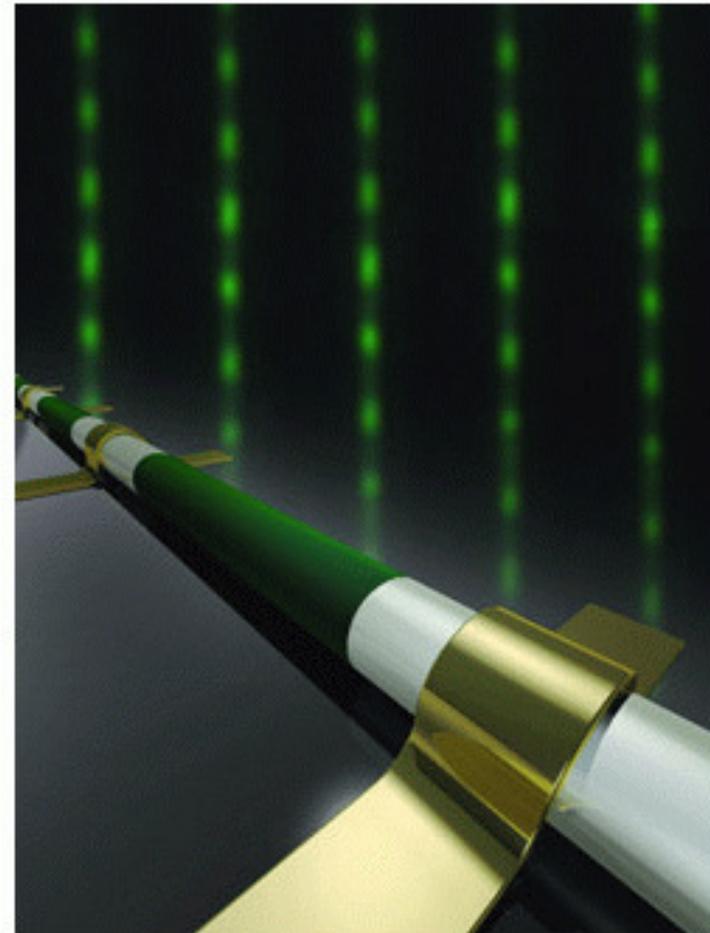
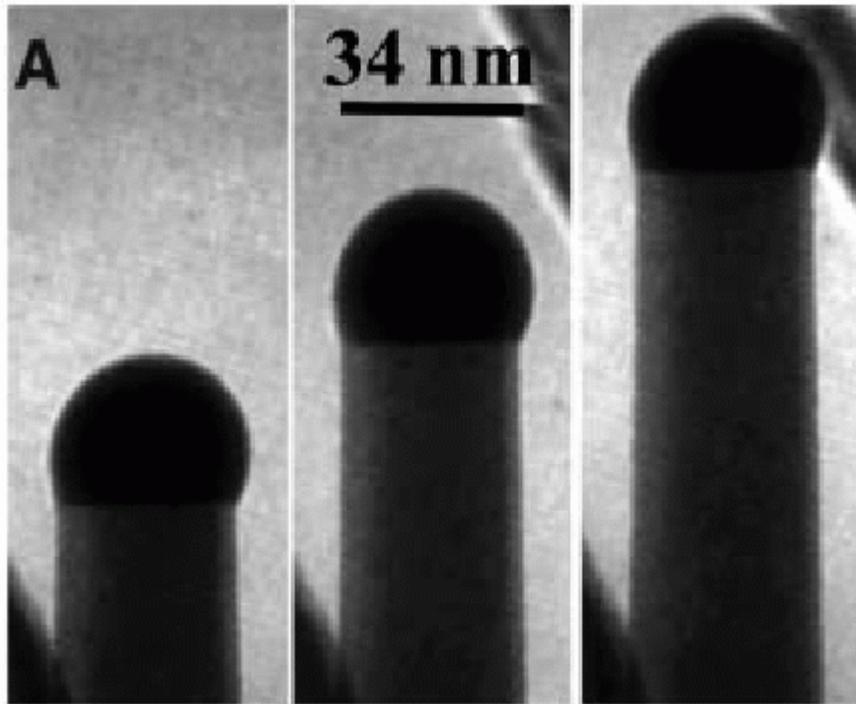
- Reactants introduced rapidly
- High temperature solvent
- Surfactant/organic capping agent
- Square superlattice (200nm scale)

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



VLS growth of nanowires

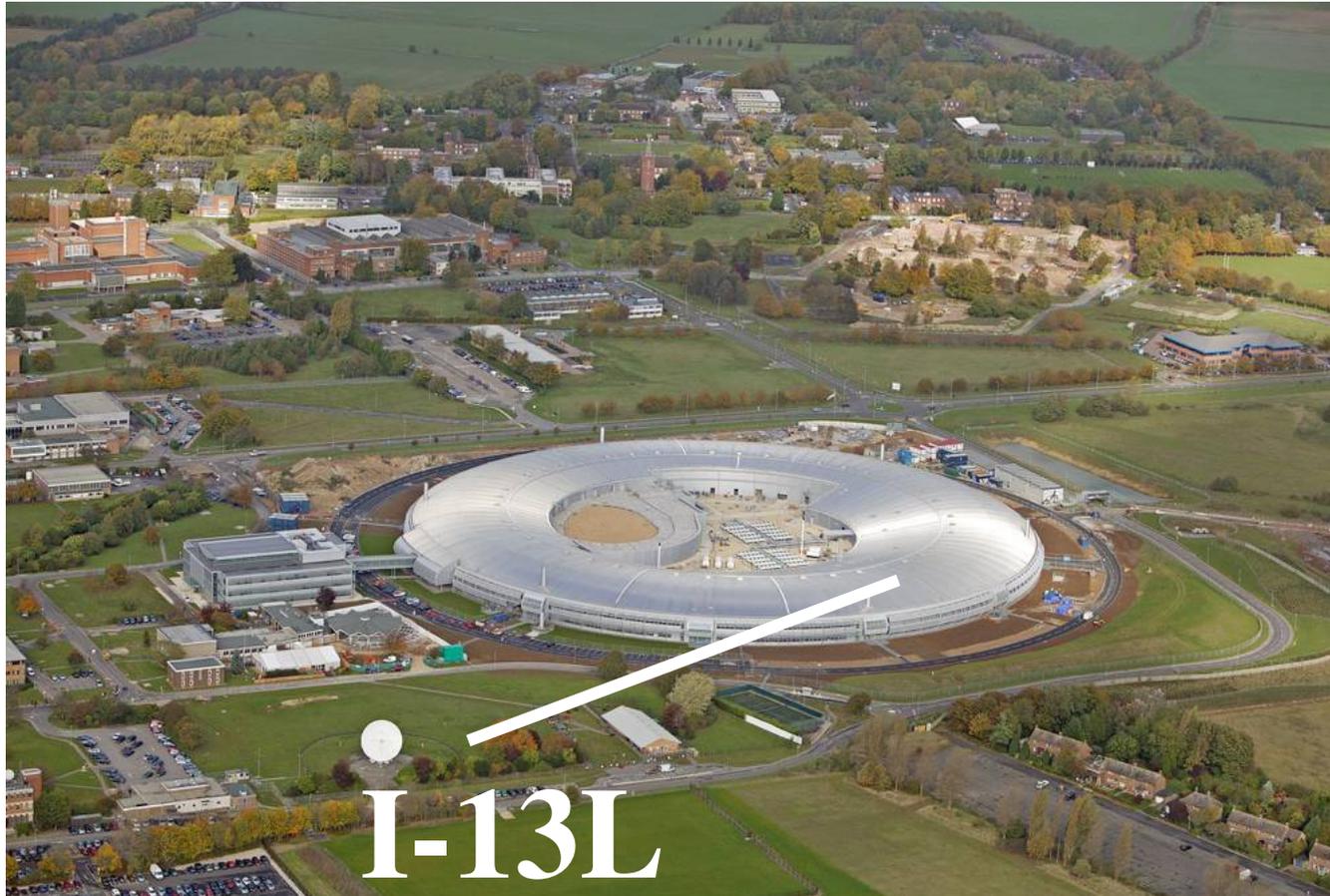
S. Kodambaka et al., *Science* 316 729 (2007)



I. K. Robinson, Kiel

NiSi/Si nanowire heterostructure devices. *Nature* **430**, 61 (2004).

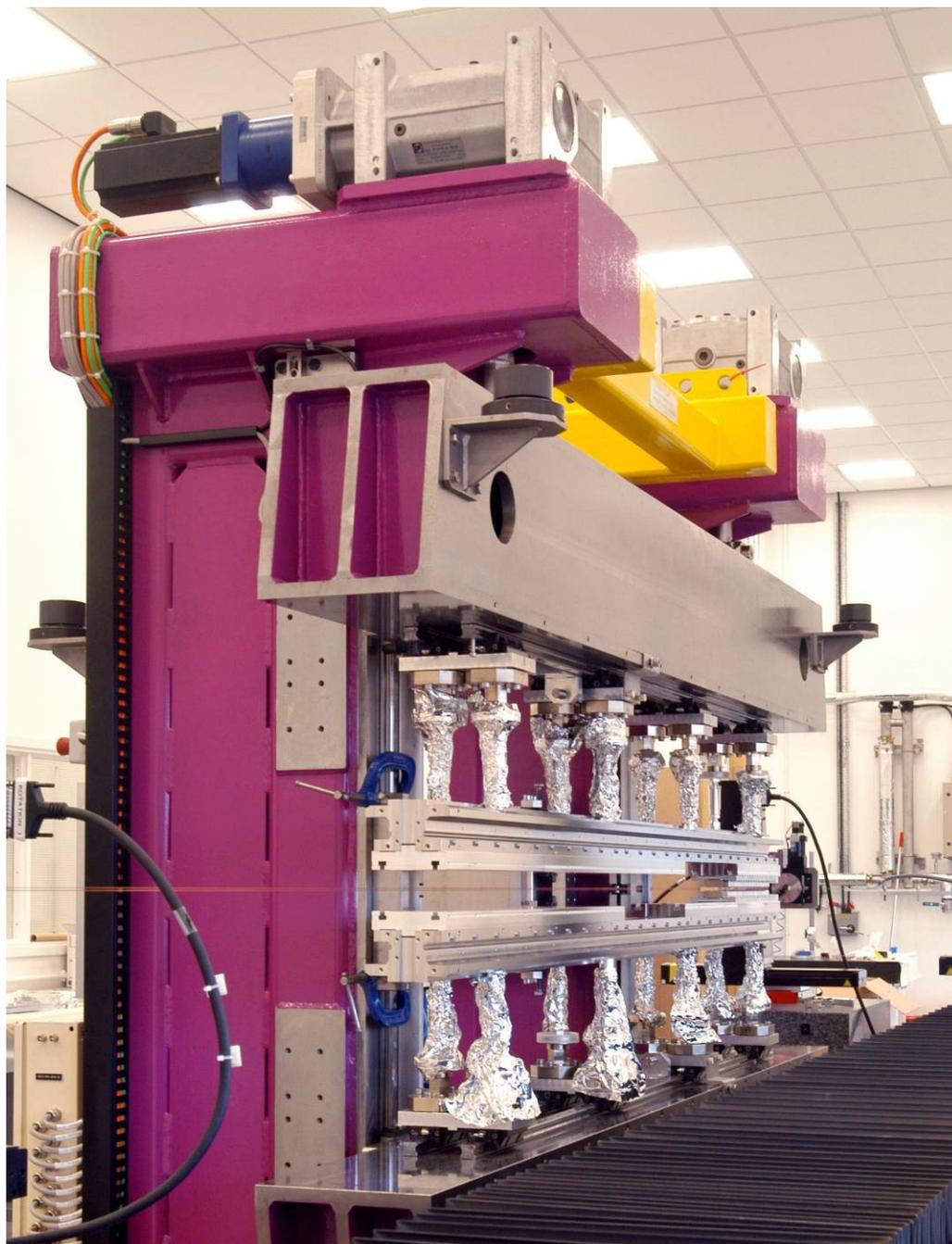
Diamond Light Source (RAL)



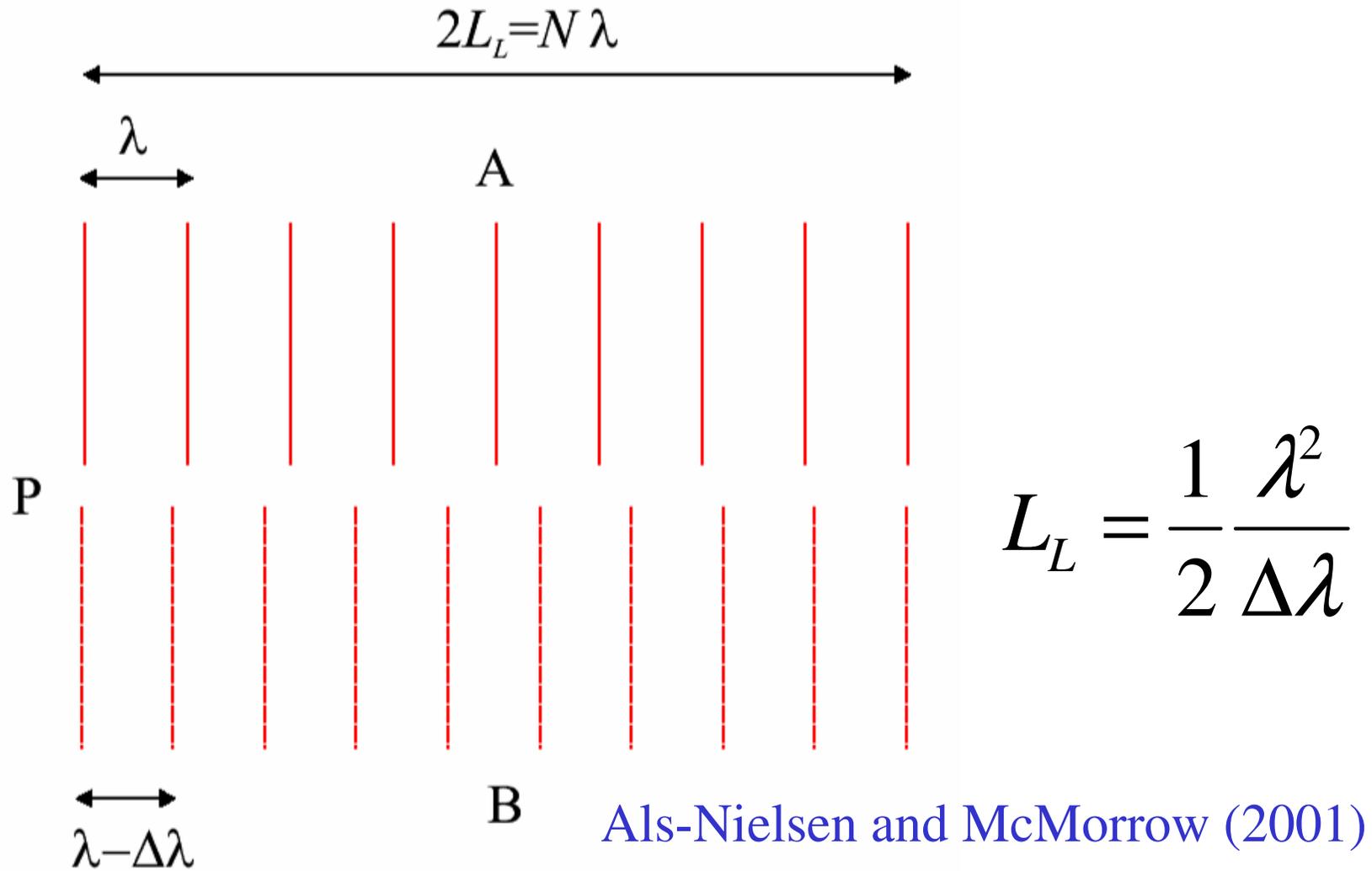
i-13L

I. K. Robinson, Kiel 2010

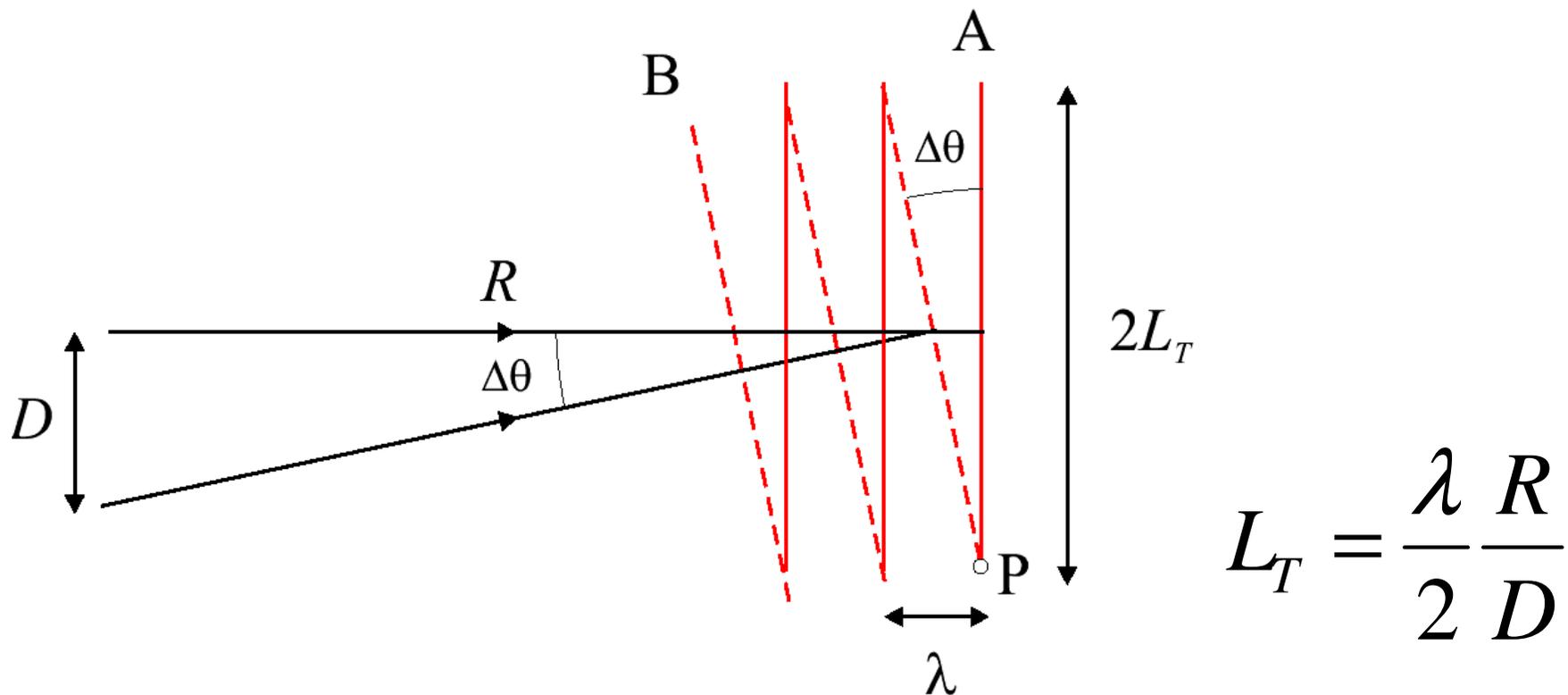
Diamond
in-vacuum
X-ray
Undulator



Longitudinal Coherence



Lateral (Transverse) Coherence



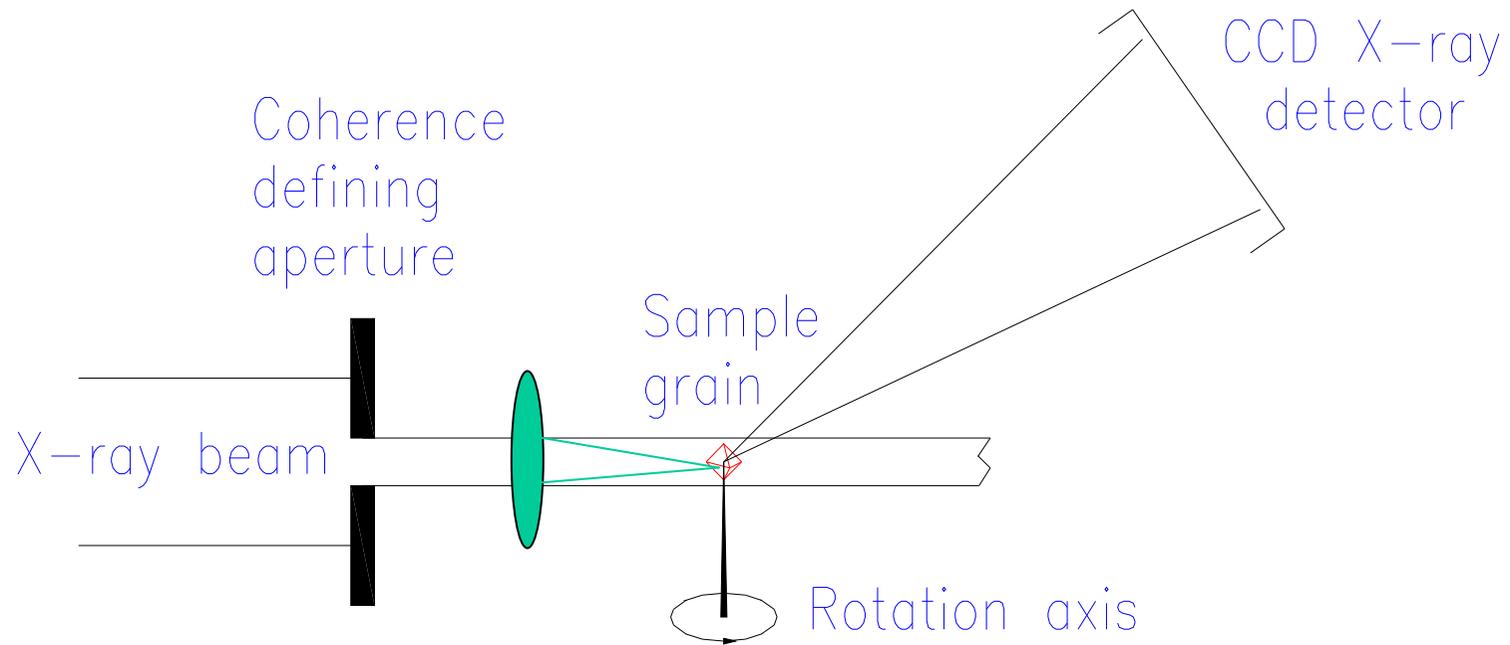
Als-Nielsen and McMorrow (2001)

Robert Hooke's microscope, 1665

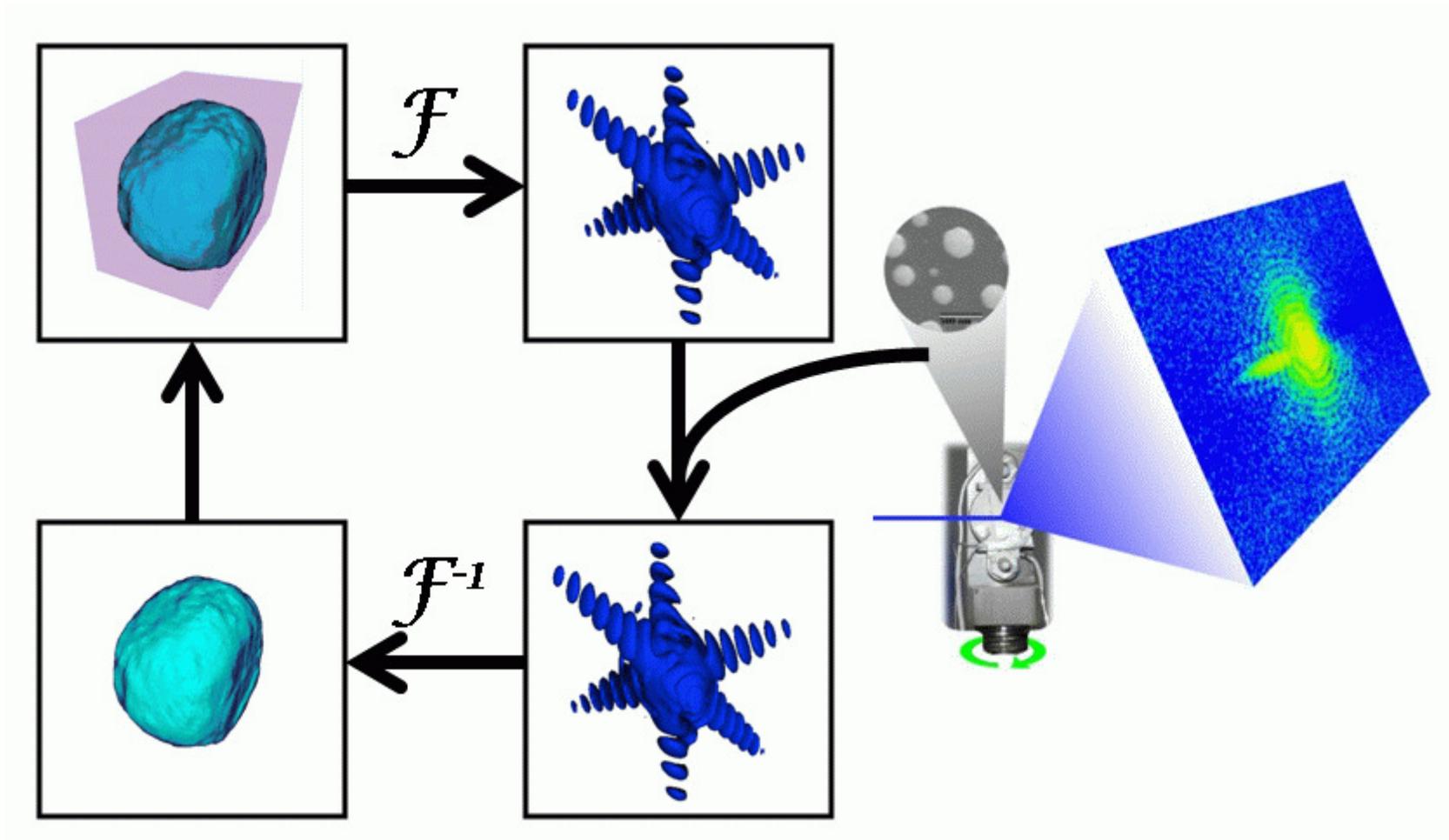
National Museum of
Health and Medicine,
Washington DC



Lensless X-ray Microscope, 2003



Generic “Error Reduction” method

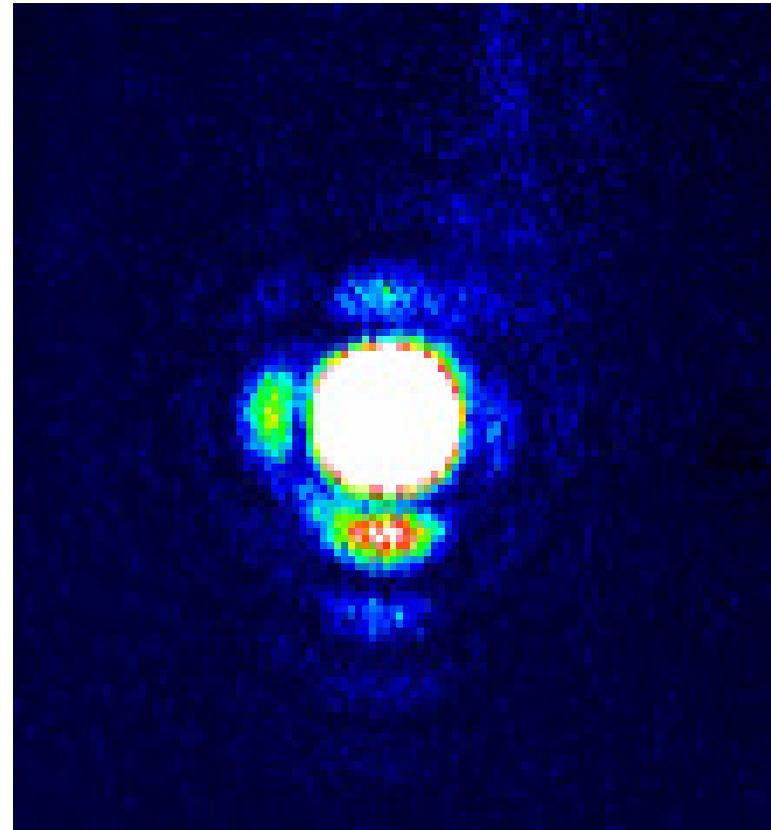
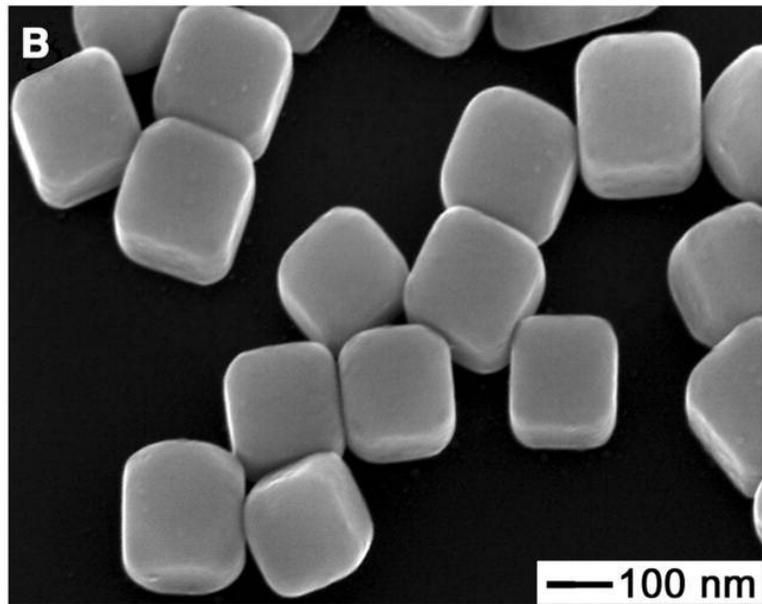


J. R. Fienup *Appl. Opt.* 21 2758 (1982)

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

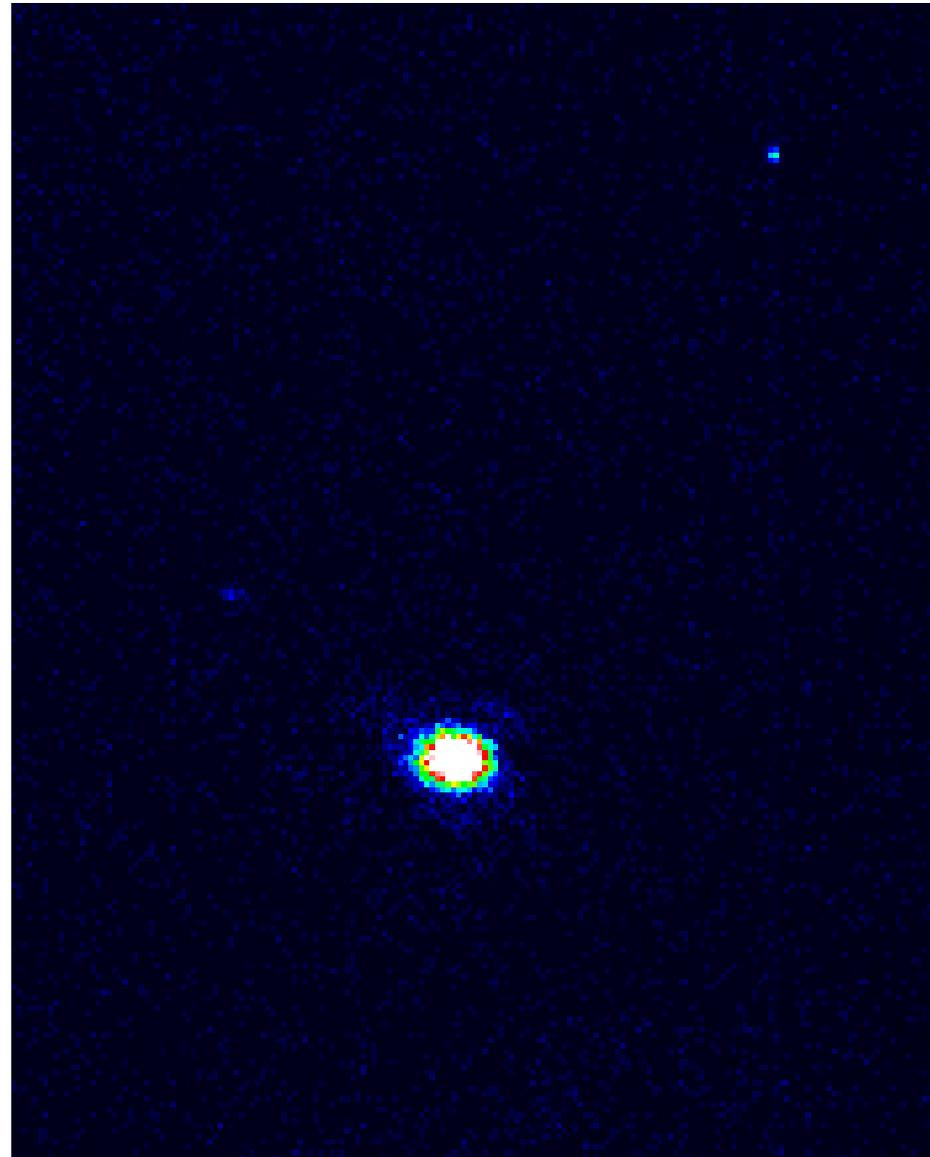
I. K. Robinson, Kiel 2010

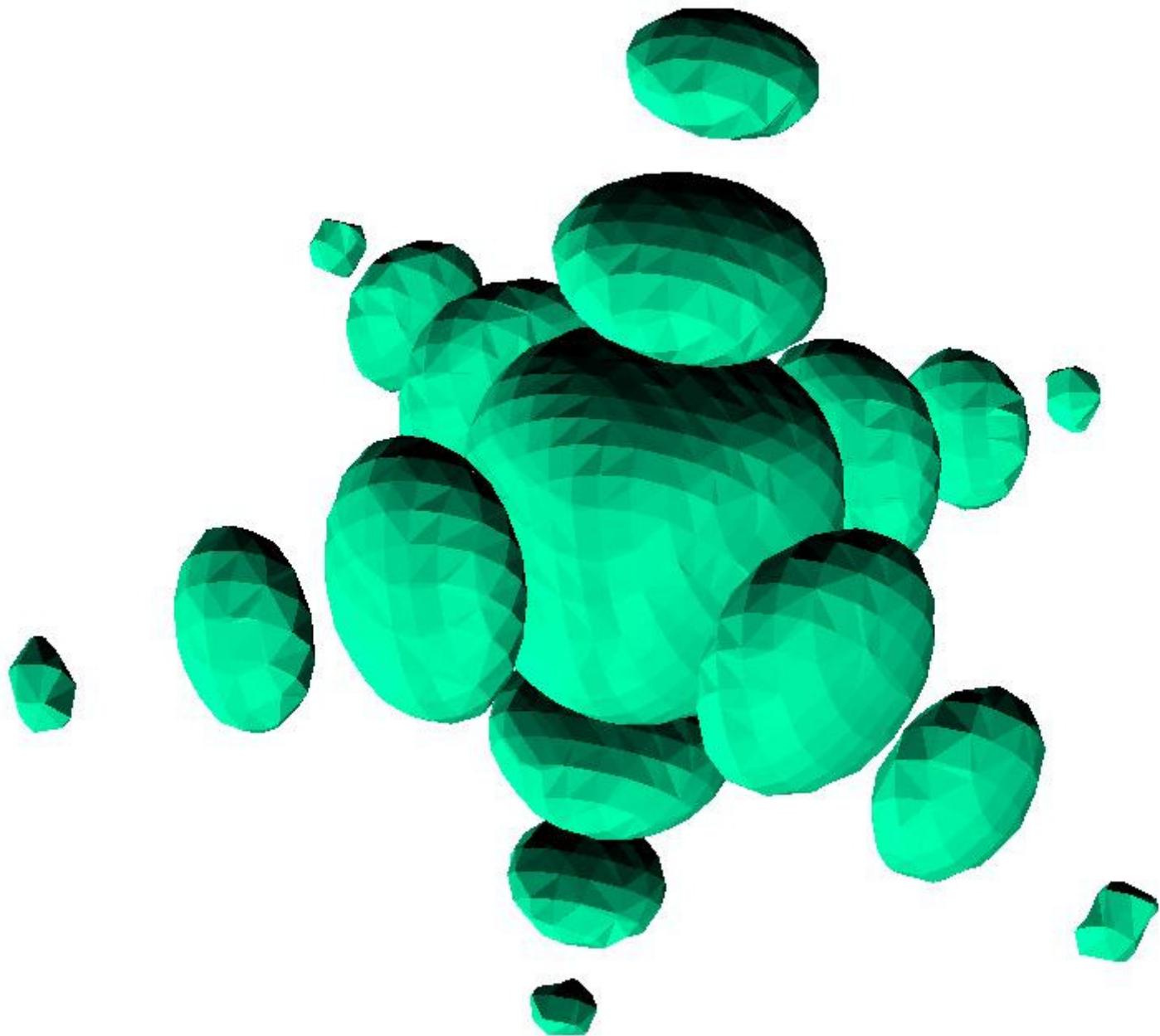
Chemically Synthesized Silver Nanocubes

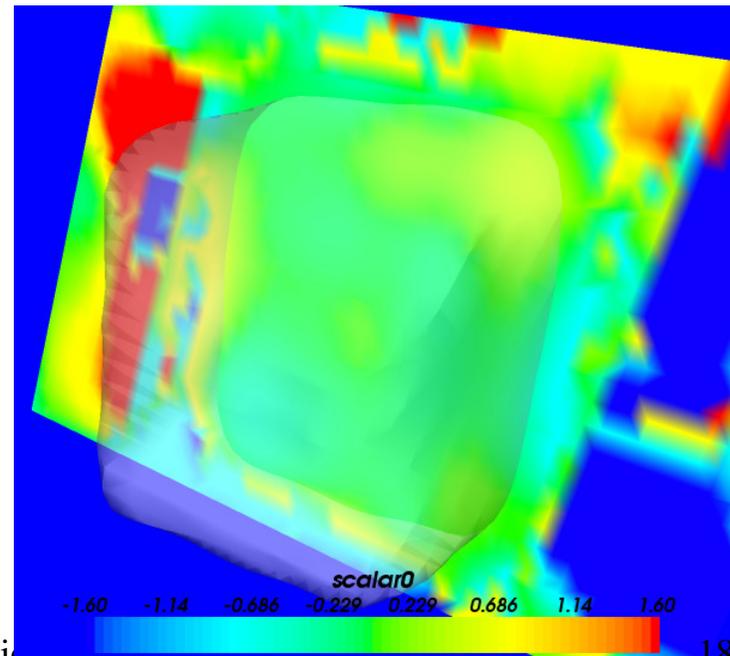
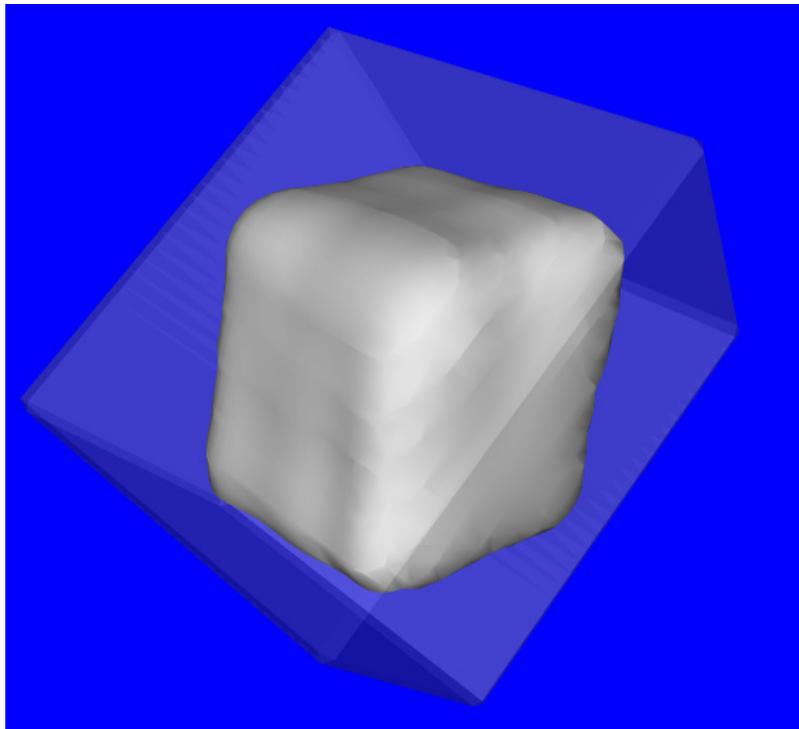
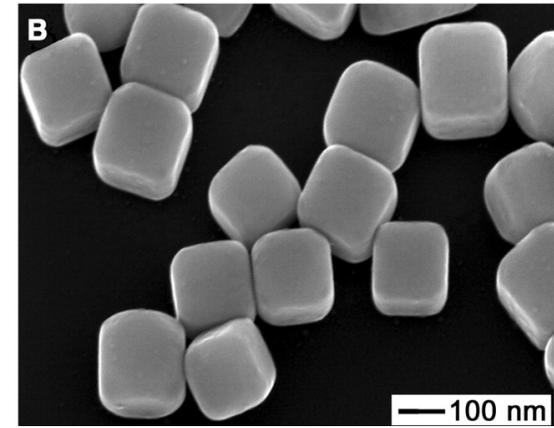
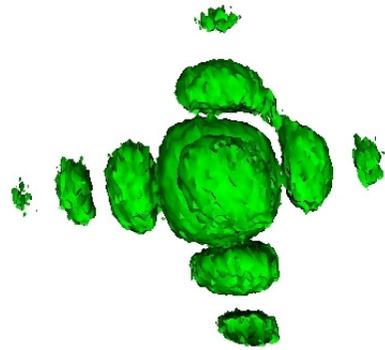
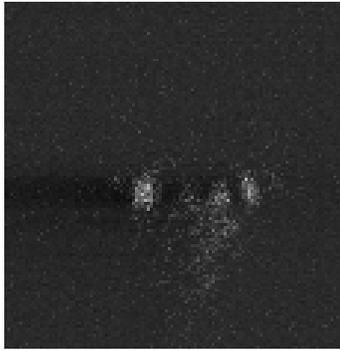


Yugang Sun and Younan Xia,
Science 298 2177 (2003)

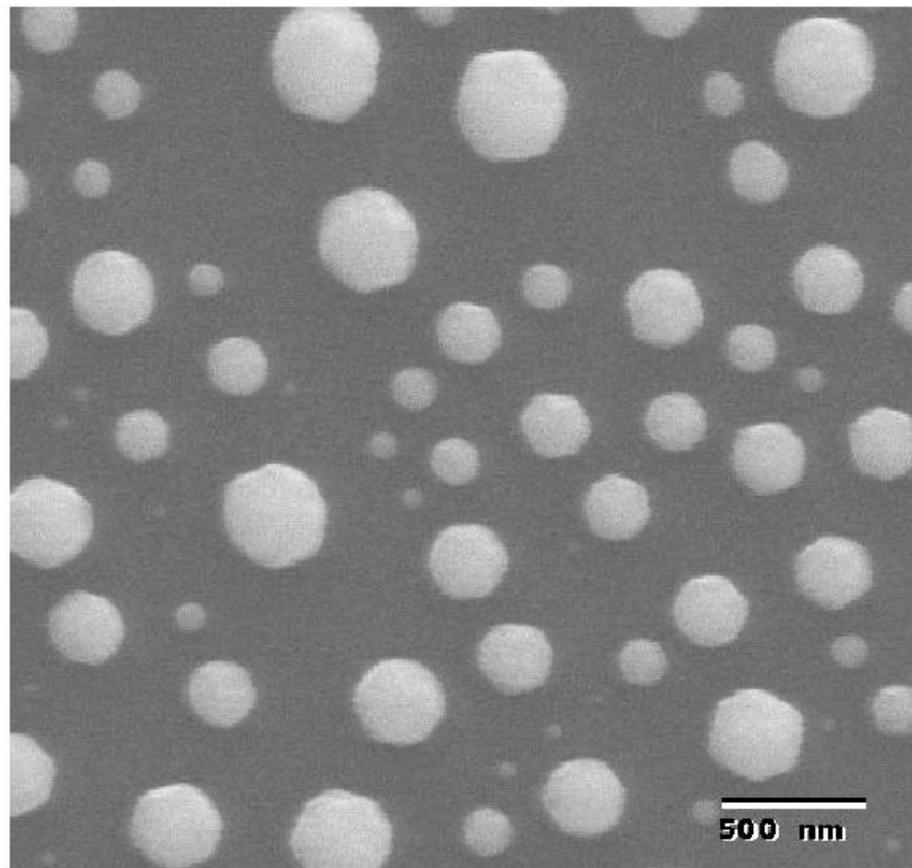
Rocking
scan of Ag
cubes with
 0.01° steps



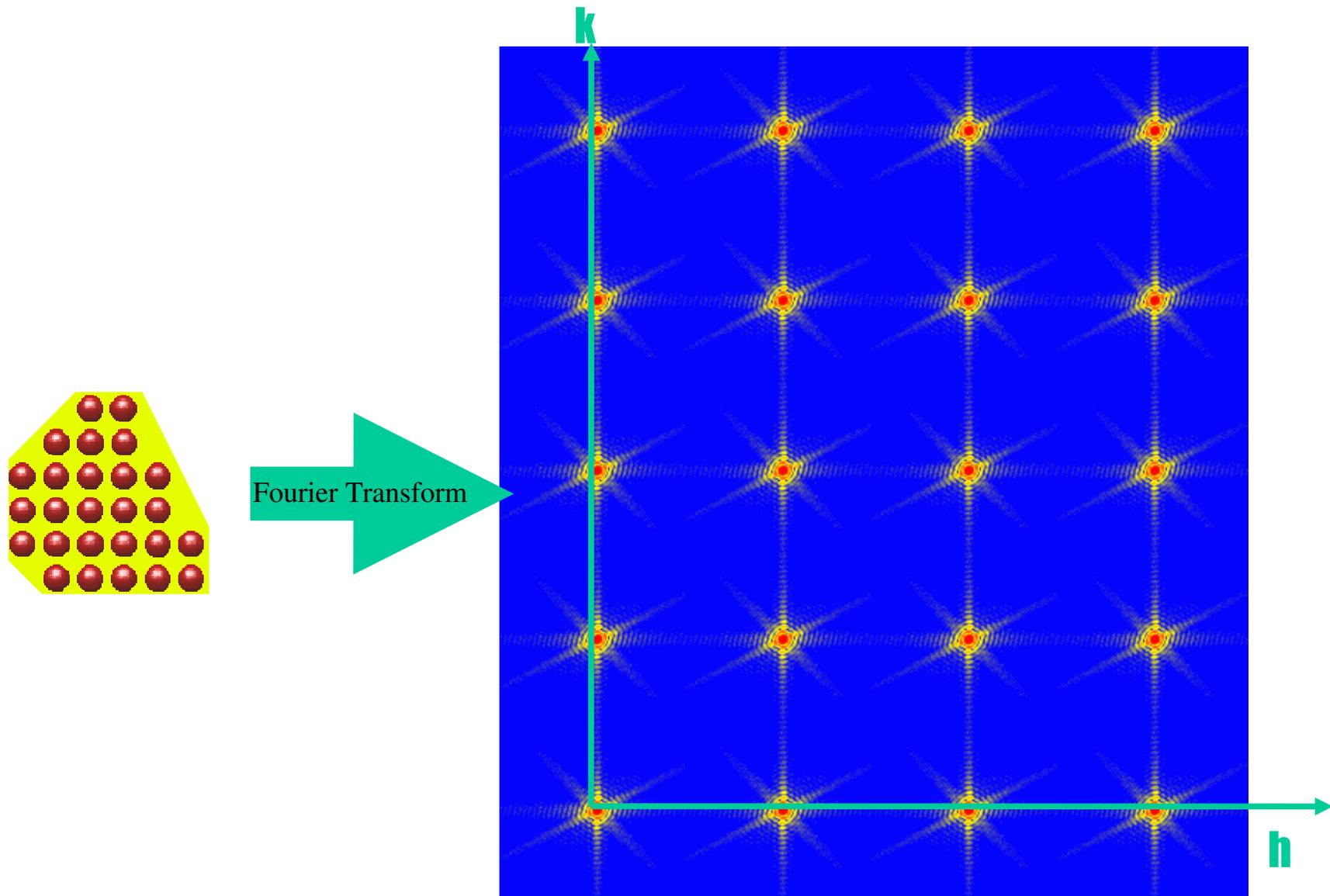




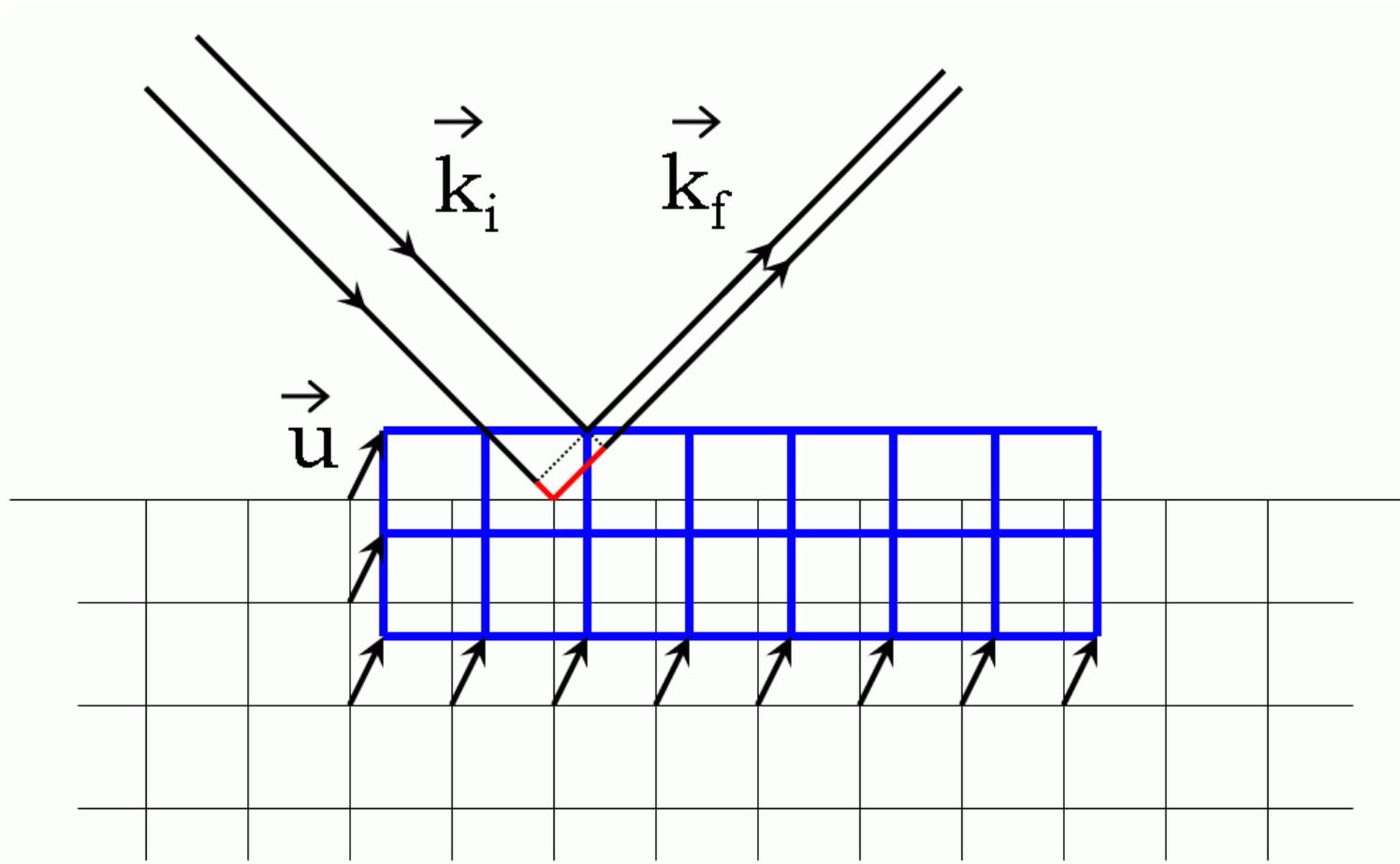
In situ growth of Pb crystals



Coherent Diffraction from Crystals



Sensitivity to strain

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


Good statistics, 3D diffraction data

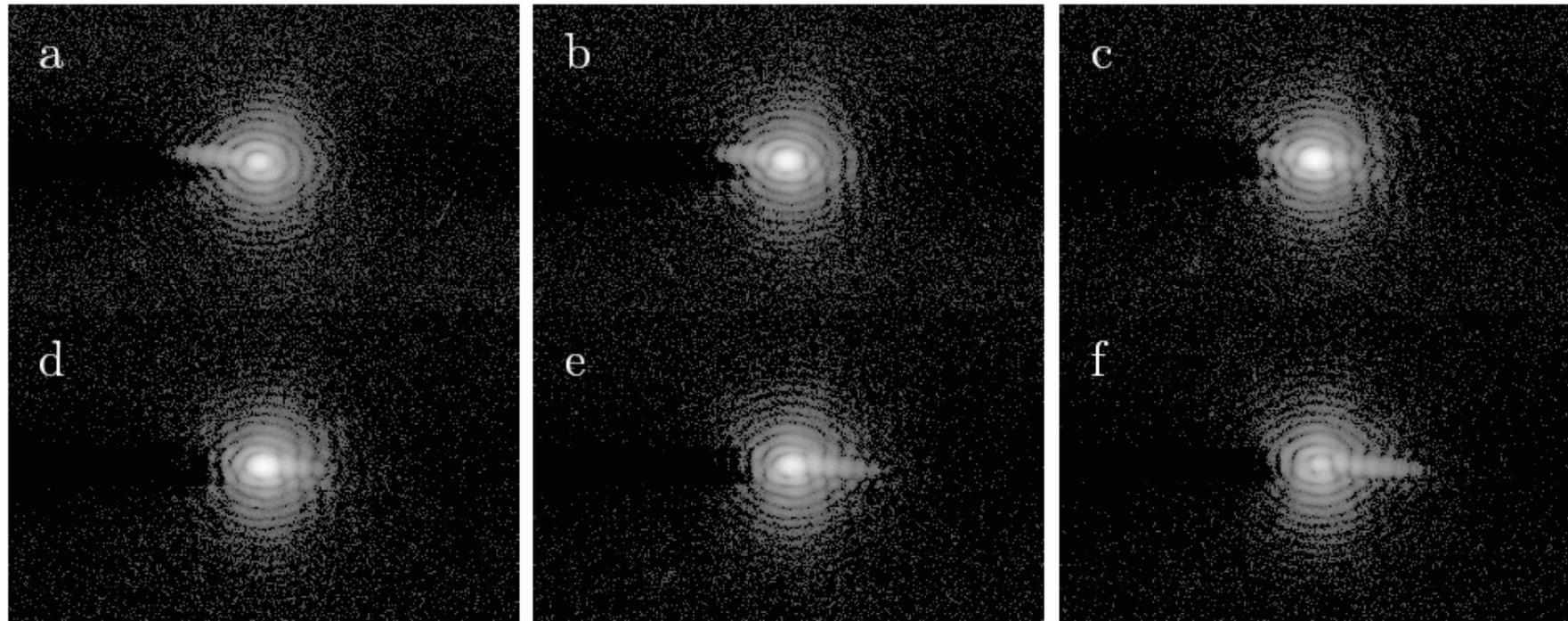
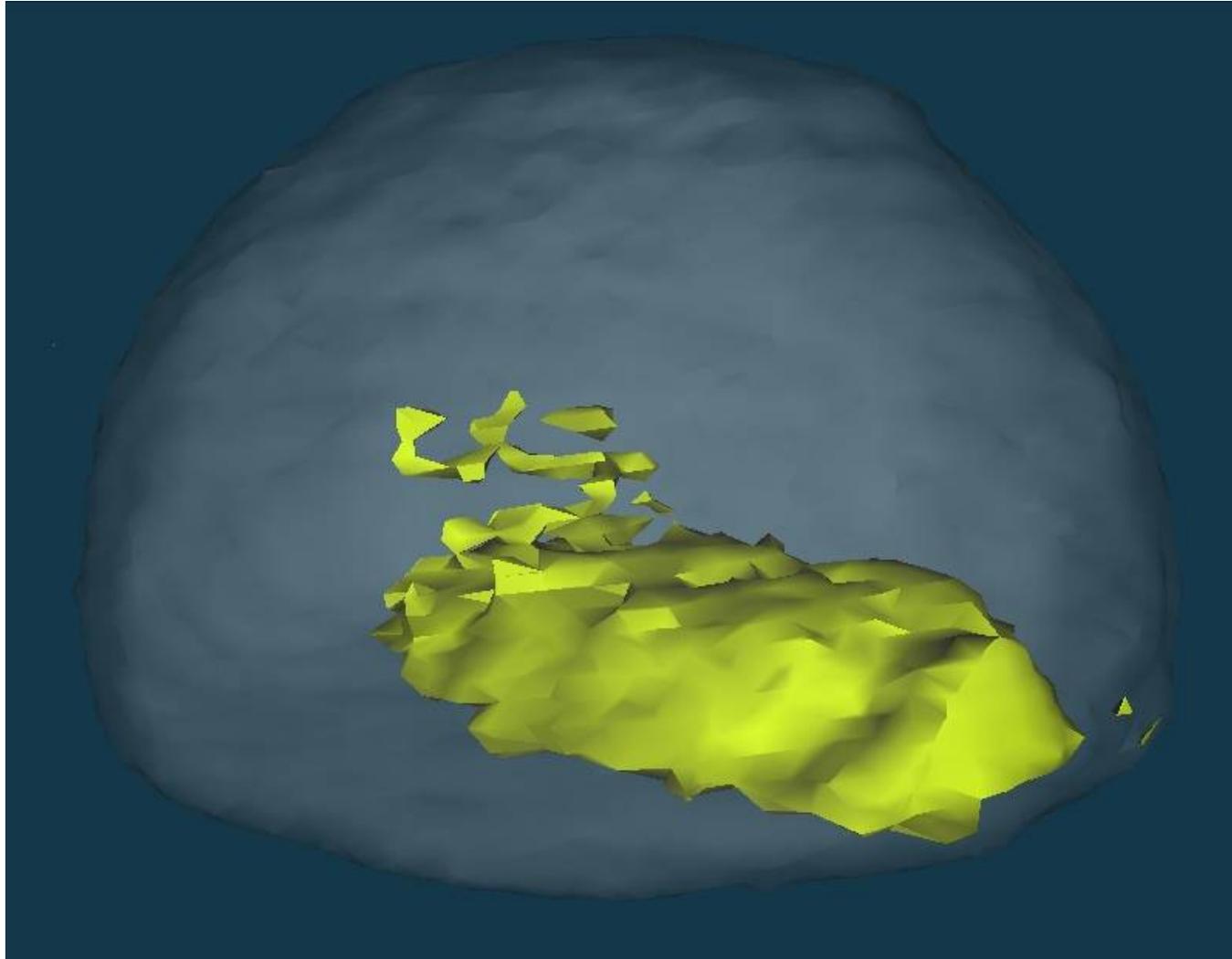


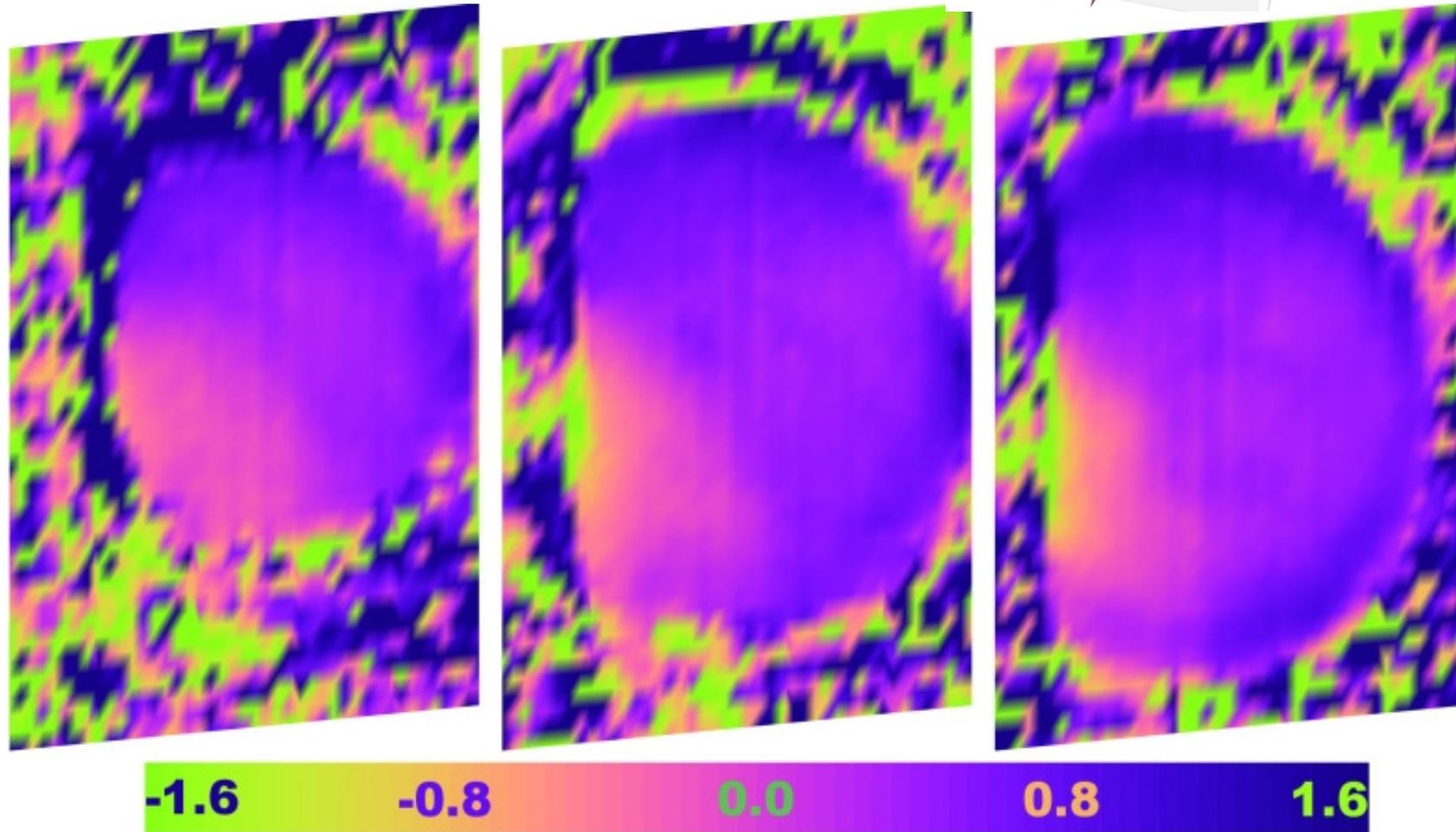
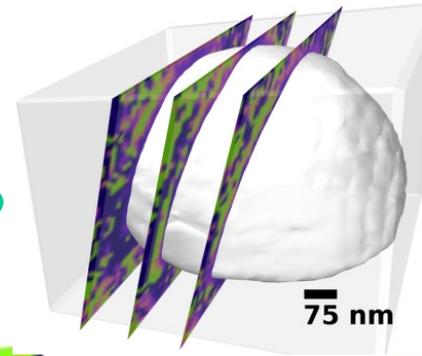
Figure 4.12: Center slices from 3D CXD pattern from Pb sample, on a log scale. Data file 296 from 10/03.

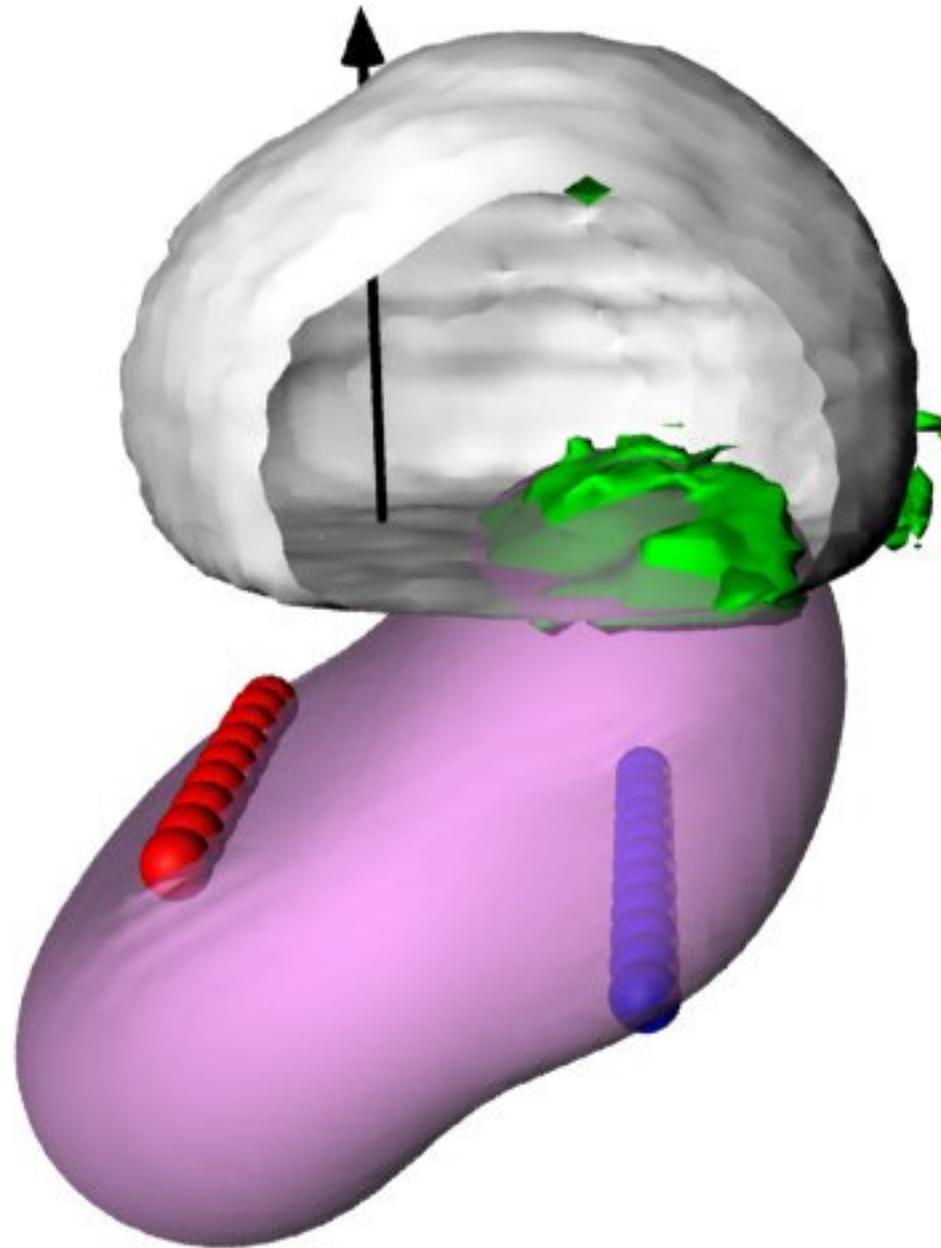
Modeling of 3D Phase Bump



I. K. Robinson, Kiel 2010

3D phase map sections



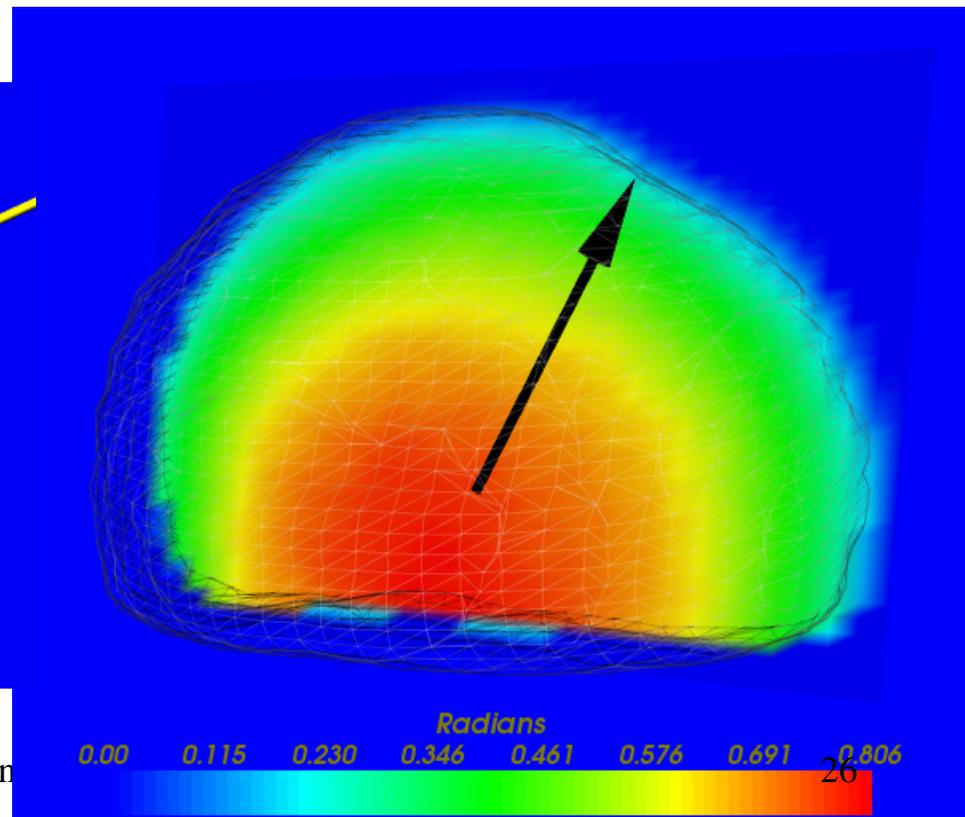
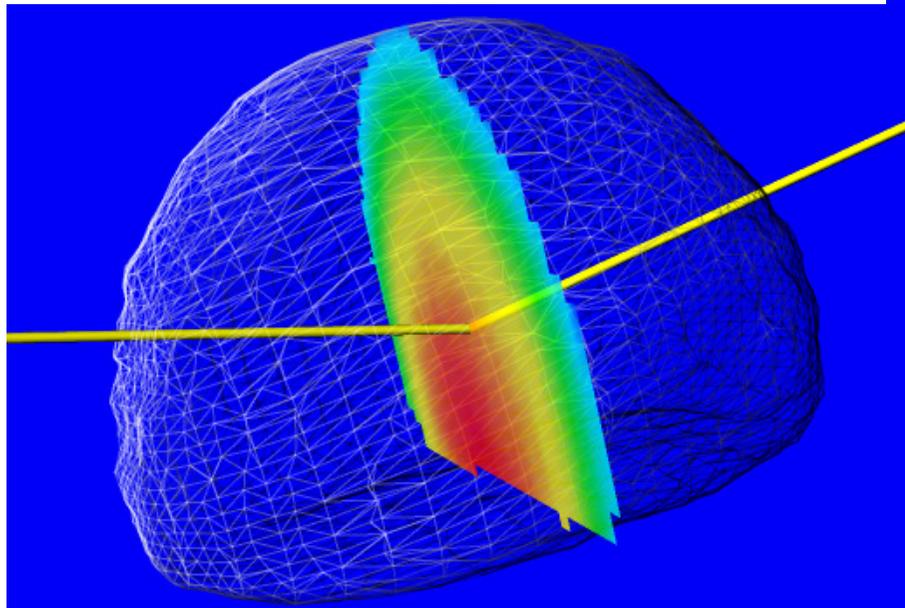


Refraction effects in Lead at 8.9keV

Phase accumulation due to refraction along scattering path

$$n=1-\delta+i\beta$$

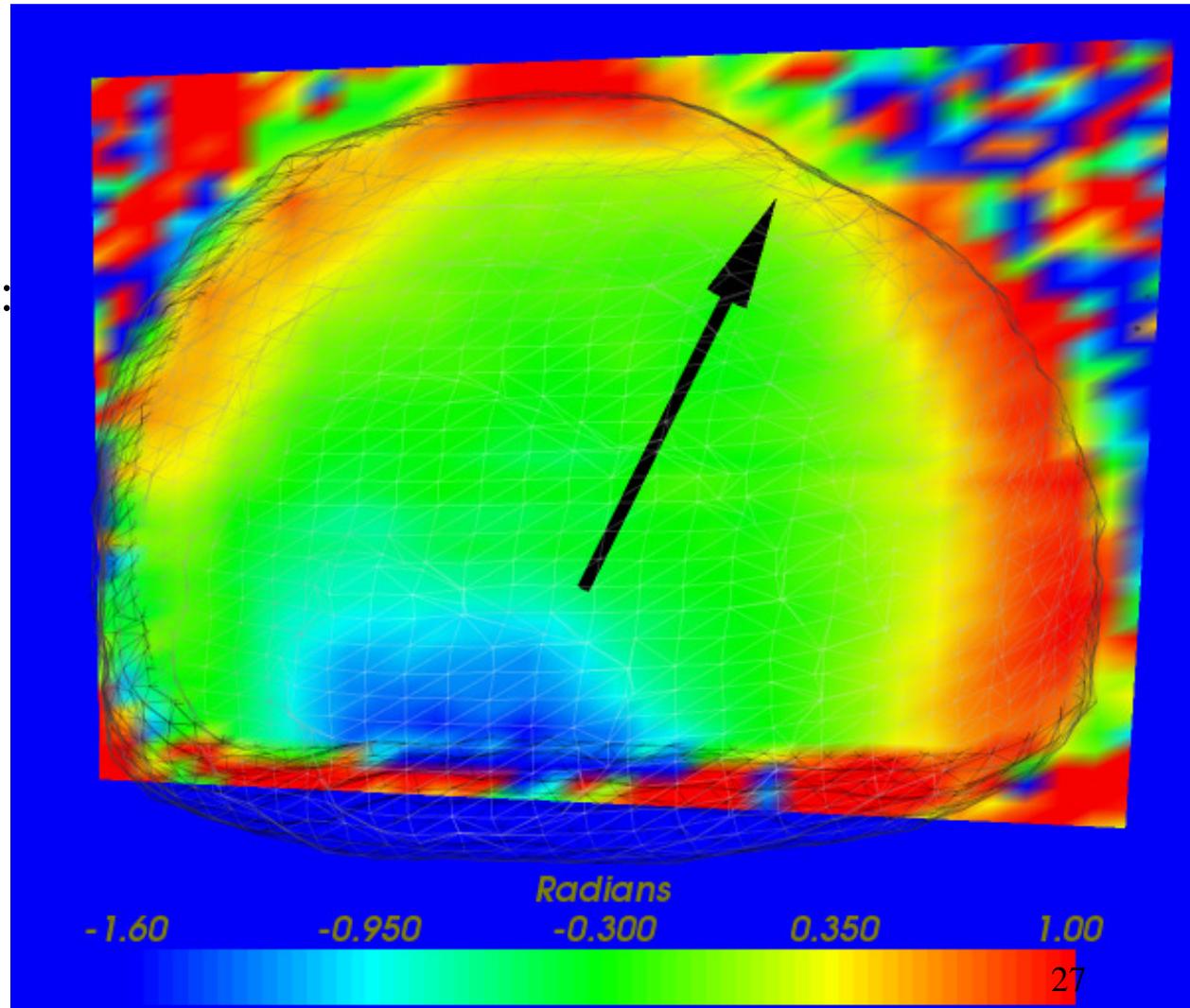
$$\delta=2.23\times 10^{-5}$$
$$\beta=2.19\times 10^{-6}$$



Refraction corrected phase map

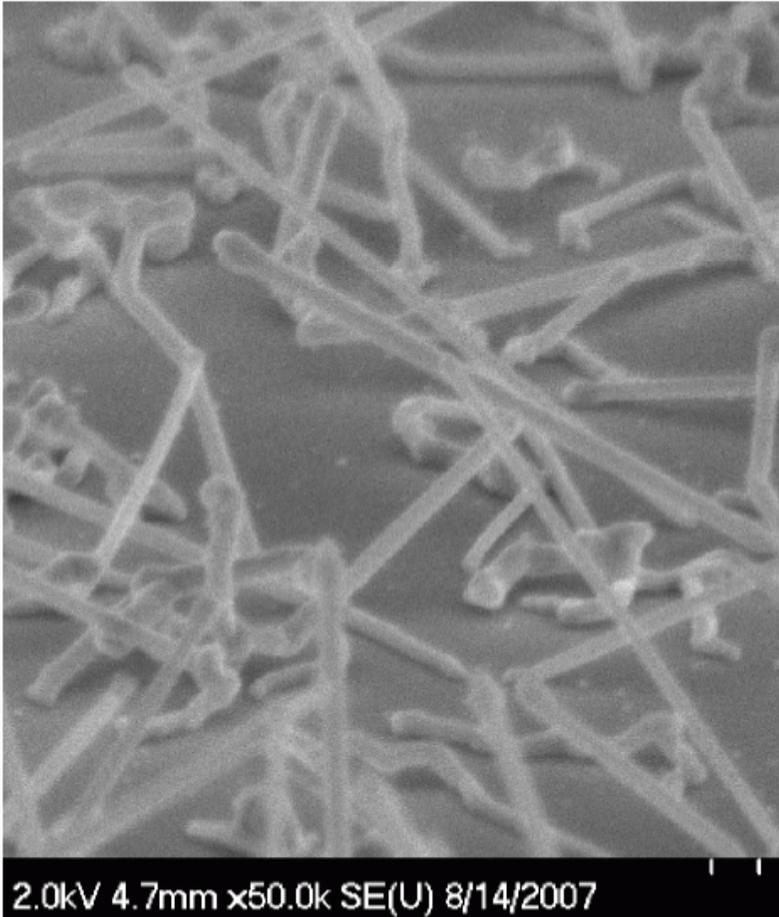
Max phase = 1.15rad
= 0.052nm

Phase on the (111) facet:
= 0.47 rad
= 0.02nm

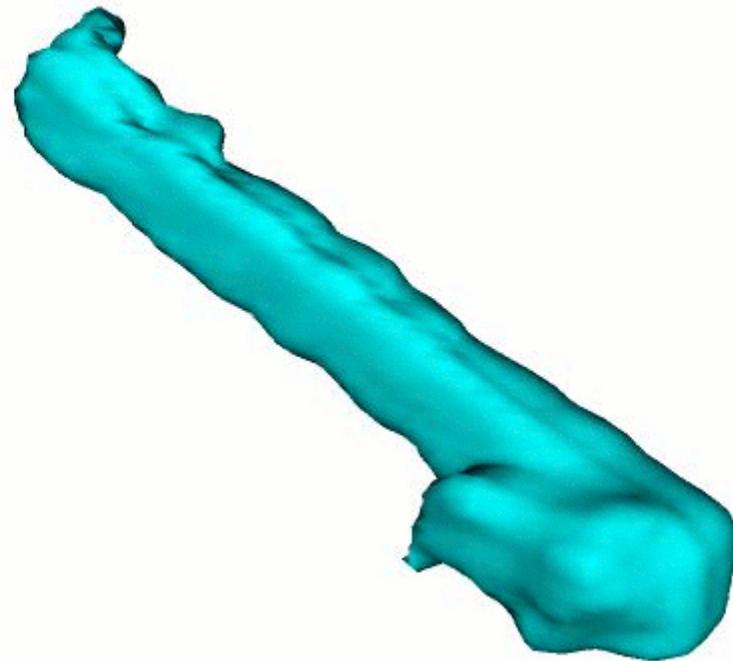


Reconstruction of InP nanowire

CVD on Si, Suneel Kodambaka, UCLA

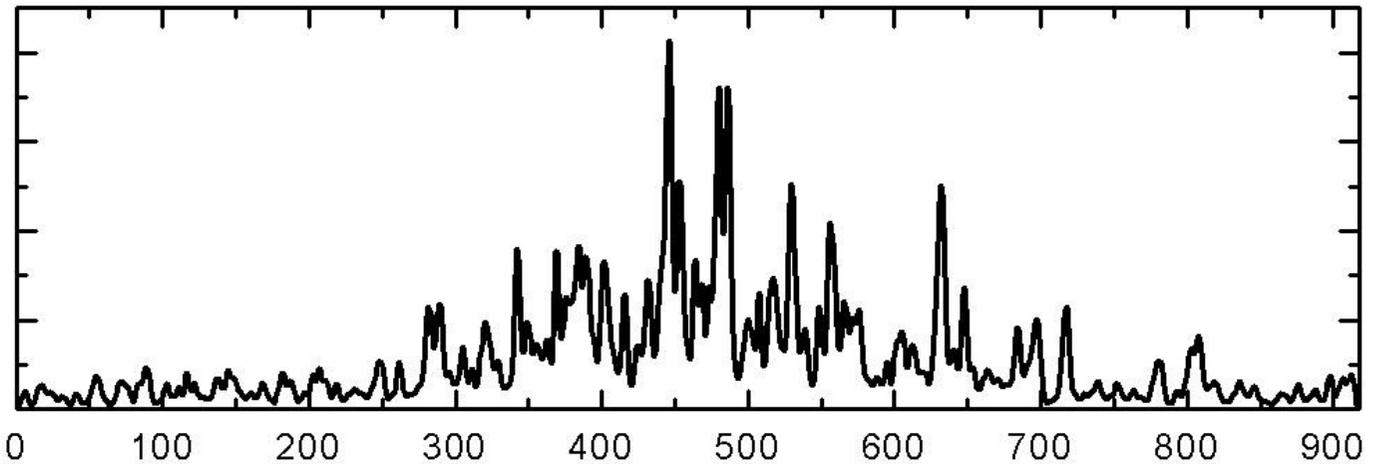
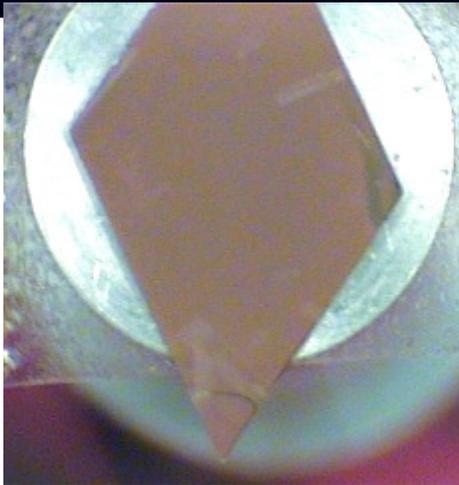
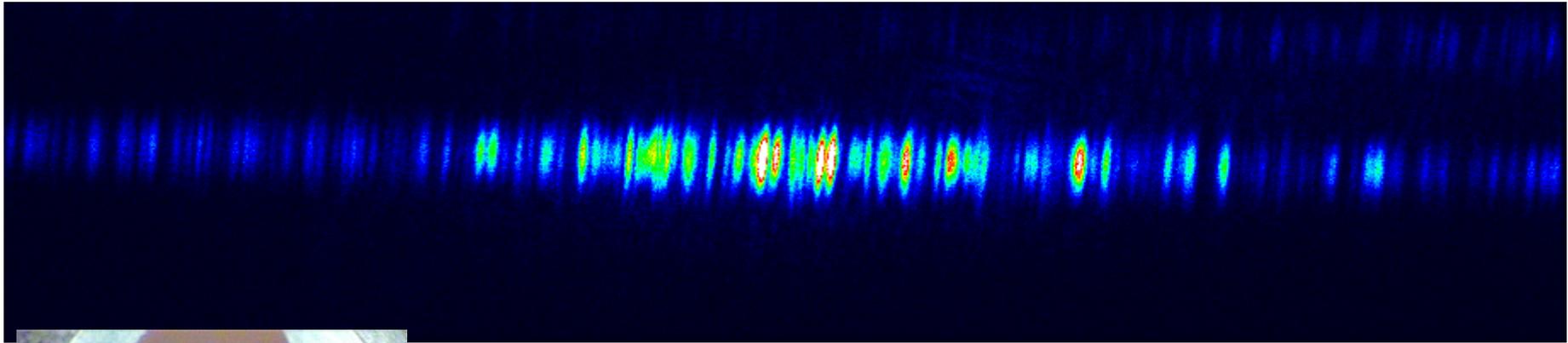


InP nanowires grown on Si (111)



GaAs Nanowire “Barcode”

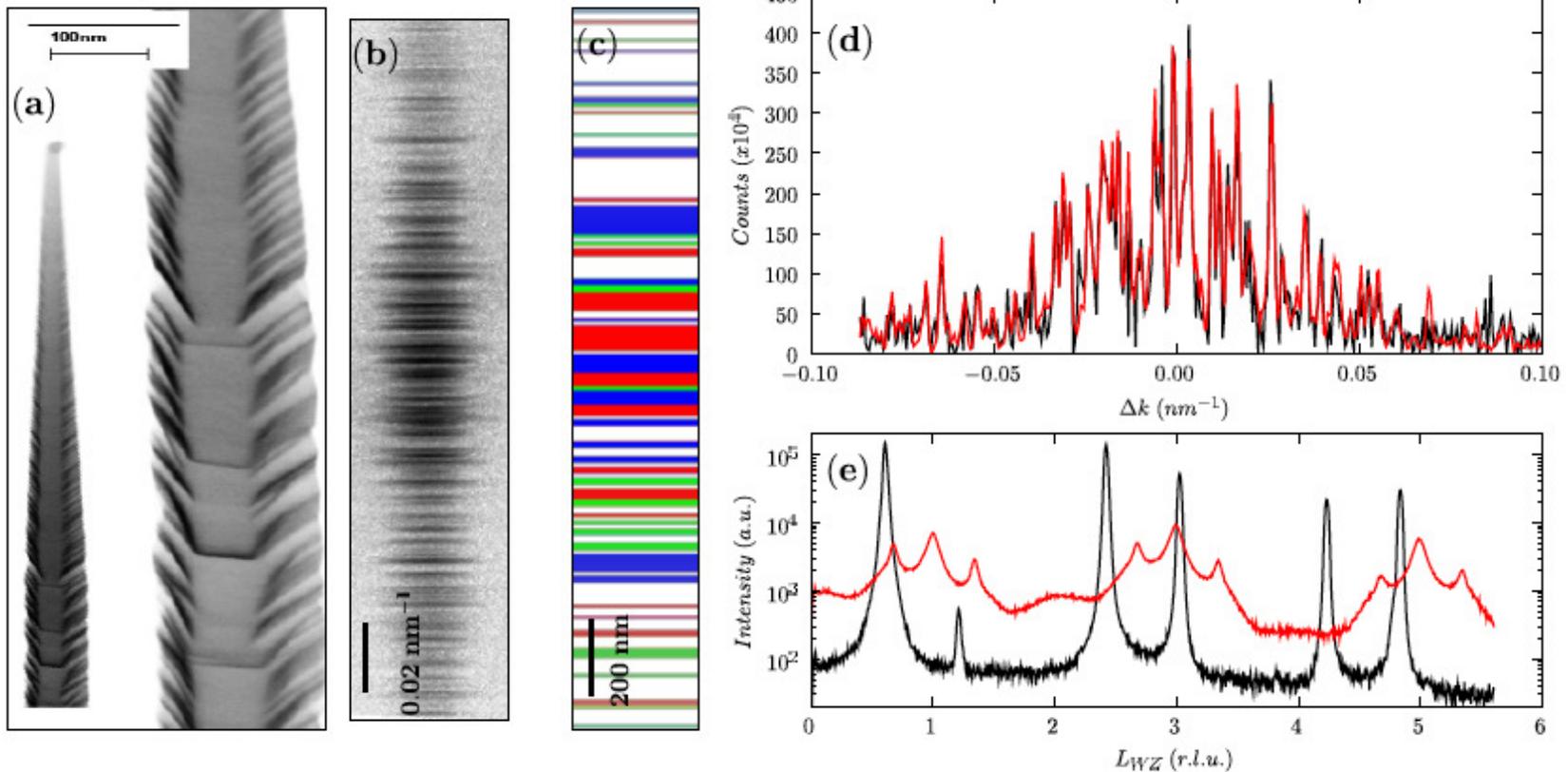
Vincent Favre-Nicolin, Joel Eymery (CEA),
Rienk Algra (Philips), Ross Harder



GaAsNW1106-22.spe
B9348 from Philips

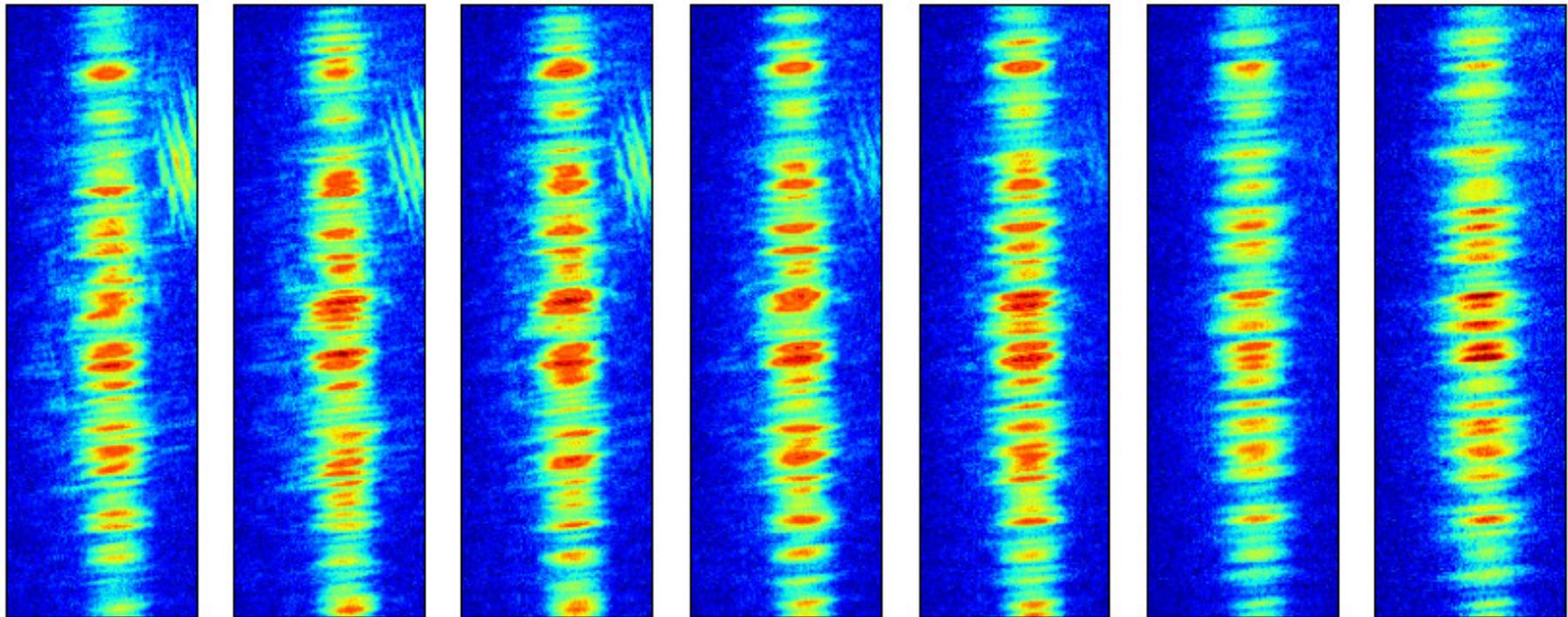
Bar-code Analysis

V Favre-Nicolin et al, New Journal of Physics 12 035013 (2010)



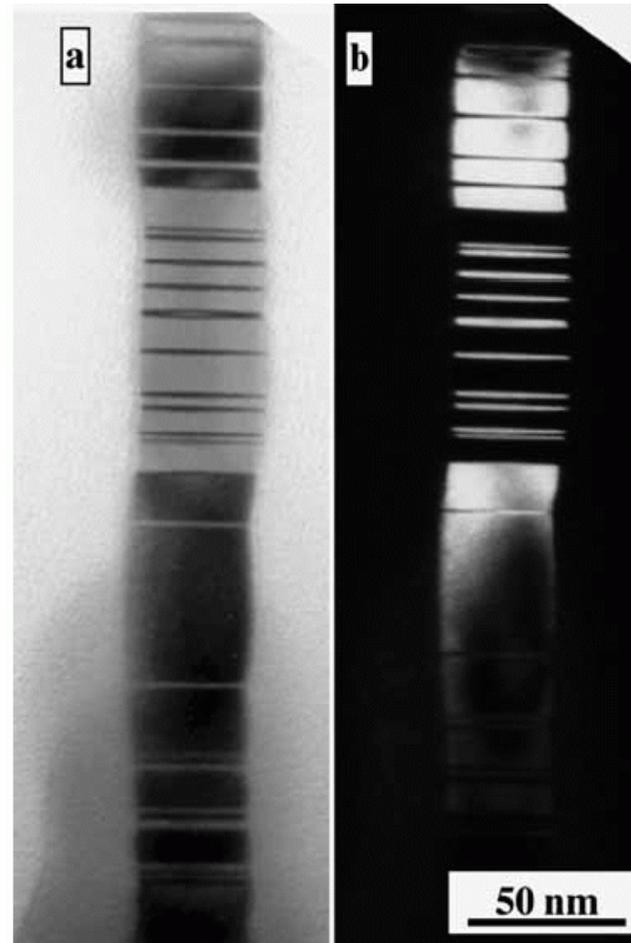
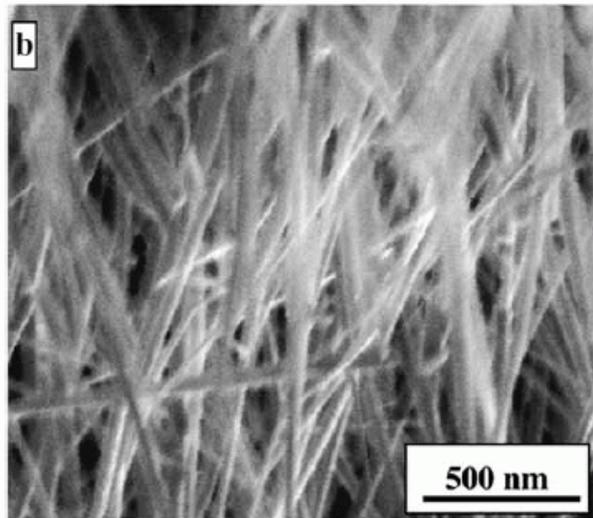
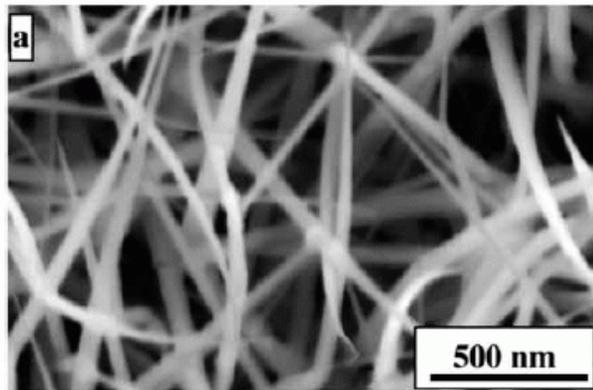
Bar-code Ptychography?

V Favre-Nicolin et al, New Journal of Physics 12 035013 (2010)

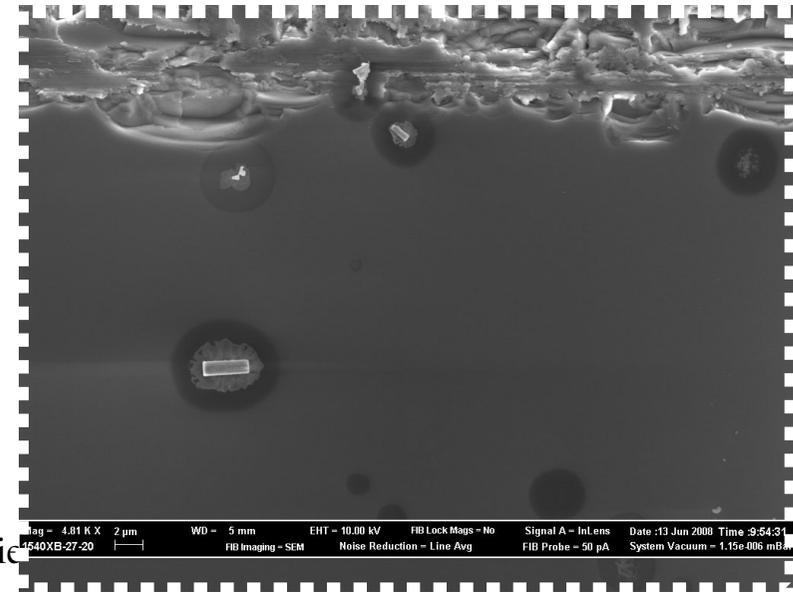
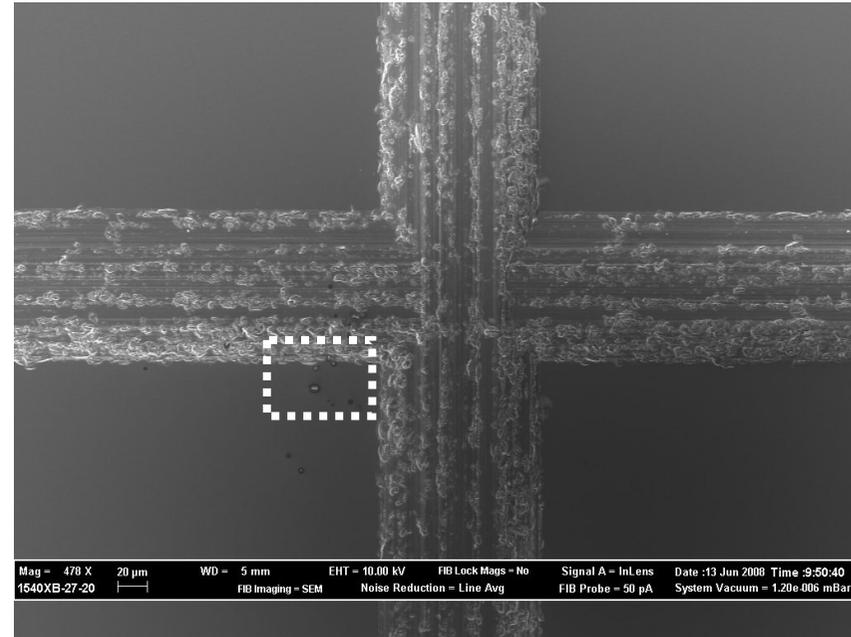
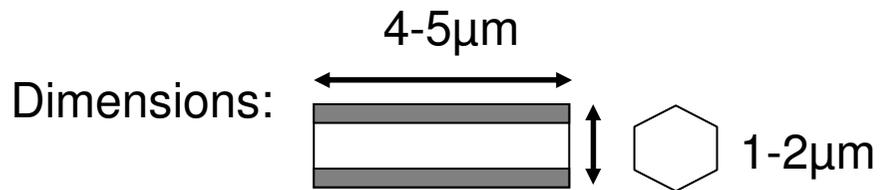
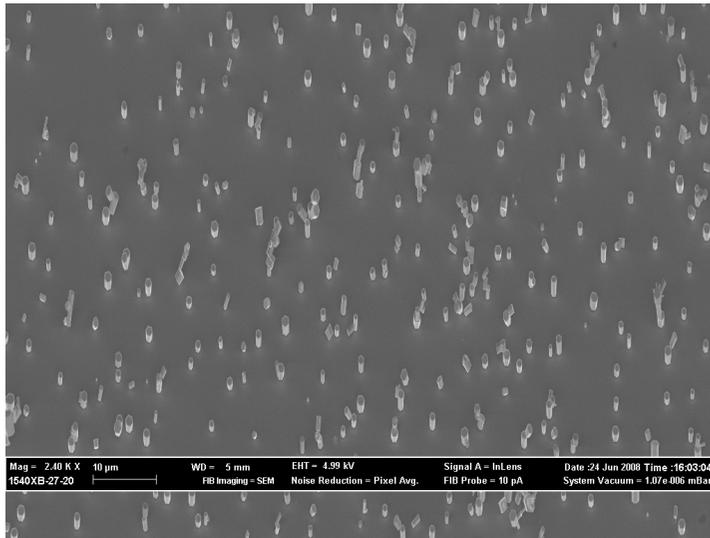


Dark Field TEM of GaAs Nanowires

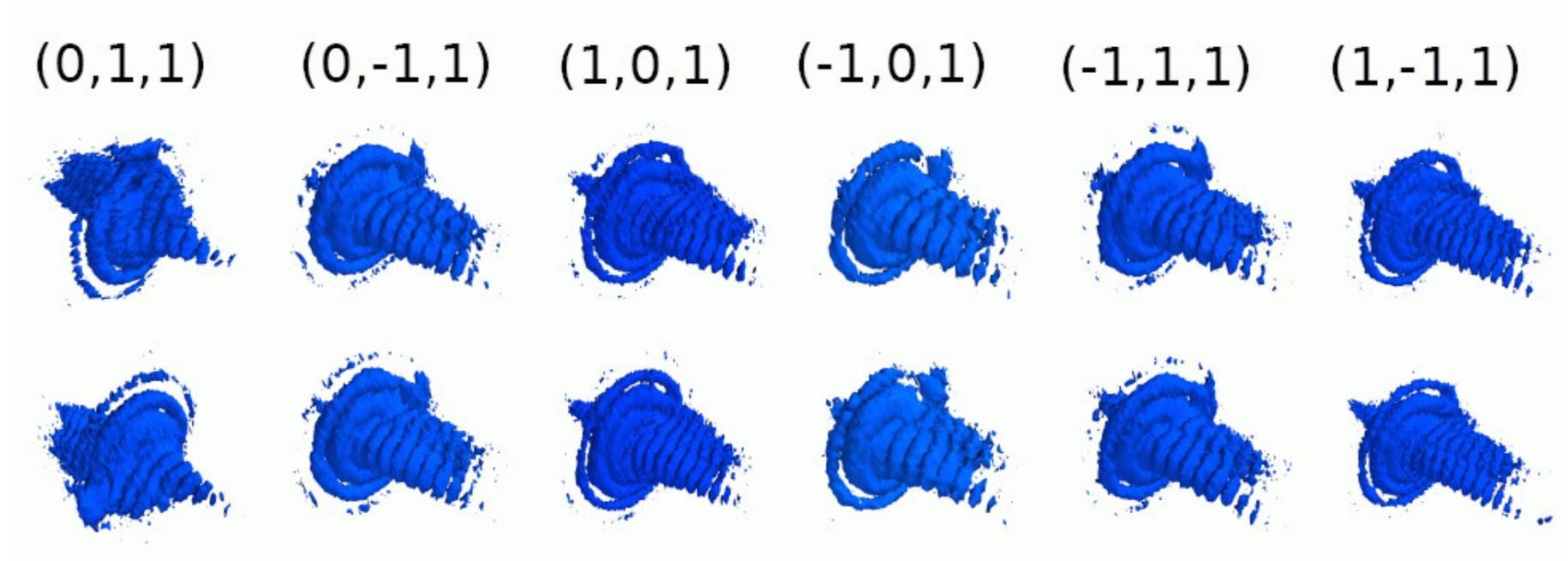
R. Banerjee et al, Phil. Mag. Lett. 86 807 (2006)



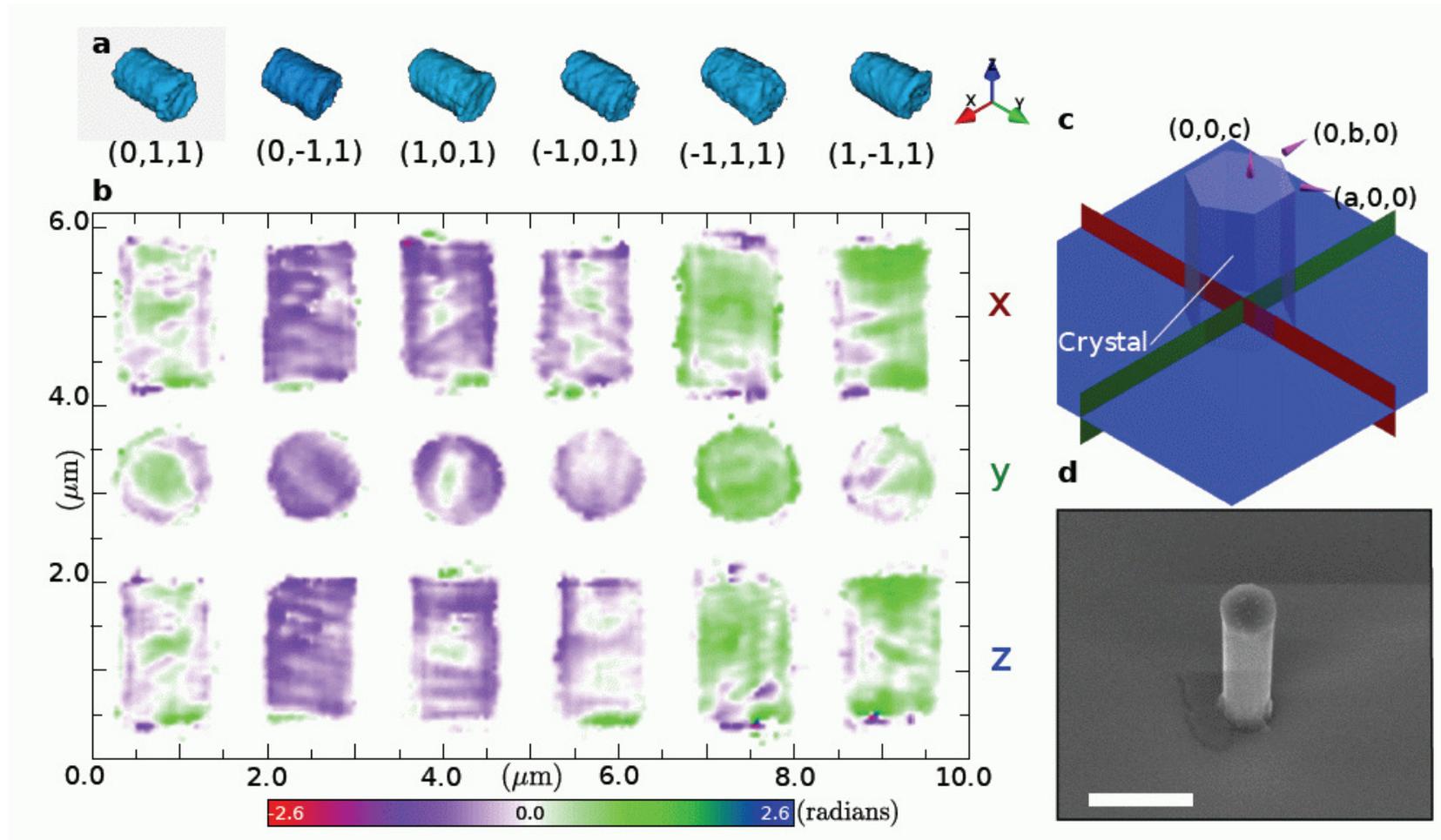
ZnO Sample Preparation



Extension to 6 Bragg Peaks

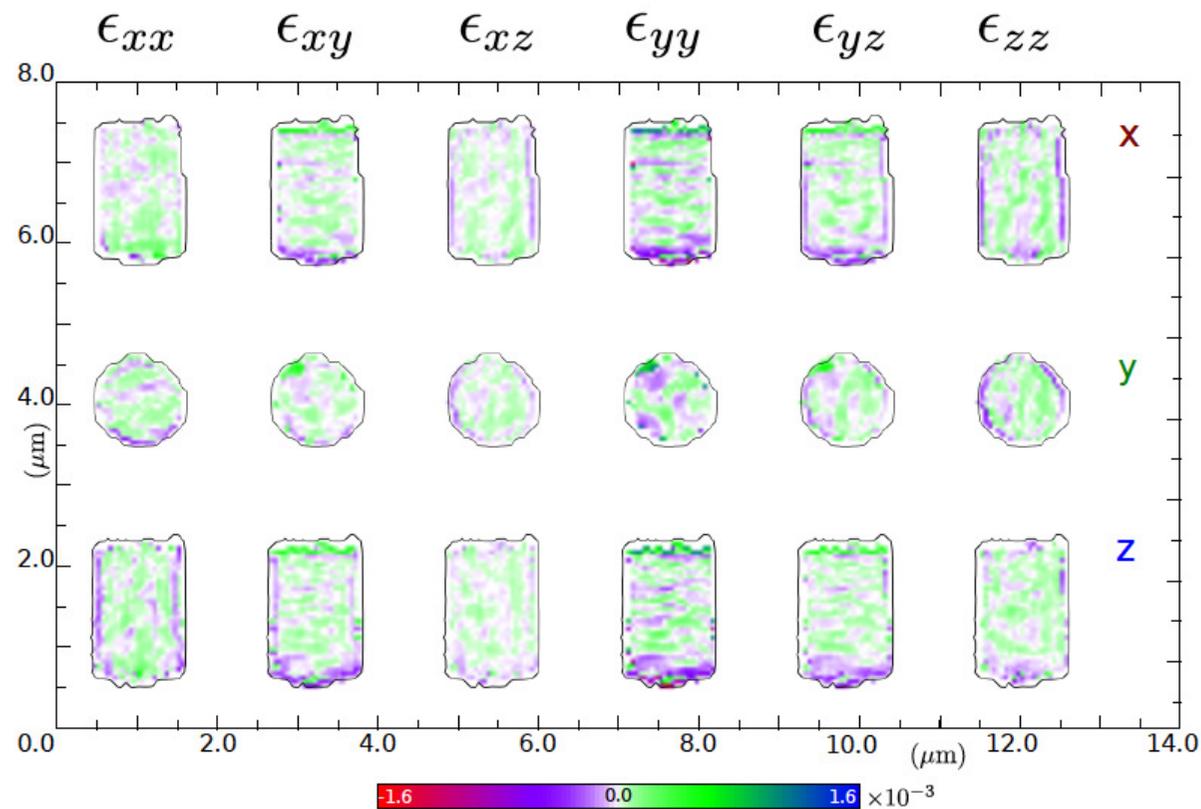


Extension to 6 Bragg Peaks

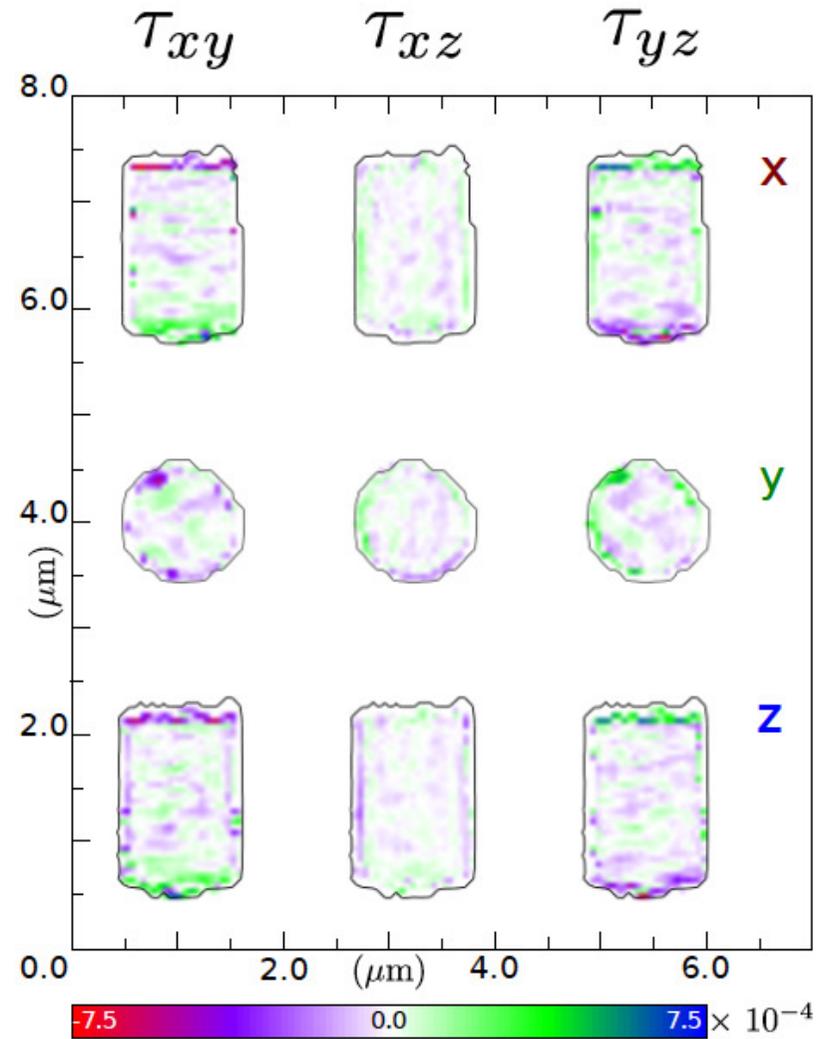


Full Strain Tensor

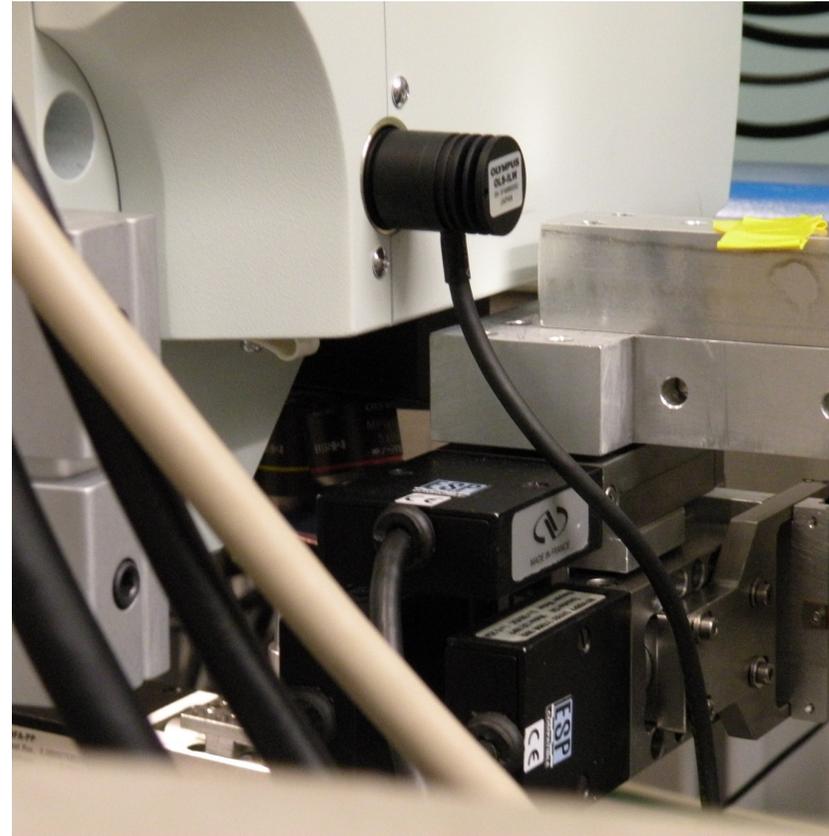
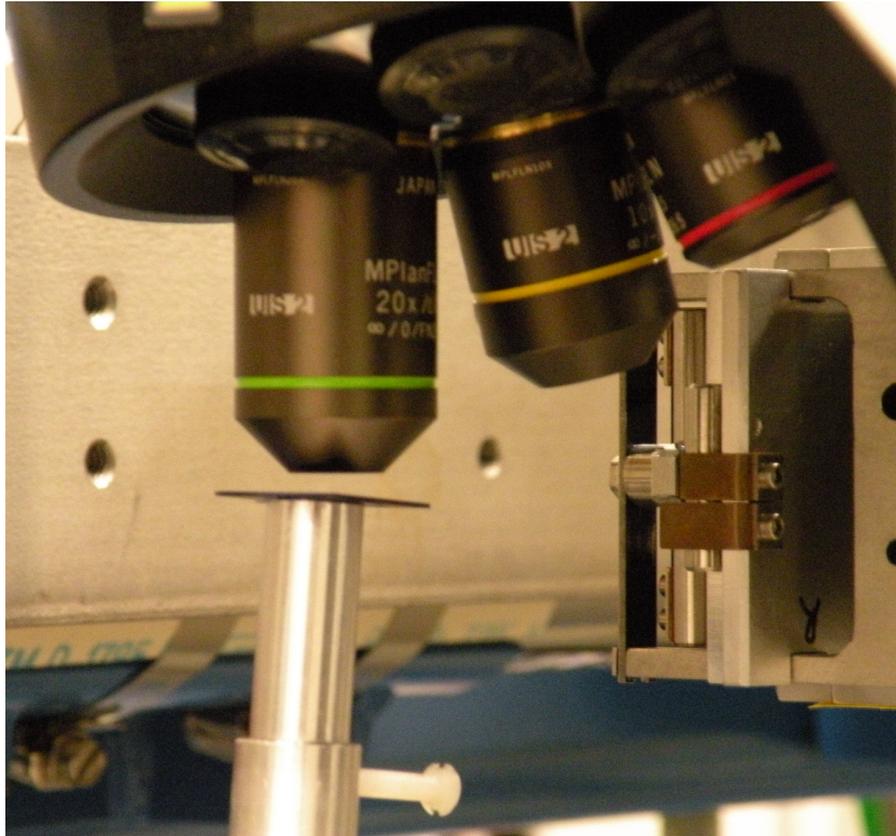
$$\epsilon_{ij} = \frac{1}{2} \left(\frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j} \right), \quad \tau_{ij} = \left(\frac{\partial u_j}{\partial x_i} - \frac{\partial u_i}{\partial x_j} \right)$$



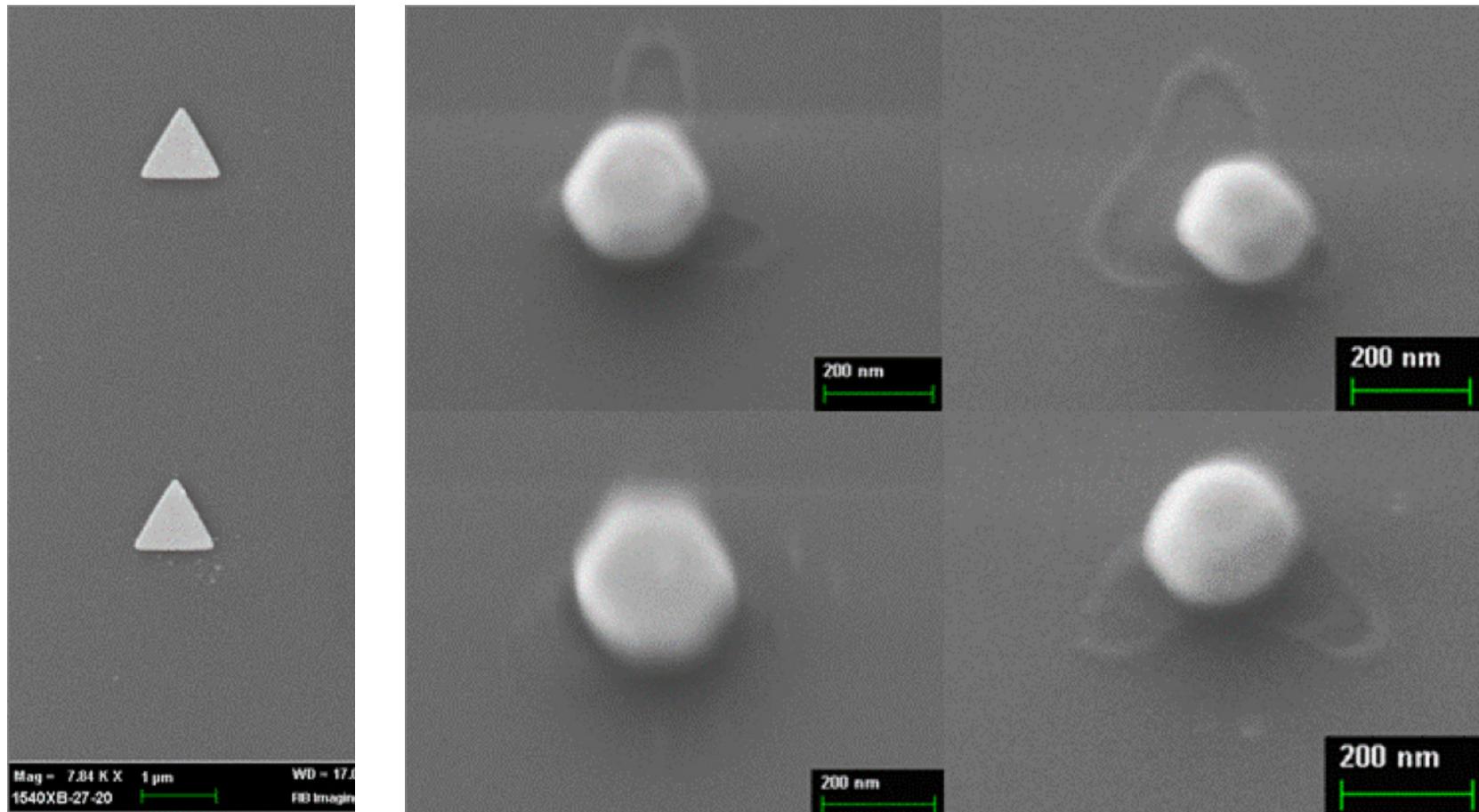
ZnO Rigid-body Rotations



Confocal Alignment Microscope

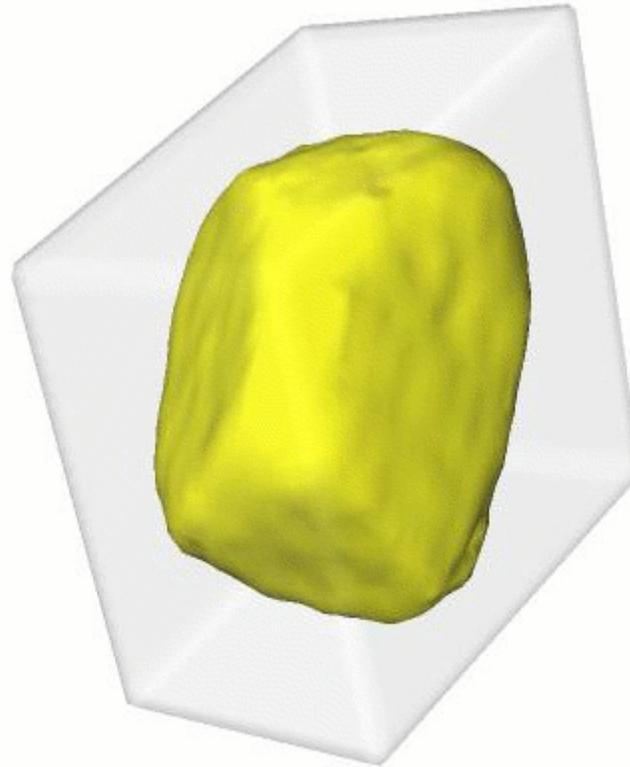
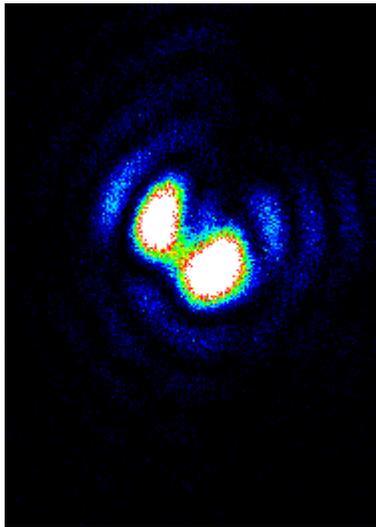


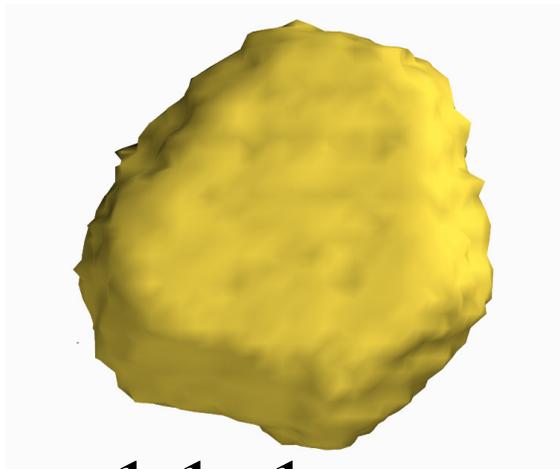
Single Au nanocrystal synthesis



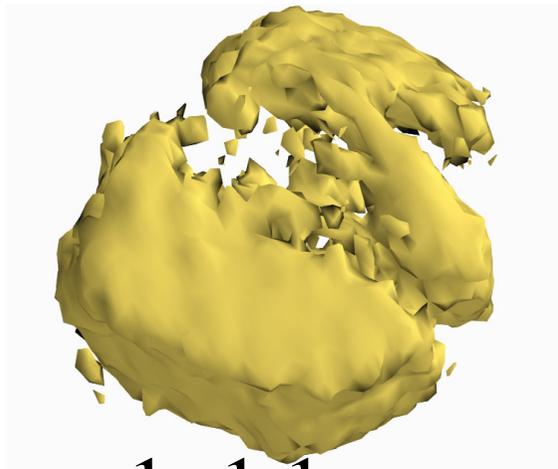
Gold nanocrystal reconstruction

showing support used for 20 HIO followed by 10 ER

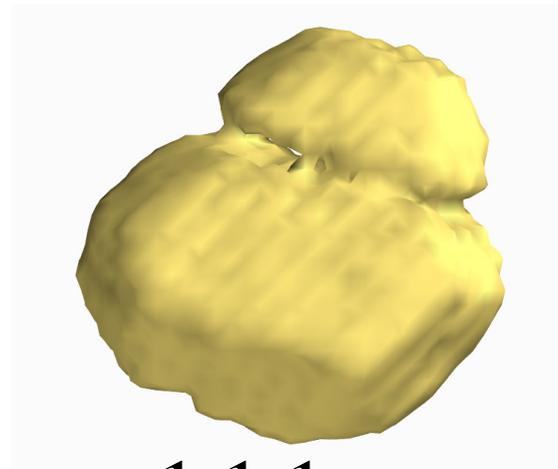




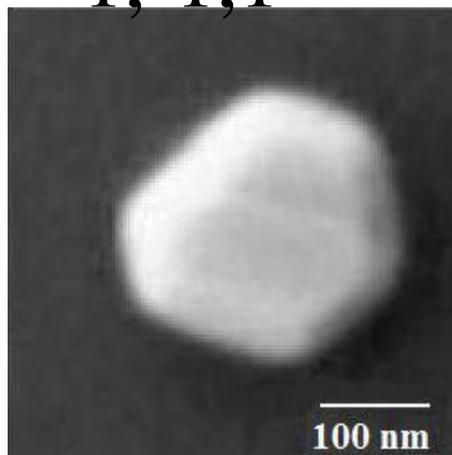
1,1,-1



1,-1,1

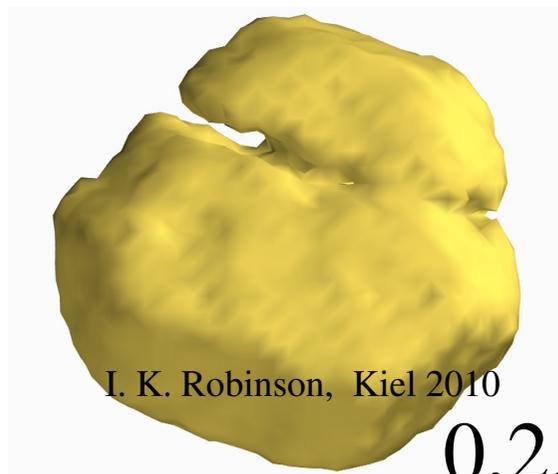
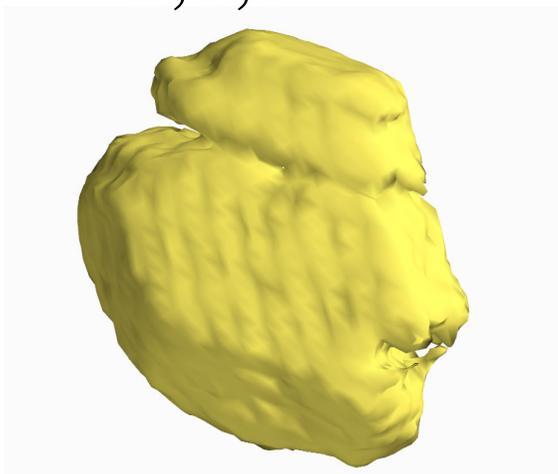


-1,1,1

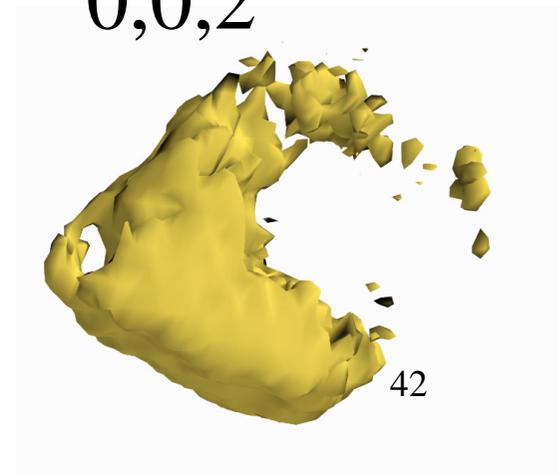


100 nm

2,0,0



0.2.0



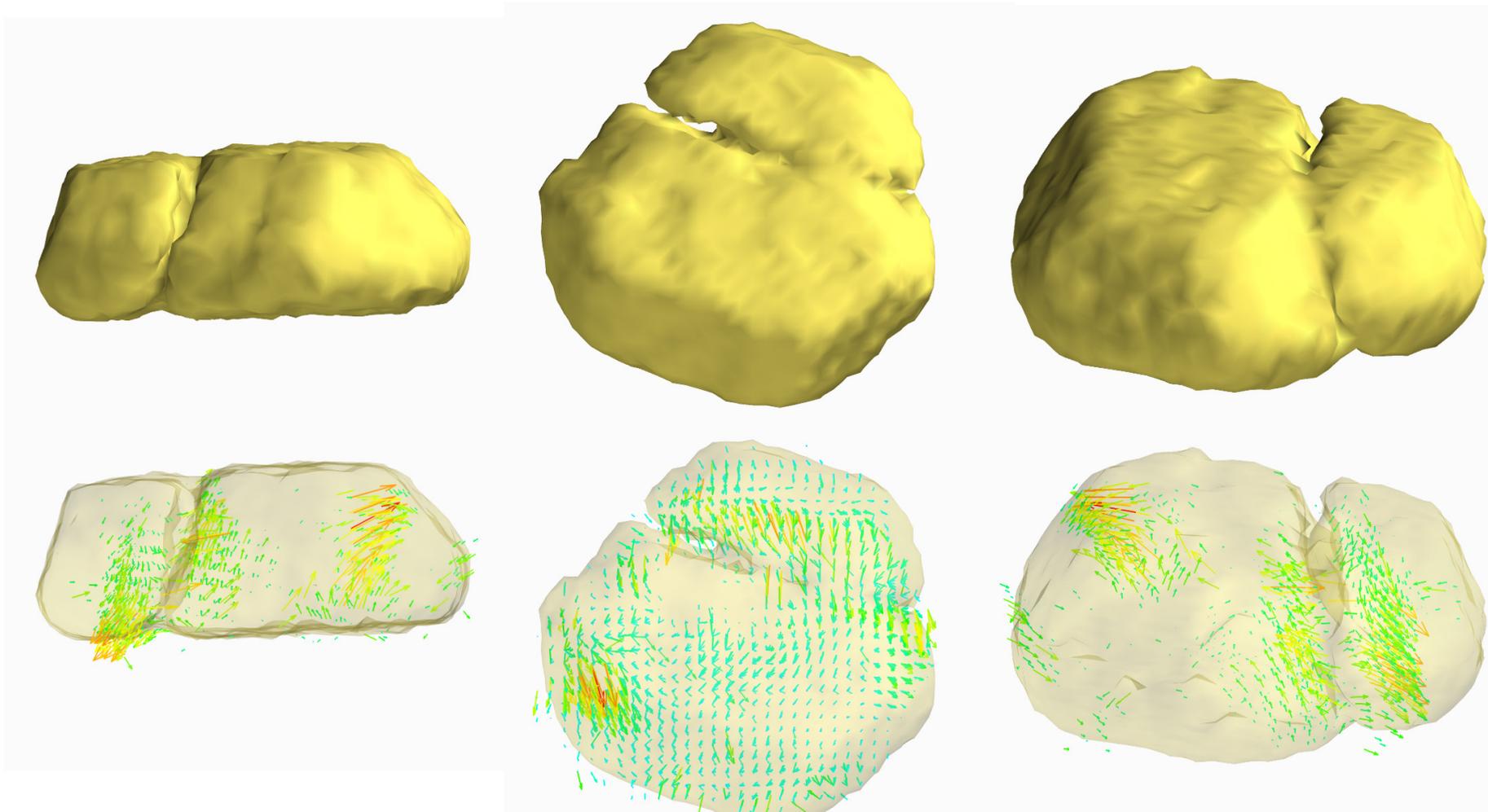
0,0,2

42

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Vector displacement field

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



I. K. Robinson, Kiel 2010

43

Charge Density Wave Dynamics?

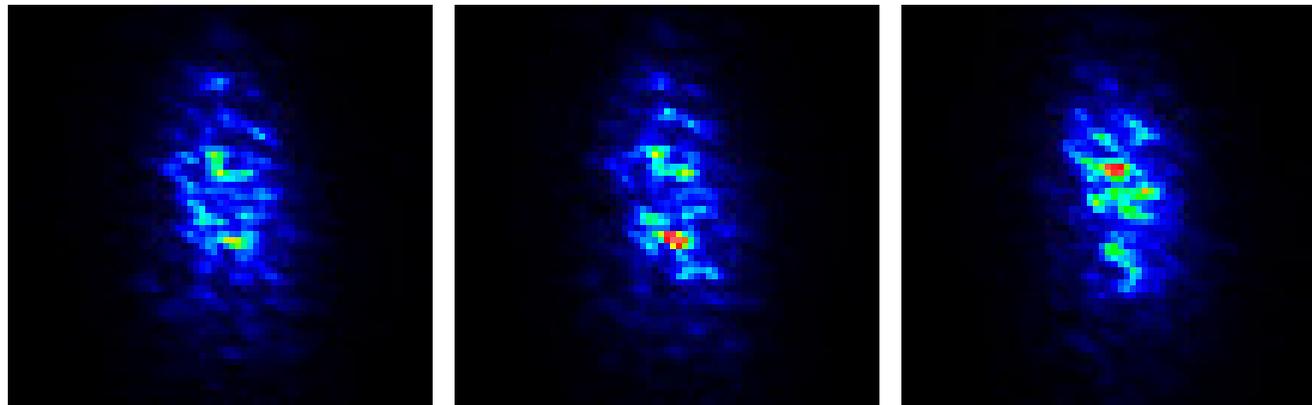
CDW peak of TaS₂ crystal at room temperature

2x2um beam, 20x20um pixels at 2m

6sec exposure, 200 counts/pixel in peak

0.5um steps between exposures

JunDar Su and Oleg Spyrko, 34-ID-C

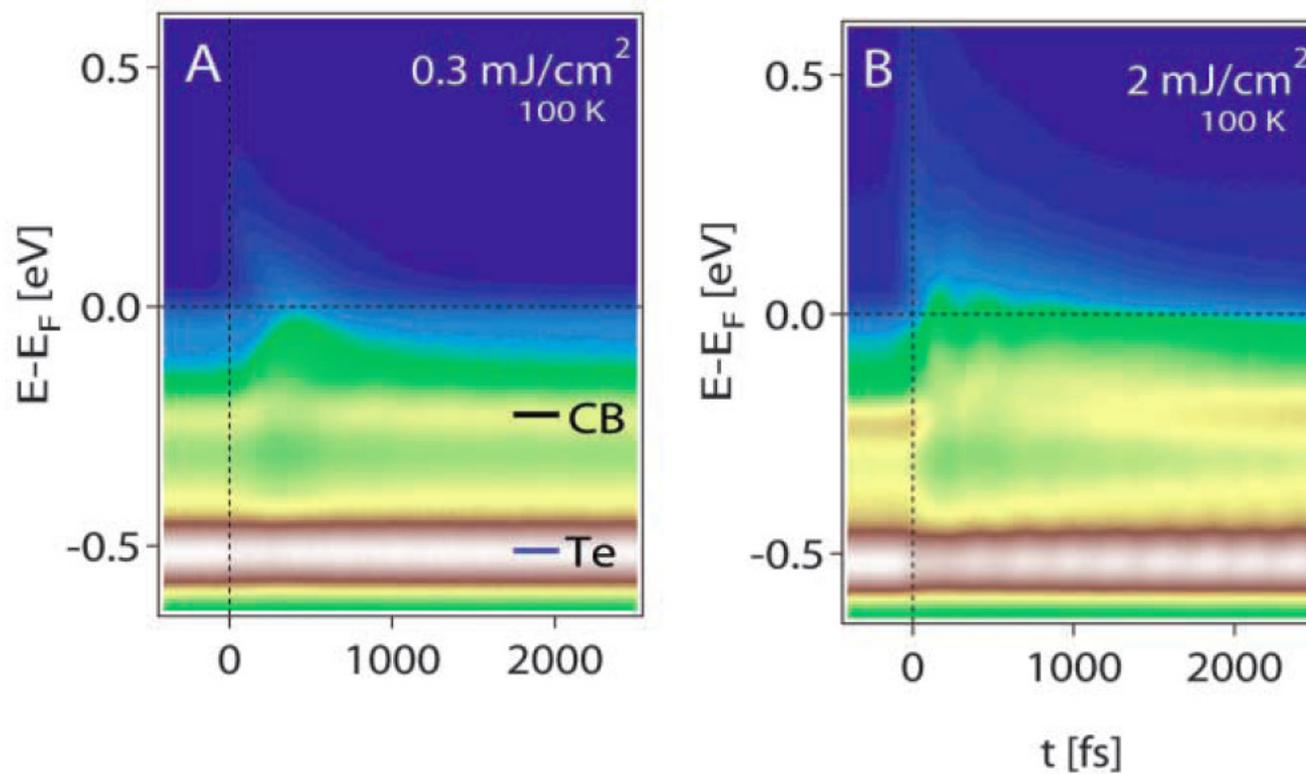


Charge Density Wave Dynamics

CDW excitation in TbTe_3 by 1.5eV IR pump

Schmitt et al, Science 321 1649 (2008)

Z-X Shen ARPES group at ALS



Conclusions

- CXD is a new branch of Crystallography
- 3D imaging practical for nanocrystals
- Phasing by computation instead of lens
- Internal structure of Ag, Au and Pb Nanocrystals
- Strain fields imaged from asymmetric patterns
- Possible applications at XFELs