

X-ray Coherence and its application to imaging Condensed Matter

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London Centre for Nanotechnology

Diamond Light Source

Physikalisches Kolloquium,

Bremen, February 2009

Outline

- Coherent x-ray diffraction
- CXD can solve the **phase** problem
- Nanocrystal structures
- Extension to **phase** objects
- Exploration of crystal strain
- Nanowire structures

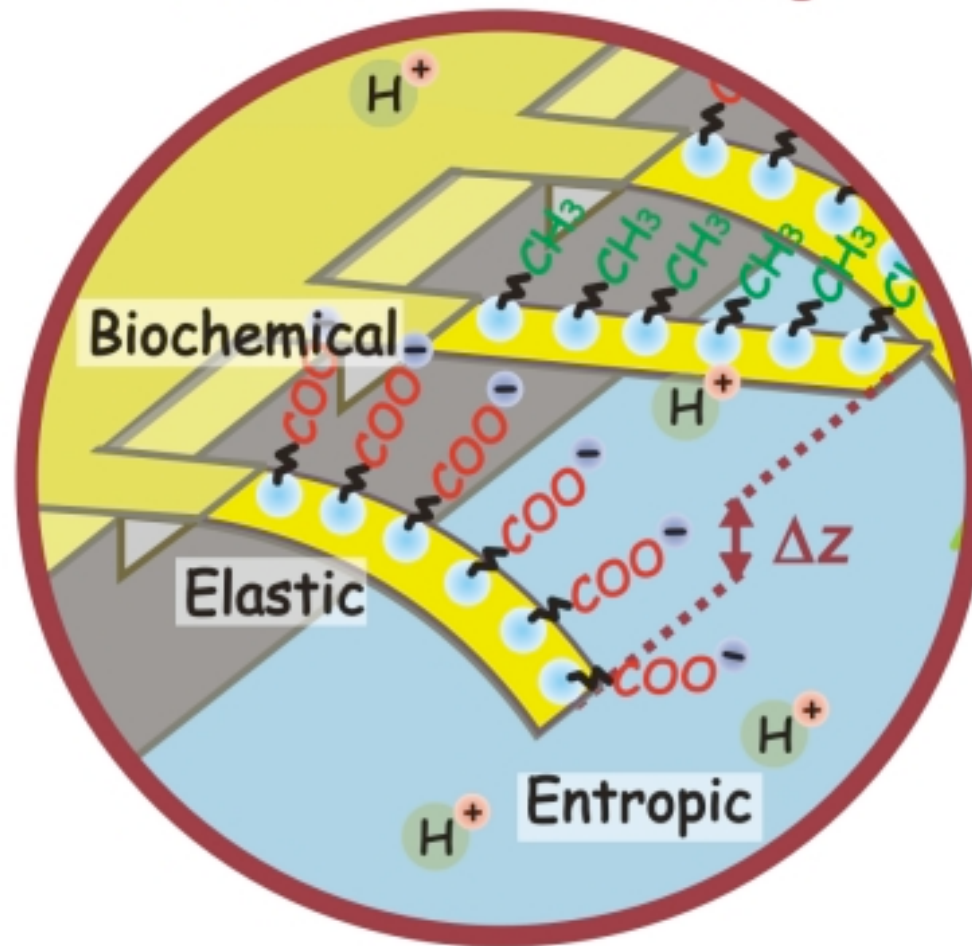
London Centre for Nanotechnology

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



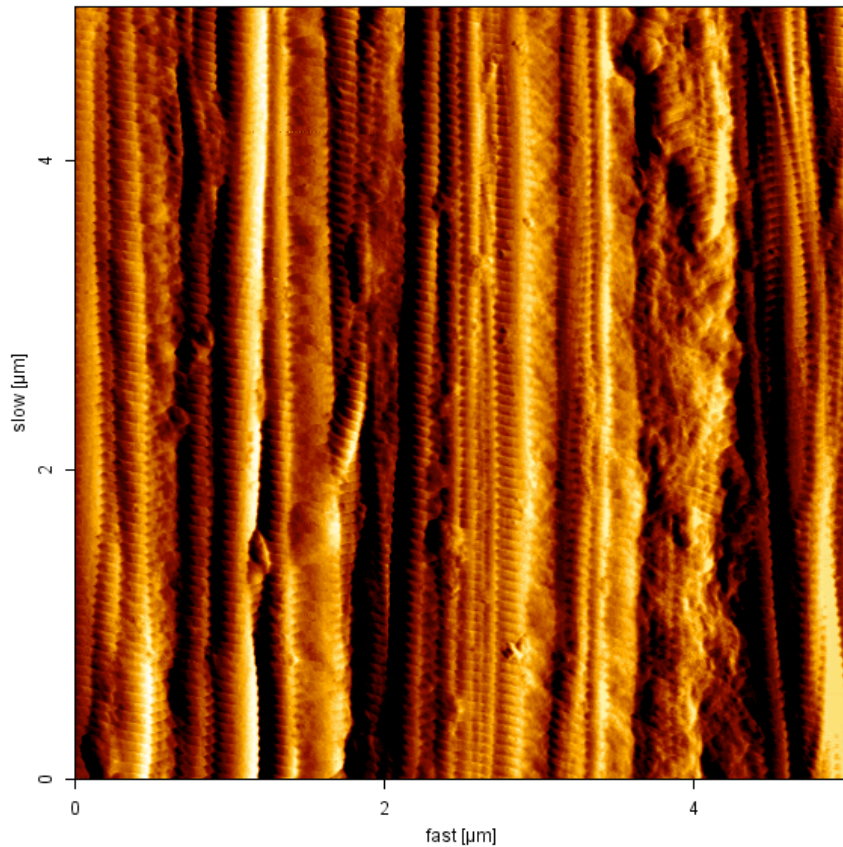
Nanocantilevers

Dr Rachel McKendrie

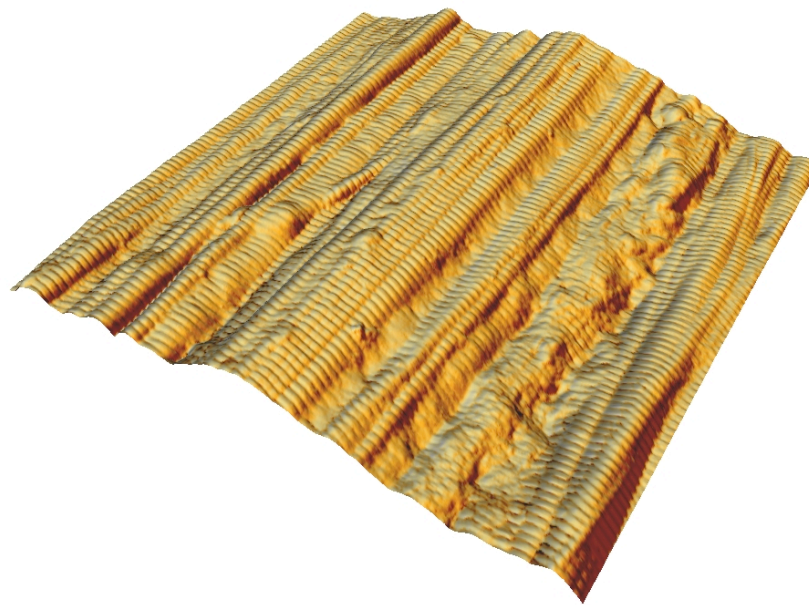


AFM imaging of Collagen Fibres

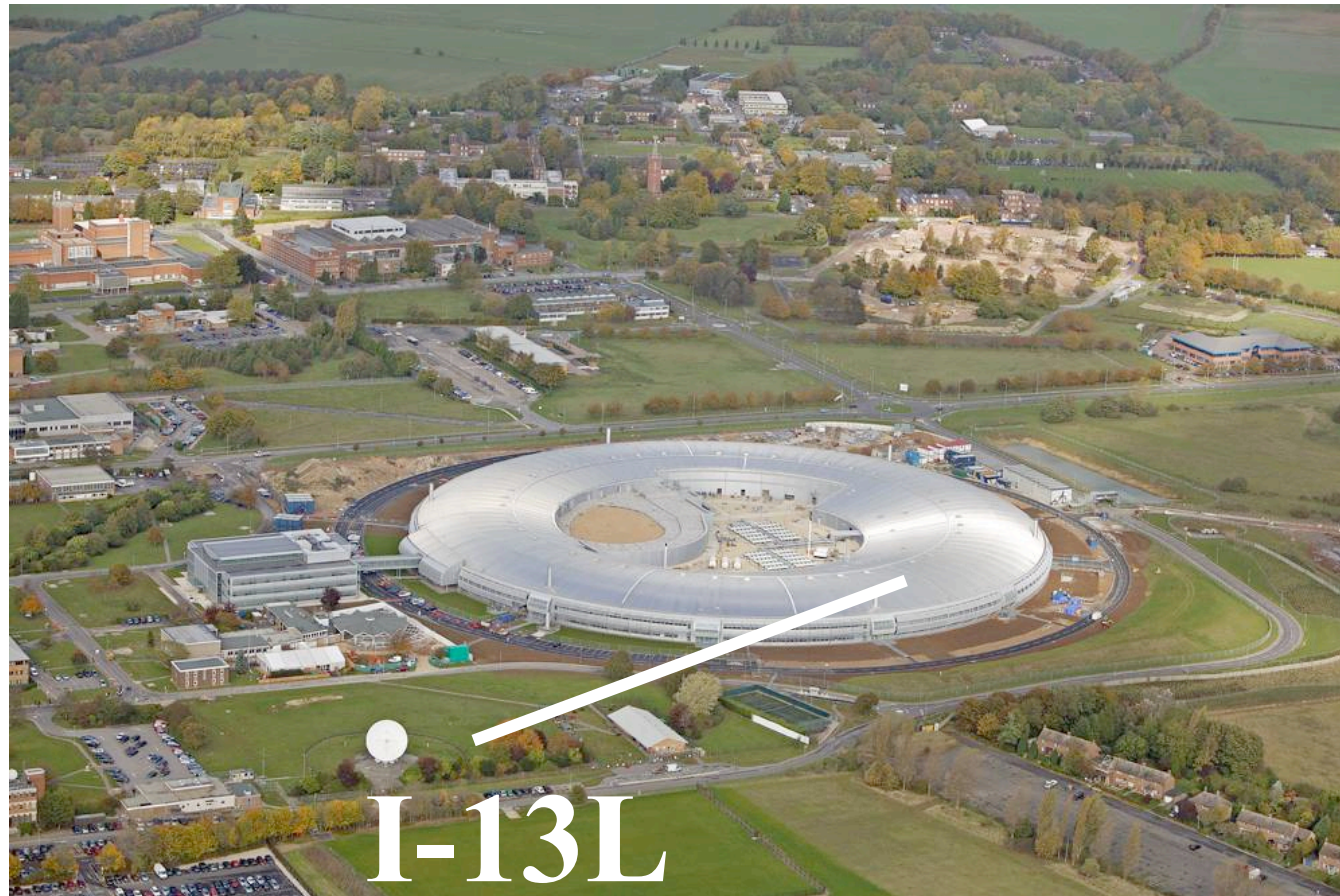
Felisa Berenguer and Marco Wenger



Dehydrated rat tail tendon tissue



Diamond Light Source (RAL)

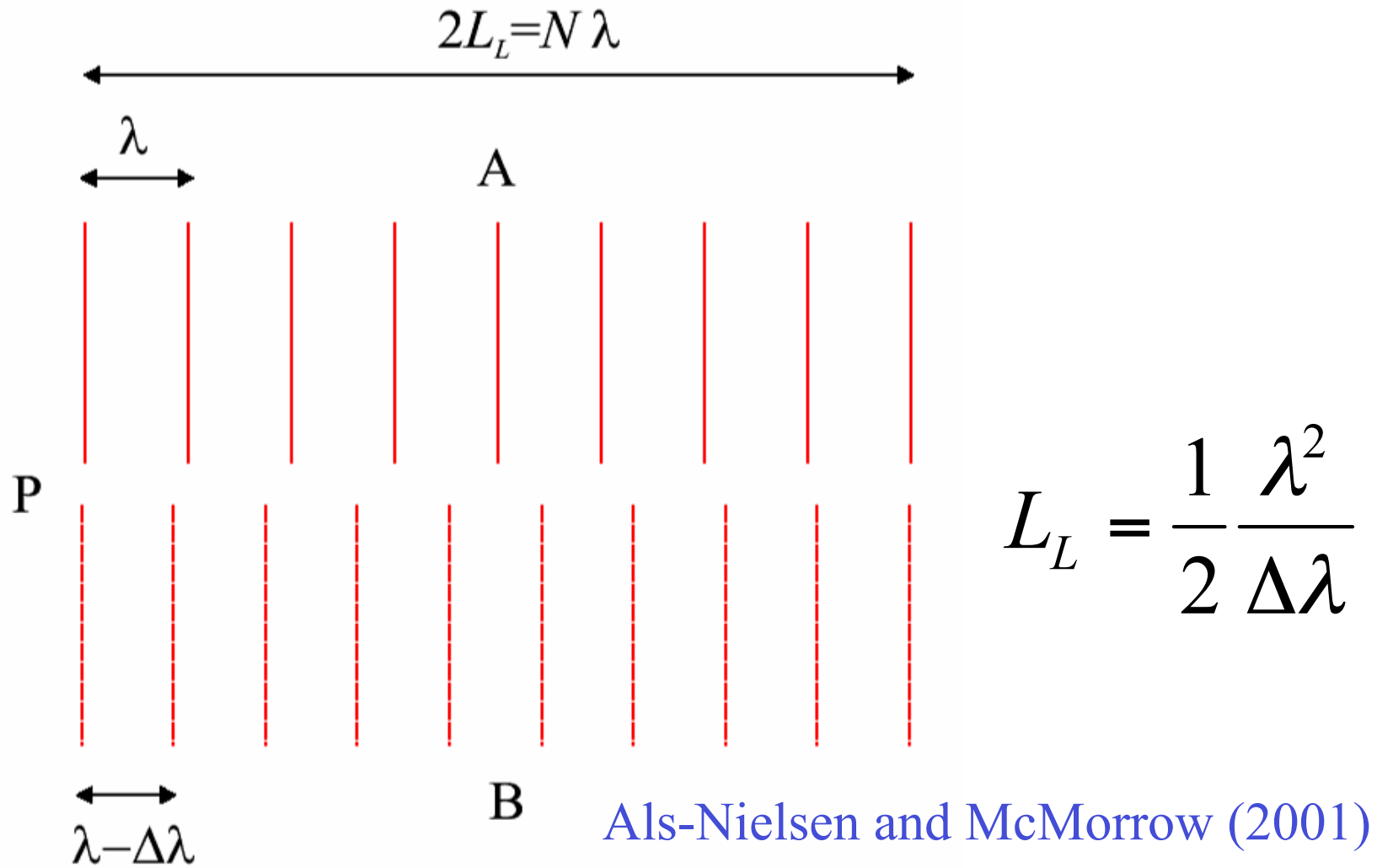


I. K. Robinson, Bremen 2009

Diamond
in-vacuum
X-ray
Undulator

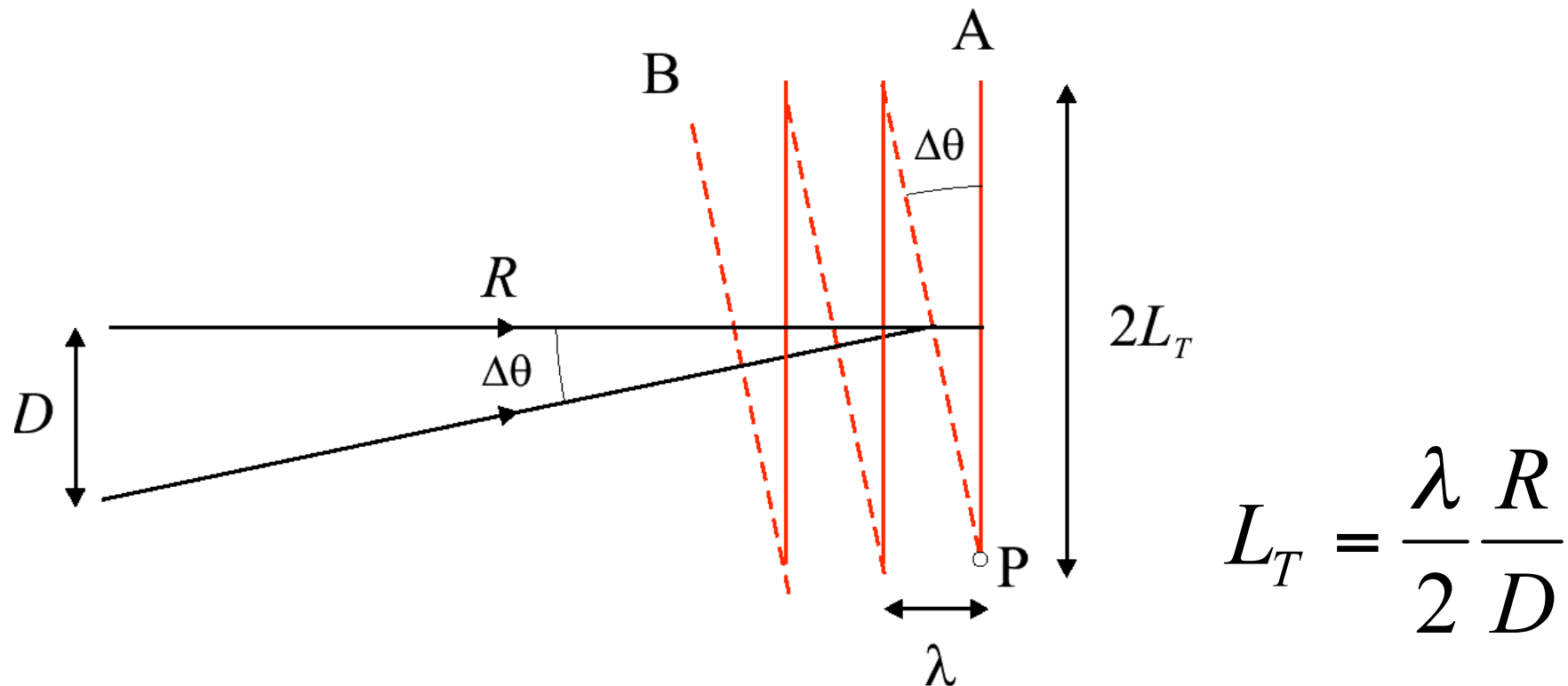


Longitudinal Coherence



Als-Nielsen and McMorro (2001)

Lateral (Transverse) Coherence

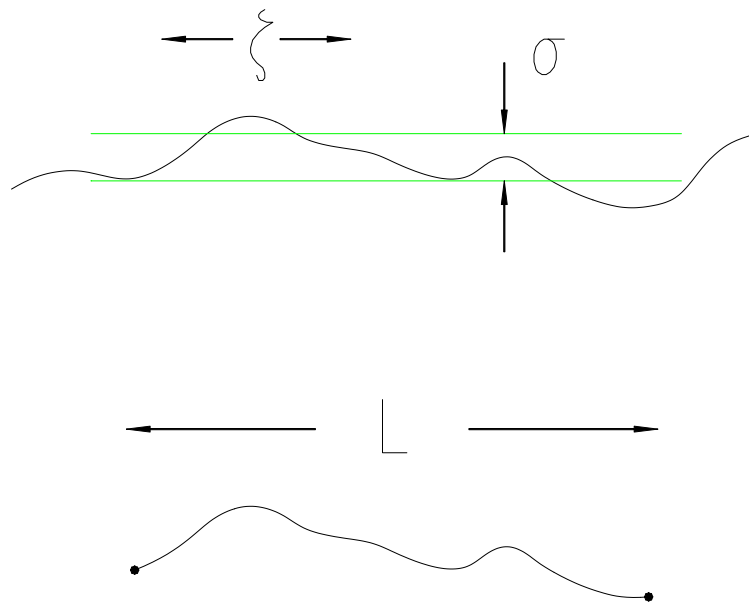


$$L_T = \frac{\lambda R}{2 D}$$

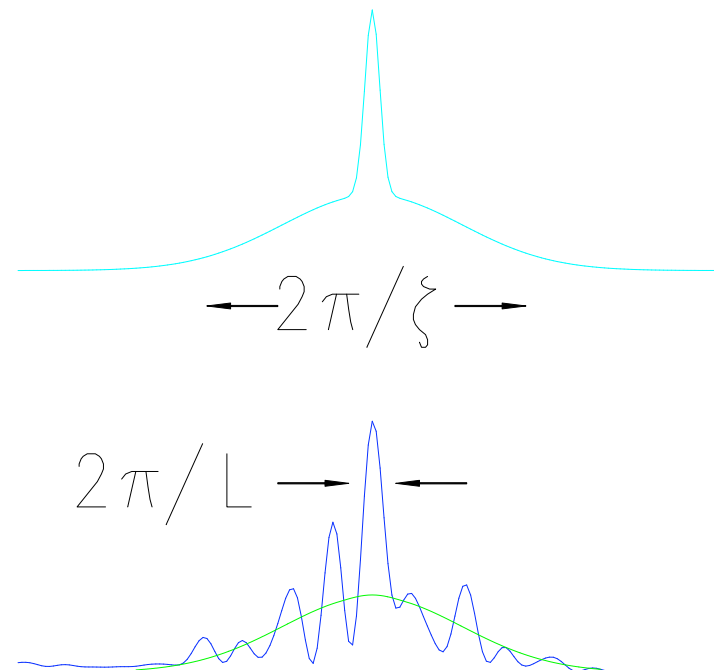
Als-Nielsen and McMorrow (2001)

Diffuse Scattering acquires fine structure with a Coherent Beam

Real Space

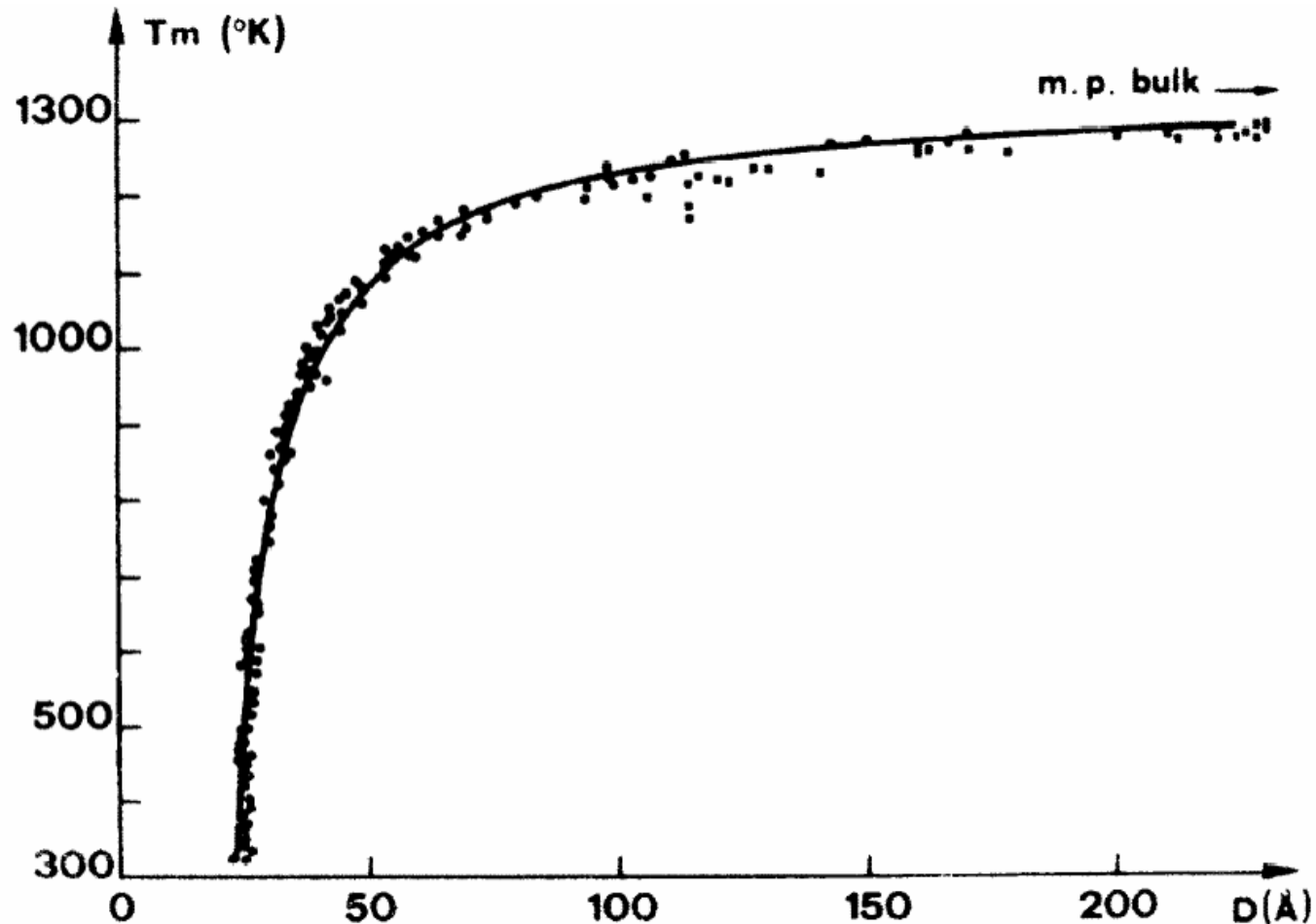


Reciprocal Space

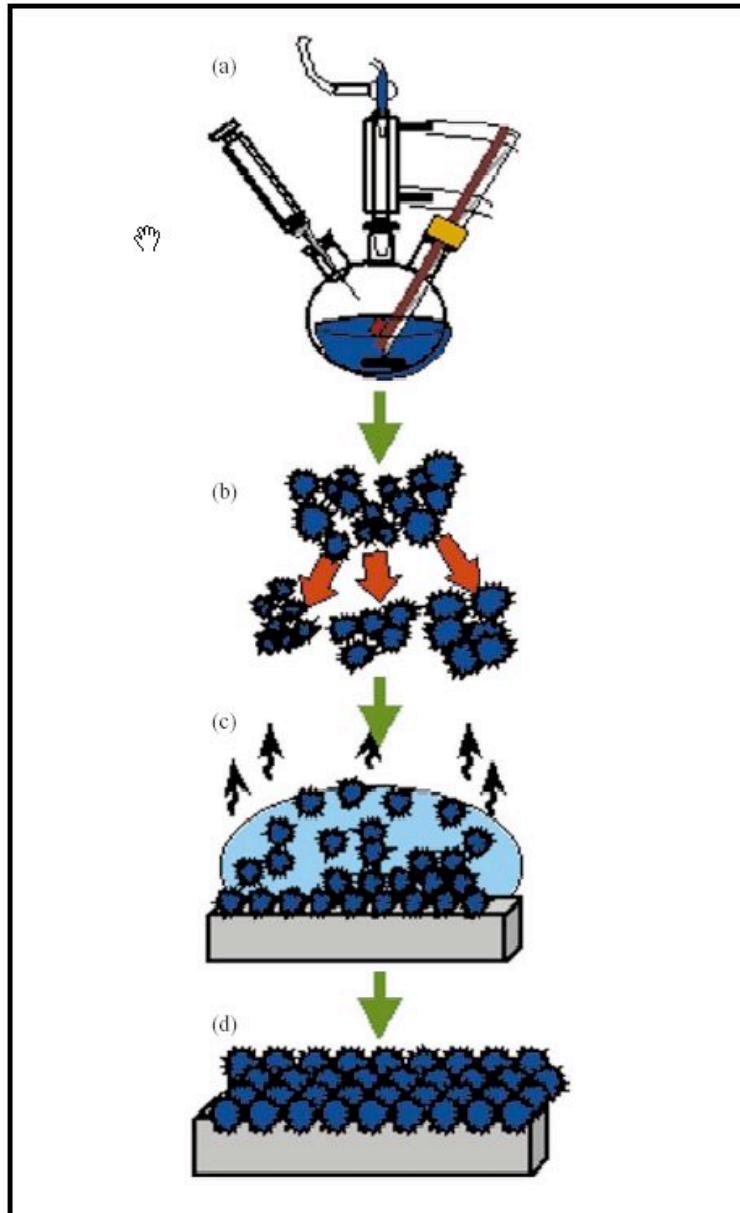


Size-dependent Melting of Au Particles

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

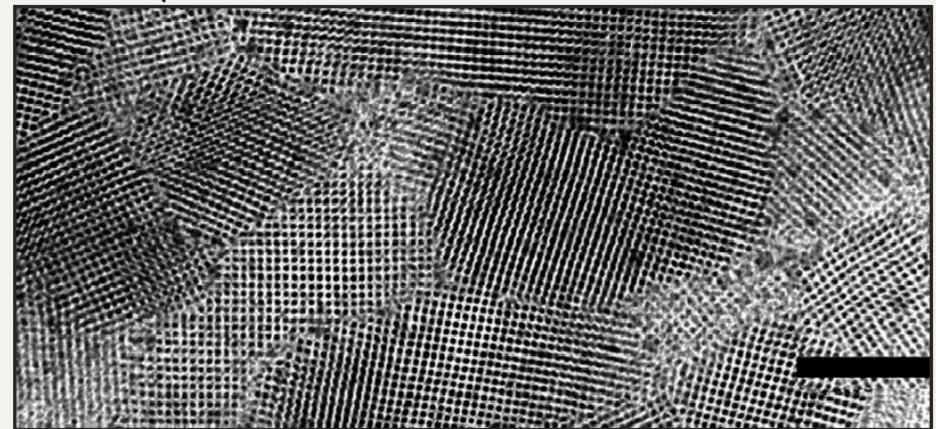


Chemical Synthesis of Nanocrystals



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

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

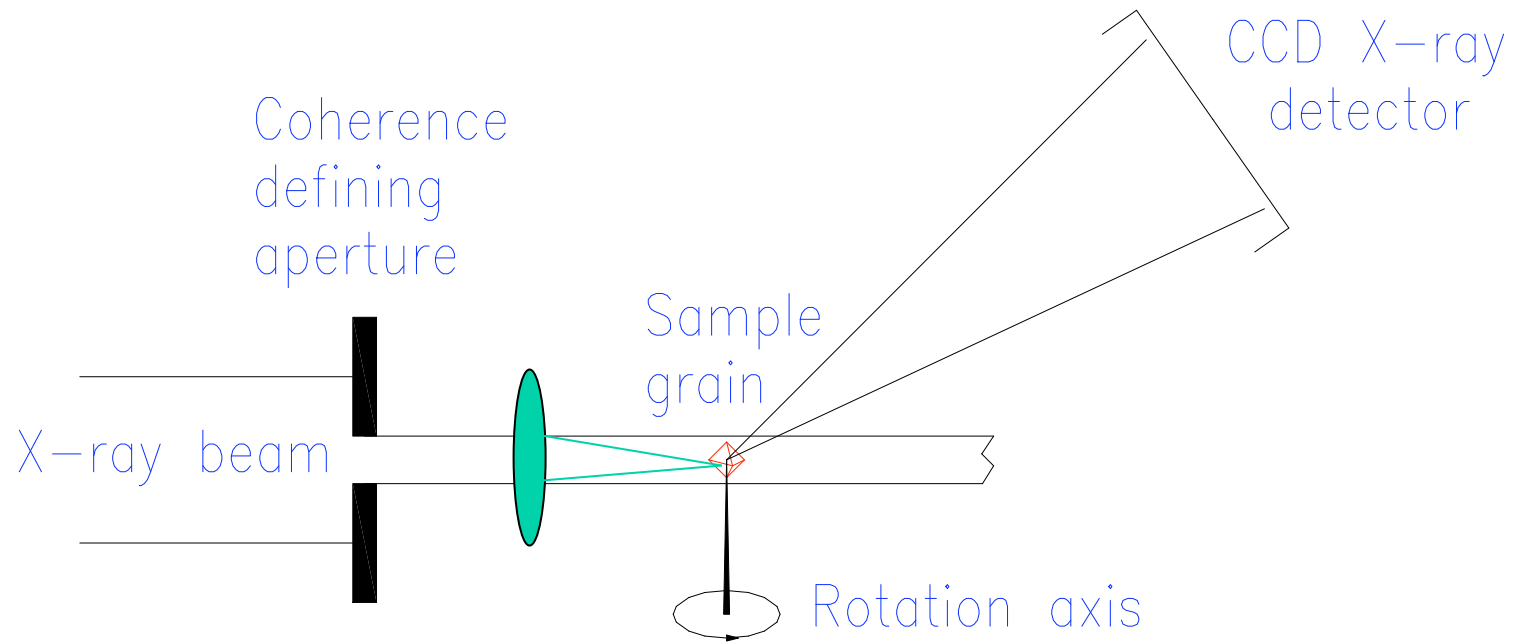


Robert Hooke's microscope, 1665

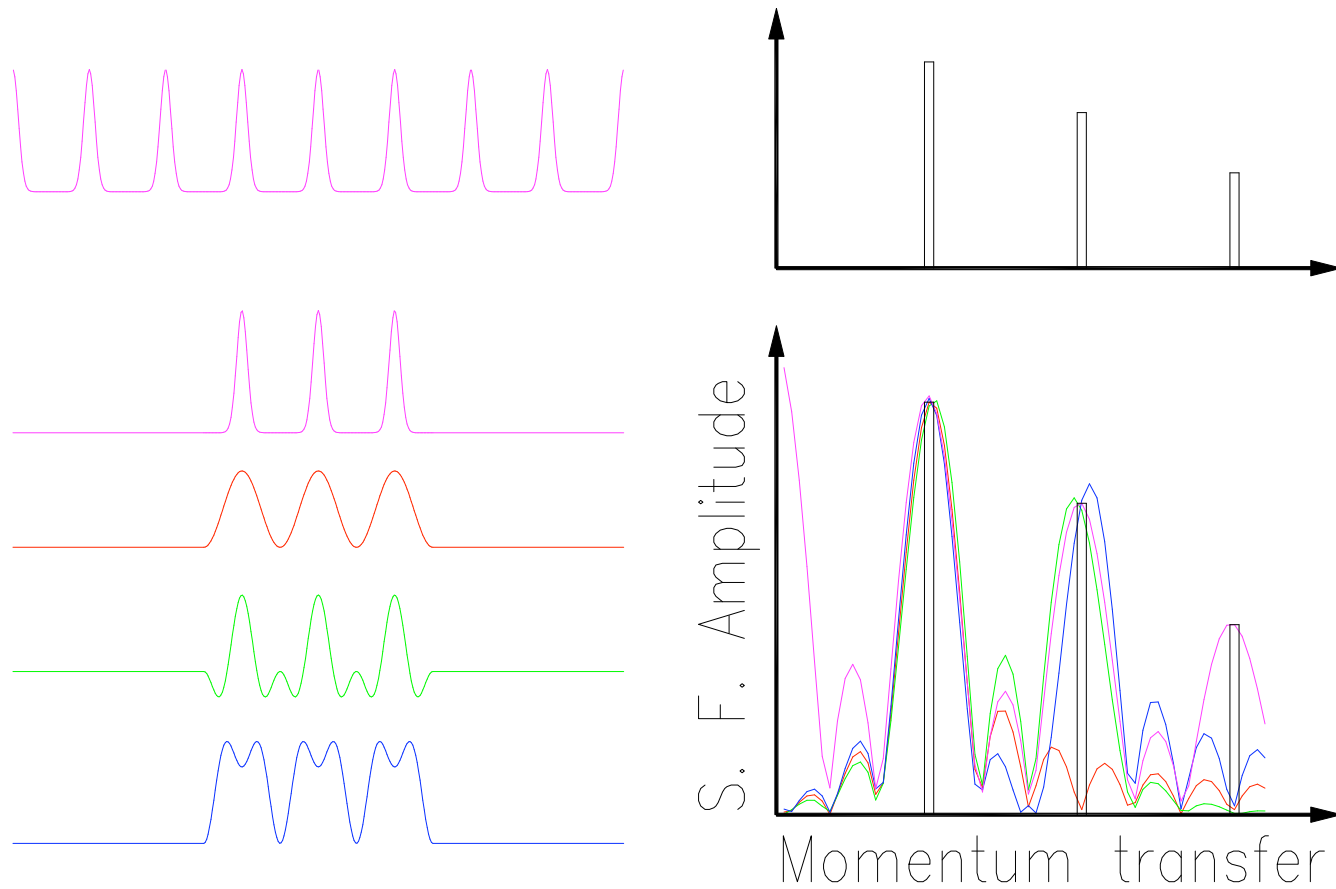
National Museum of Health
and Medicine, Washington
DC



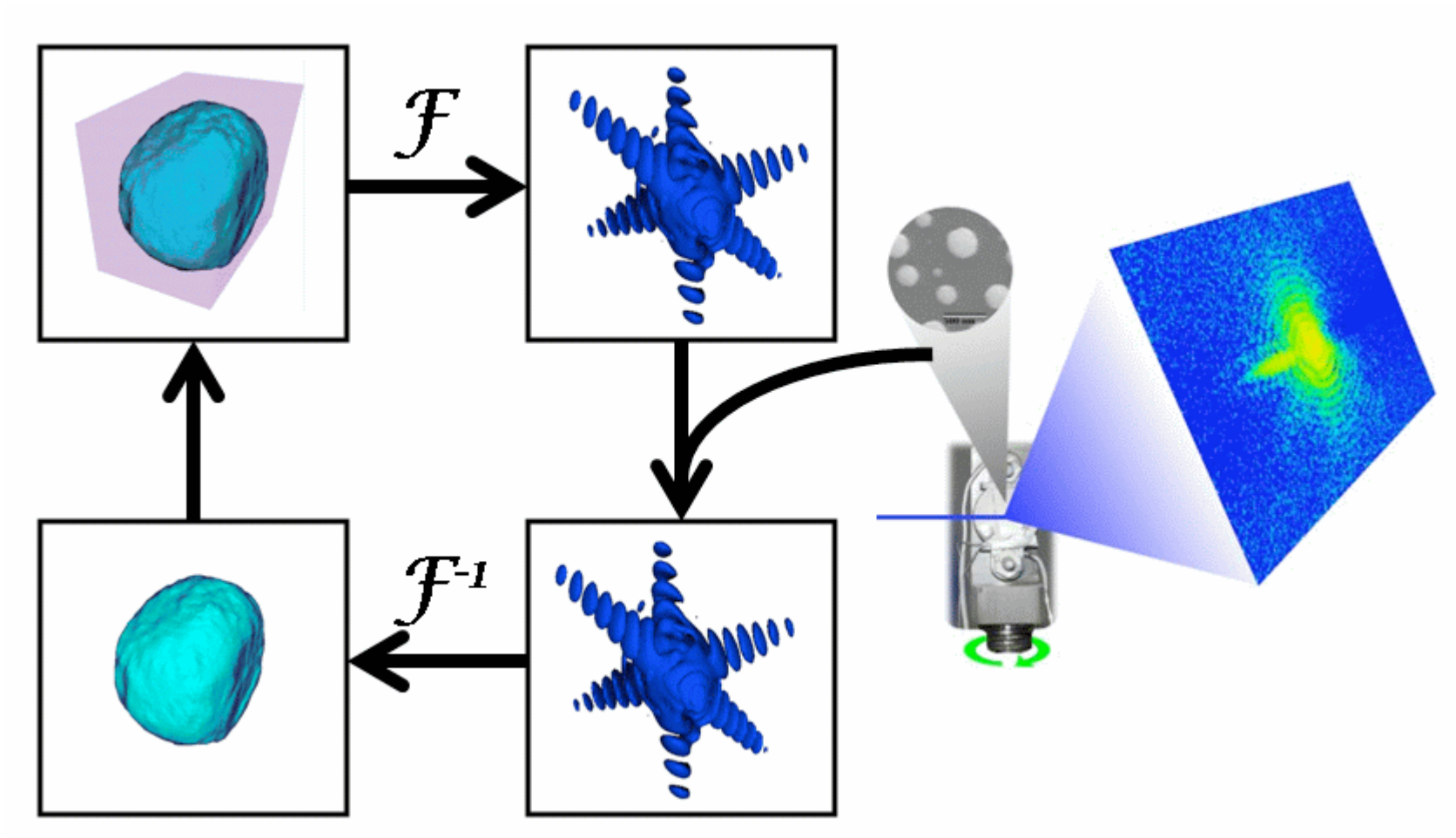
Lensless X-ray Microscope, 2003



Oversampling solves Phase Problem



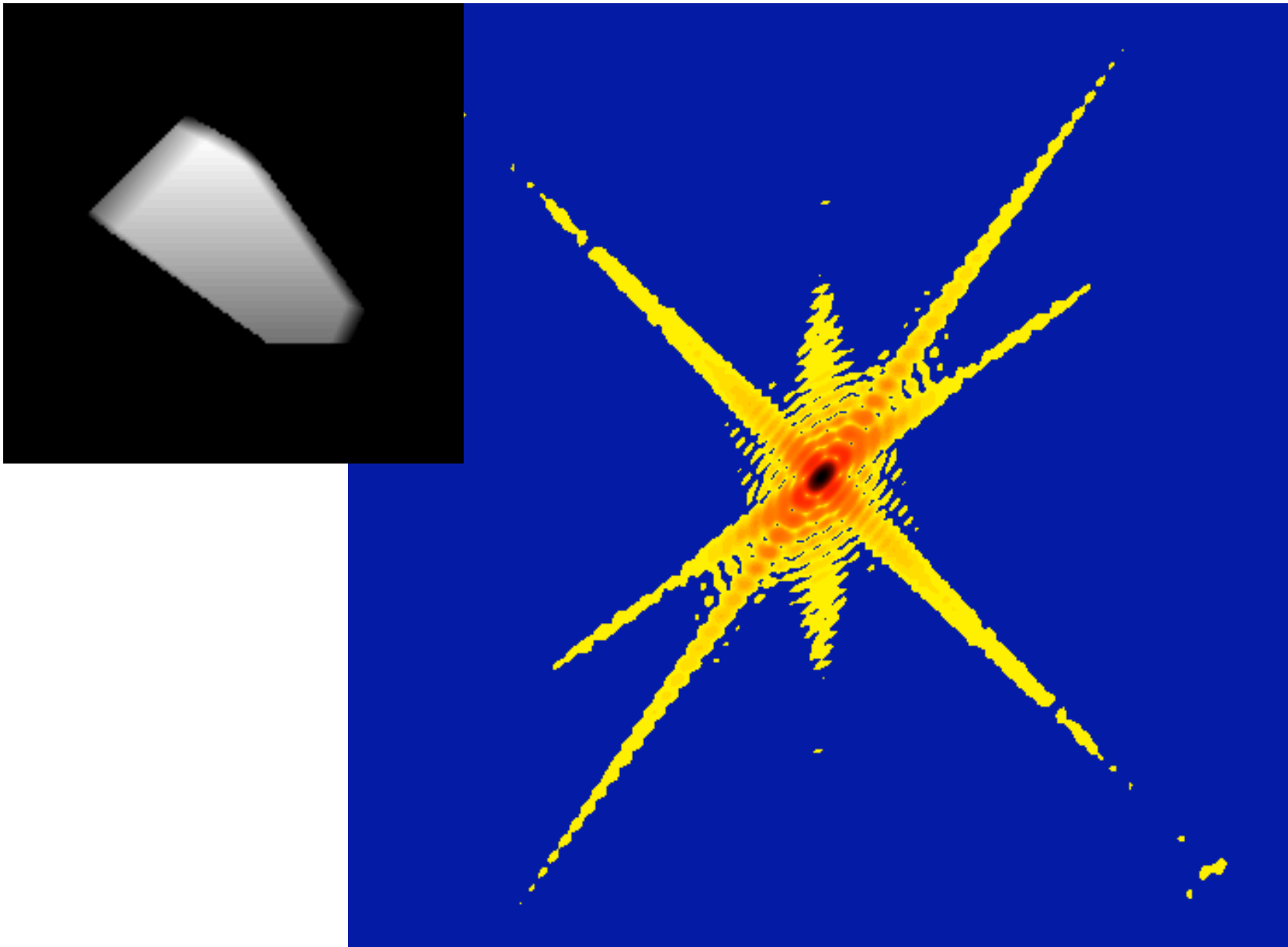
Generic “Error Reduction” method



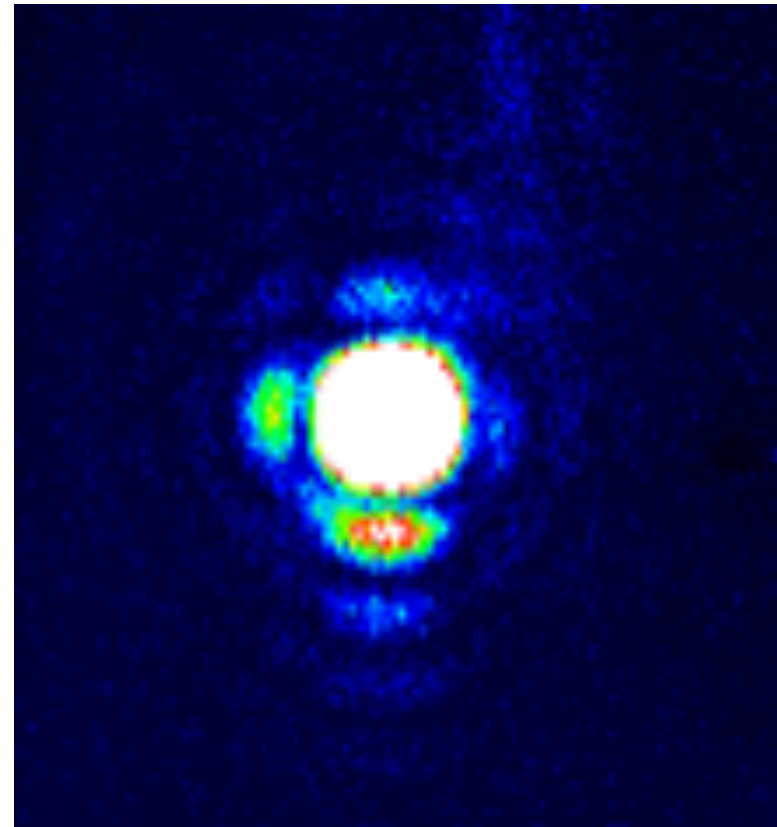
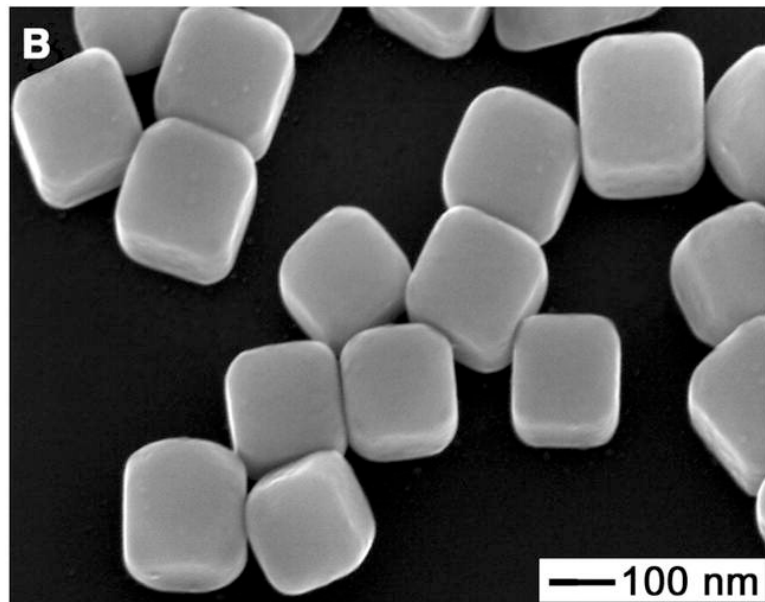
J. R. Fienup *Appl. Opt.* 21 2758 (1982)

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

I. K. Robinson, Bremen 2009

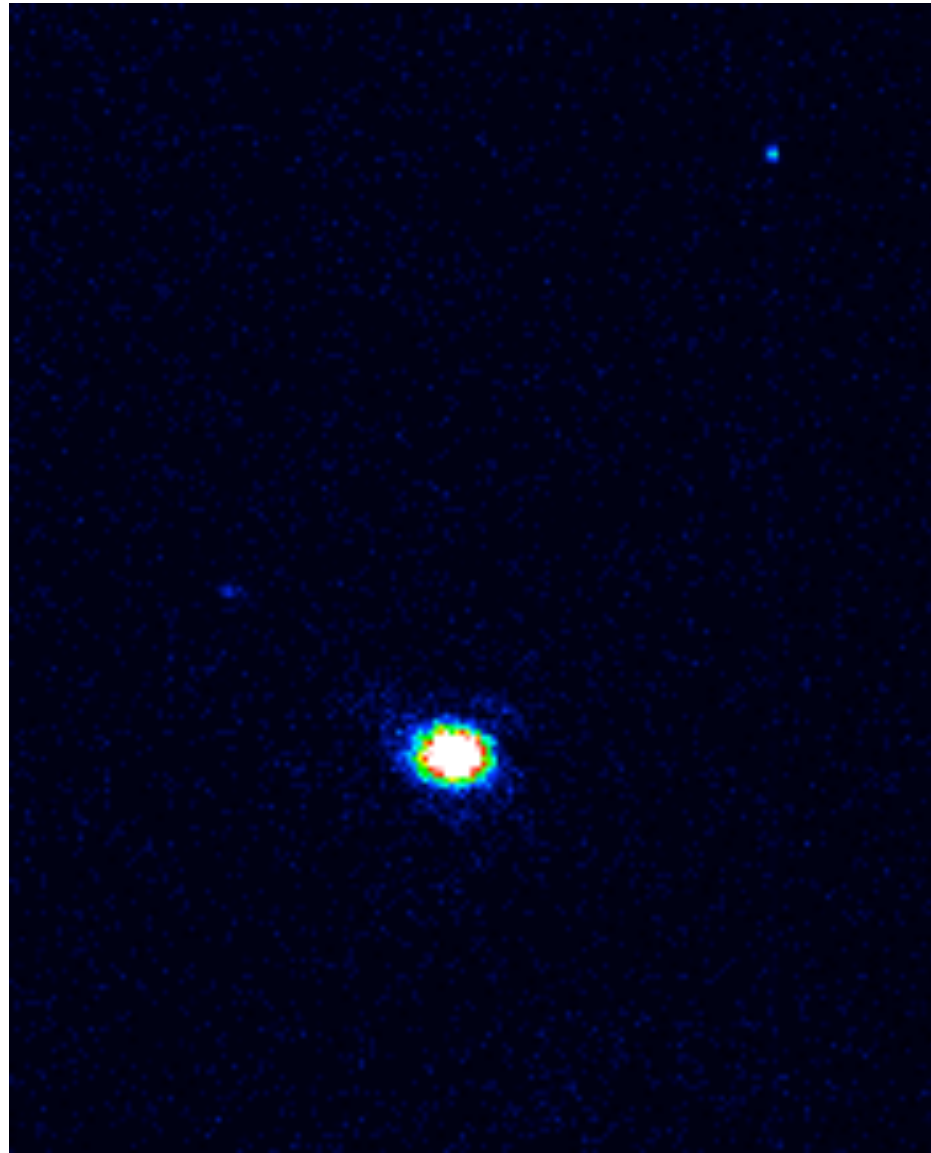


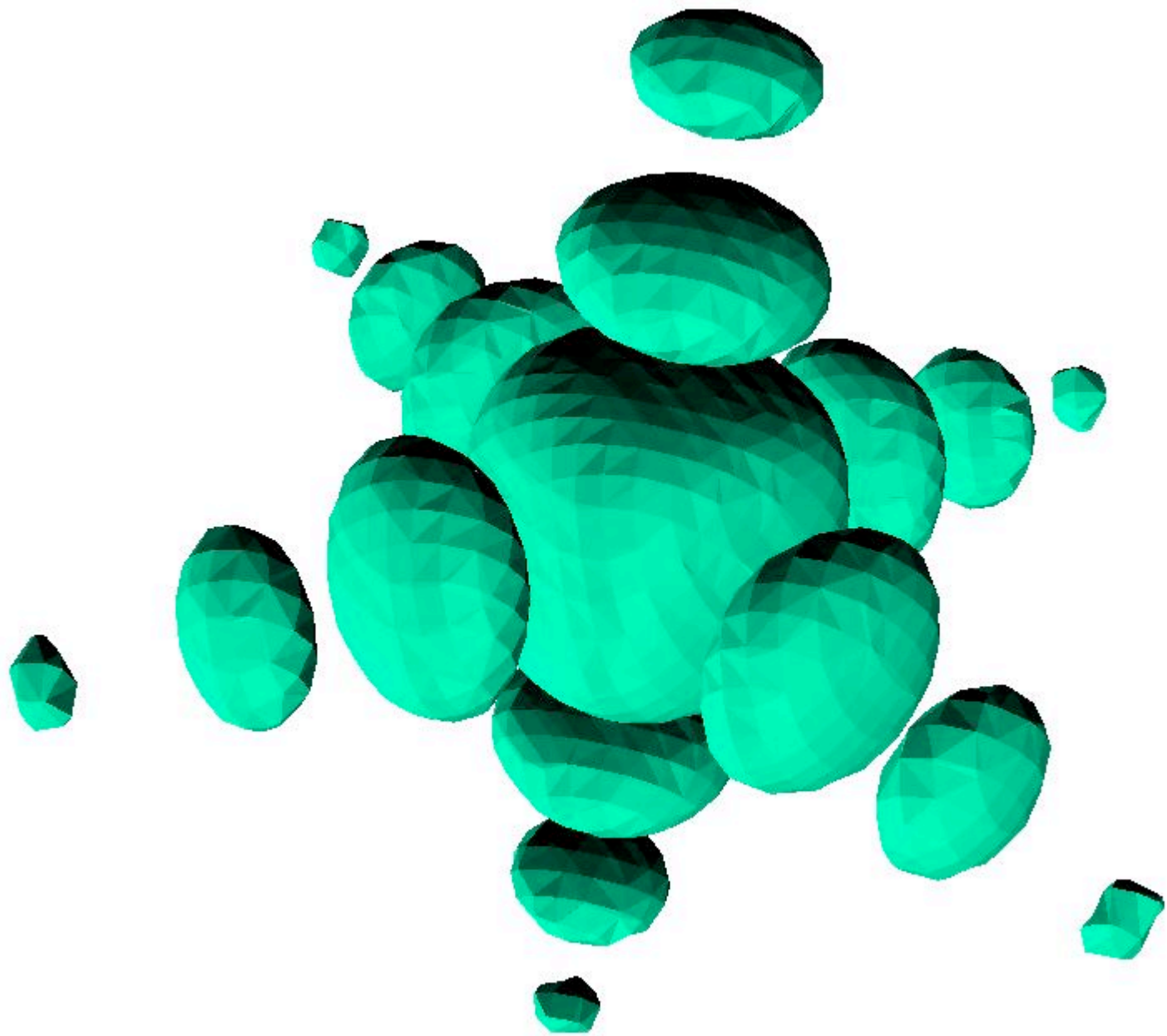
Chemically Synthesized Silver Nanocubes

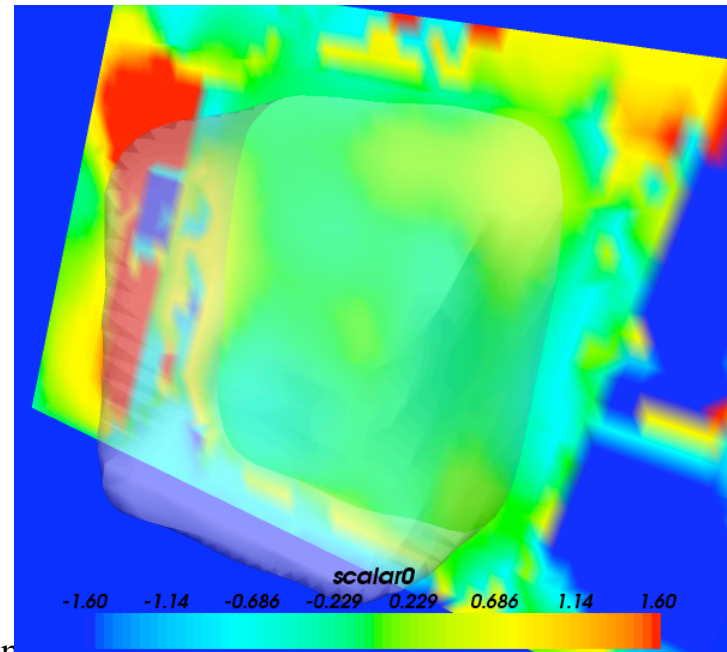
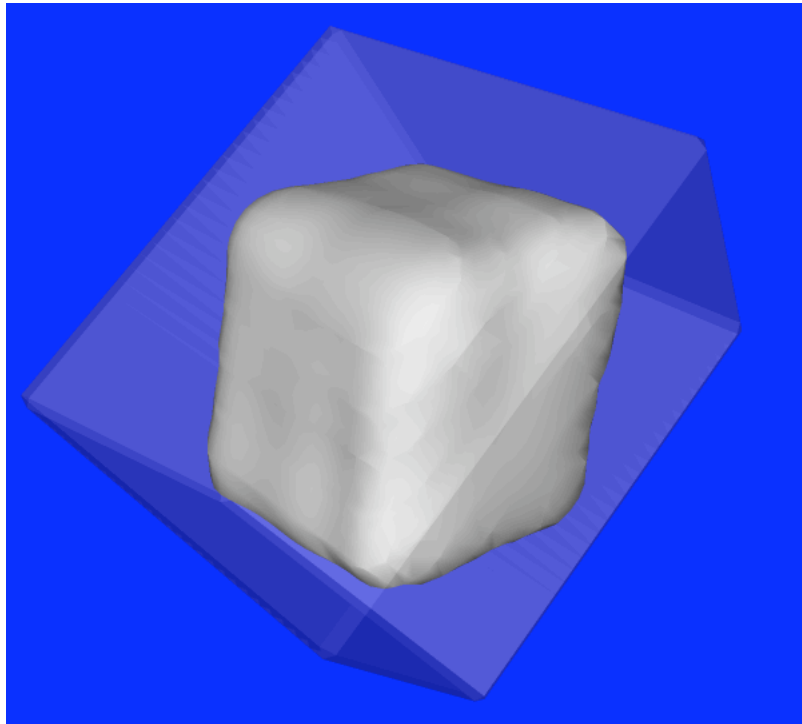
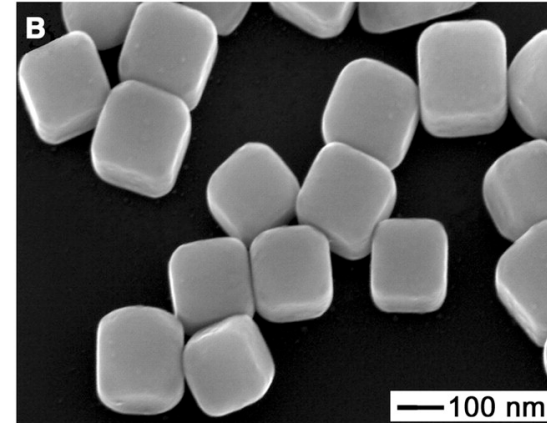
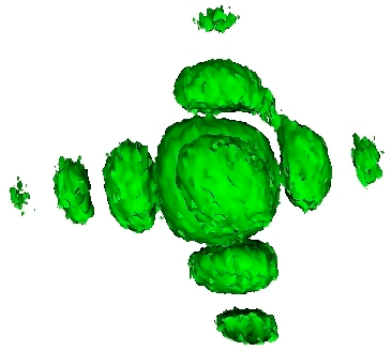
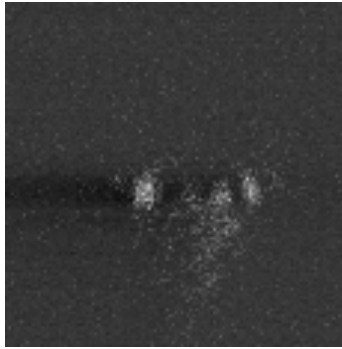


Yugang Sun and Younan Xia,
Science 298 2177 (2003)

Rocking
scan of Ag
cubes with
 0.01° steps



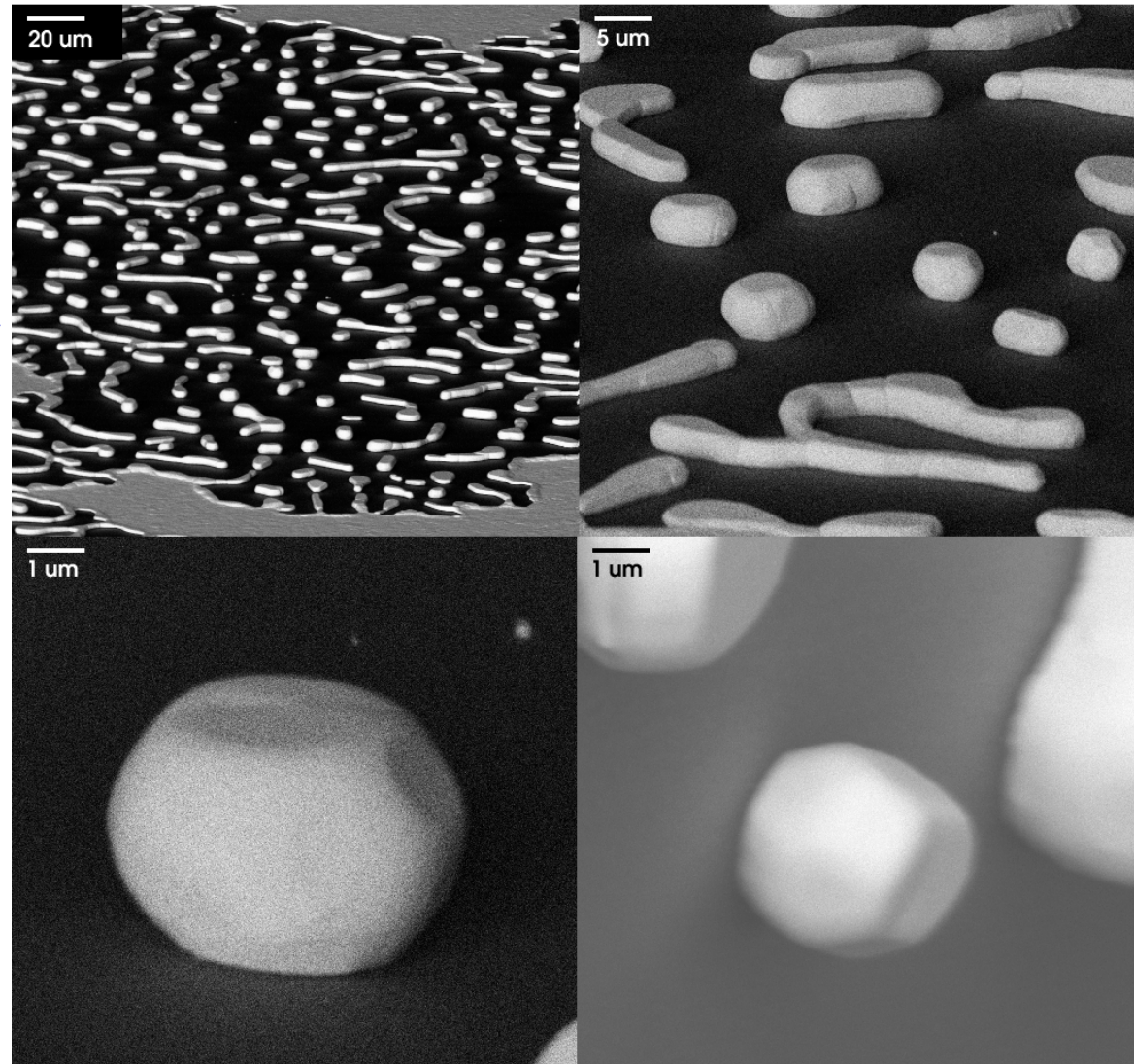




W. H. Robinson, Brenner 2007

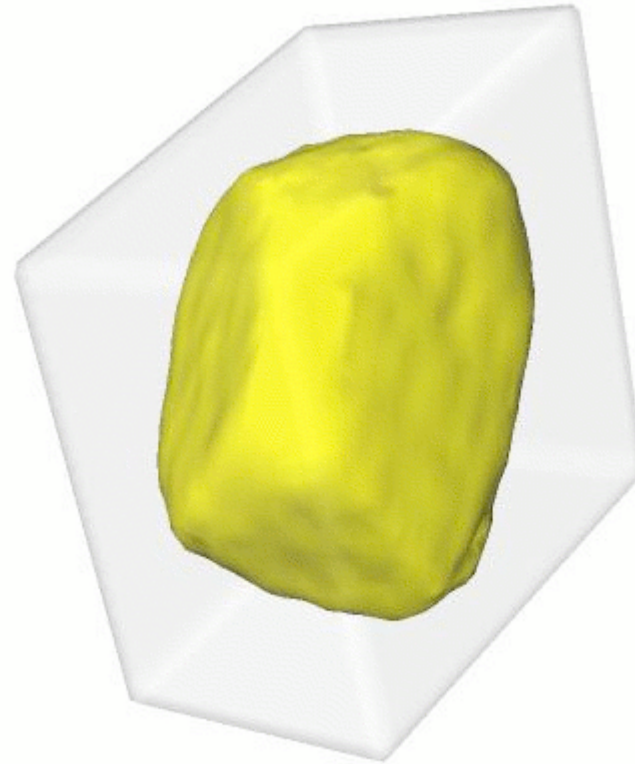
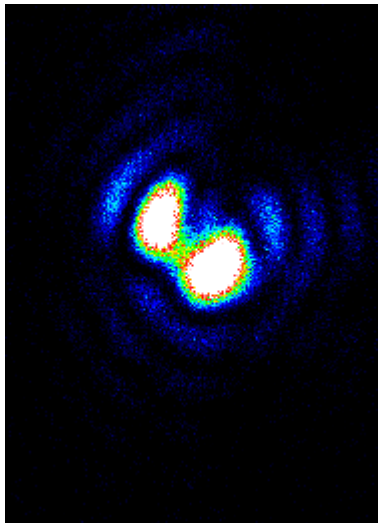
SEMS

- Au blanket film
- Quartz substrate
- Annealed at 950°C for 70 hrs.

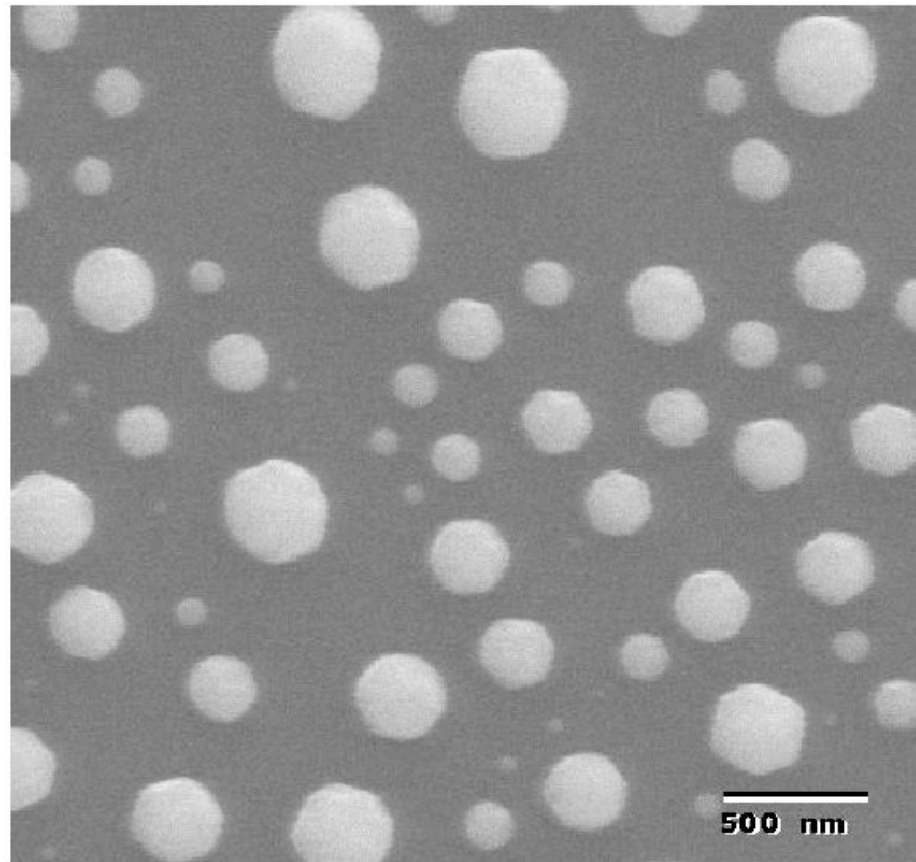
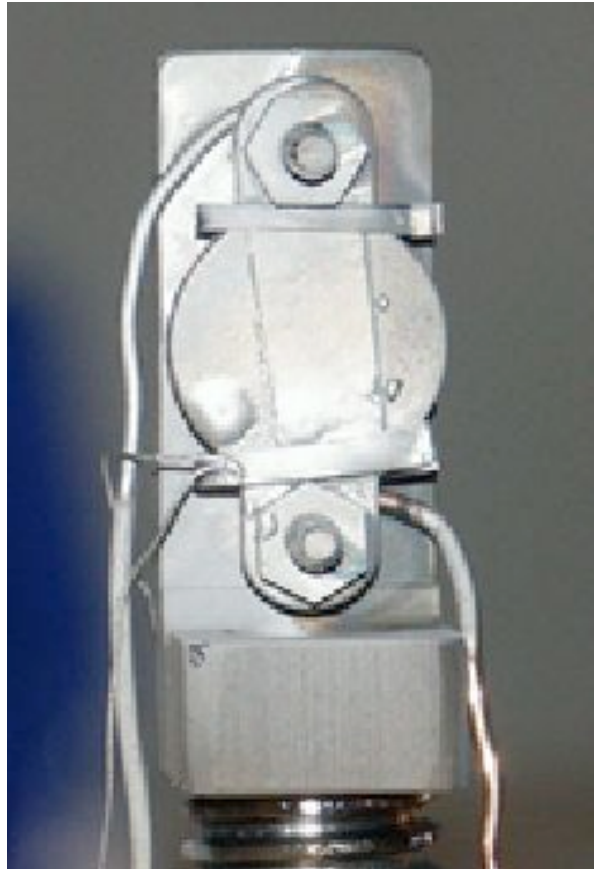


Gold nanocrystal reconstruction

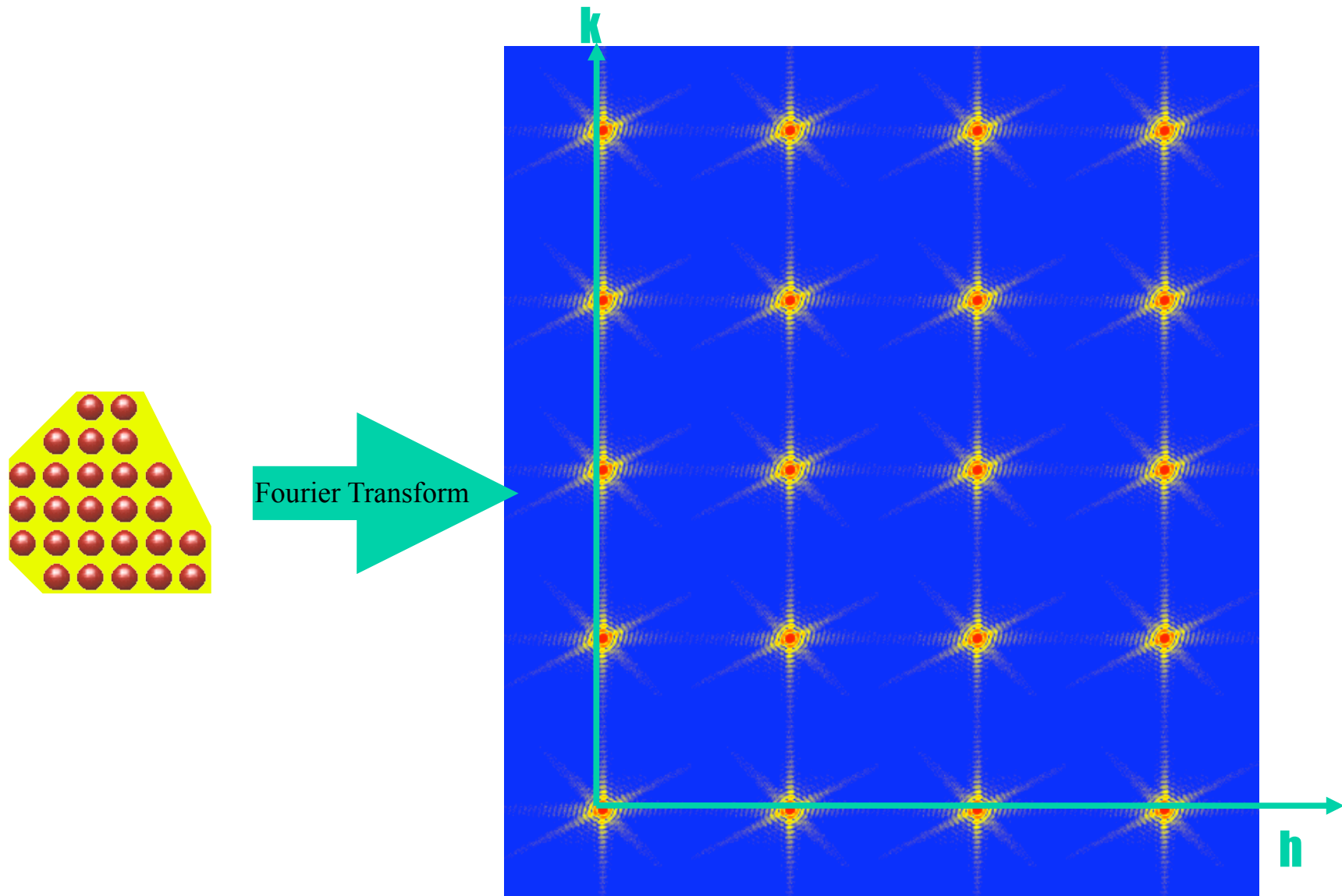
showing support used for 20 HIO followed by 10 ER



In situ growth of Pb crystals

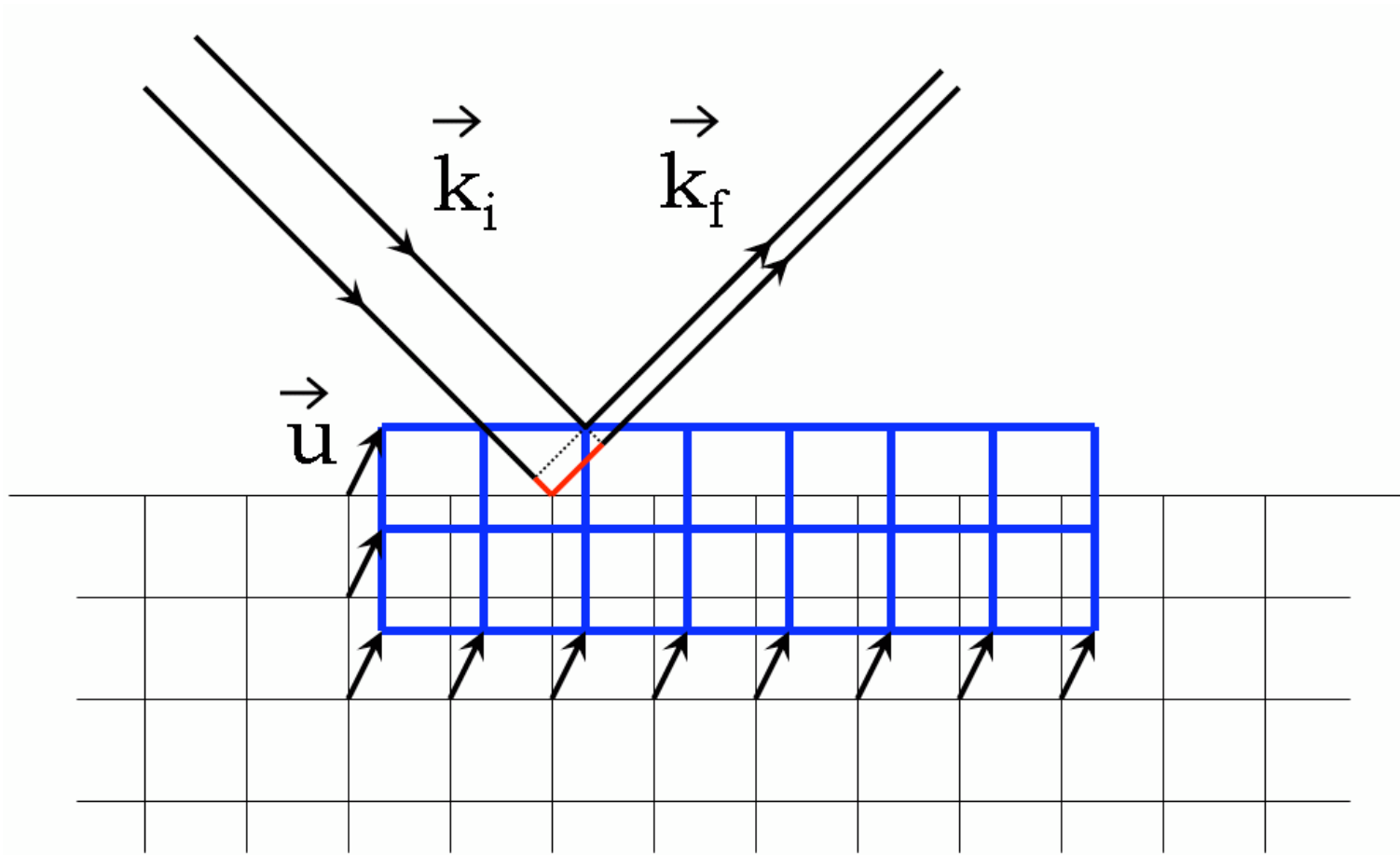


Coherent Diffraction from Crystals



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

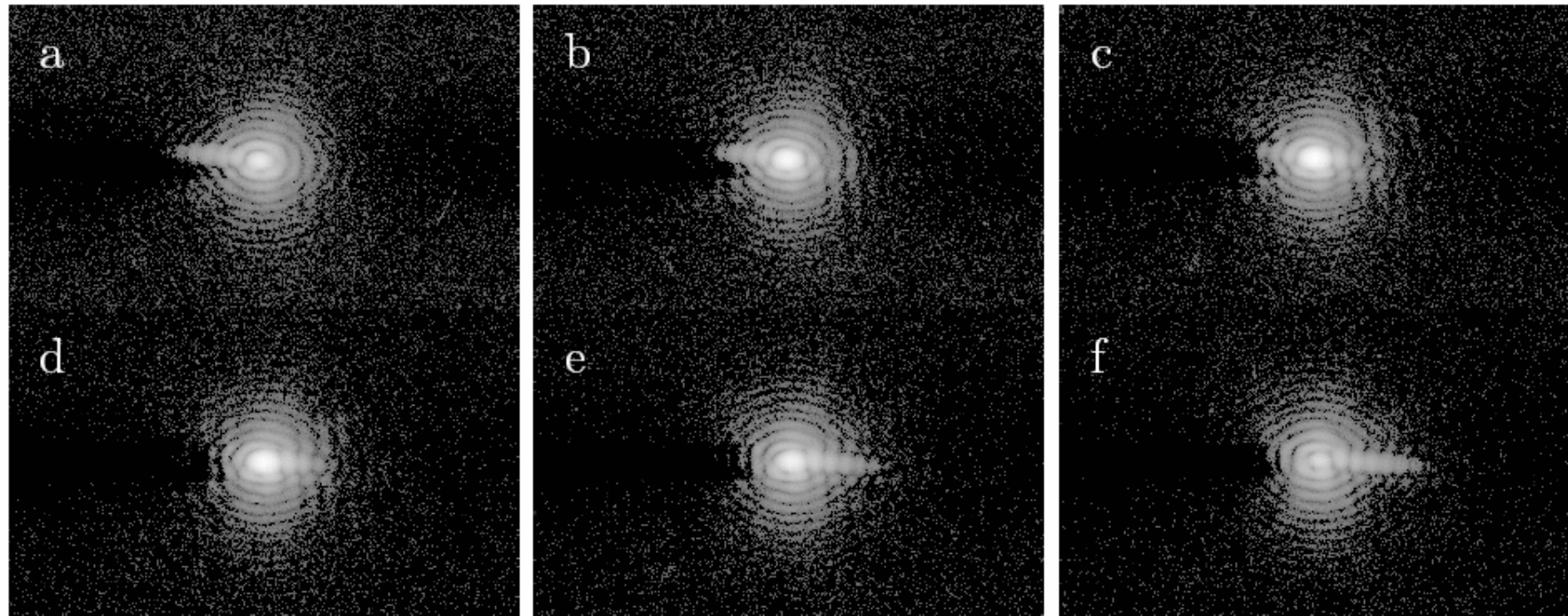
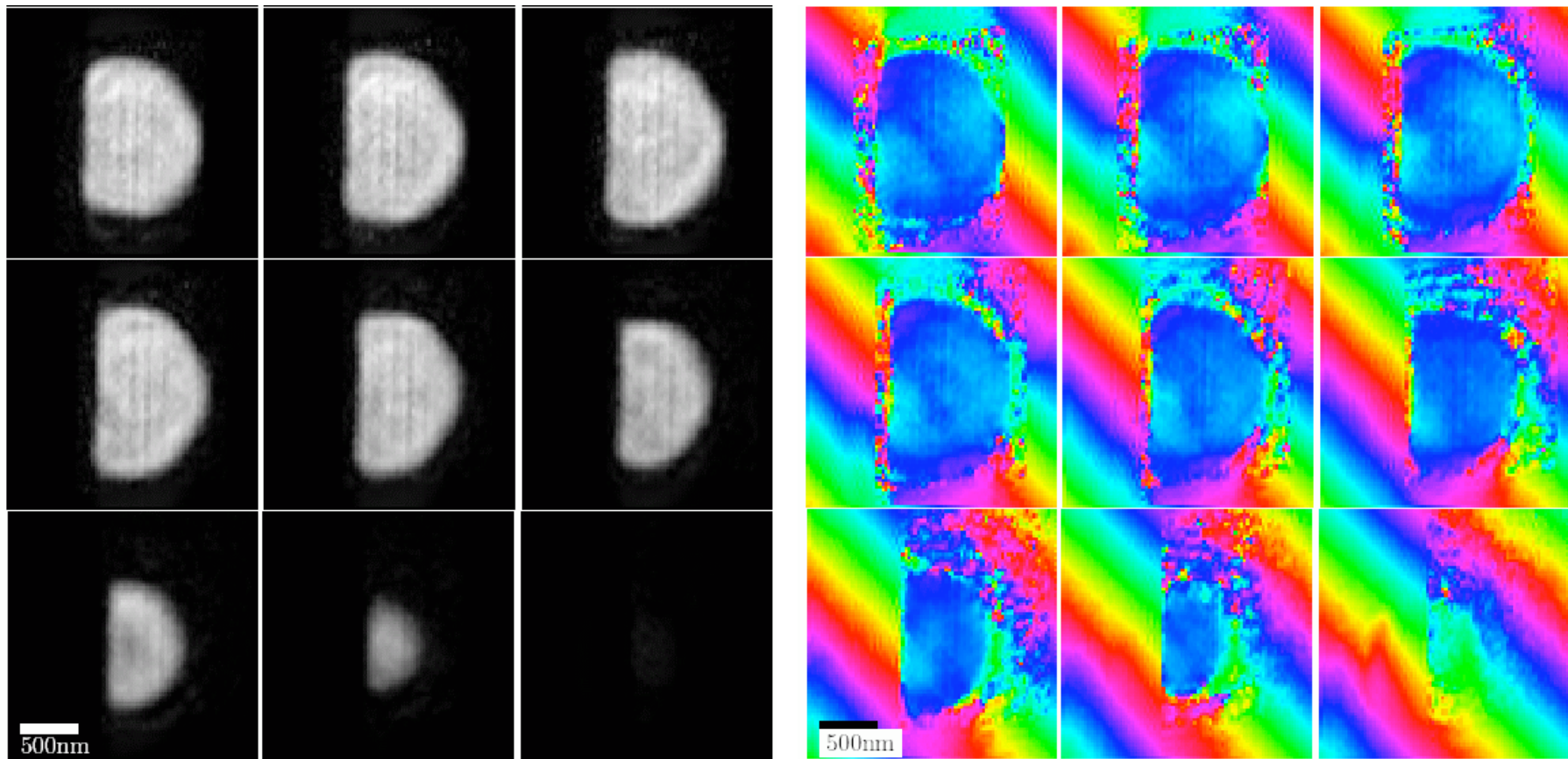
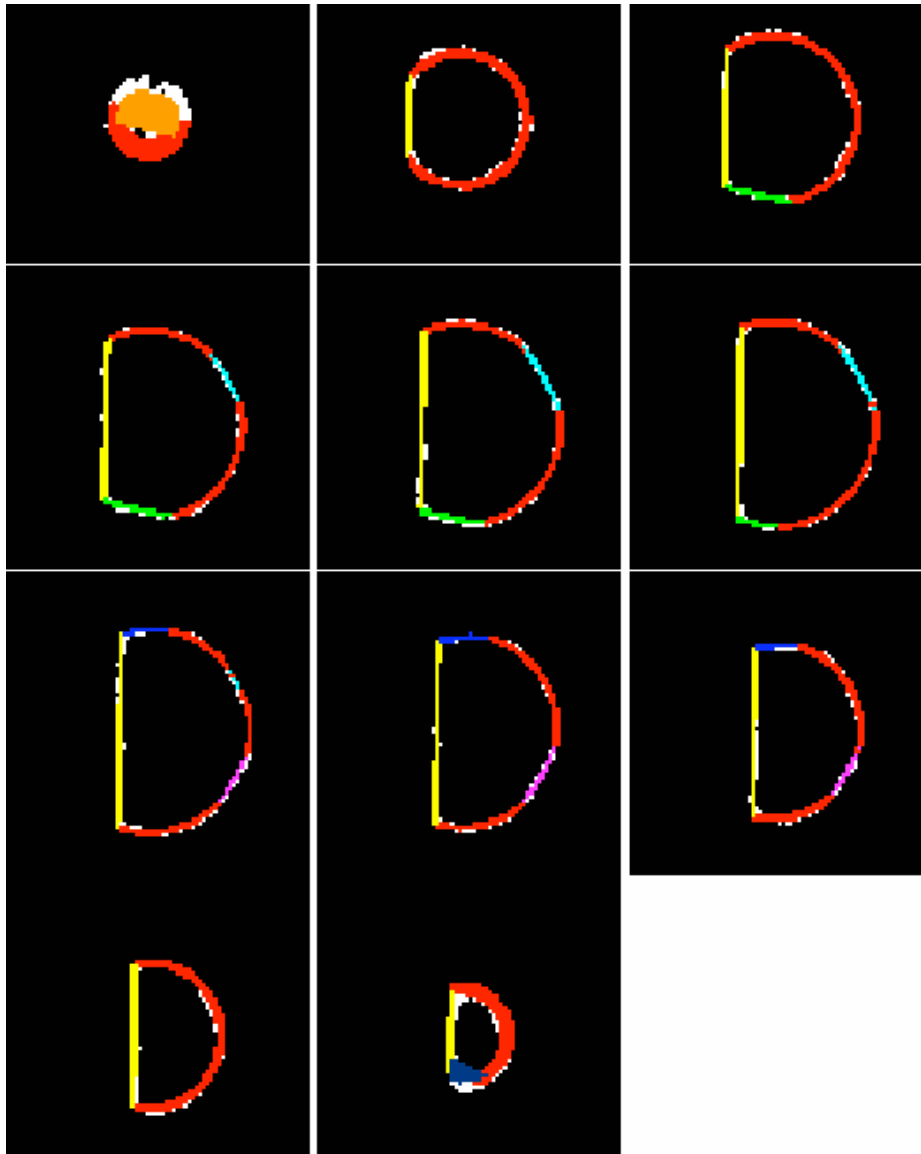


Figure 4.12: Center slices from 3D CXD pattern from Pb sample, on a log scale. Data file 296 from 10/03.

Complex Density (amplitude *and* phase)

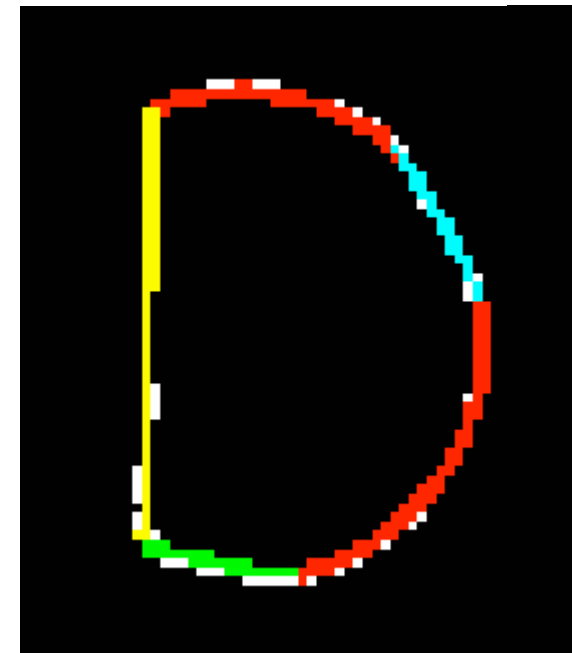


Fitting to faceted shape

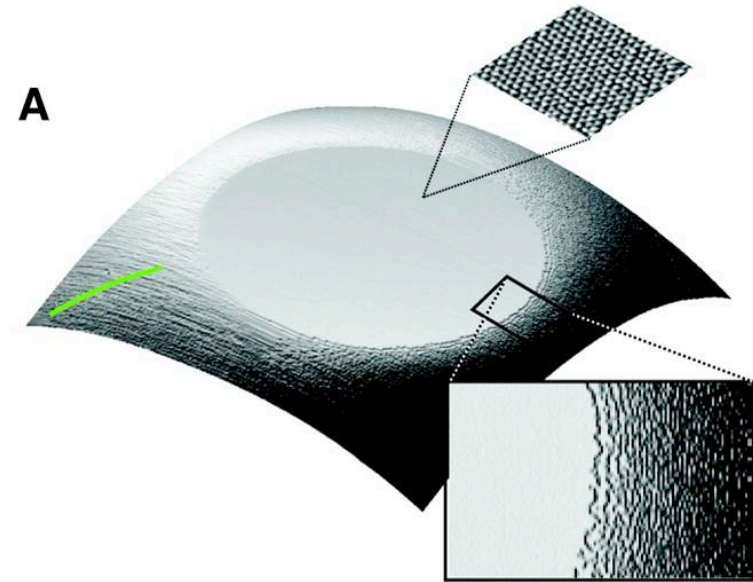


	$ R $		P0	P1	P2	P3	P4	P5	P6
	9.4	P0	0	85	149	79	134	106	71
	25.7	P1		0	123	164	83	76	102
	25.1	P2			0	72	67	74	110
	25.9	P3				0	111	106	76
	25.4	P4					0	113	68
	25.4	P5						0	176
	26.0	P6							0 0

Angles between facets

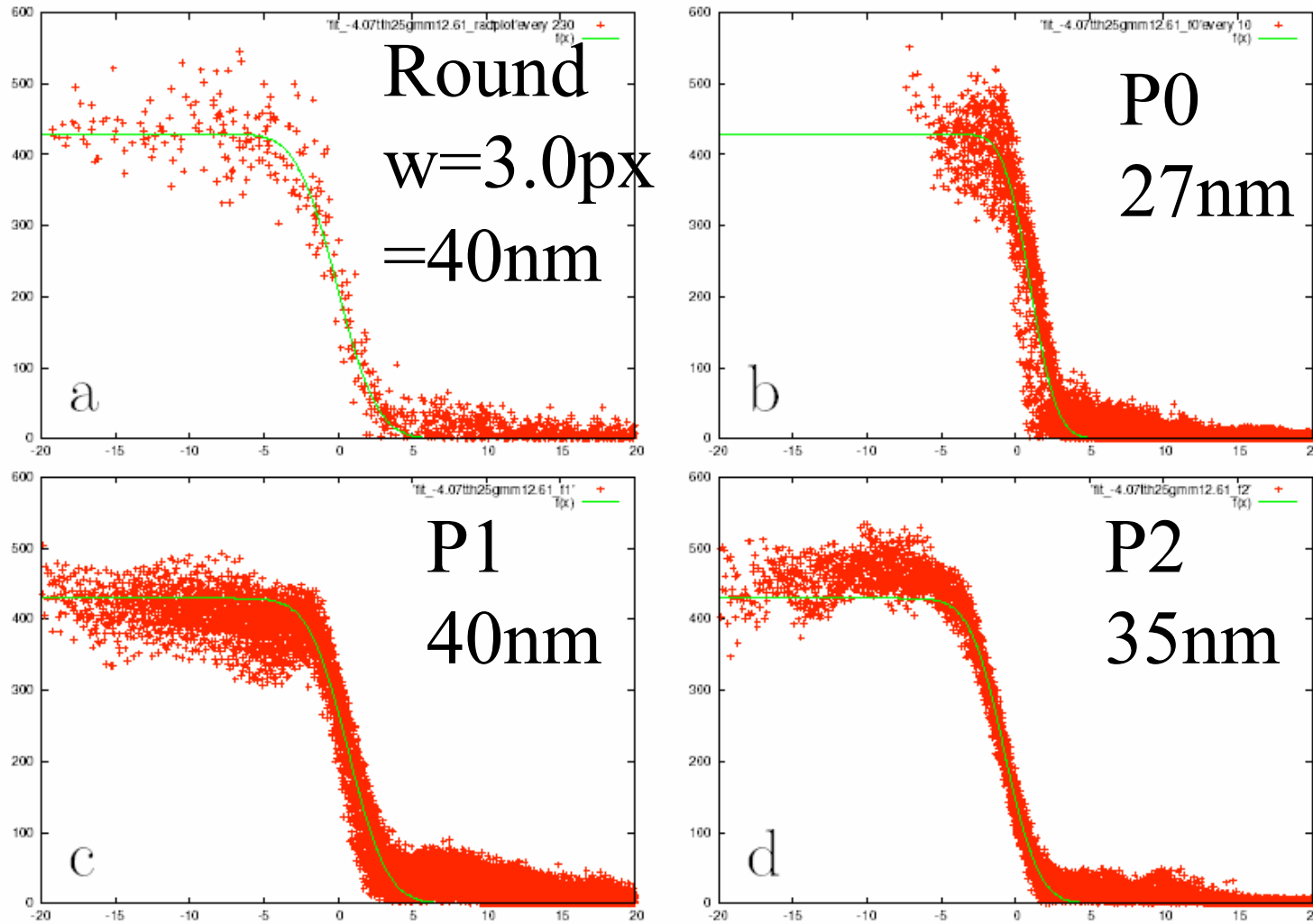


Facets of Equilibrium Crystal Shape

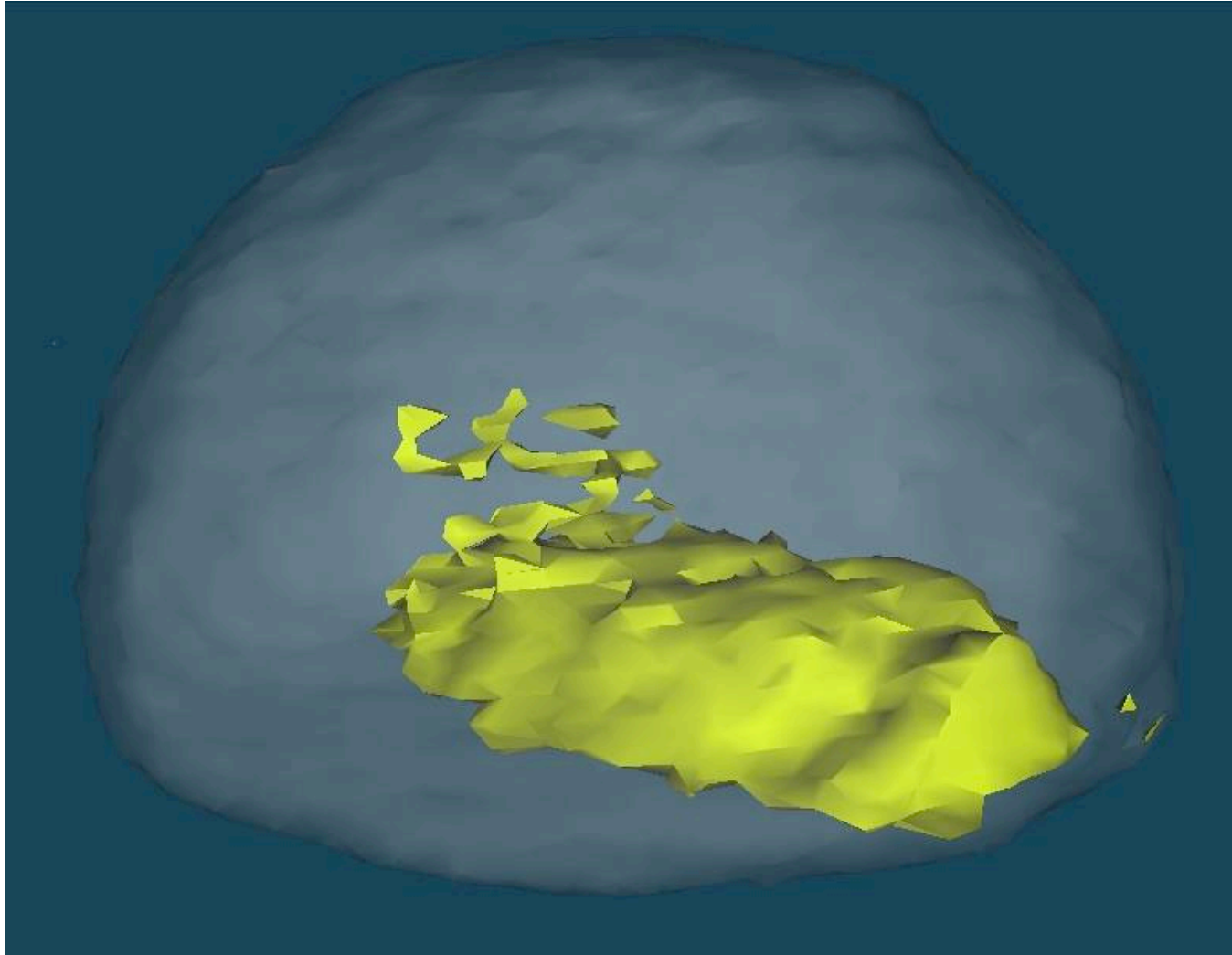


Thurmer K, Williams E, Reutt-Robey J
Science **297** 2033 (2002)

Density distribution across surface

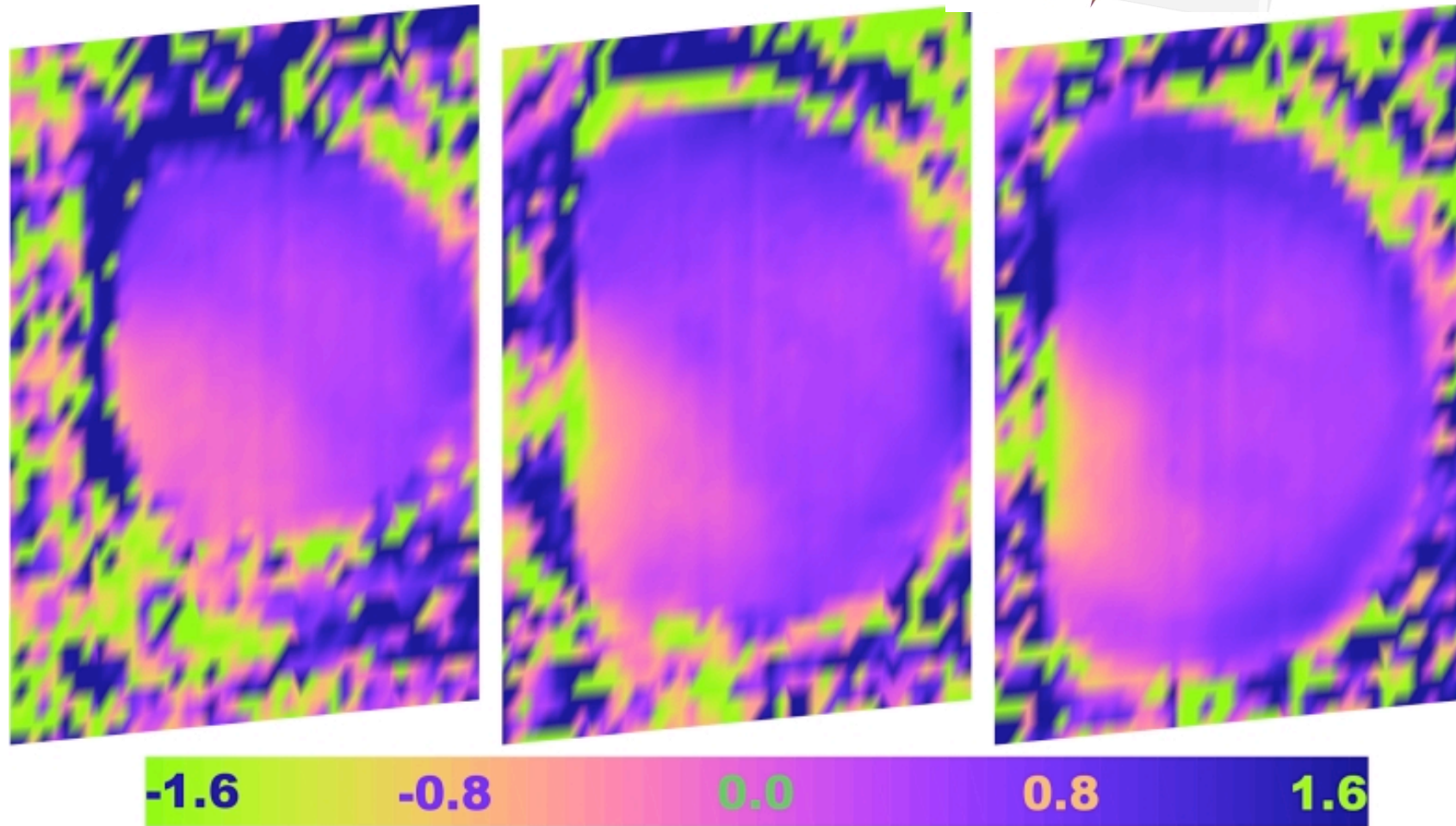
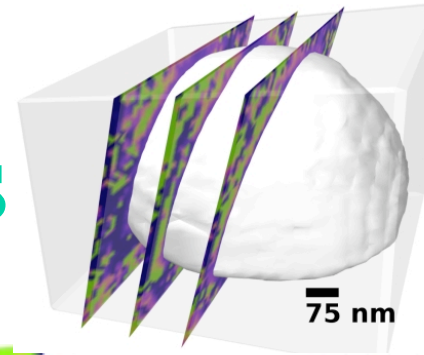


Modeling of 3D Phase Bump

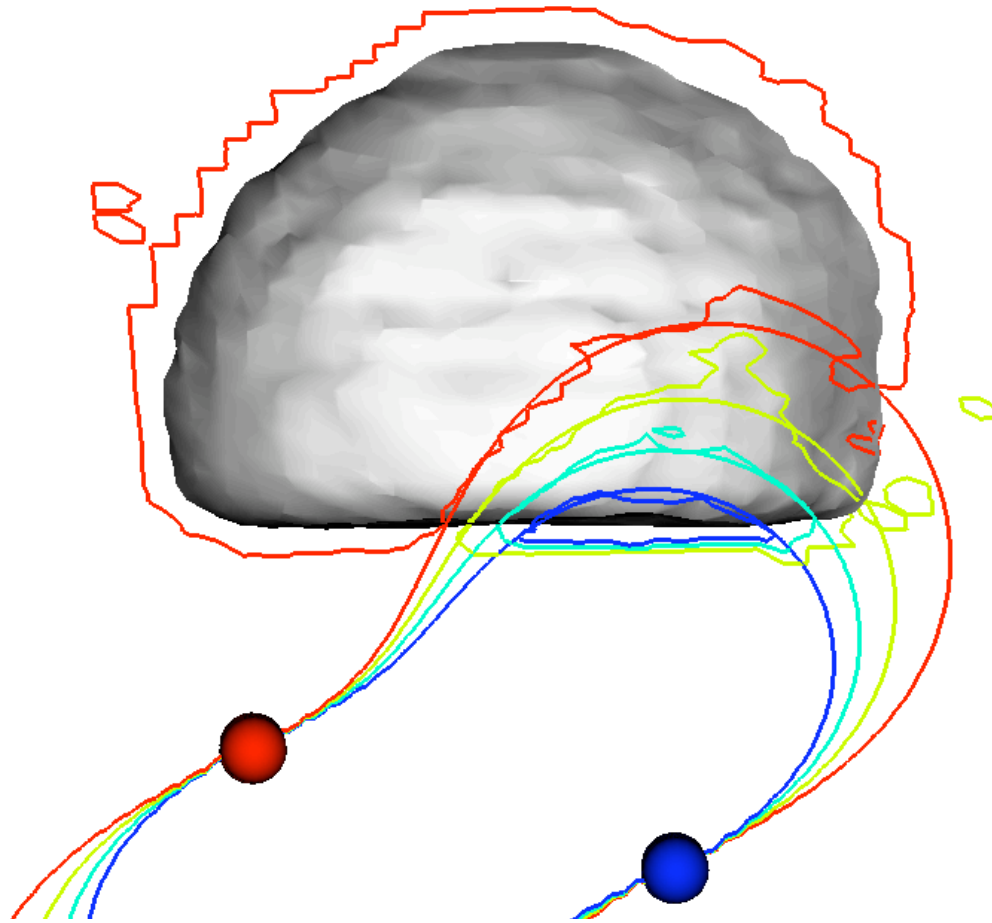


I. K. Robinson, Bremen 2009

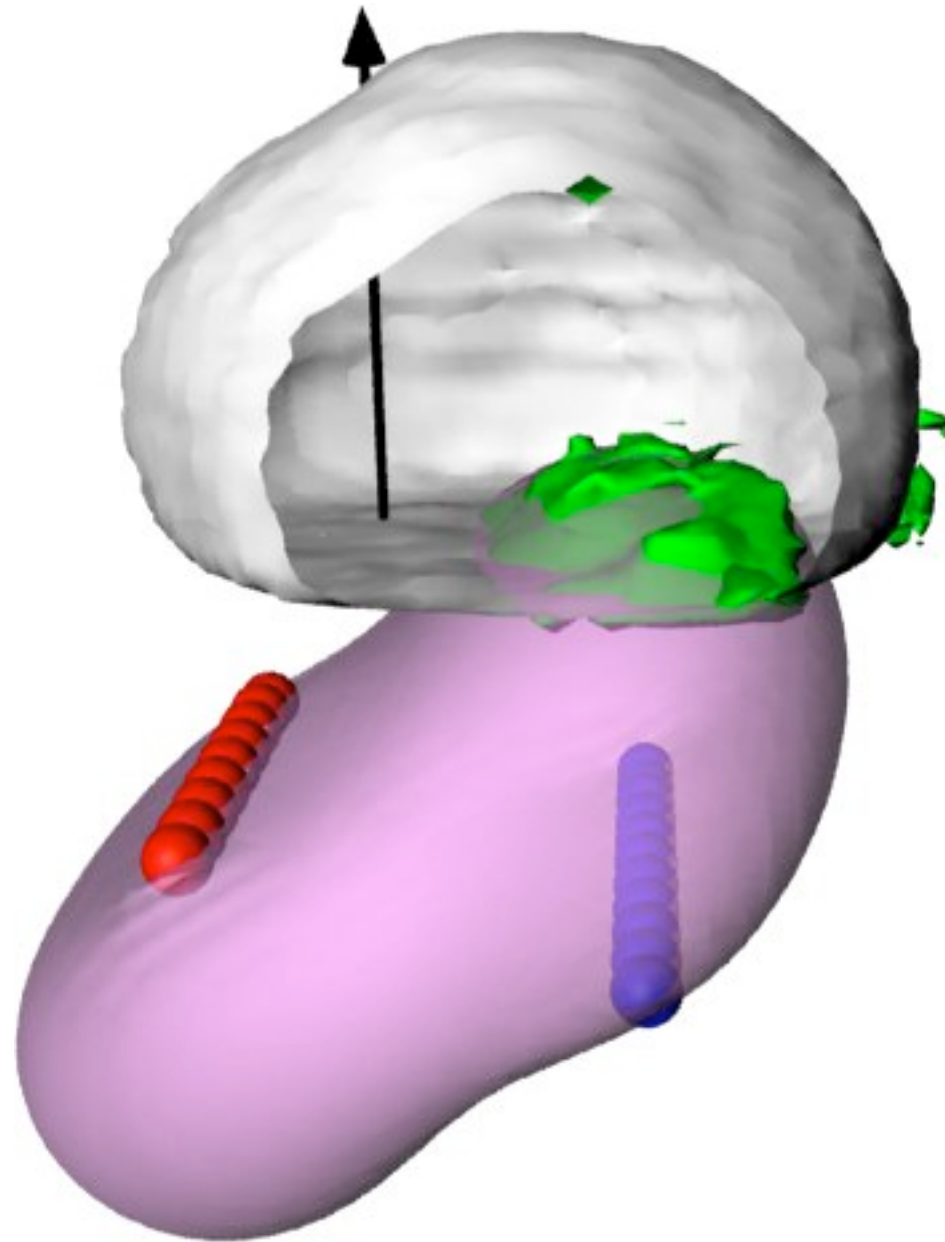
3D phase map sections



Field lines of “Point Charges”



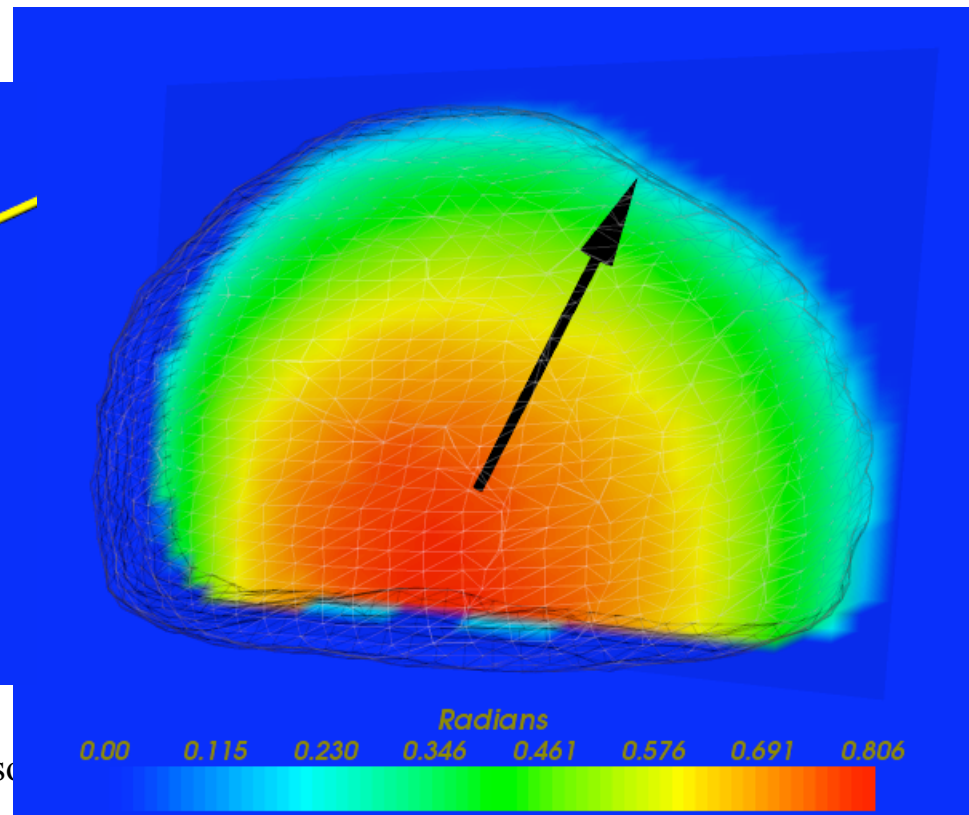
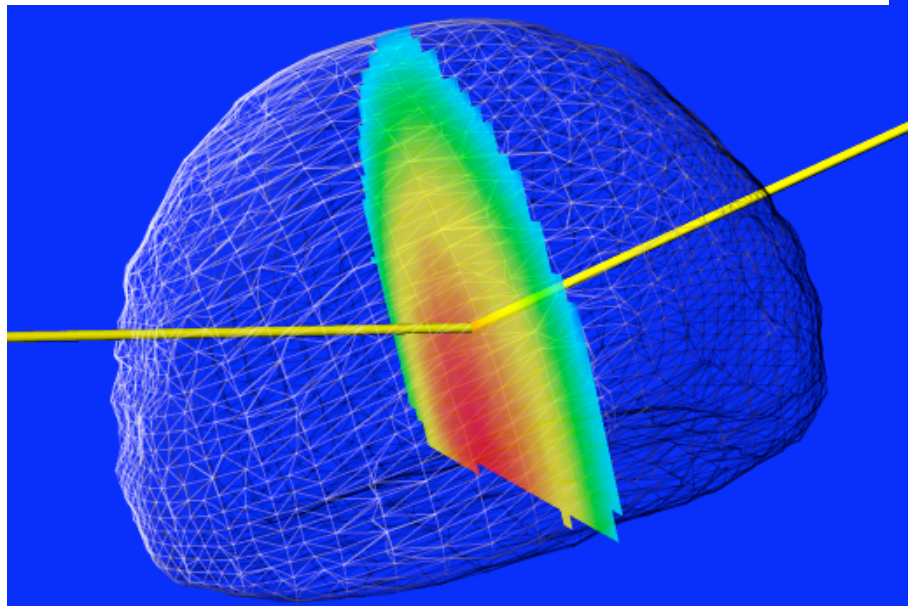
I. K. Robinson, Bremen 2009



Refraction effects in Lead at 8.9keV

Phase accumulation due to refraction along scattering path
 $n=1-\delta+i\beta$

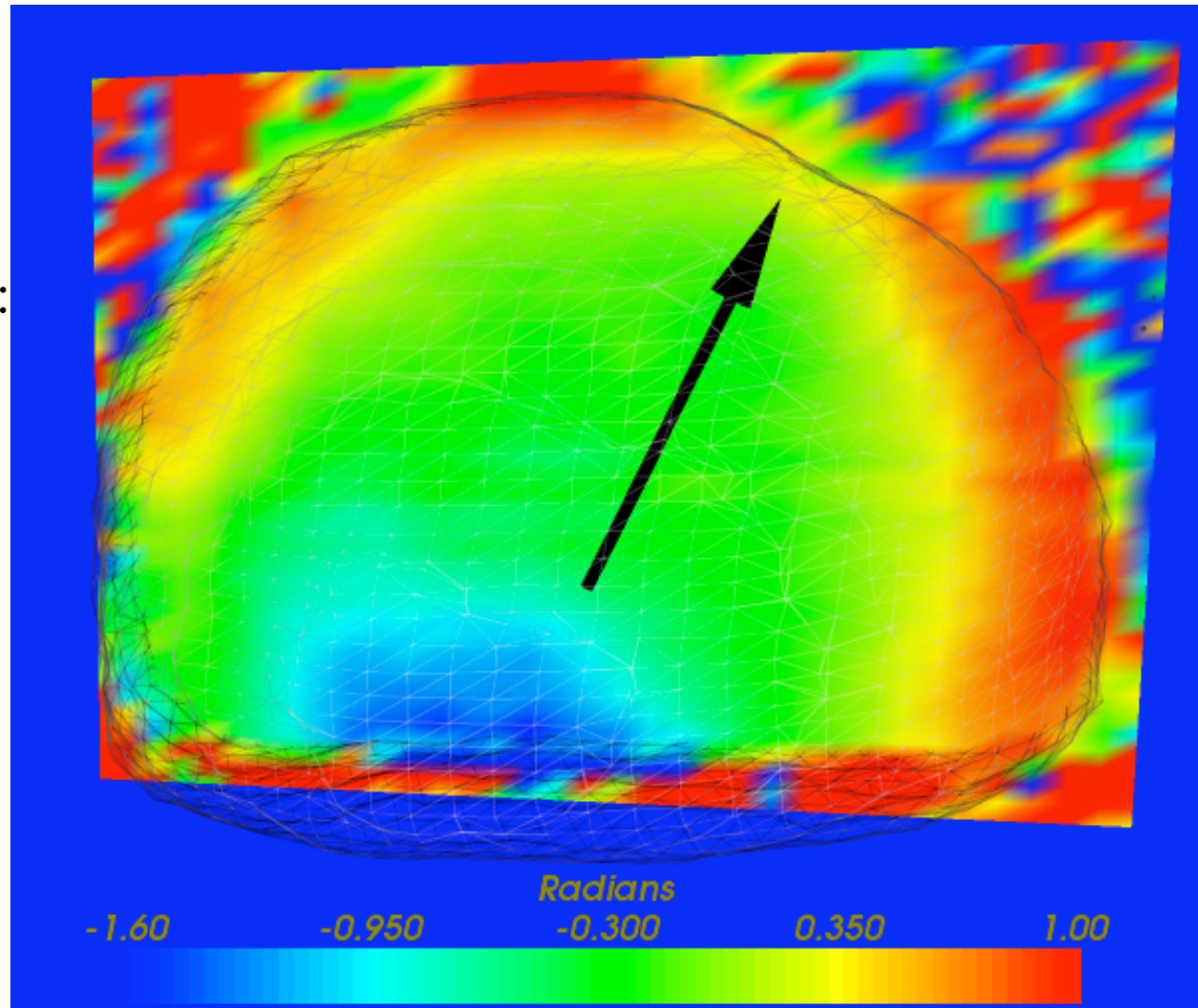
$$\delta=2.23\times 10^{-5}$$
$$\beta=2.19\times 10^{-6}$$



Refraction corrected phase map

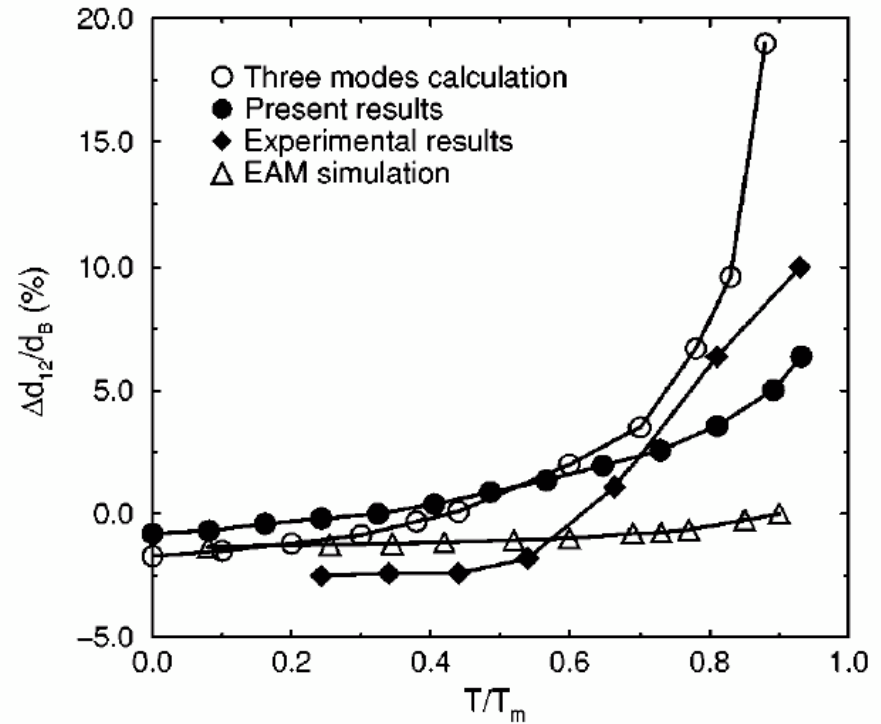
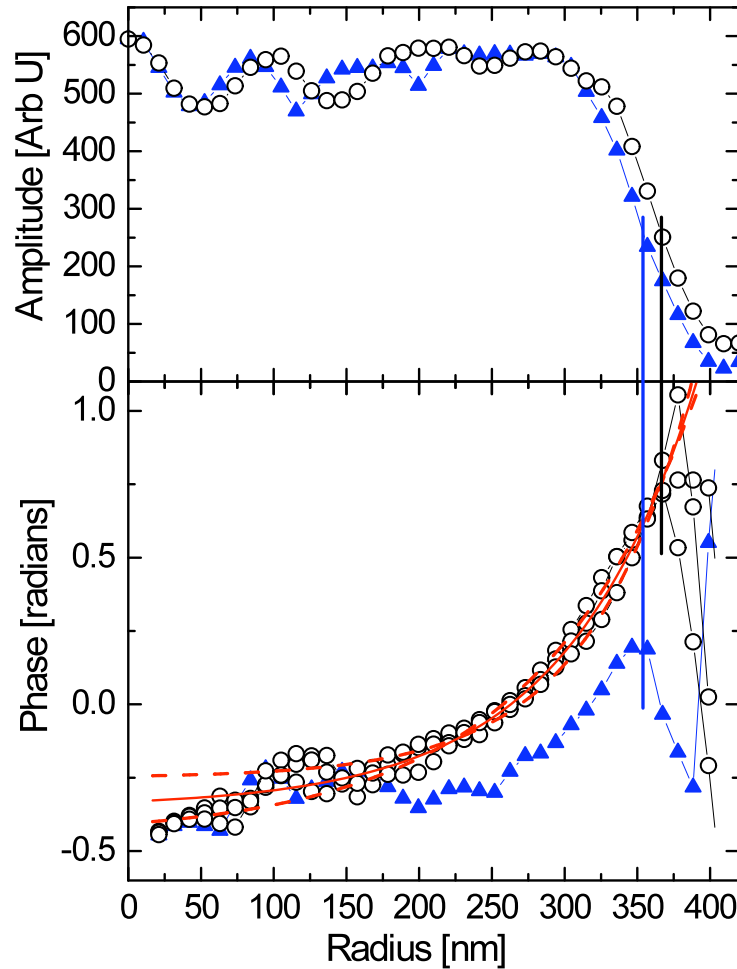
Max phase = 1.15rad
= 0.052nm

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



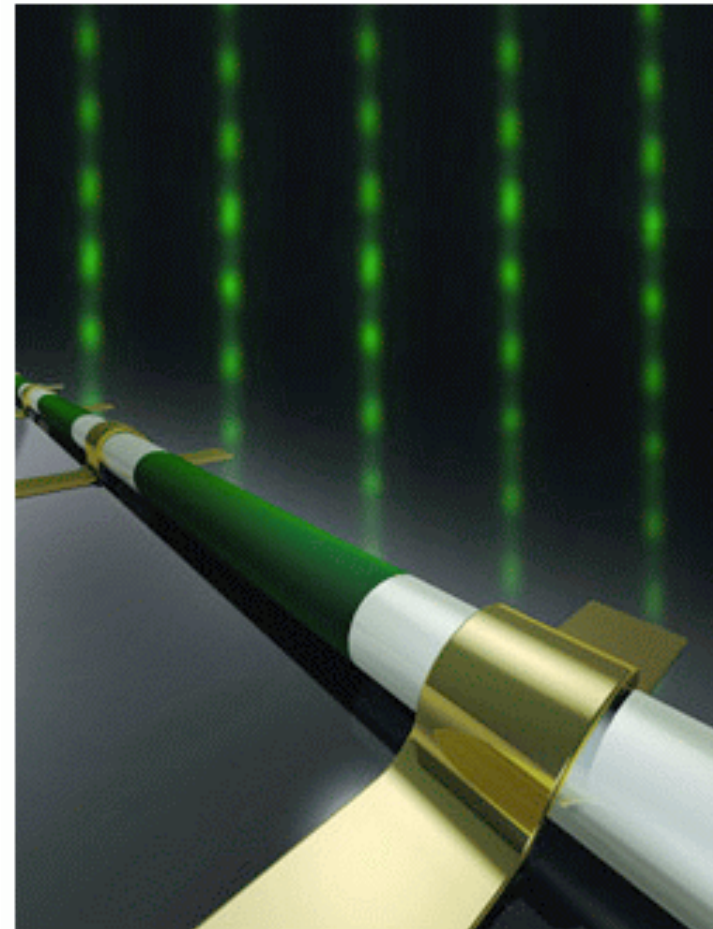
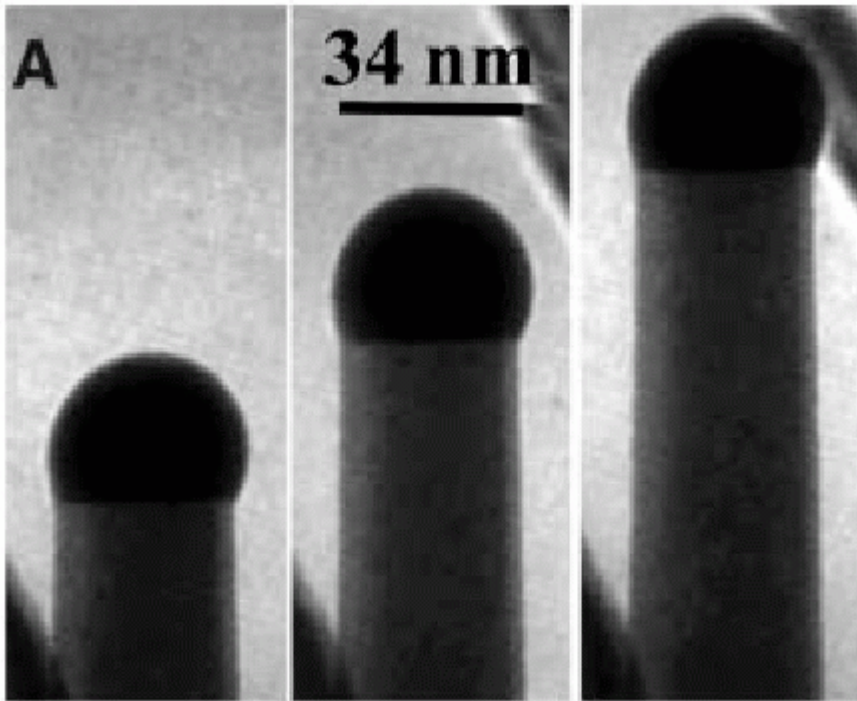
Surface Thermal Expansion

Ag(111): Scheffler et al PRB 59 970 (1999)



VLS growth of nanowires

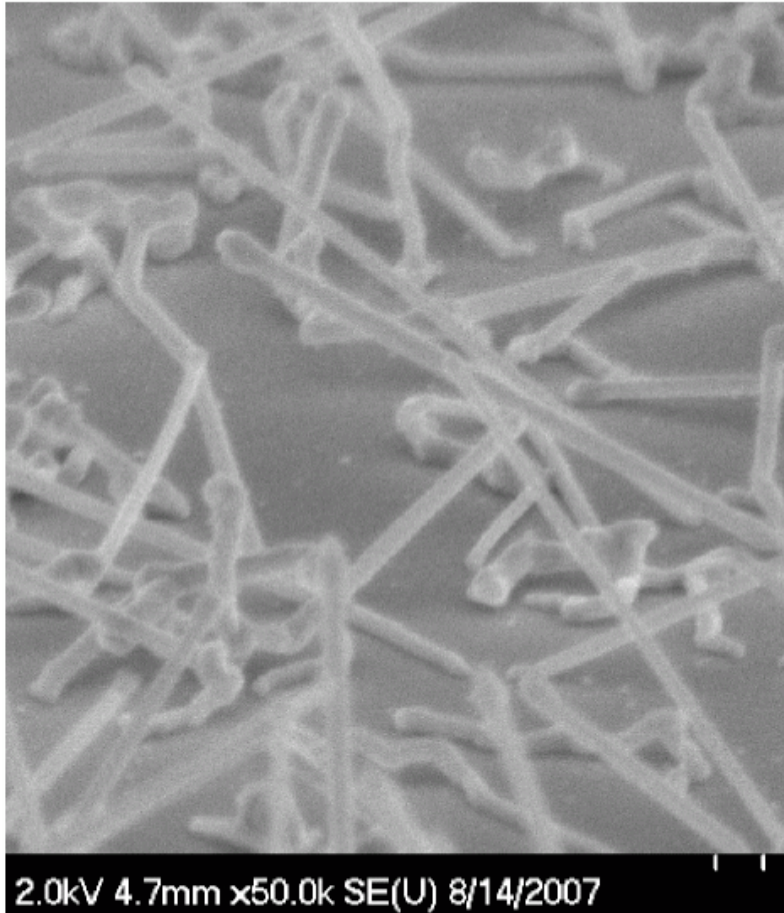
S. Kodambaka et al., *Science* 316 729 (2007)



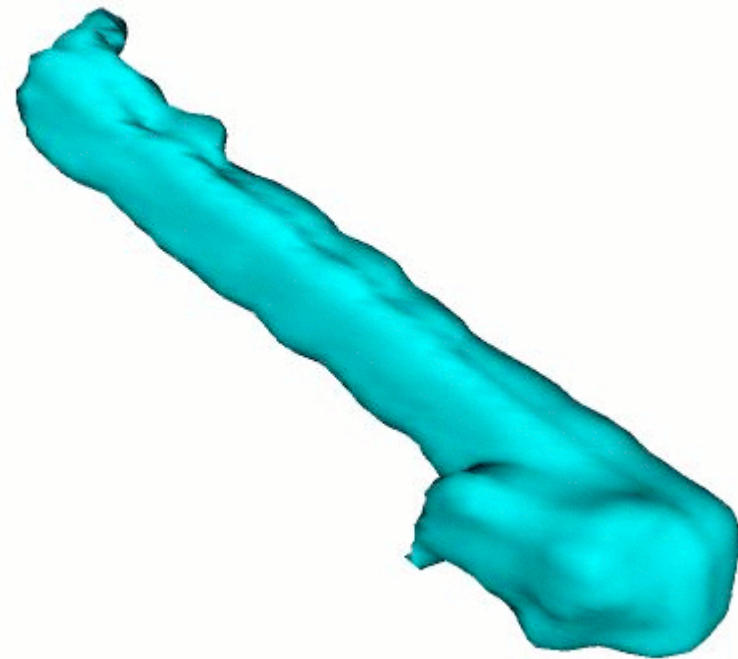
I. K. Robinson, Brem
NiSi/Si nanowire heterostructure
devices. *Nature* **430**, 61 (2004).

Reconstruction of InP nanowire

CVD on Si, Suneel Kodambaka, UCLA

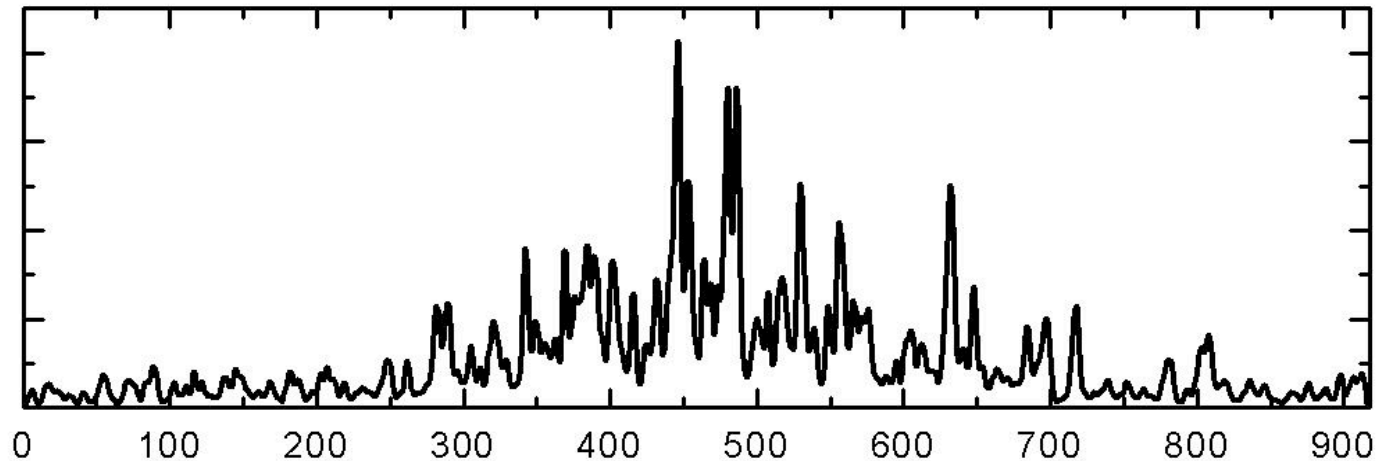
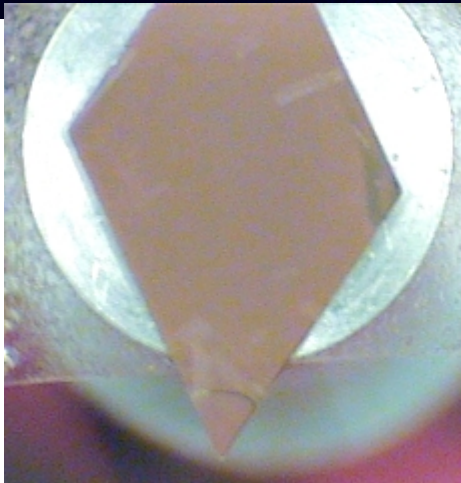
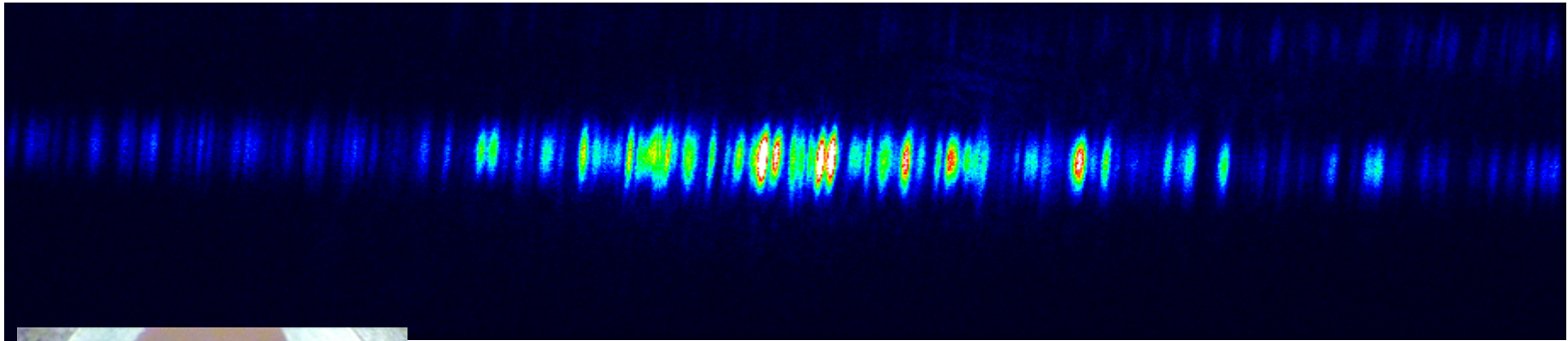


InP nanowires grown on Si (111)



GaAs Nanowire “Barcode”

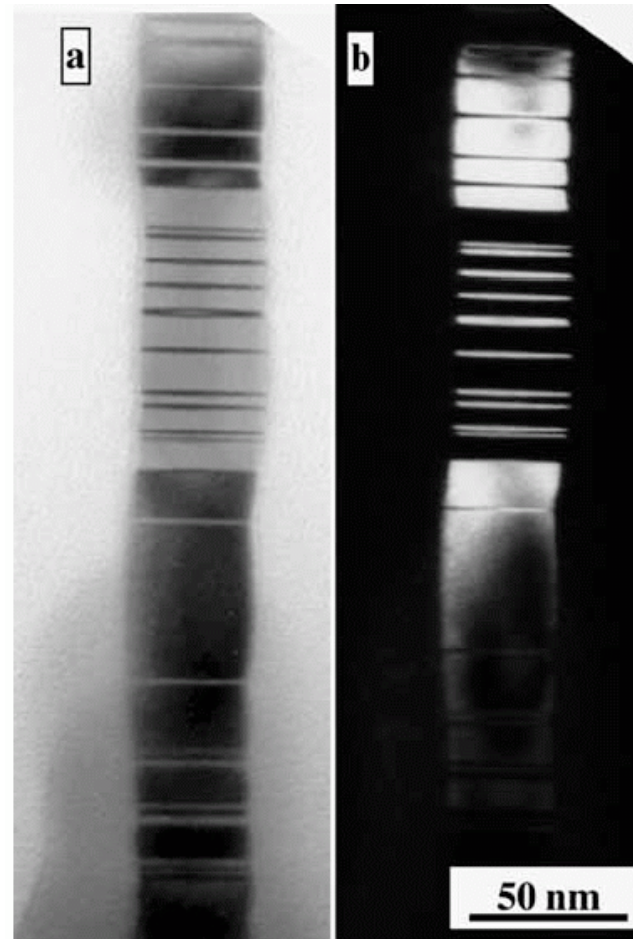
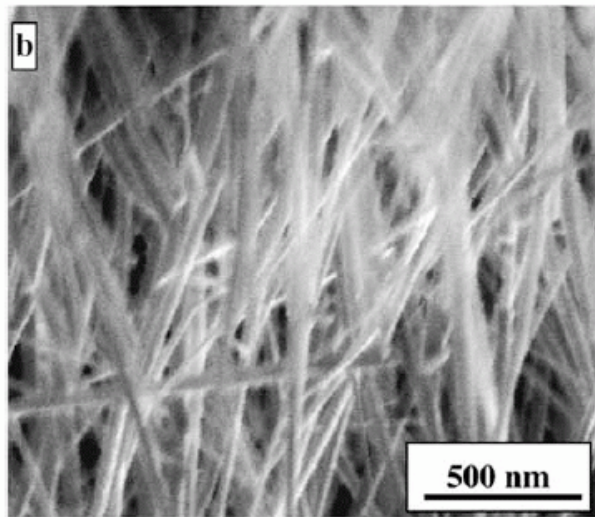
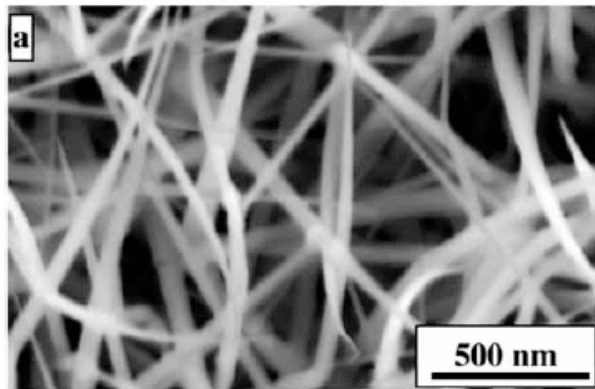
Vincent Favre-Nicolin, Joel Eymery (CEA),
Rienk Algra (Philips), Ross Harder



GaAsNW1106-22.spe
B9348 from Philips

Dark Field TEM of GaAs Nanowires

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

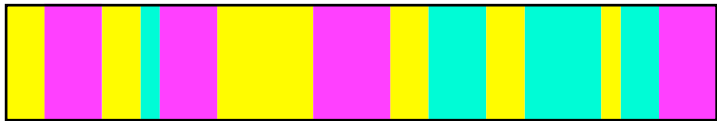


Models of Barcode Diffraction

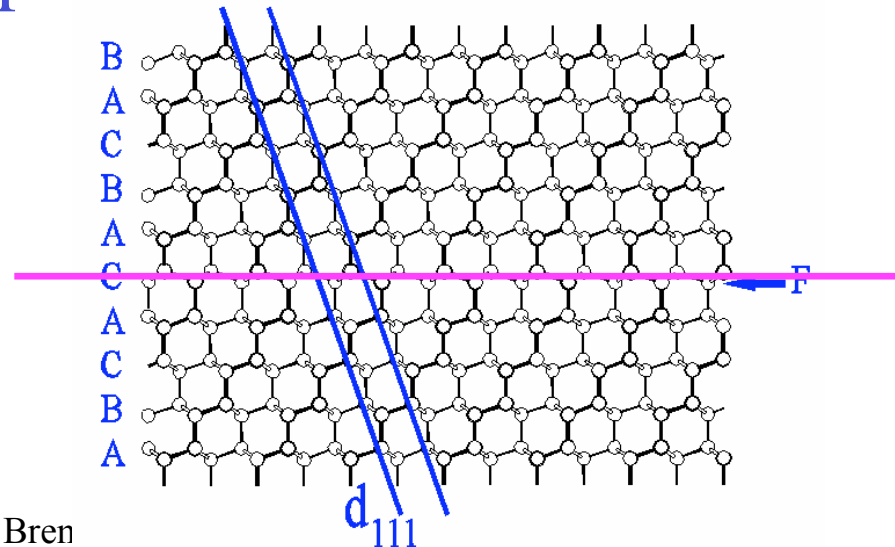
(111) wires at (11-1) reflection



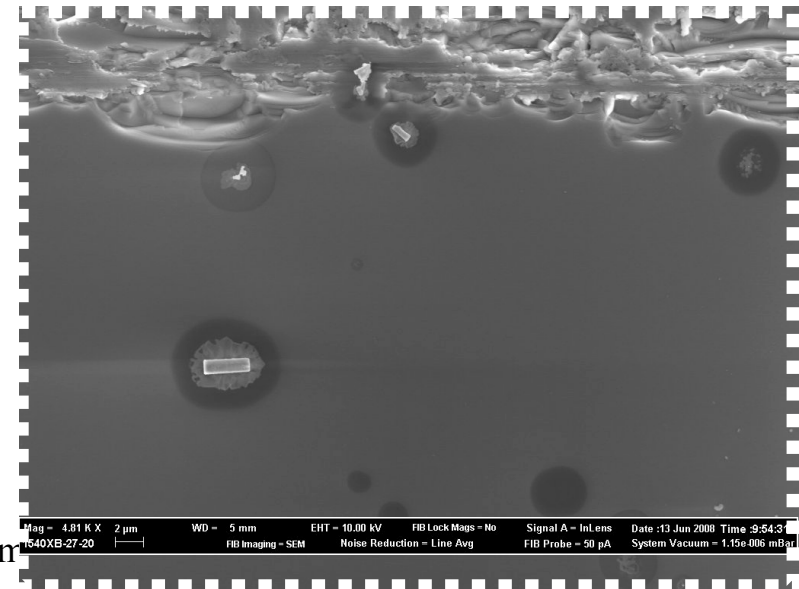
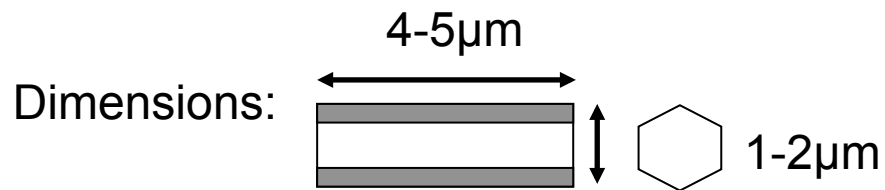
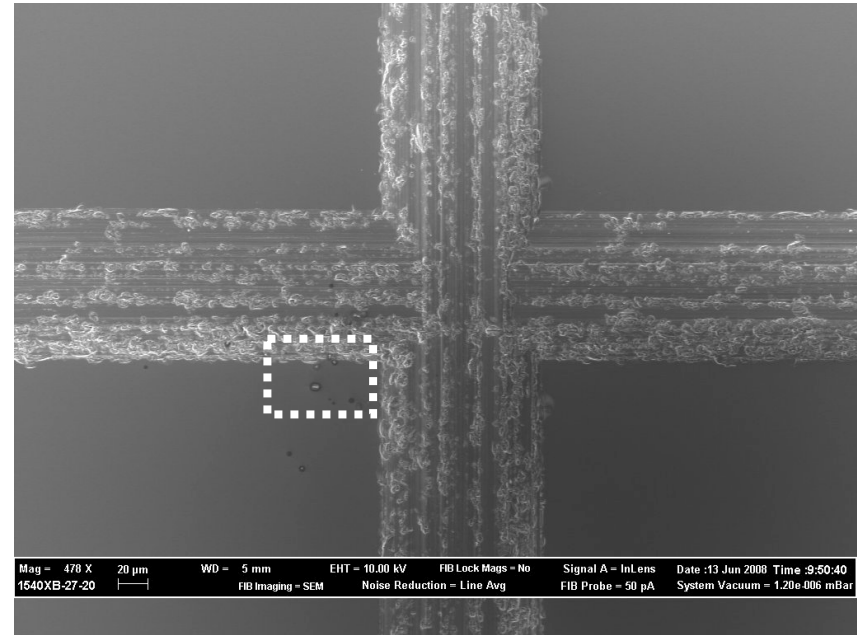
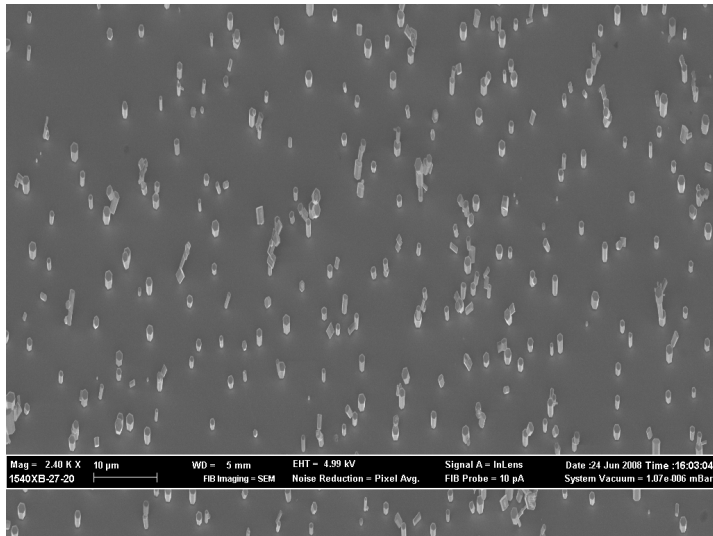
- Twinned stacking sequence



- Deformation faults



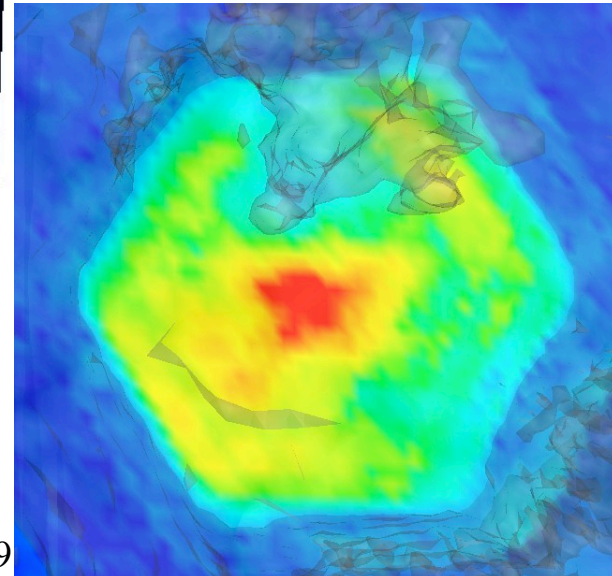
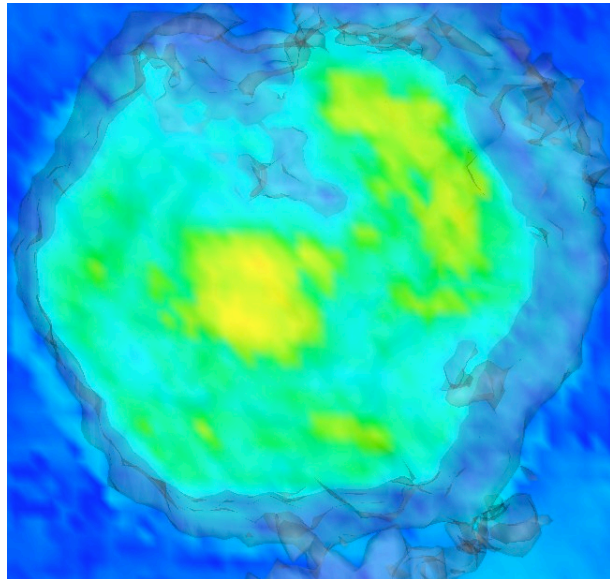
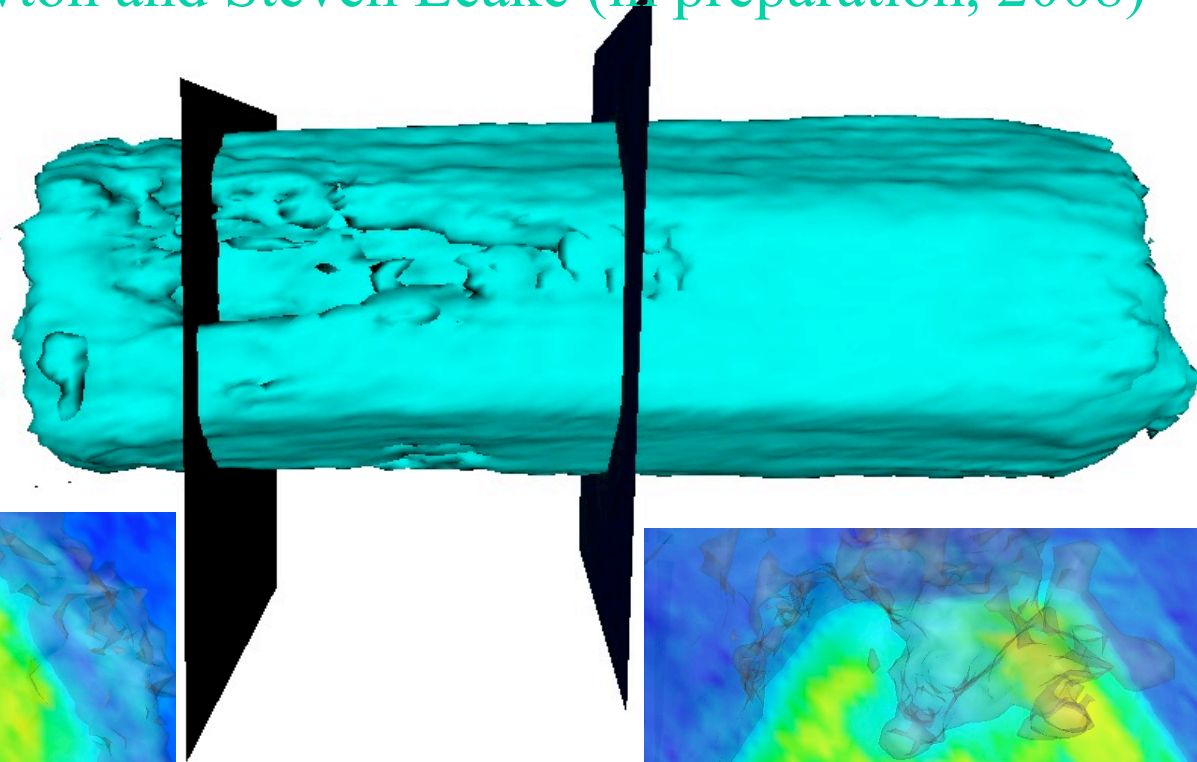
ZnO Sample Preparation



I. K. Robinson, Bremen

Density sections ZnO-39 (010)

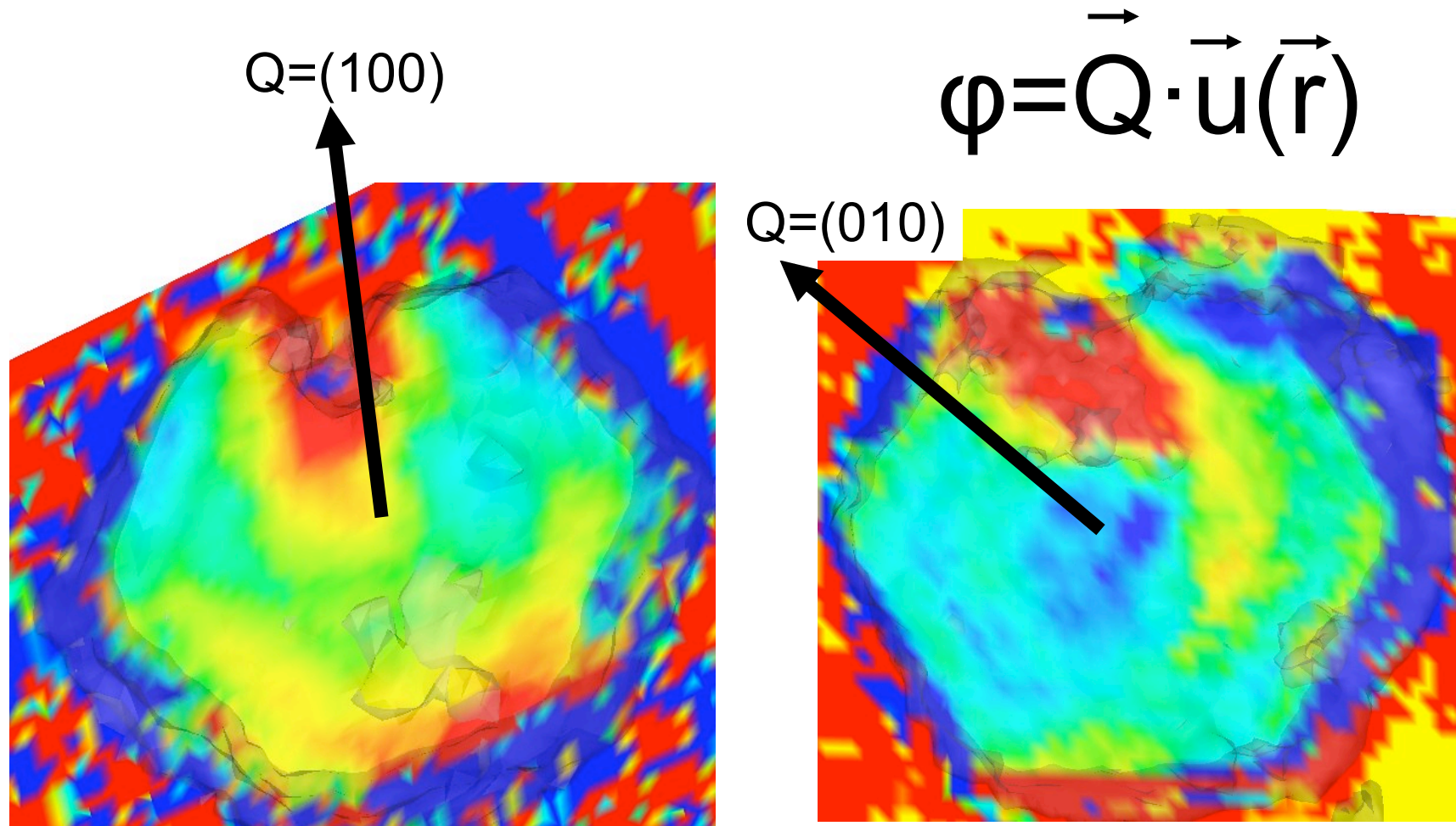
Marcus Newton and Steven Leake (in preparation, 2008)



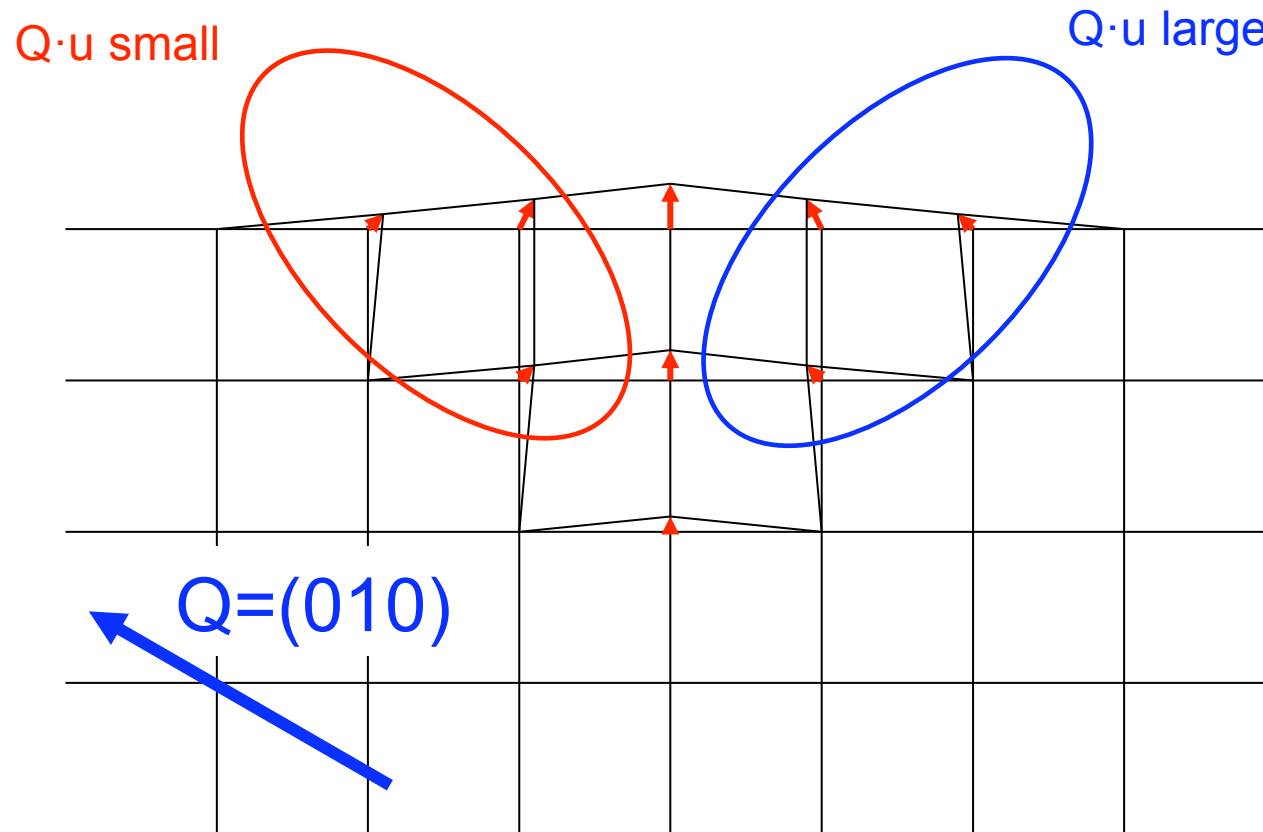
I. K. Robinson, Bremen 2009

Phase maps from 2 Bragg peaks

Blue-Red is +2 radians. Slice at -1500nm from centre ZnO-5 -39

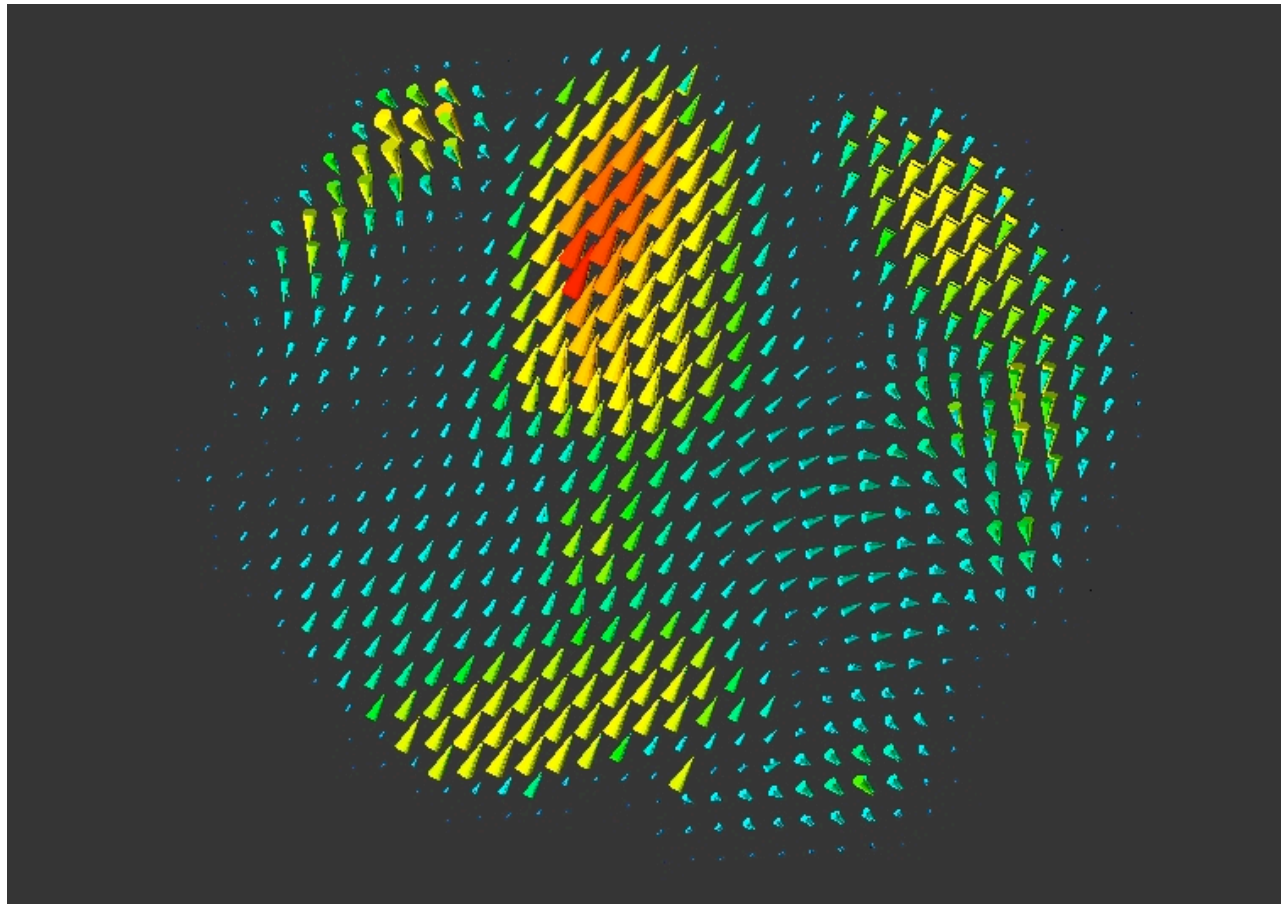


Typical displacement field



2D vector field of displacements

Marcus Newton, UCL, Jan 2009



Conclusions

- Internal structure of Ag and Pb Nanocrystals
- 3D imaging practical for nanocrystals
- Phasing by computation instead of lens
- Strain fields imaged from asymmetric patterns
- Contact Forces cause strain inside crystal
- Surface strain has orientation dependence