Coherent X-ray Diffraction for Mapping Strains

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London Centre for Nanotechnology
Diamond Light Source

University of Malaga, Spain
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Outline

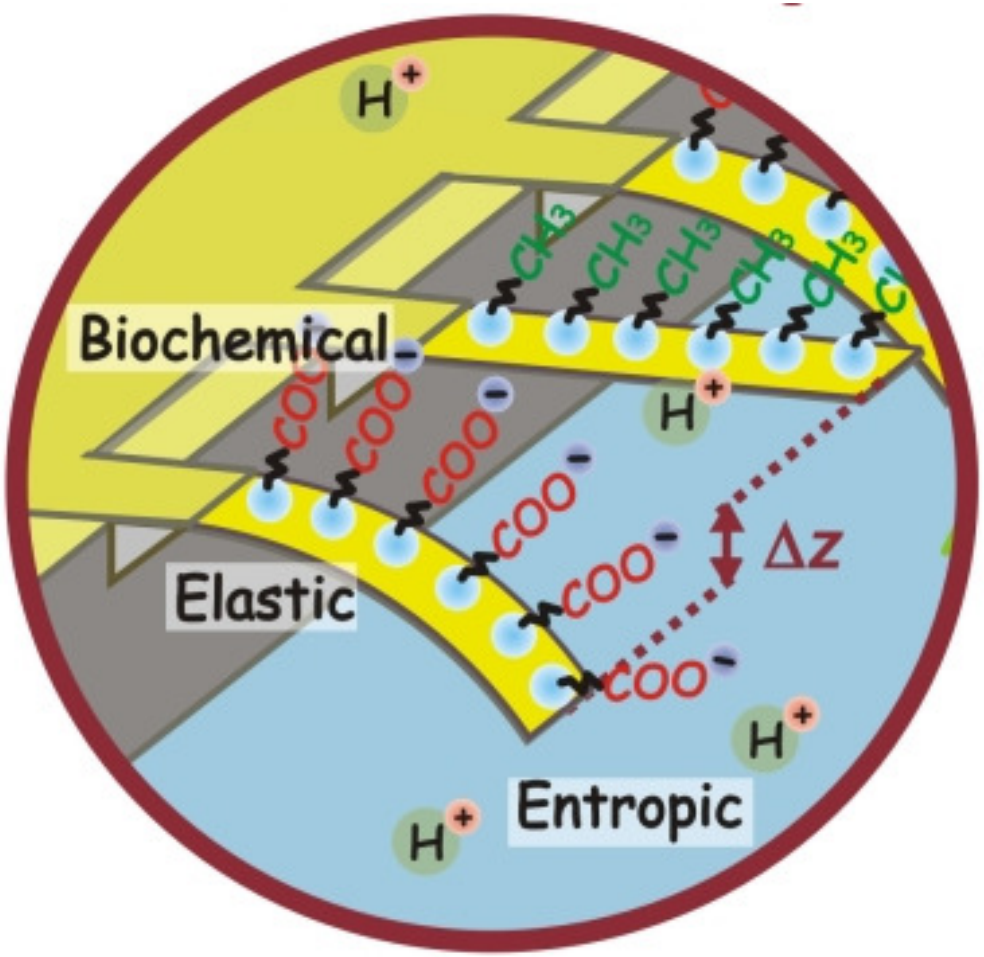
- Coherent x-ray diffraction
- Exploration of crystal strain
- Nanowire structures, Zinc Oxide
- Gold nanocrystal strains
- XFEL experiments

London Centre for Nanotechnology

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

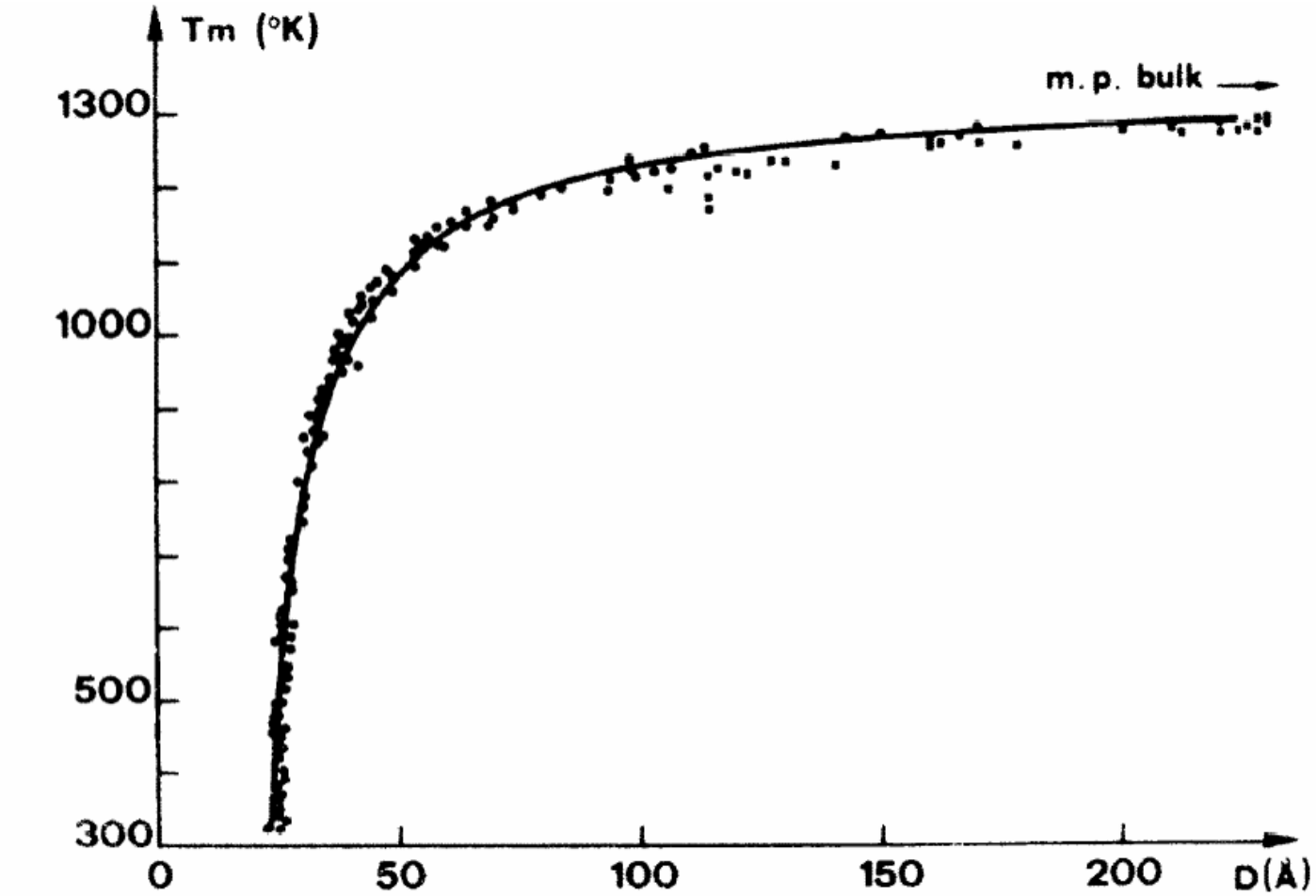
Nanocantilevers

Dr Rachel McKendrie

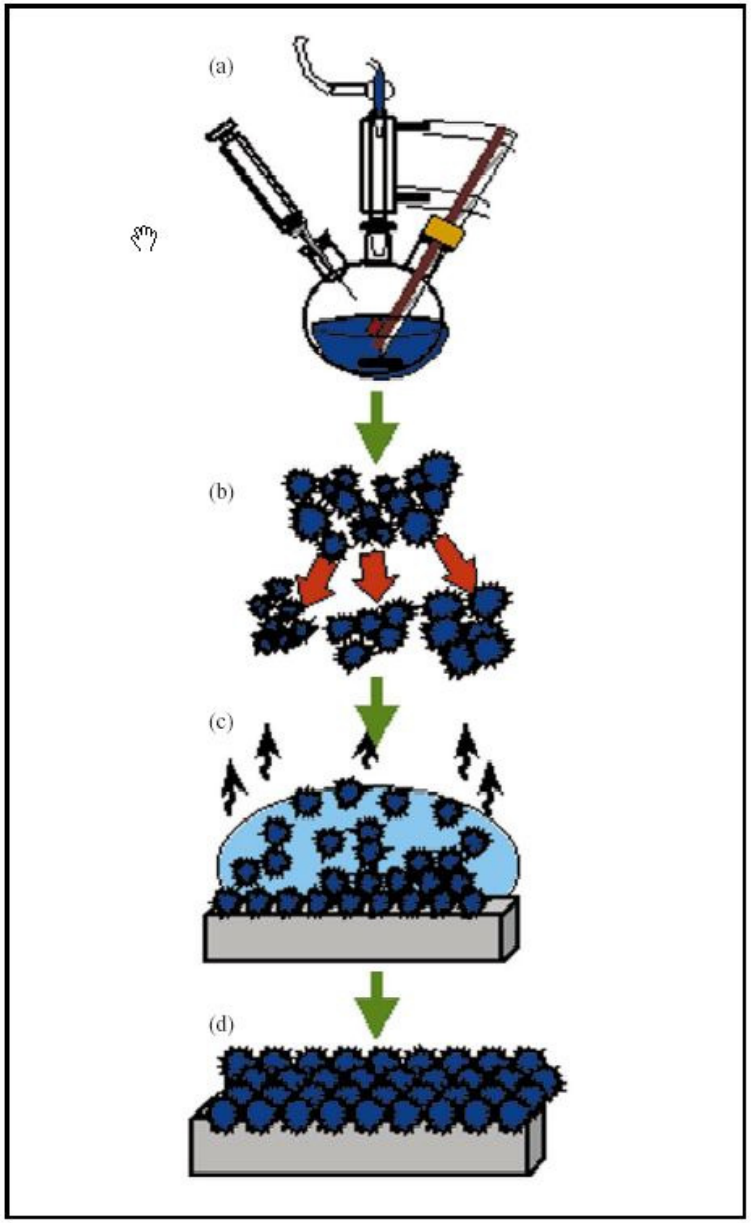


Size-dependent Melting of Au Particles

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

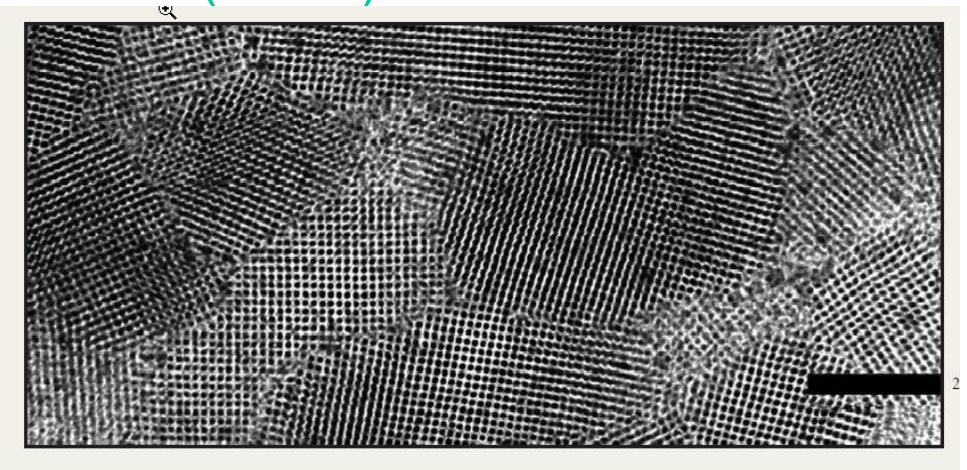


Chemical Synthesis of Nanocrystals



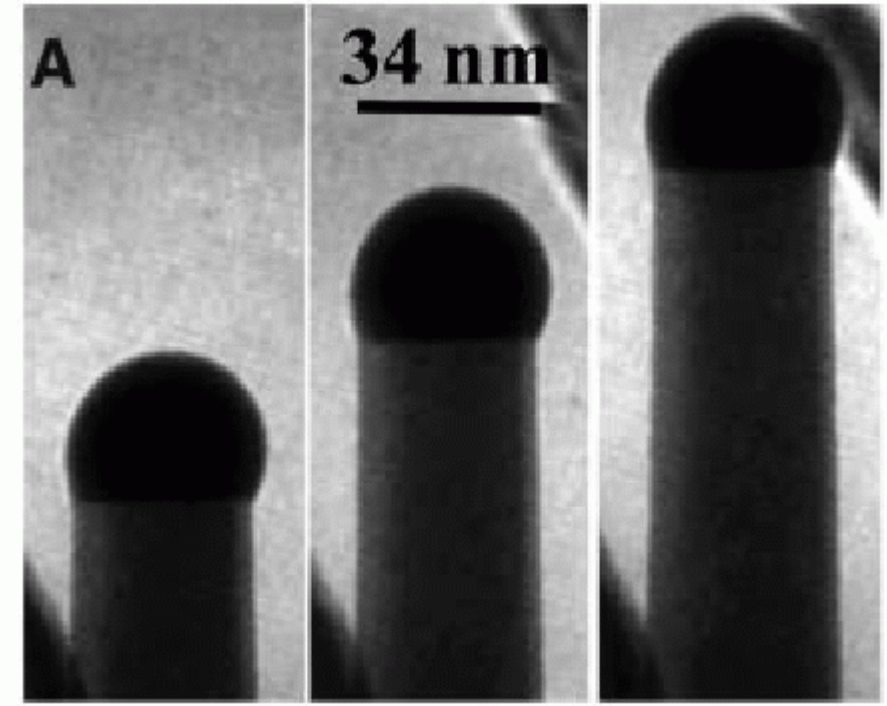
- Reactants introduced rapidly
- High temperature solvent
- Surfactant/organic capping agent
- Square superlattice (200nm scale)

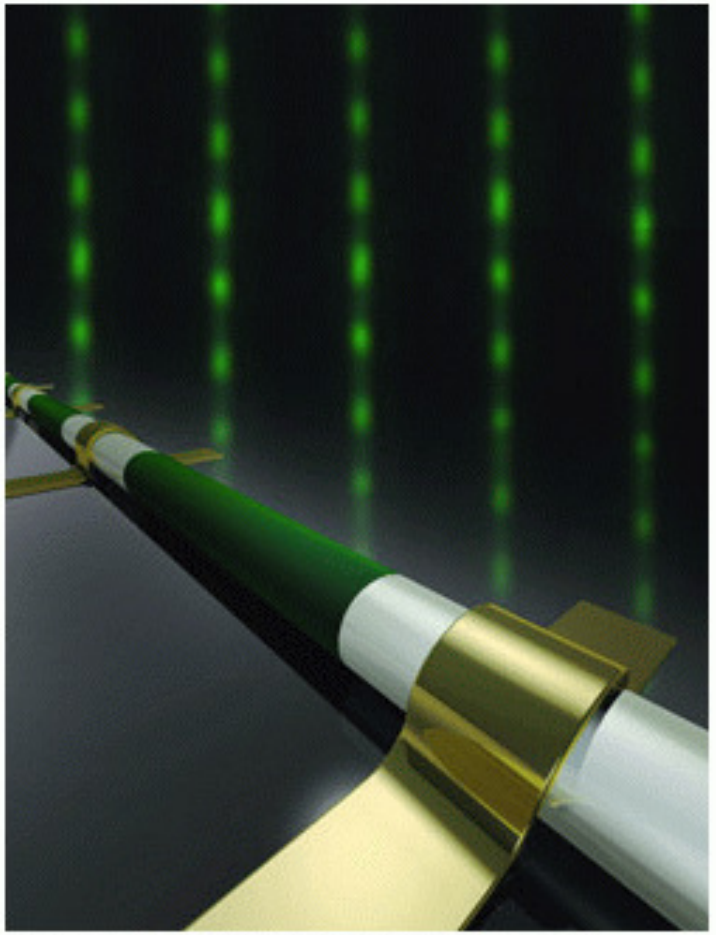
C. B. Murray, IBM J. Res. & Dev. **45** 47 (2001)



VLS growth of nanowires

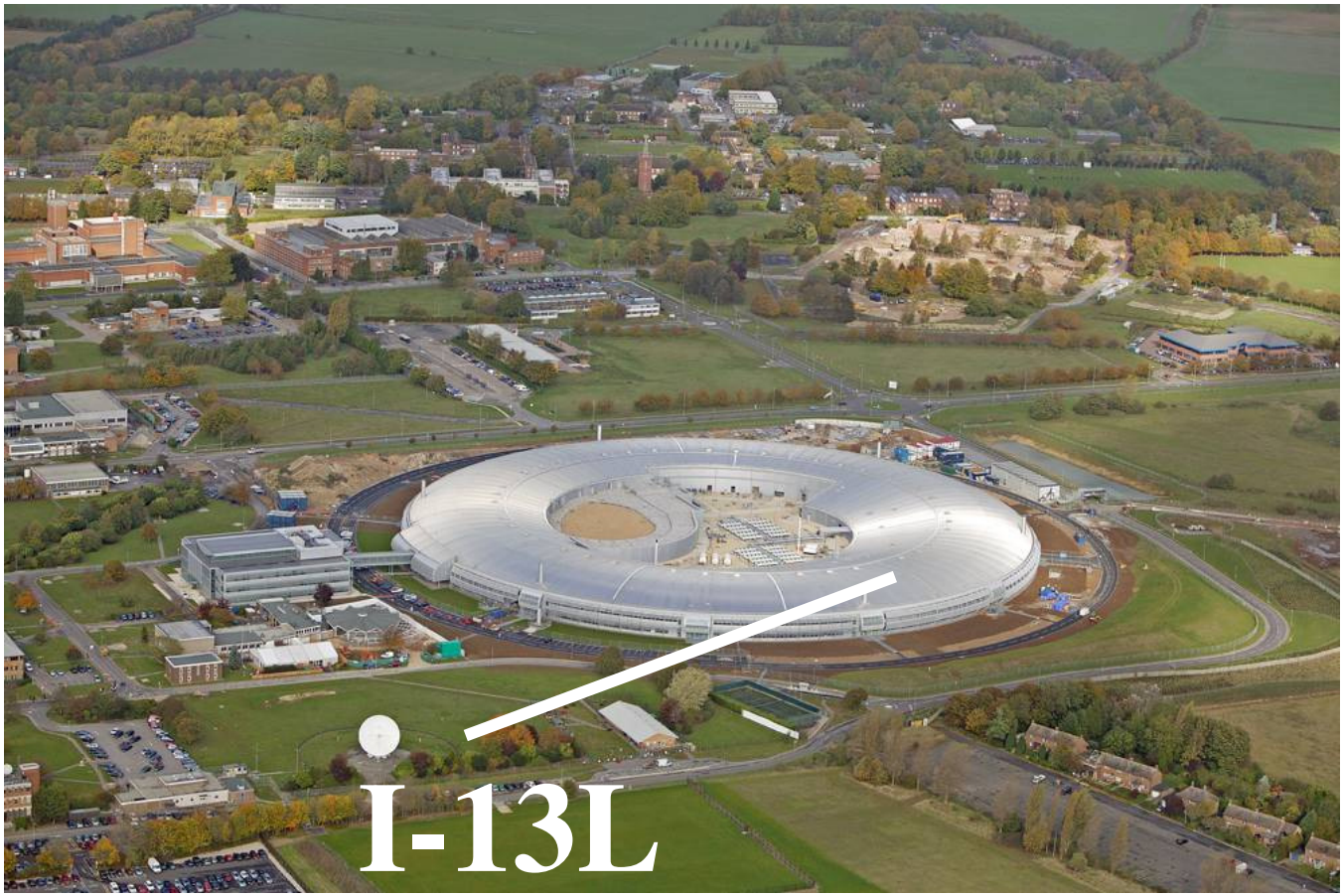
S. Kodambaka et al., Science 316 729 (2007)



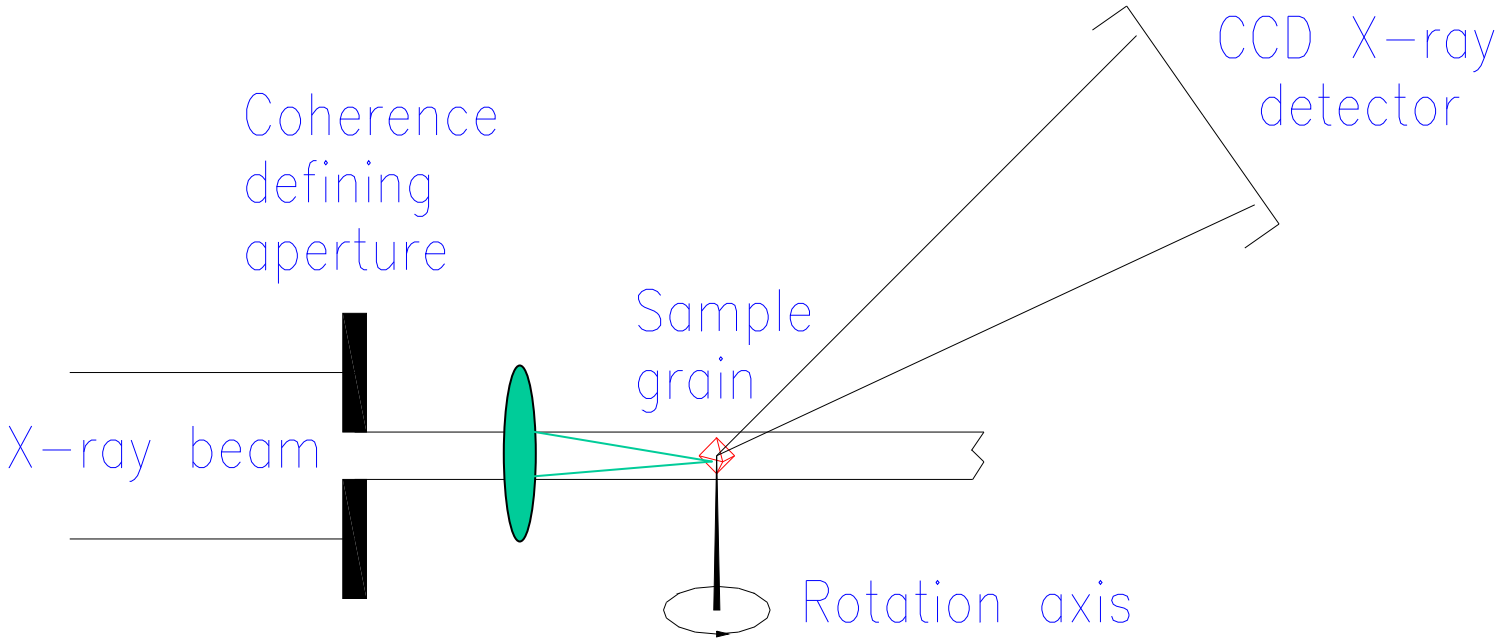


NiSi/Si nanowire heterostructure devices. *Nature* **430**, 61 (2004).

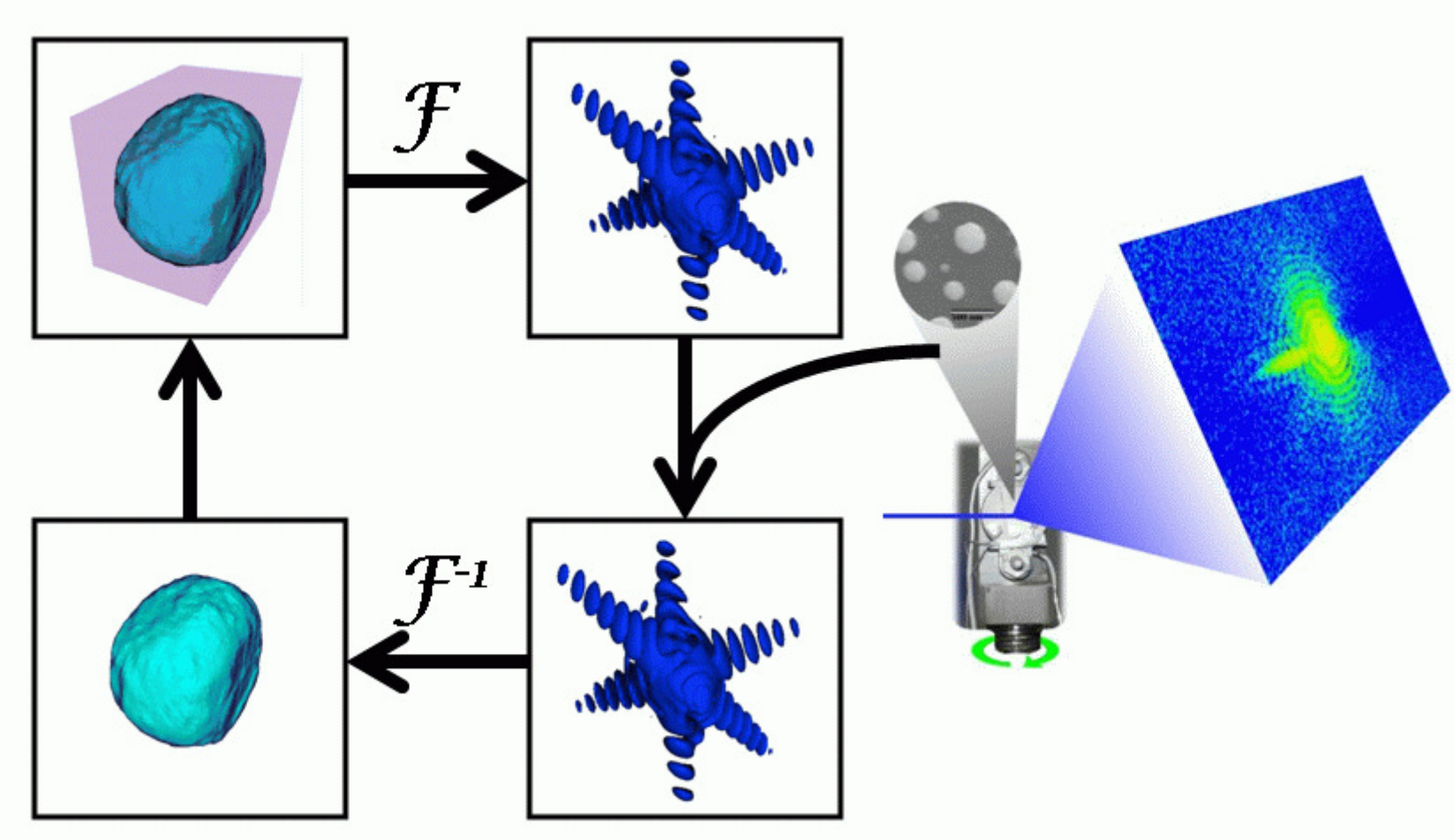
Diamond Light Source (RAL)



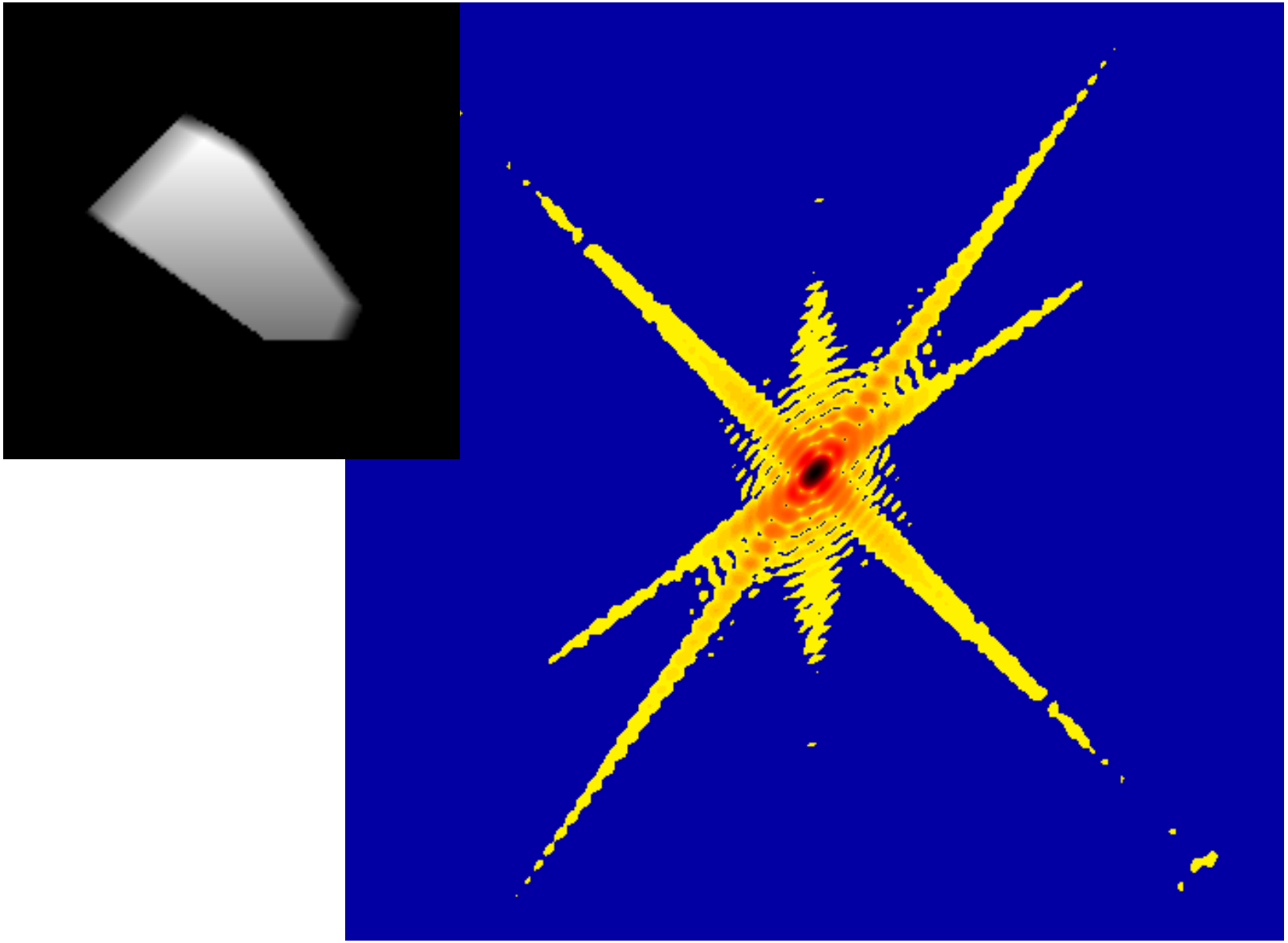
Lensless X-ray Microscope, 2003



Generic "Error Reduction" method

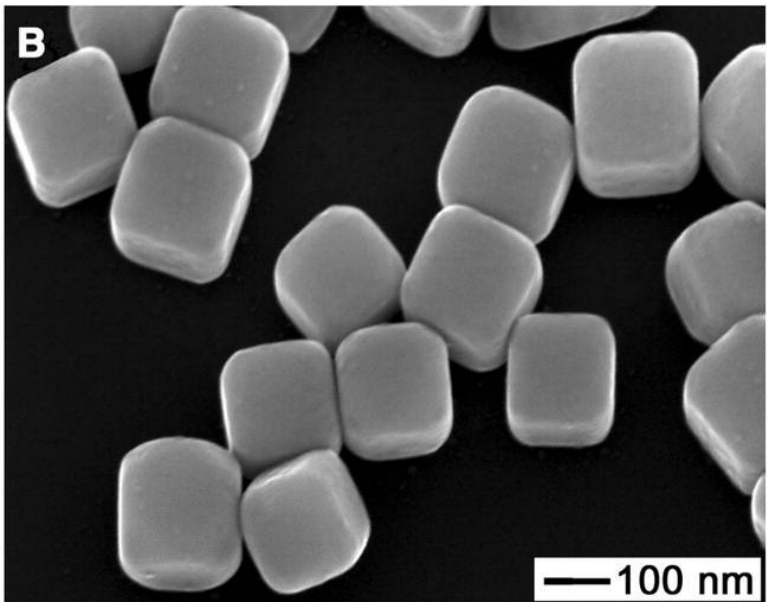


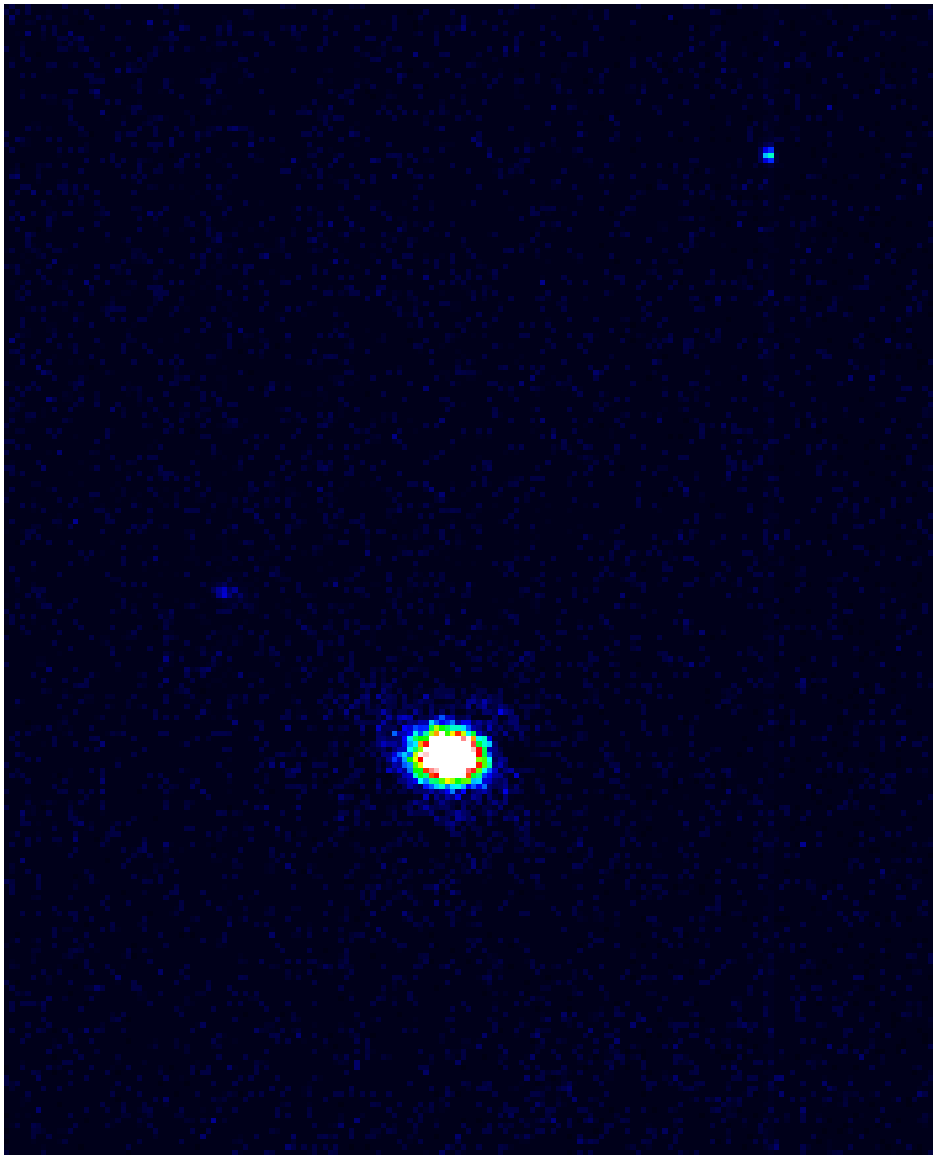
J. R. Fienup Appl. Opt. 21 2758 (1982)
R. W. Gerchberg and W. O. Saxton Optik 35 237 (1972)

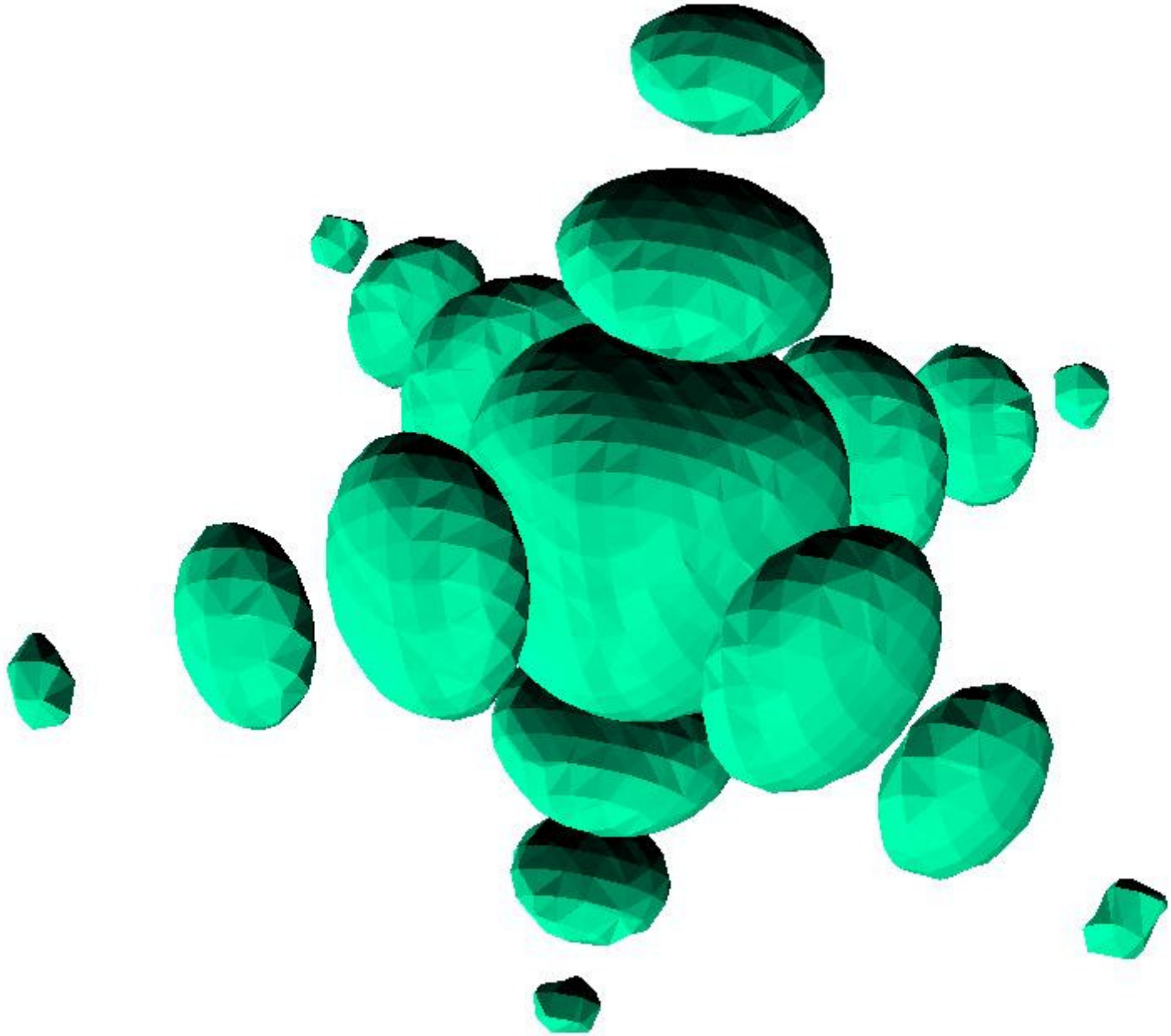


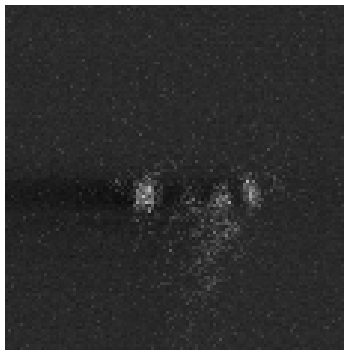
Chemically Synthesized Silver Nanocube Rock with 0.01° steps

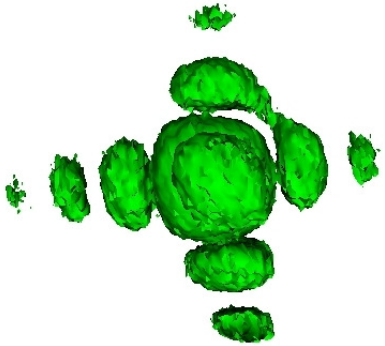
Yugang Sun and Younan Xia, Science 298 2177 (2003)

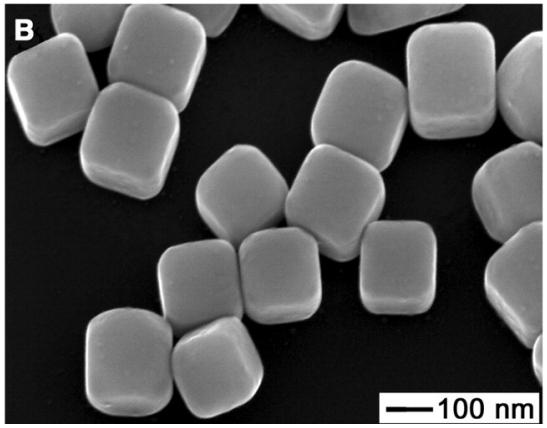


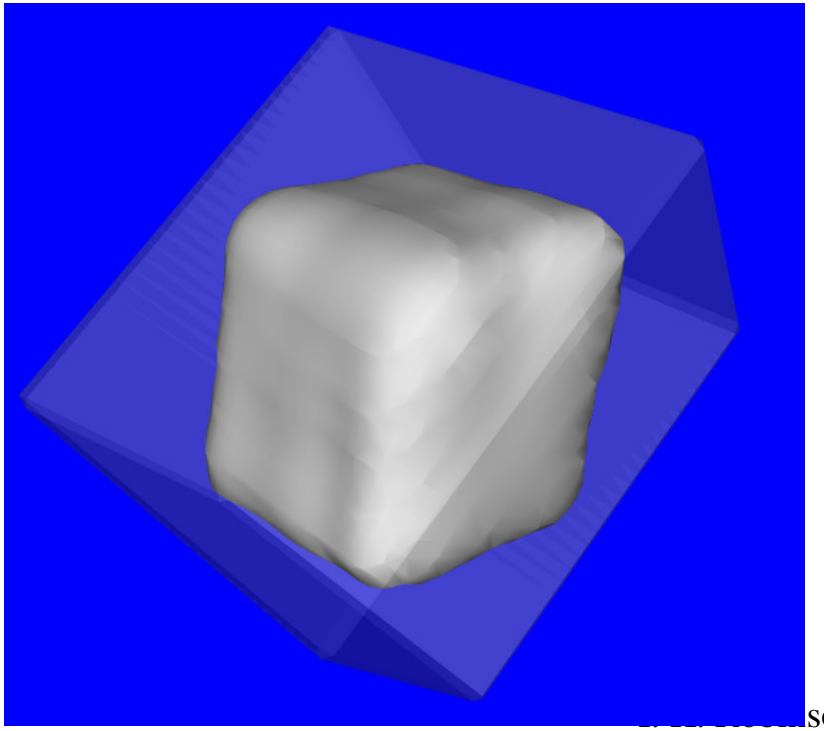


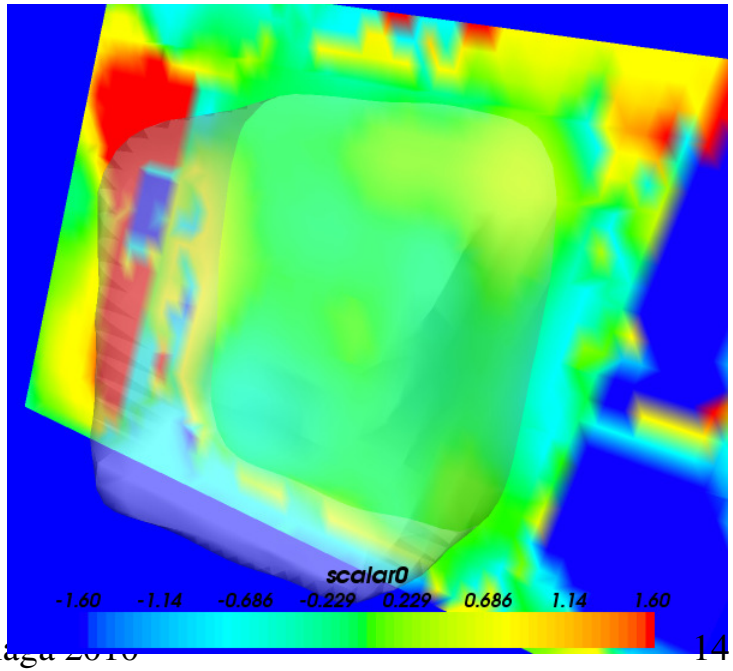






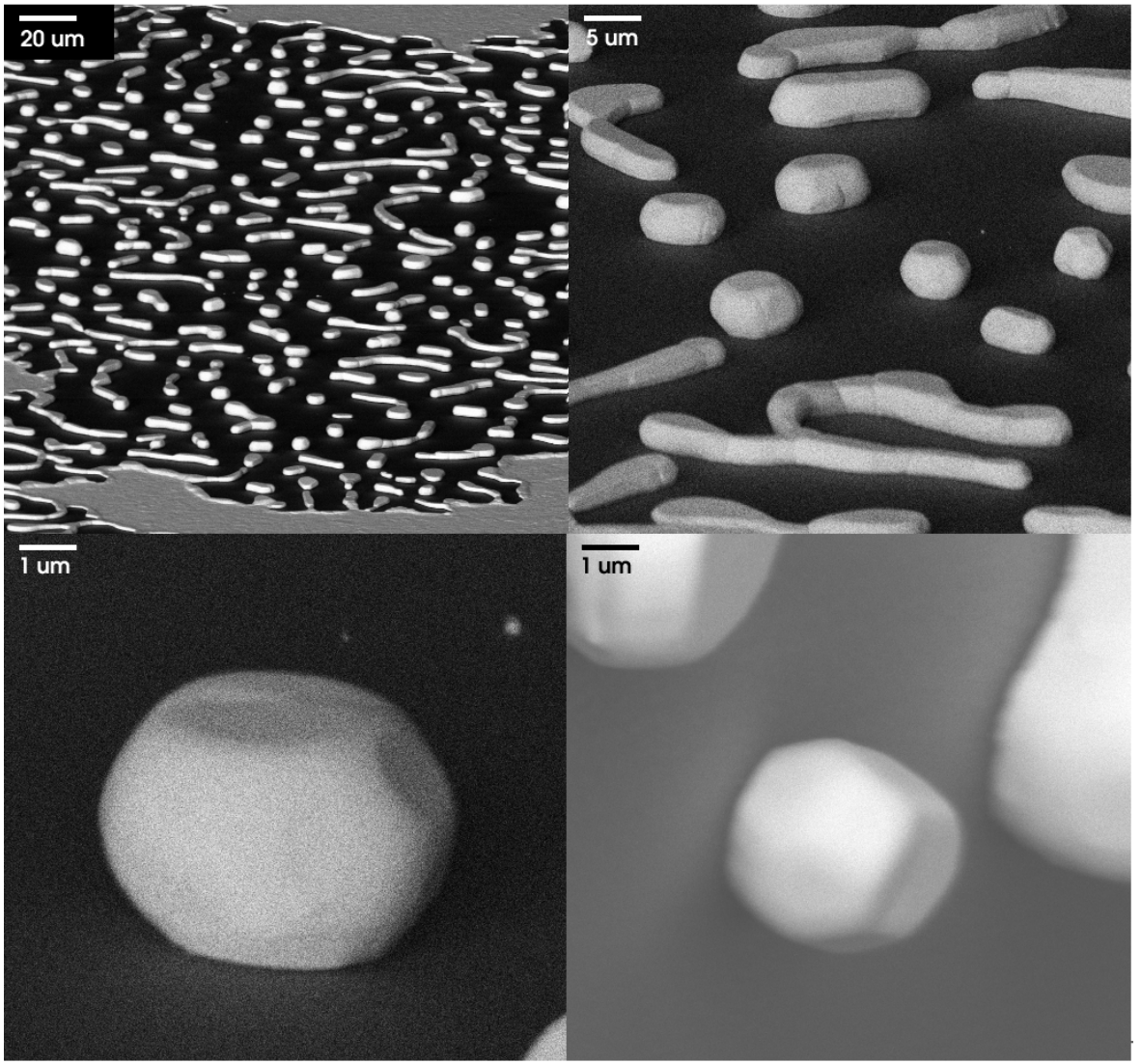

B
100 nm




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

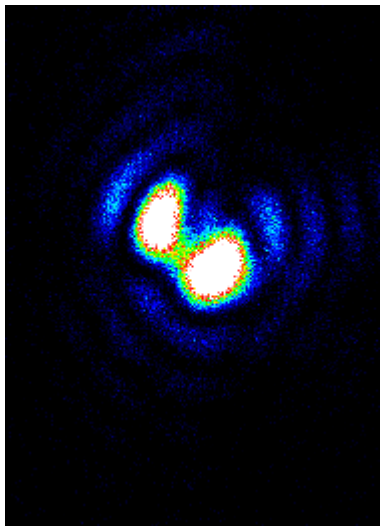
SEMS

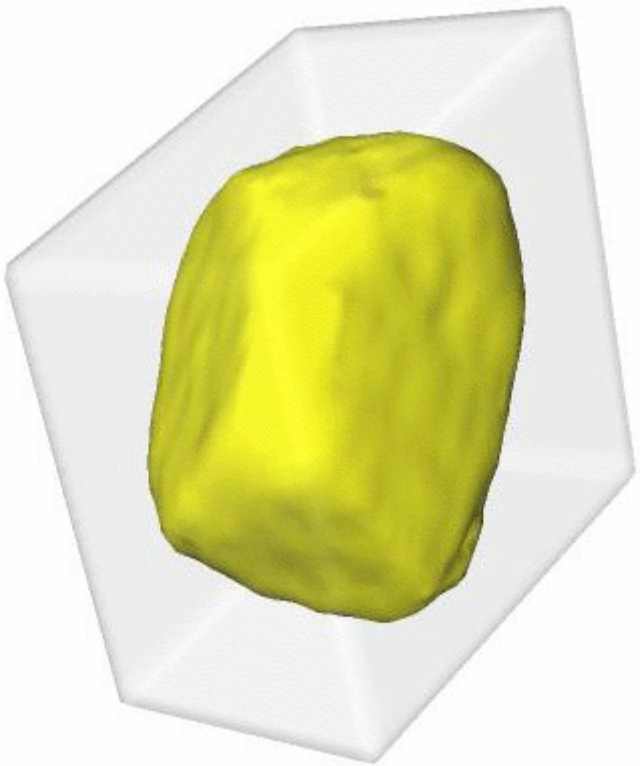
- Au blanket film
- Quartz substrate
- Annealed at 950℃ for 70 hrs.



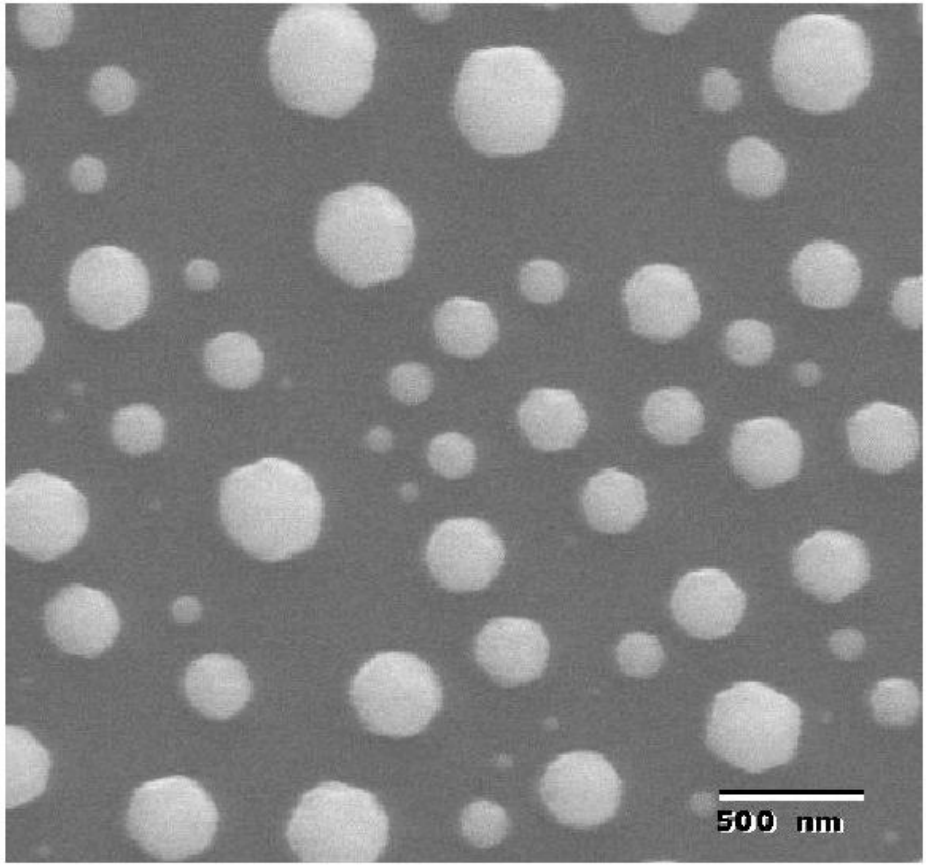
Gold nanocrystal reconstruction

showing support used for 20 HIO followed by 10 ER

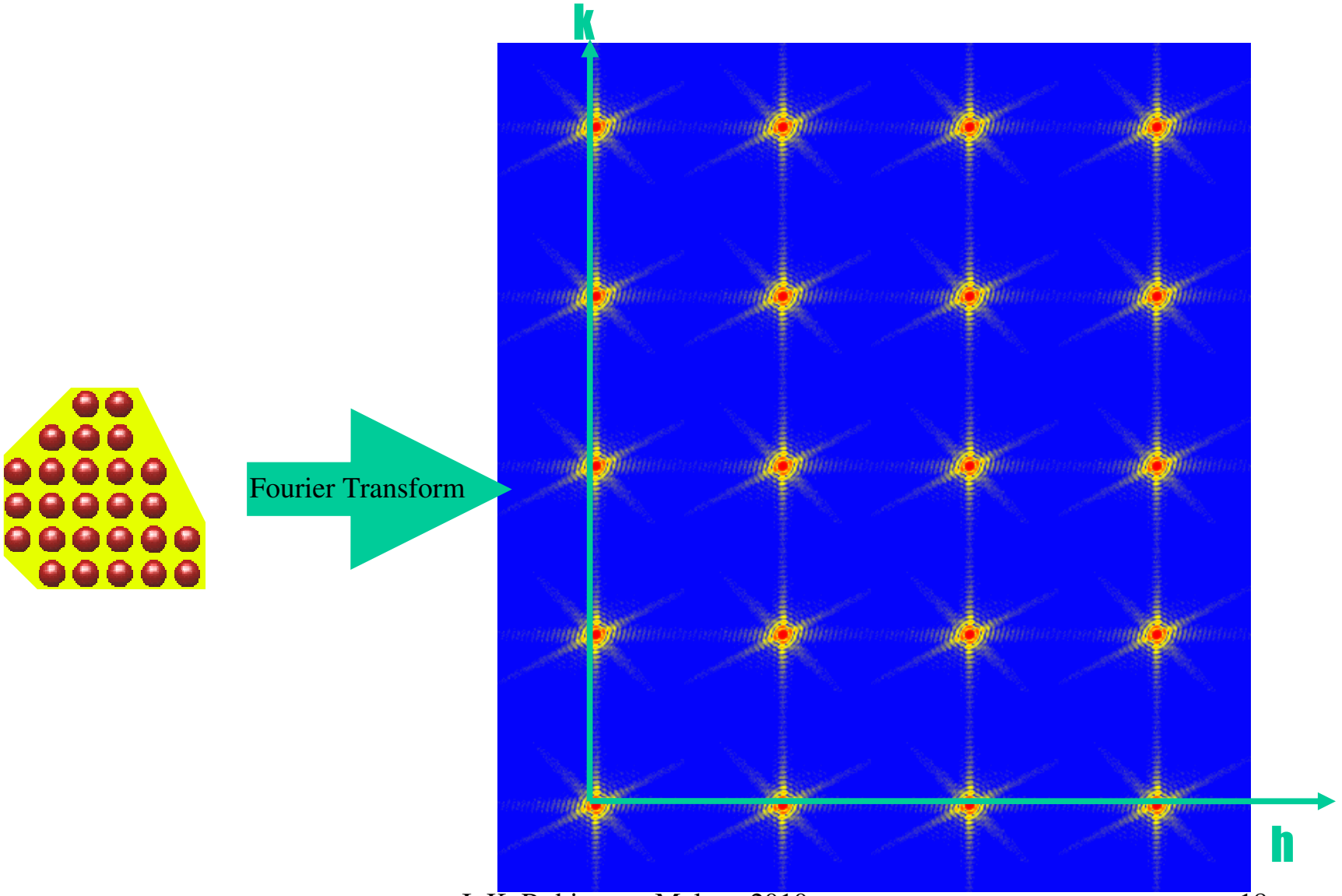




In situ growth of Pb crystals

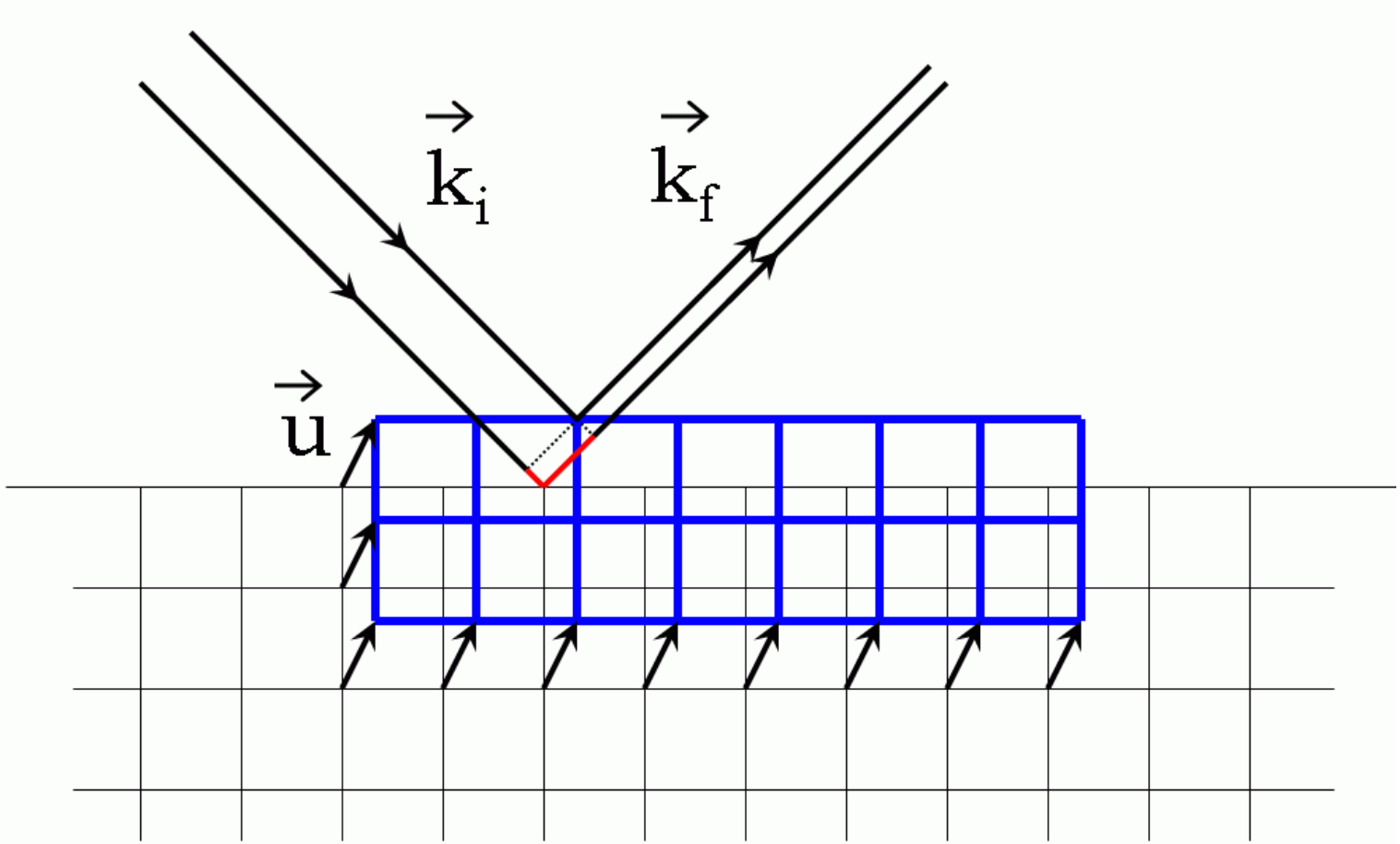


Coherent Diffraction from Crystals



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

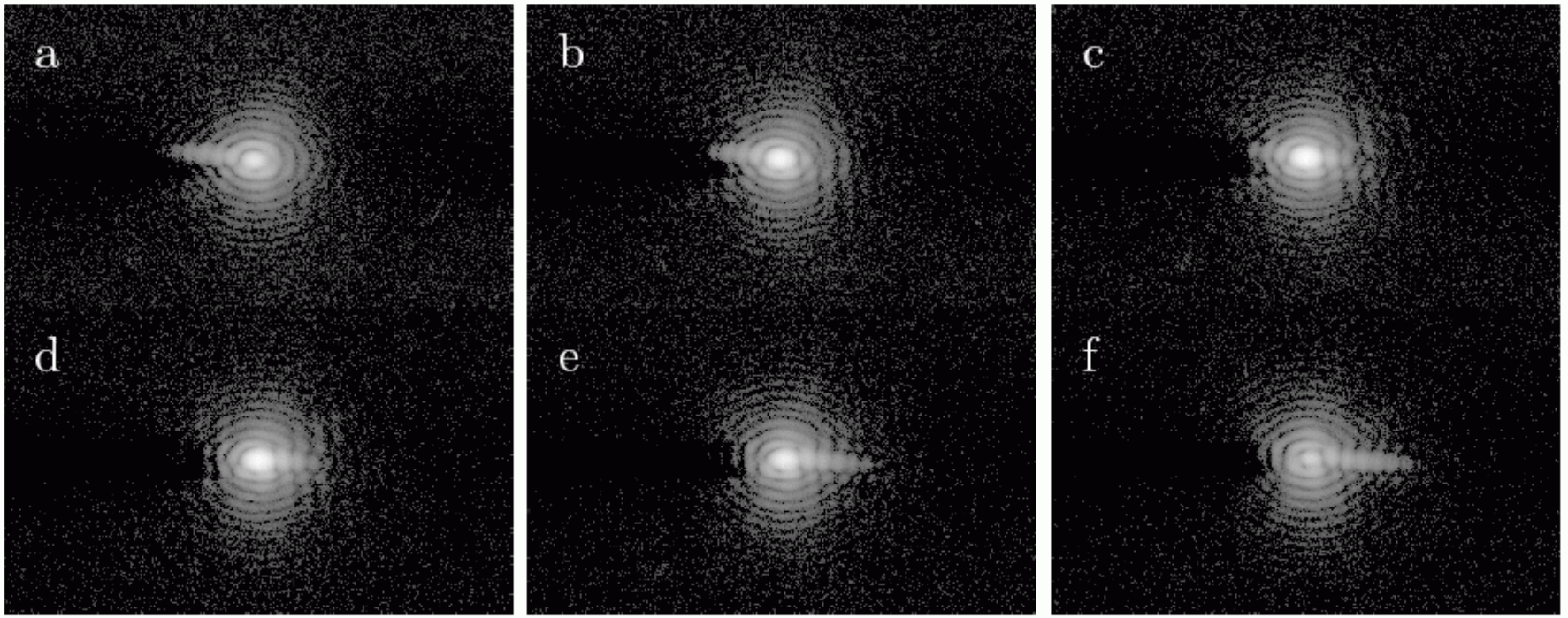
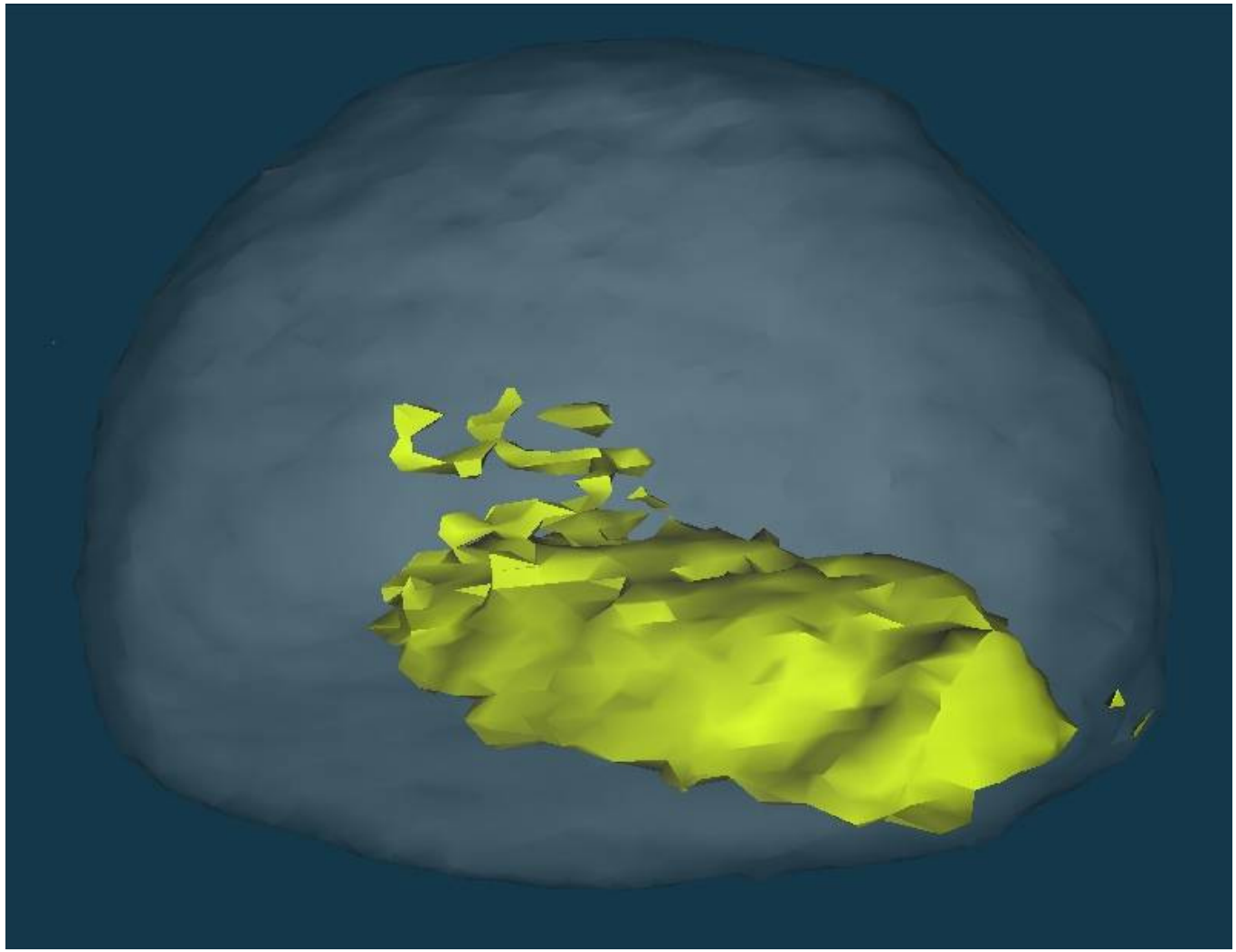
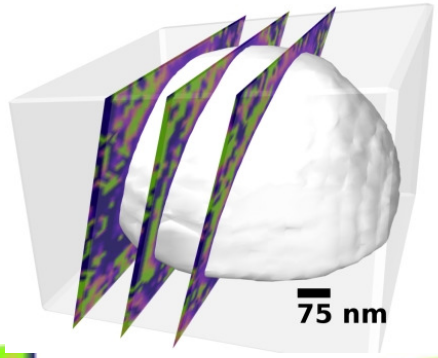


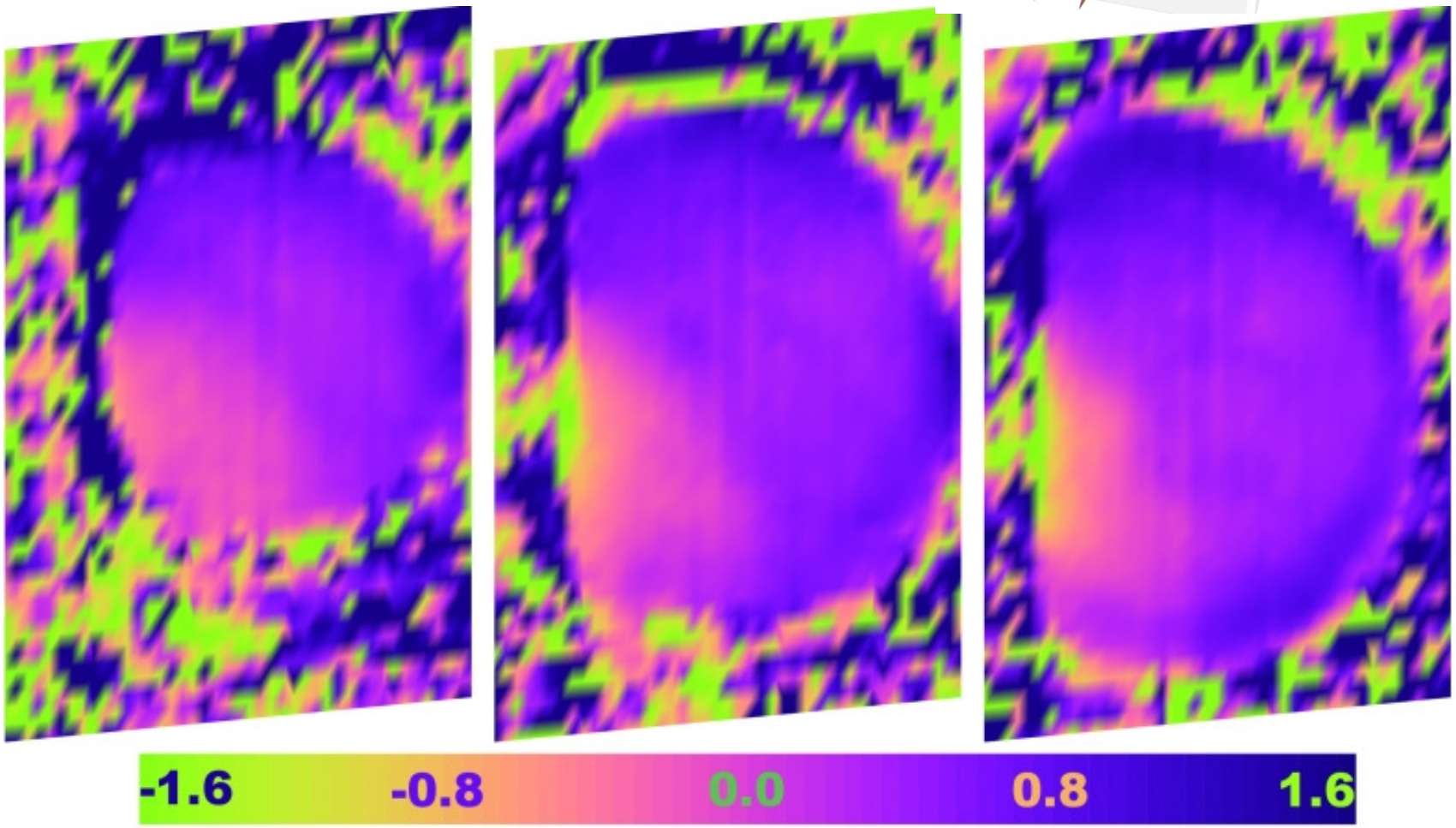
Figure 4.12: Center slices from 3D CXD pattern from Pb sample, on a log scale. Data file 296 from 10/03.

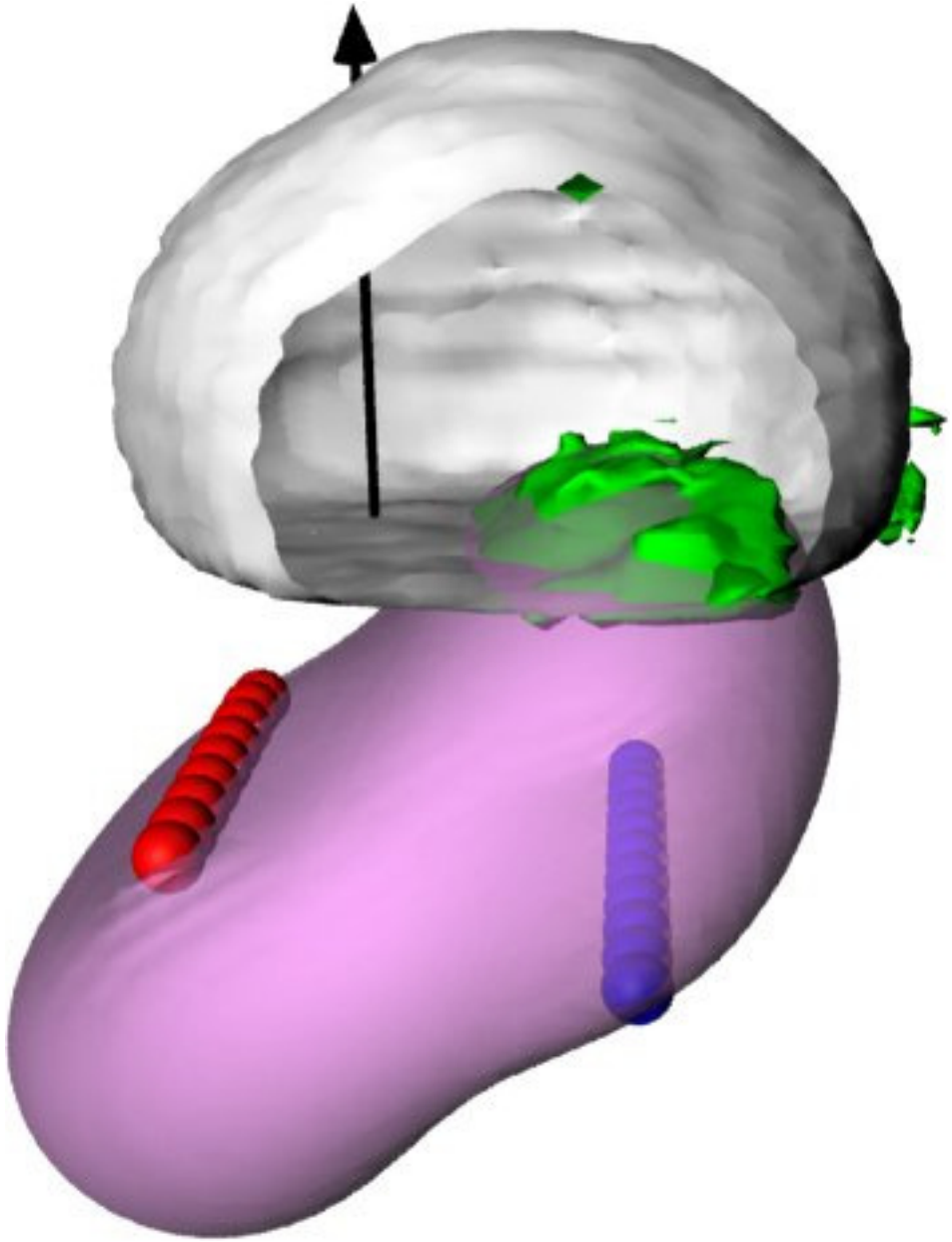
Modeling of 3D Phase Bump



3D phase map sections





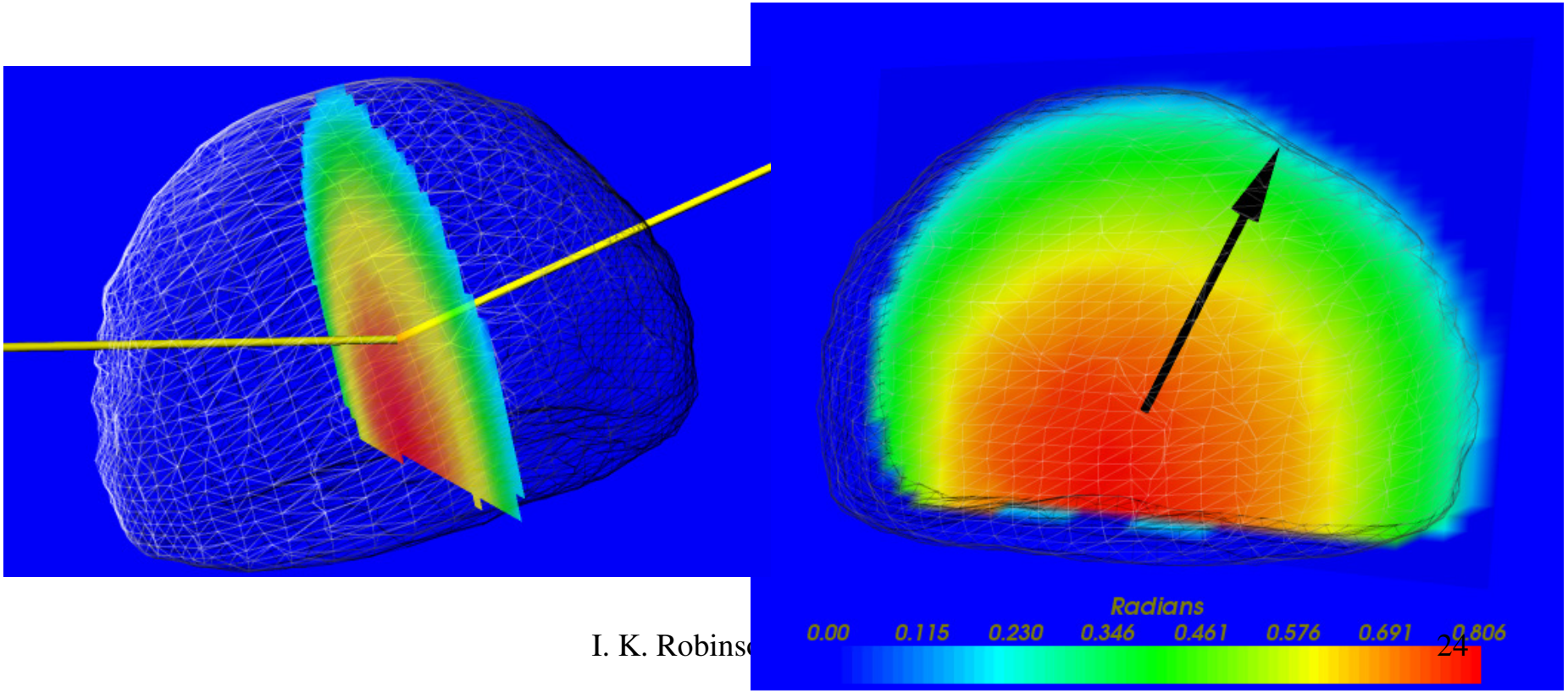


Refraction effects in Lead at 8.9keV

Phase accumulation due to refraction along scattering path

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

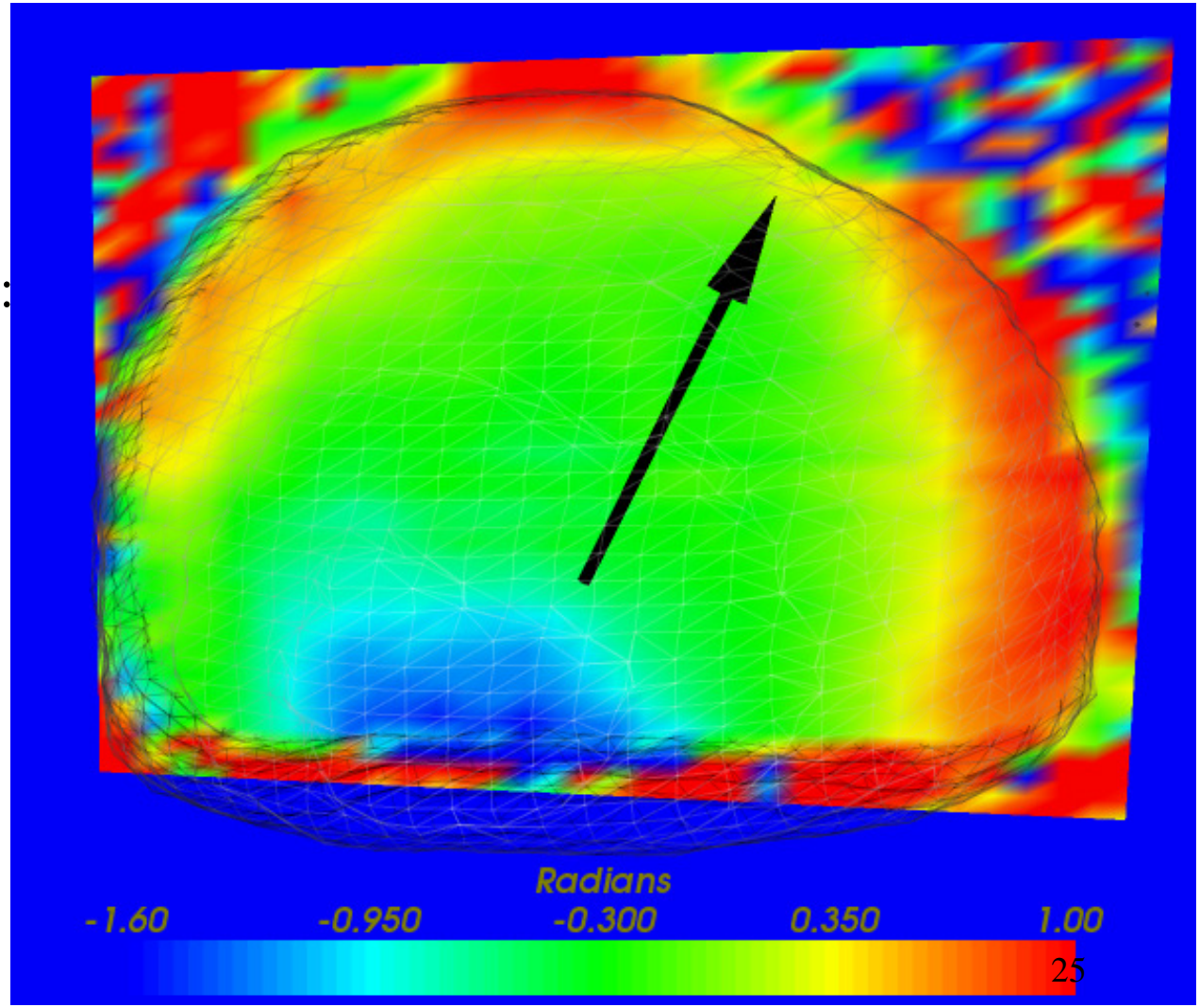
$$\delta=2.23\text{x}10^{-5}$$
$$\beta=2.19\text{x}10^{-6}$$



Refraction corrected phase map

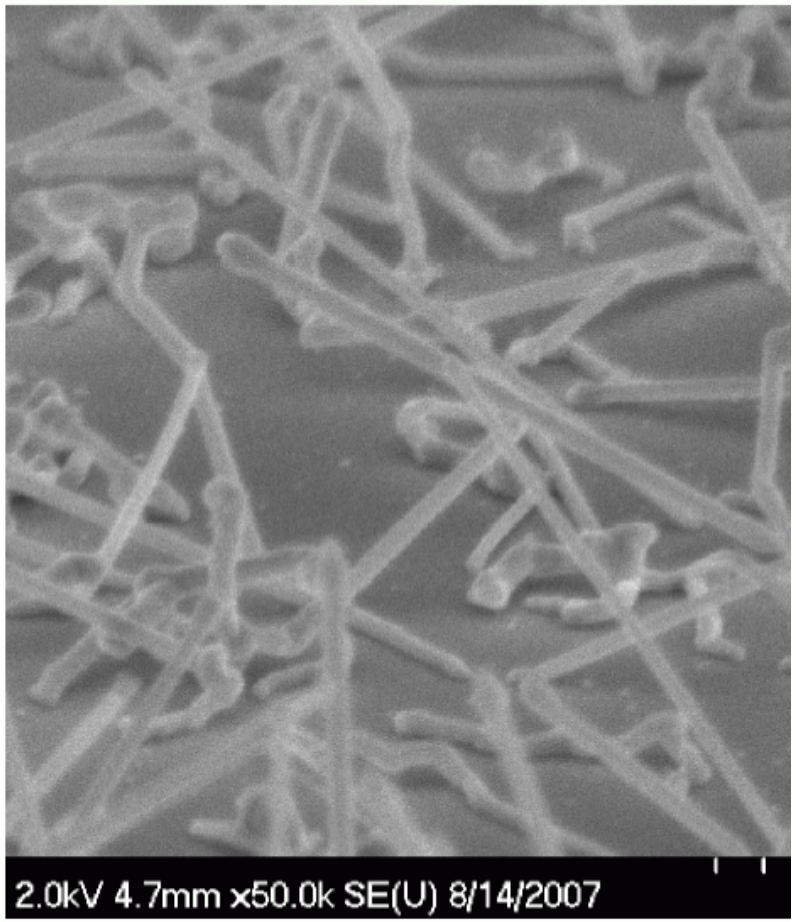
Max phase = 1.15rad
= 0.052nm

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

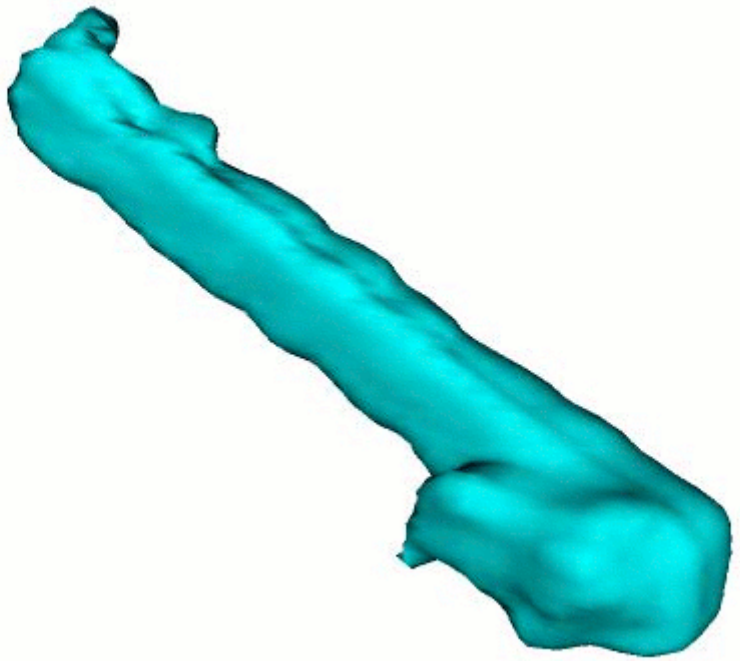


Reconstruction of InP nanowire

CVD on Si, Suneel Kodambaka, UCLA

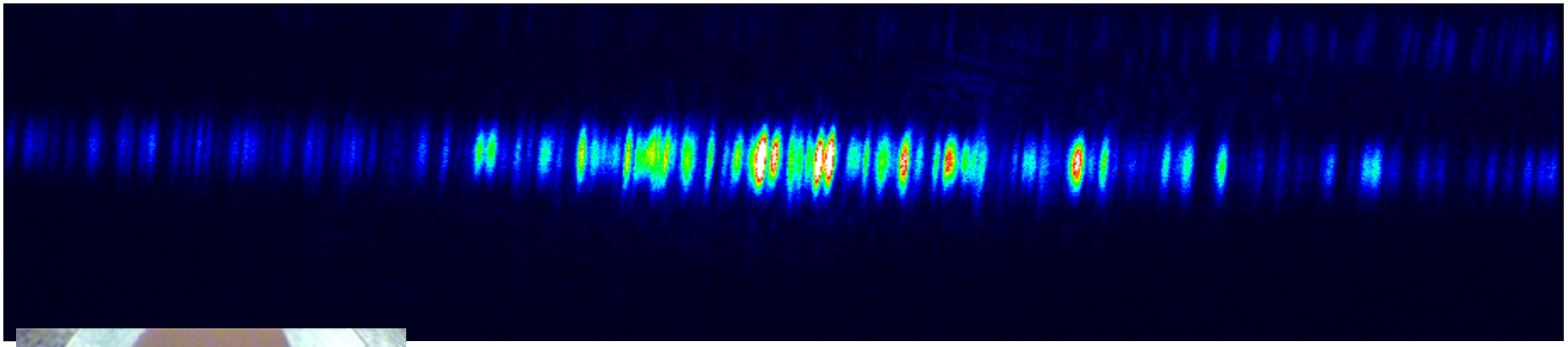


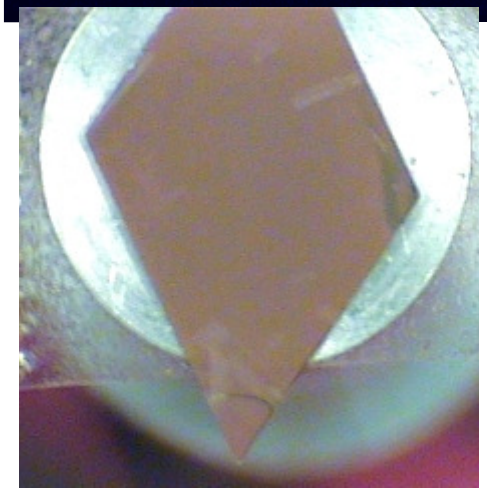
InP nanowires grown on Si (111)

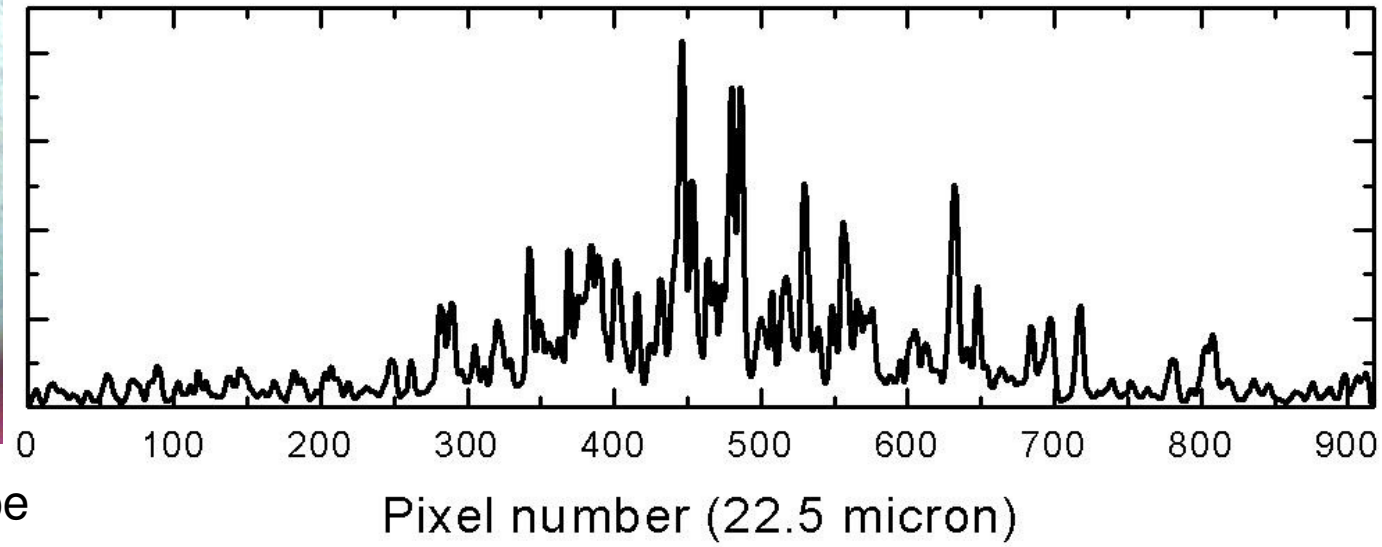


GaAs Nanowire "Barcode"

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





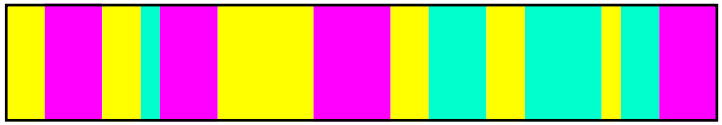


GaAsNW1106-22.spe
B9348 from Philips

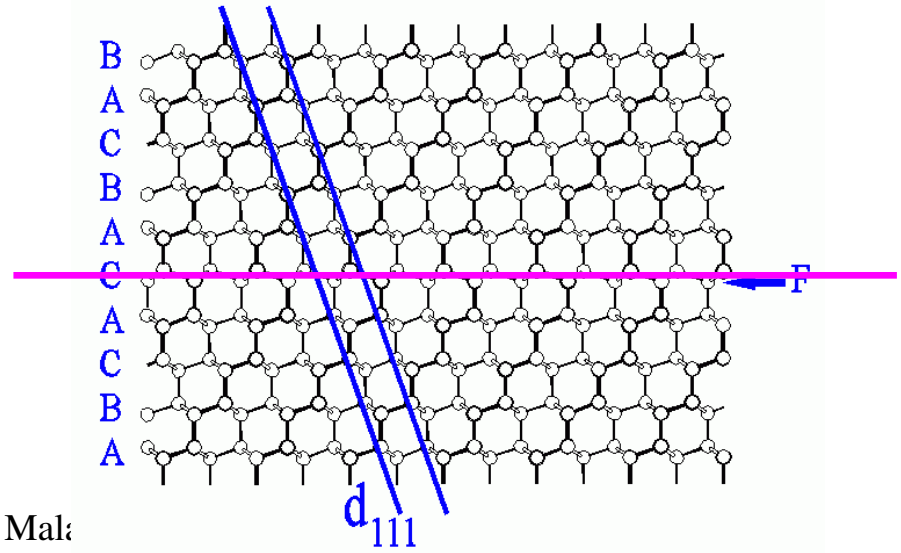
Models of Barcode Diffraction

(111) wires at (11-1) reflection

- Twinned stacking sequence

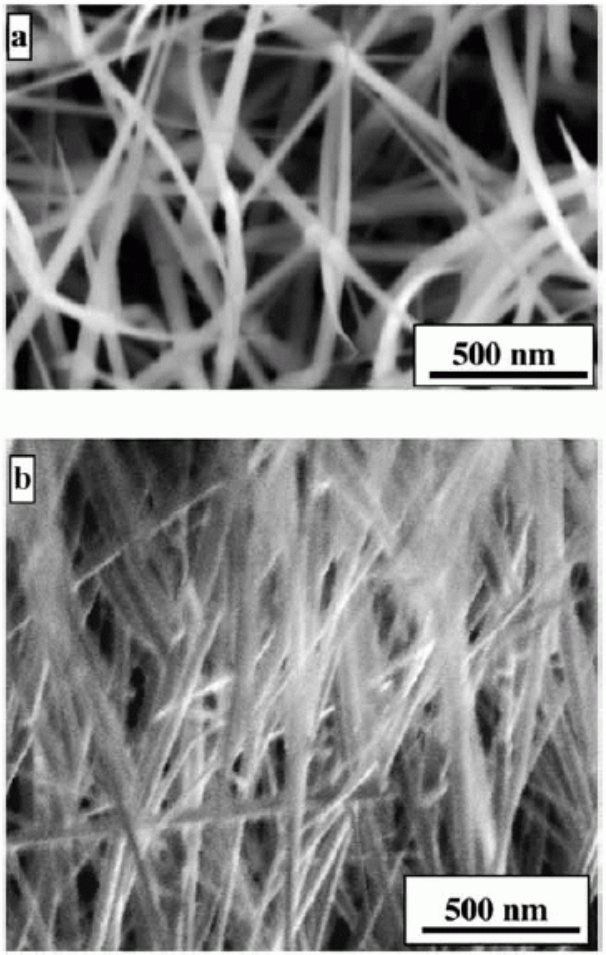


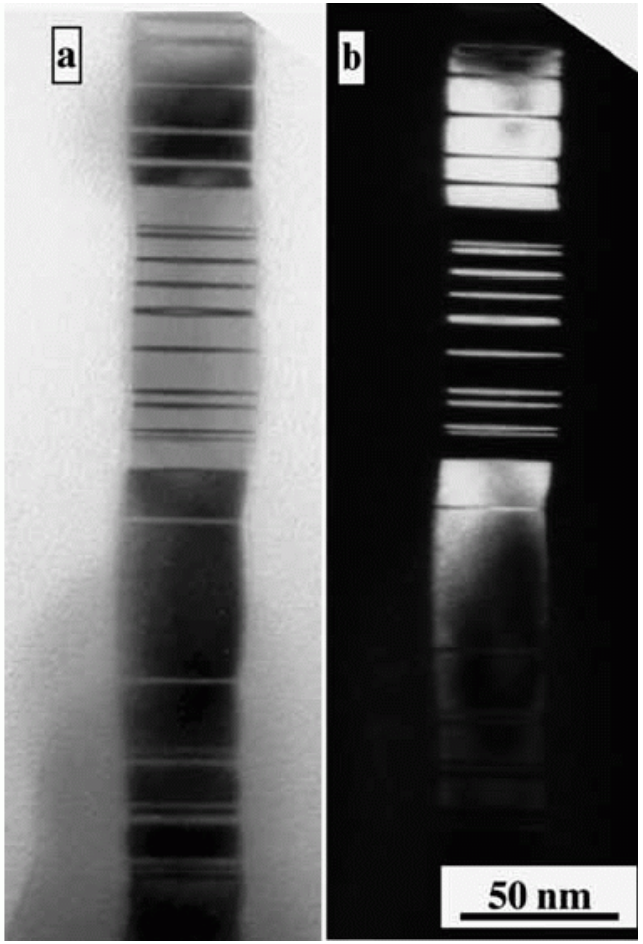
- Deformation faults



Dark Field TEM of GaAs Nanowires

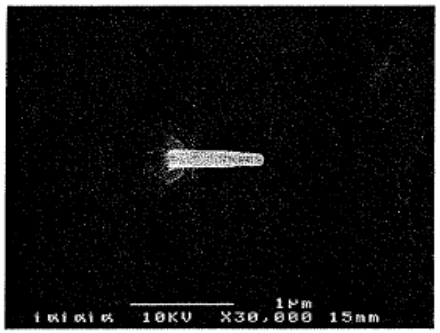
R. Banerjee et al, Phil. Mag. Lett. 86 807 (2006)



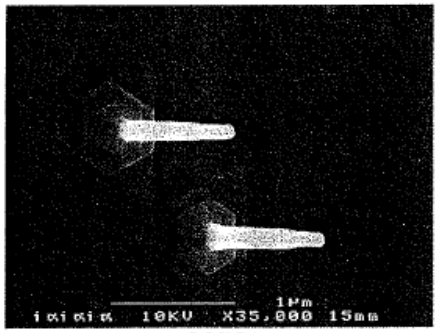


Lund sample 2657 InAs/InP NW

Jonas Johansson & Lars Samuelson SOI-nov09-98.spe



2659



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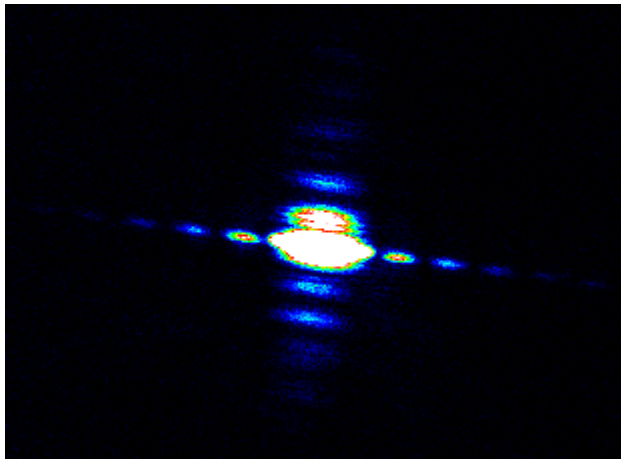

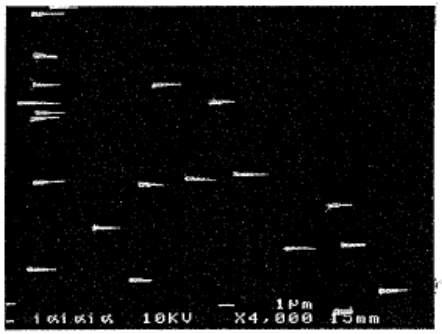

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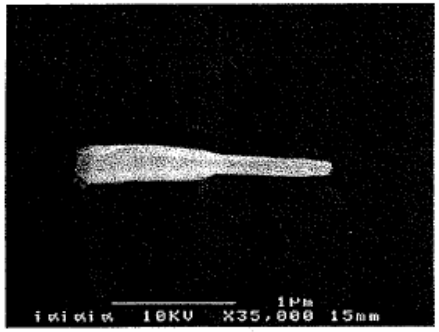

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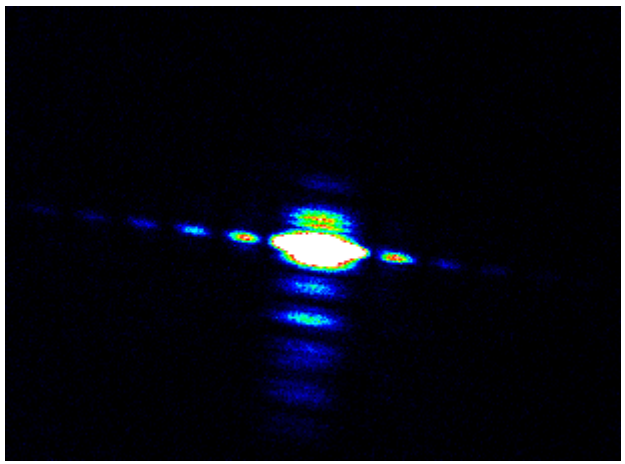
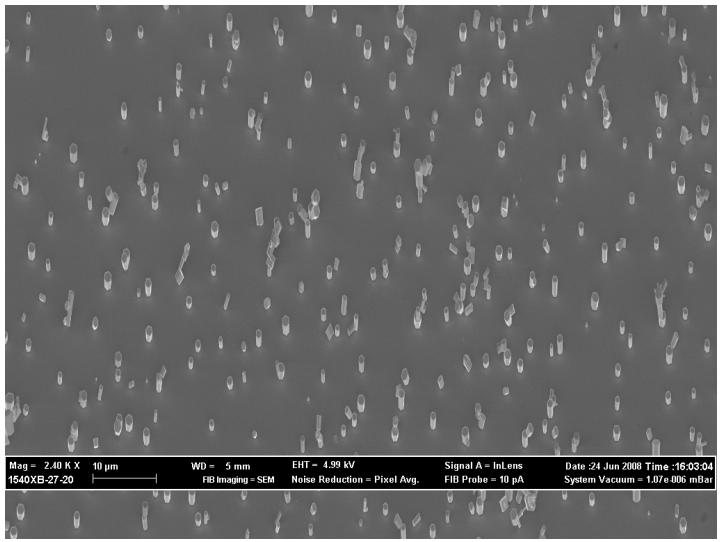
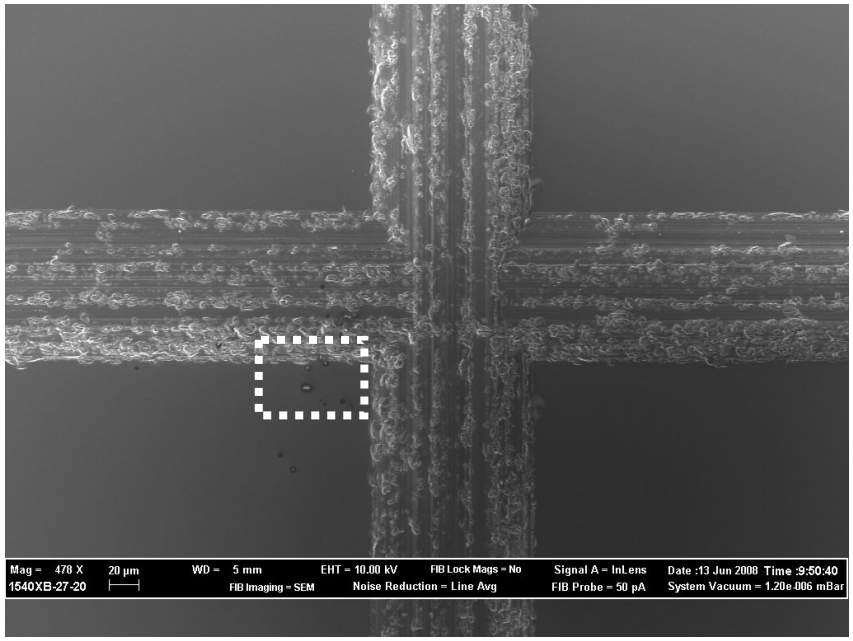
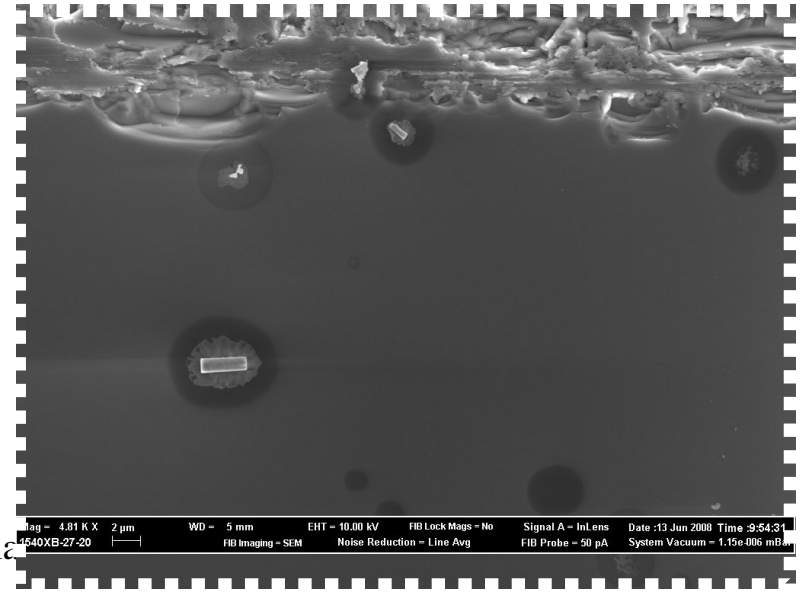


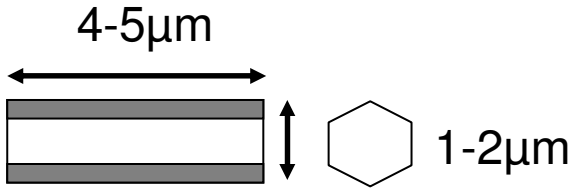
ZnO Sample Preparation







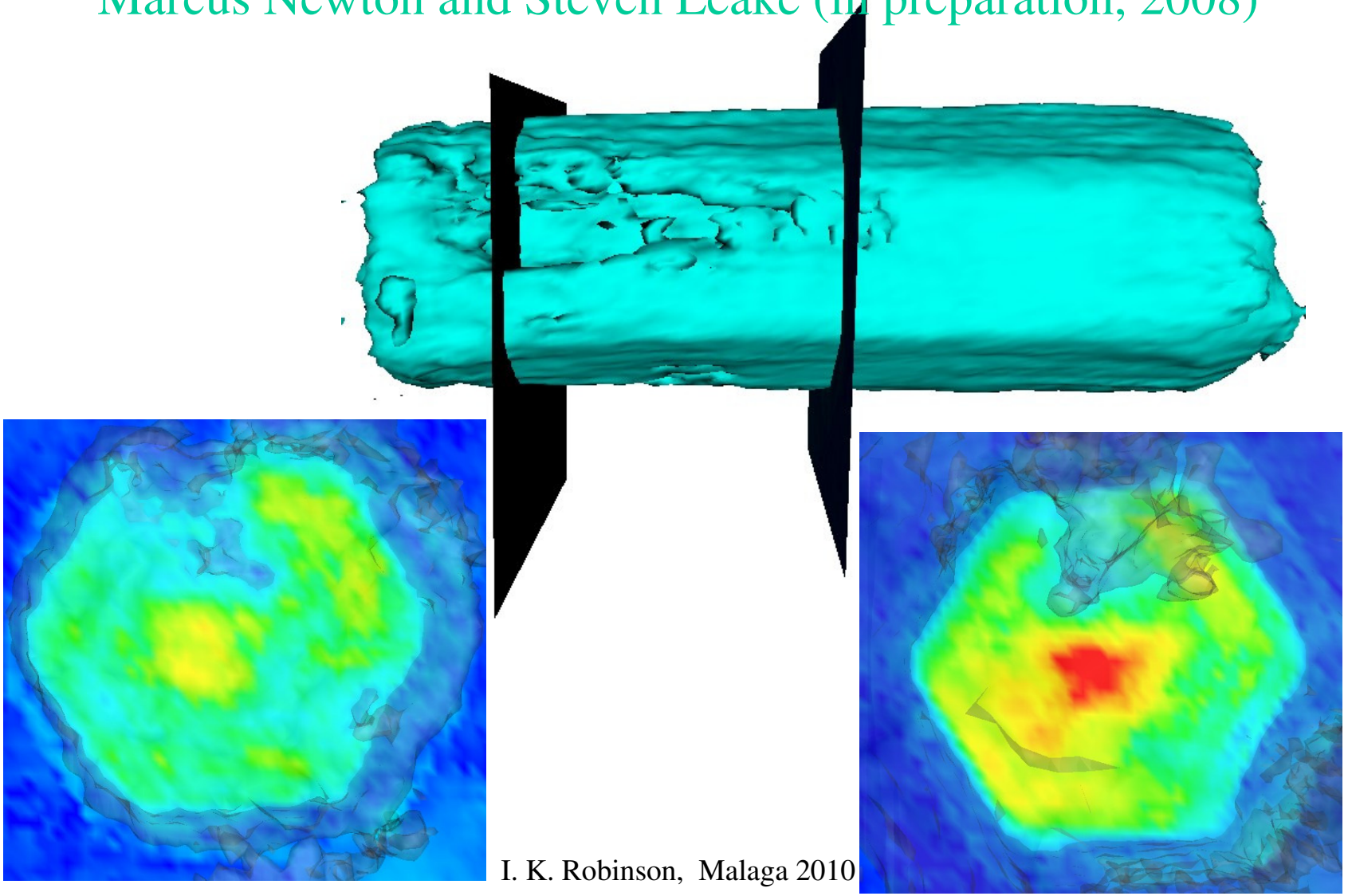
Dimensions:



I. K. Robinson, Mala

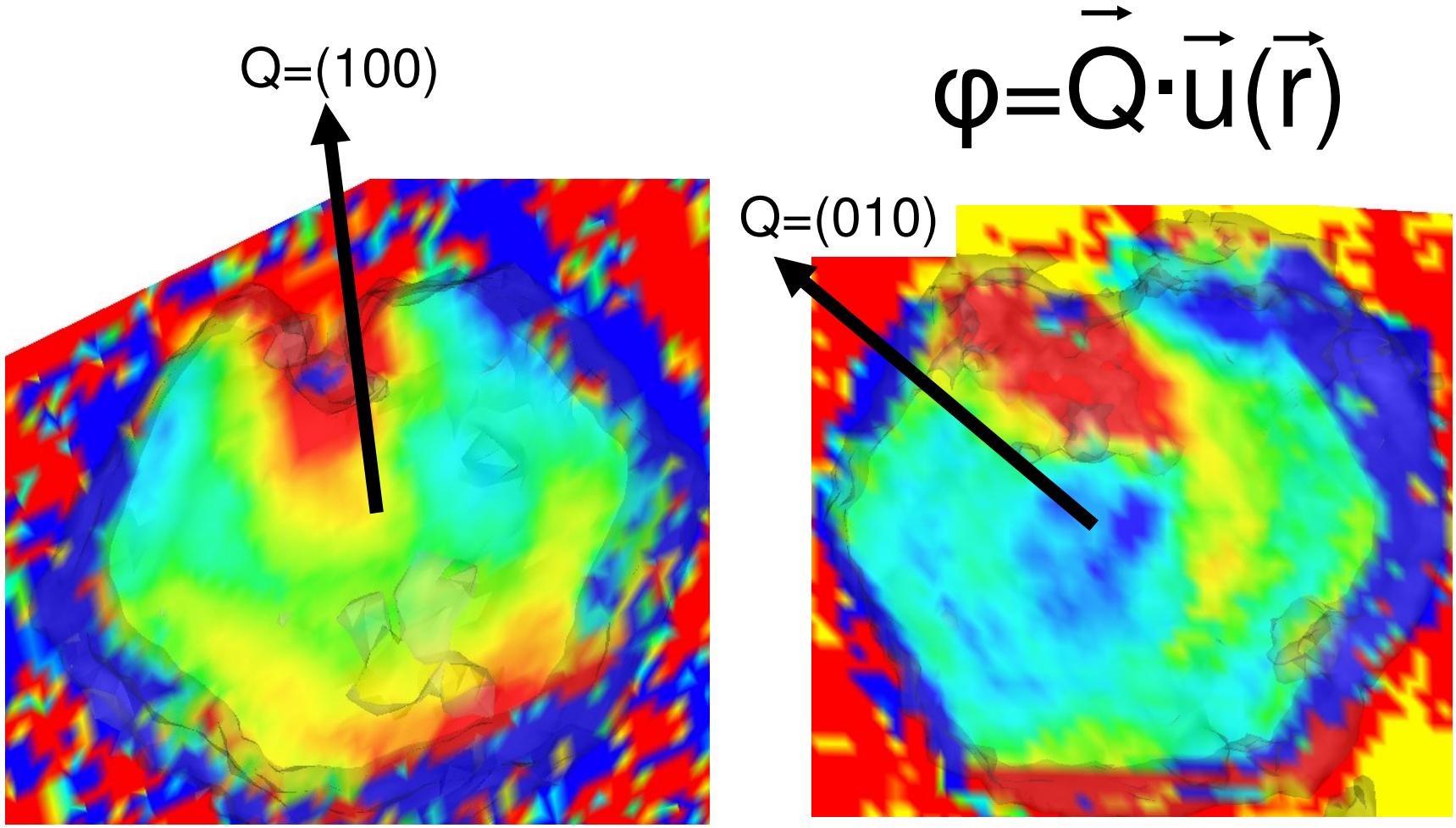
Density sections ZnO-39 (010)

Marcus Newton and Steven Leake (in preparation, 2008)

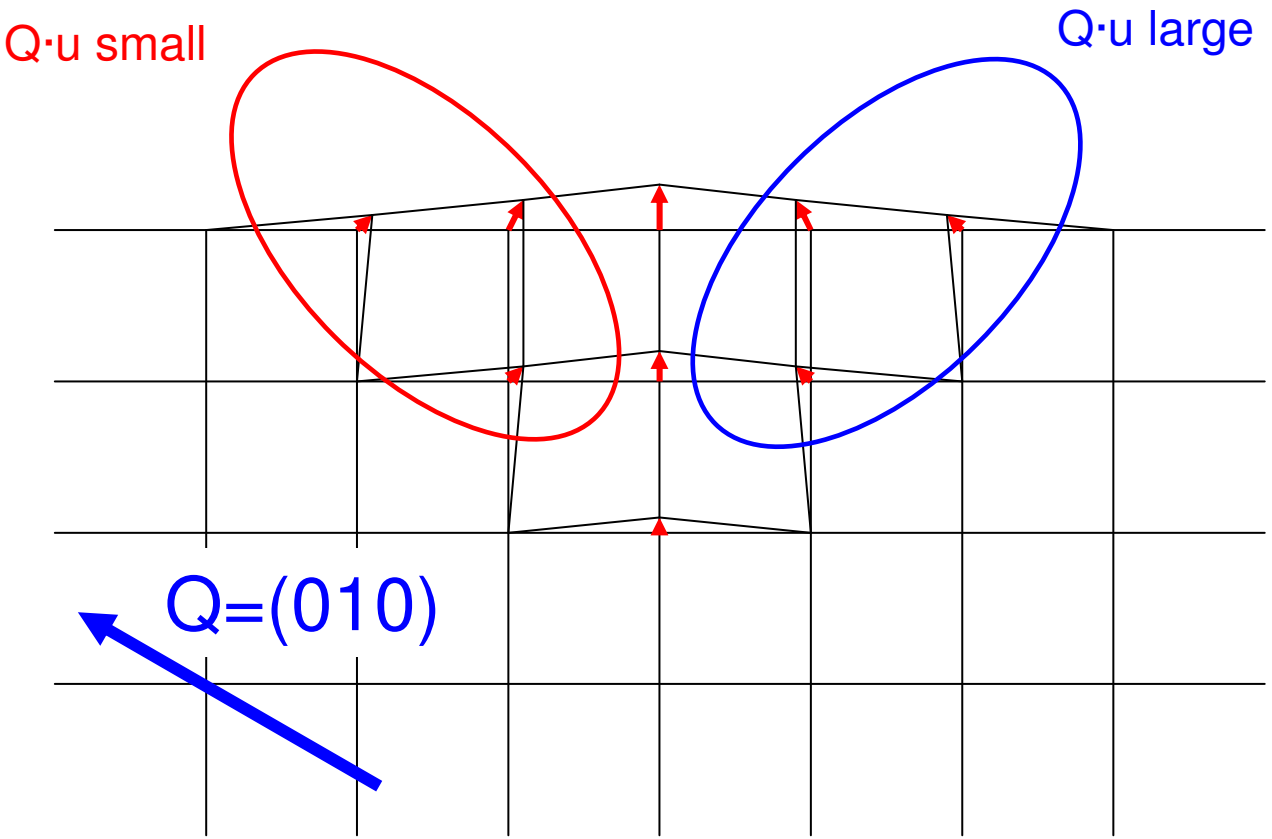


Phase maps from 2 Bragg peaks

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

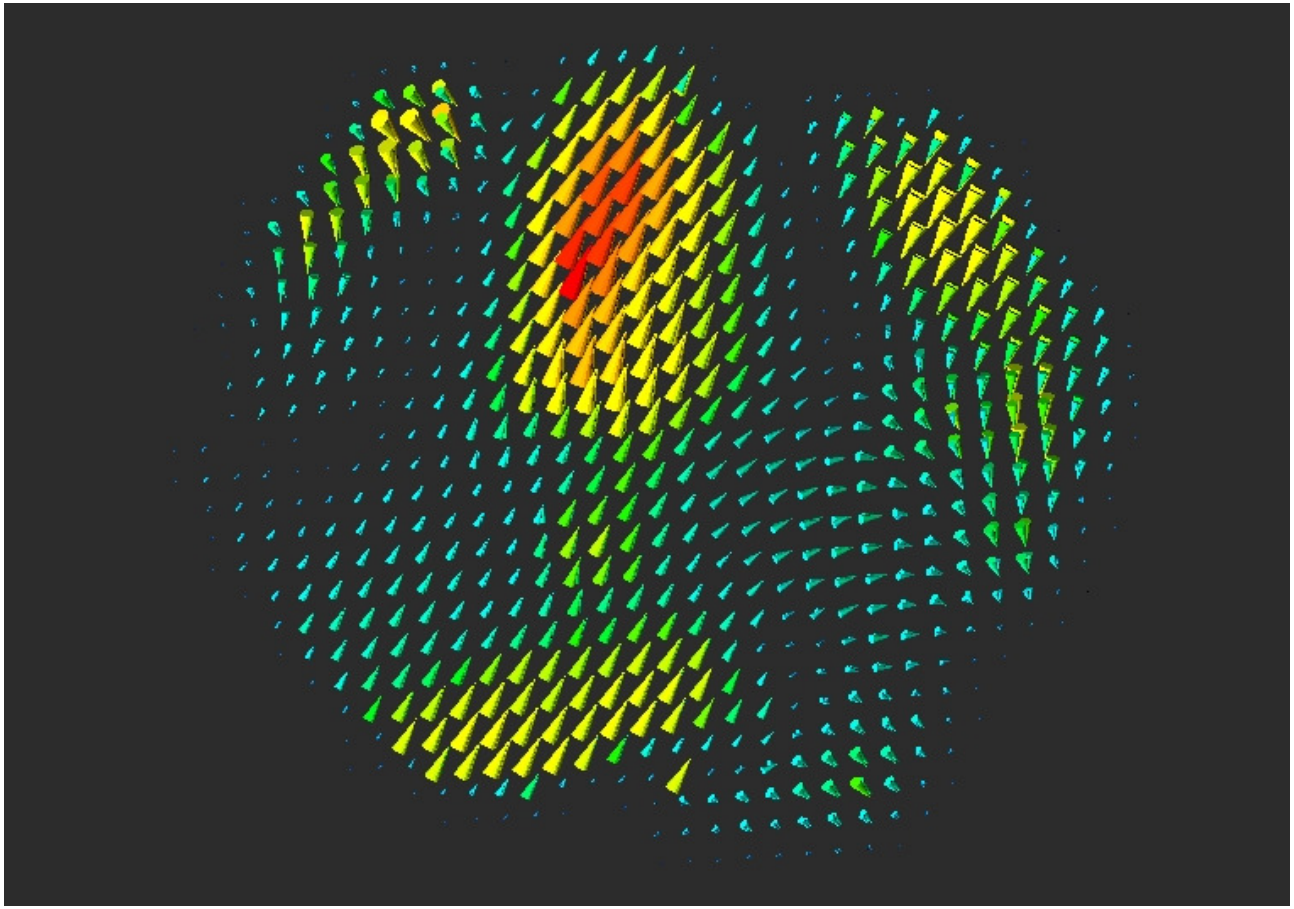


Typical displacement field

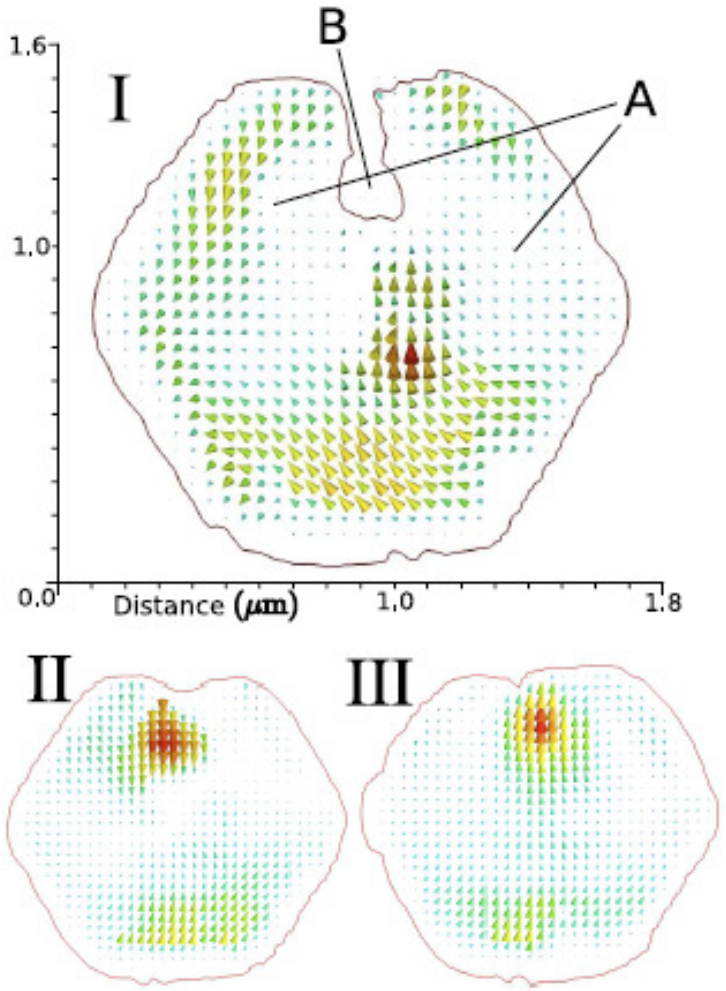


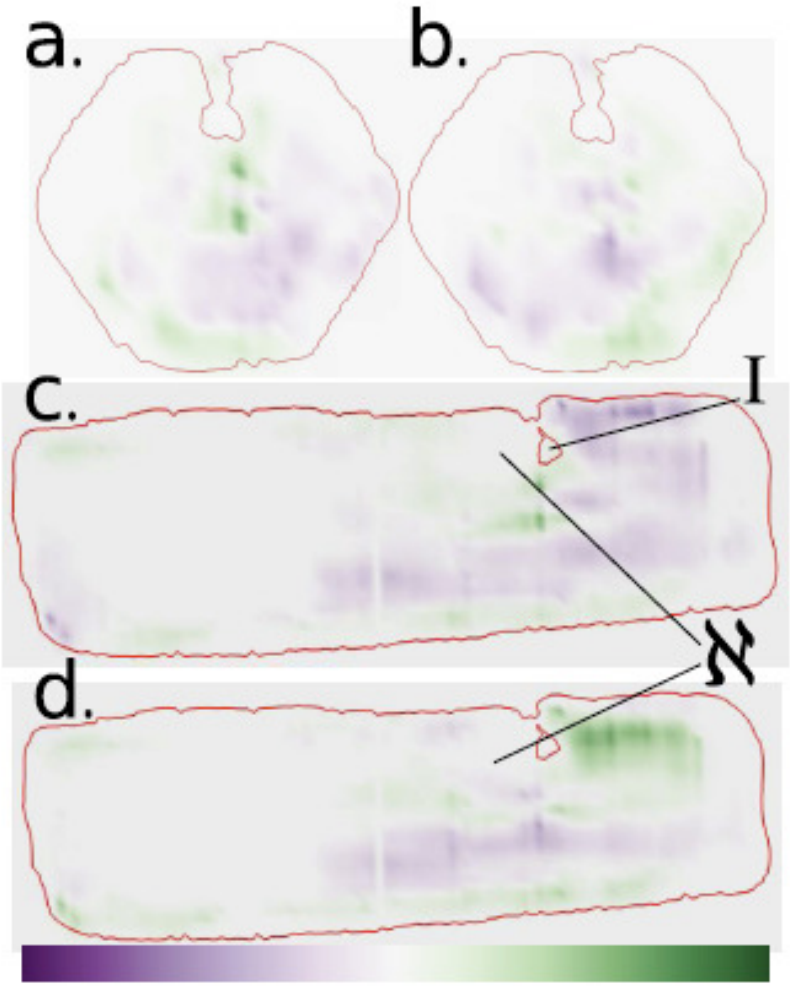
2D vector field of displacements

Marcus Newton, UCL, Jan 2009

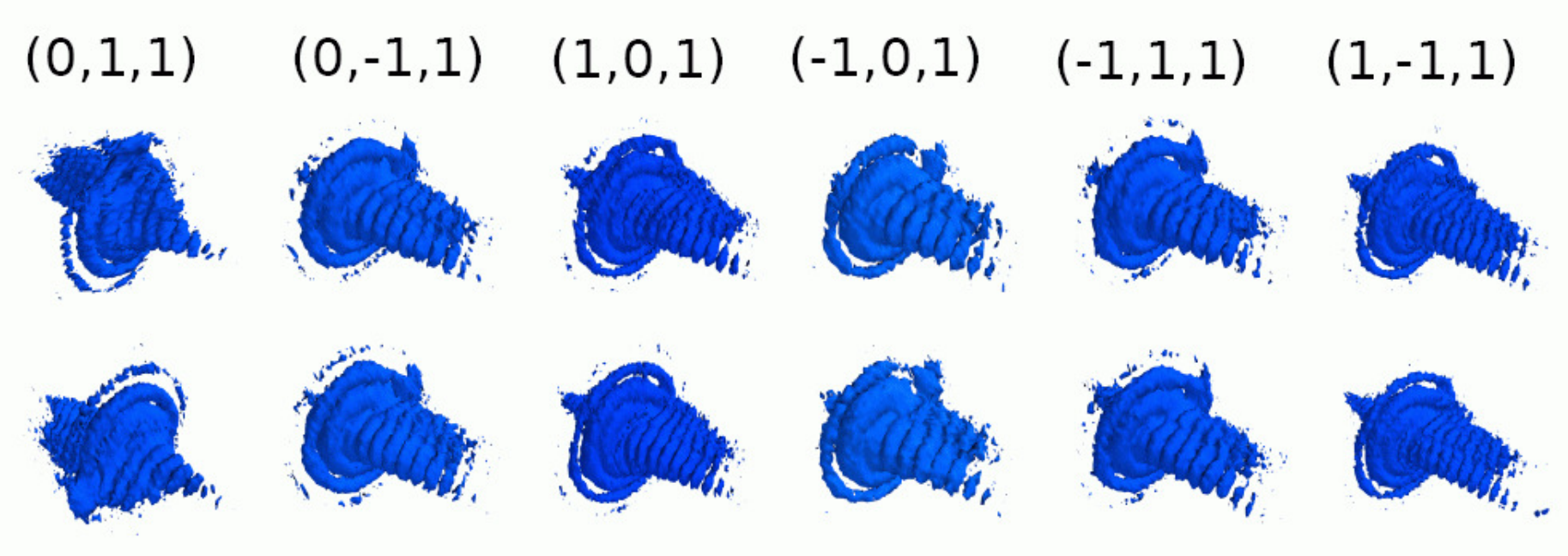


Strain and Rotation fields

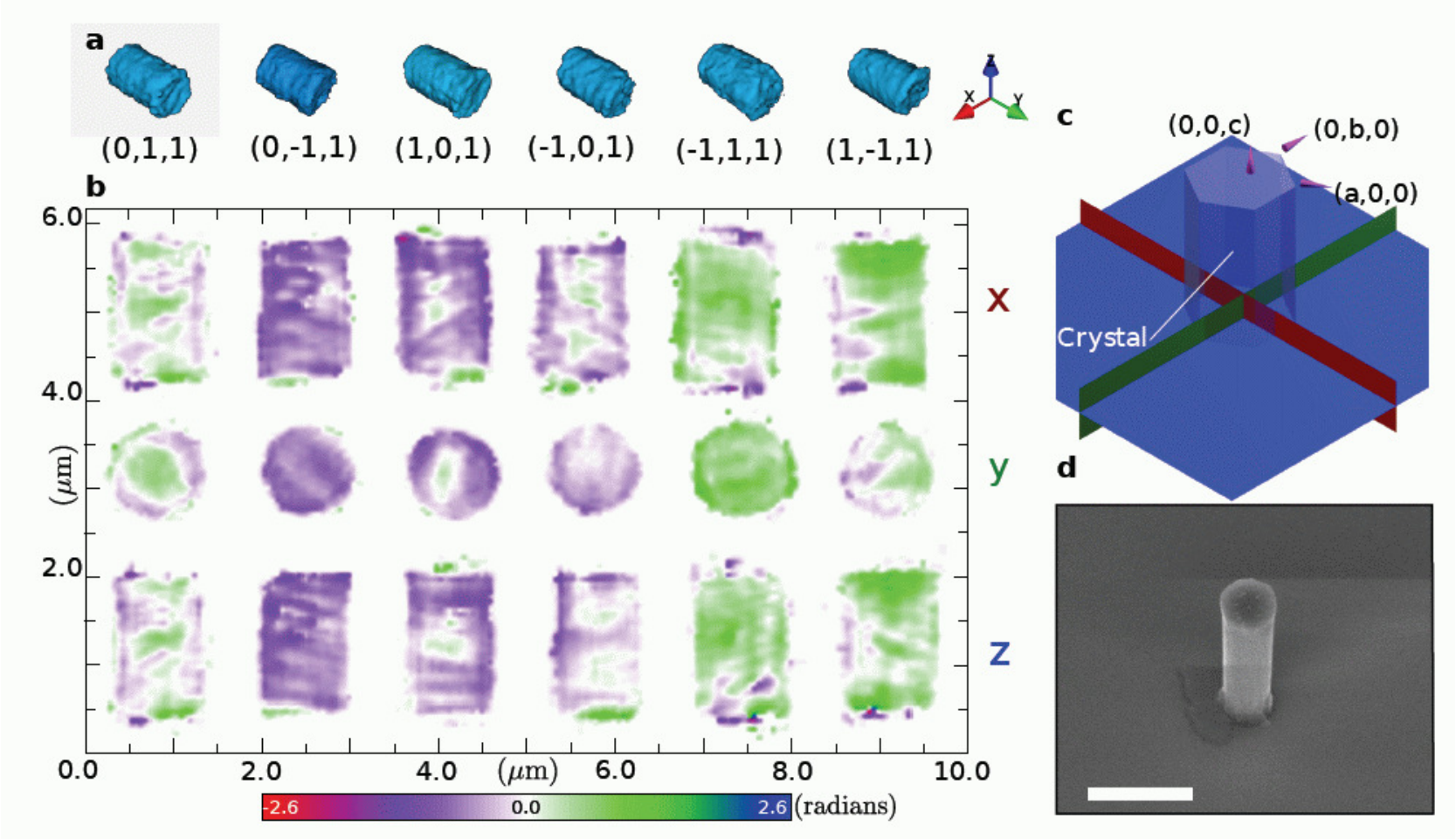




Extension to 6 Bragg Peaks

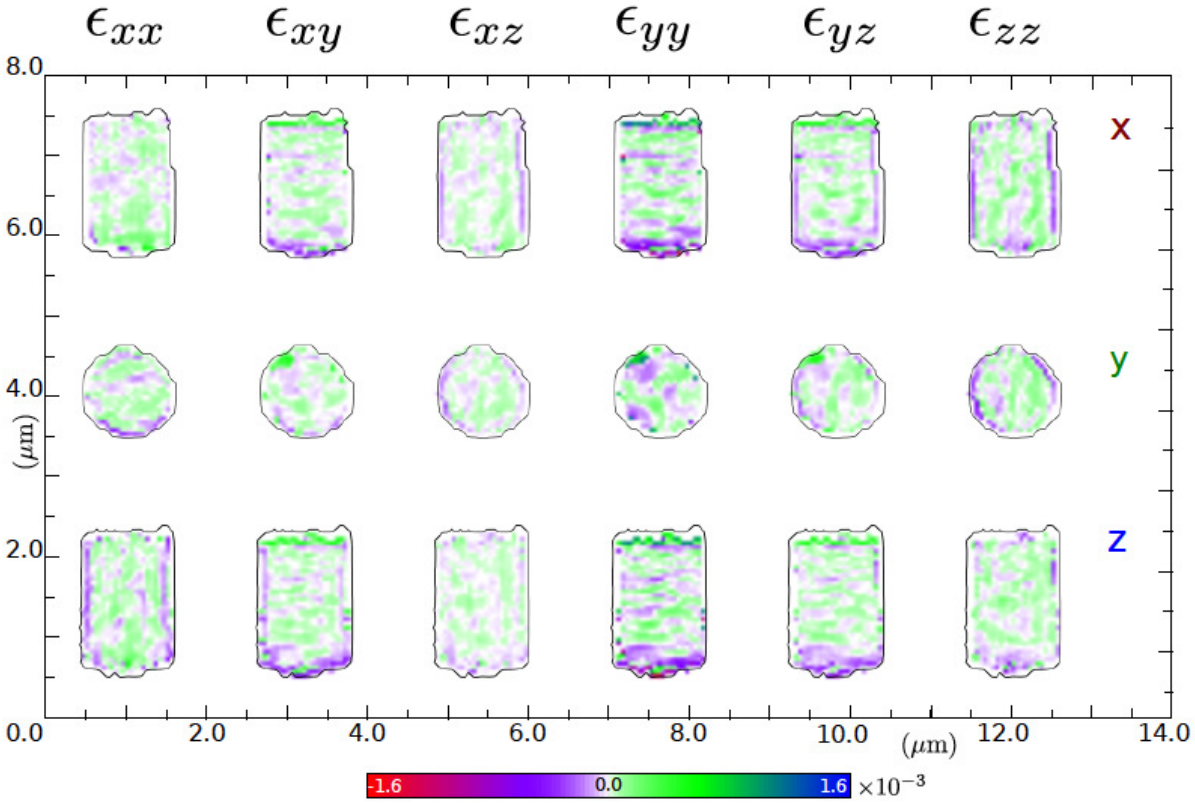


Extension to 6 Bragg Peaks

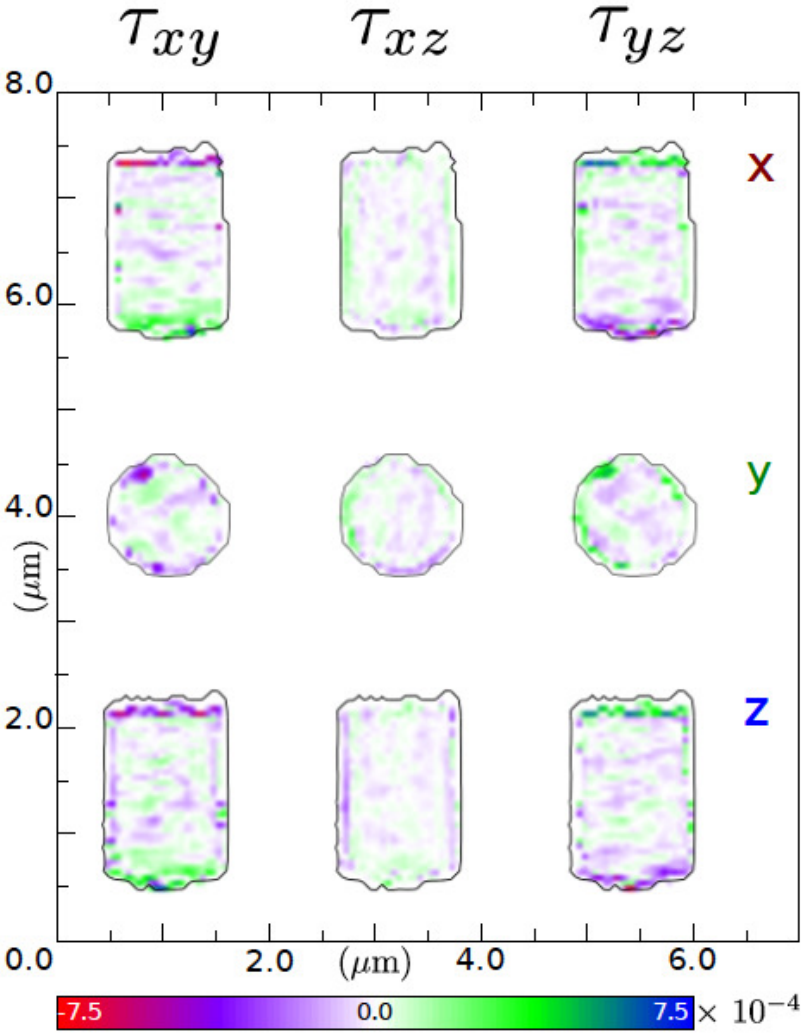


Full Strain Tensor

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

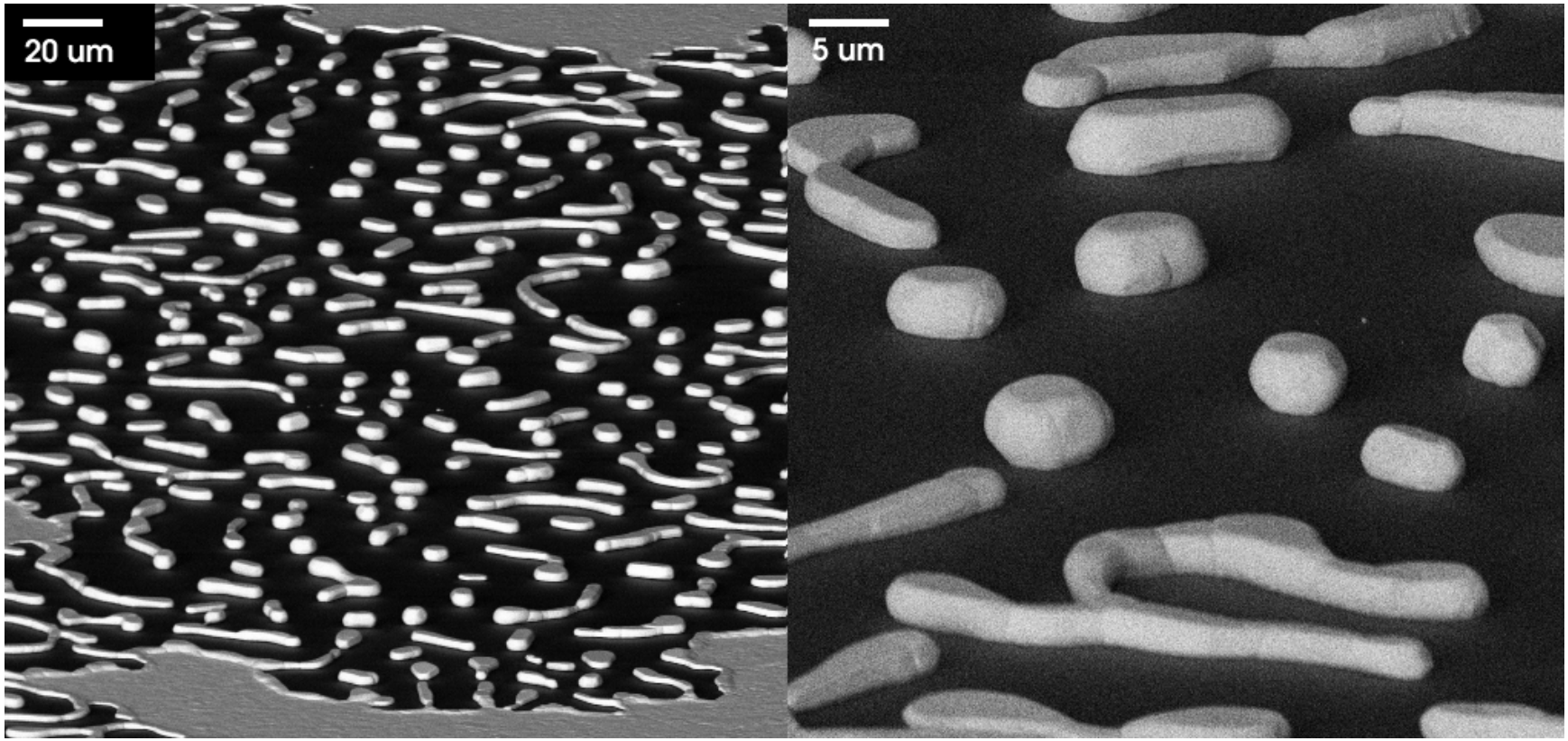


ZnO Rigid-body Rotations



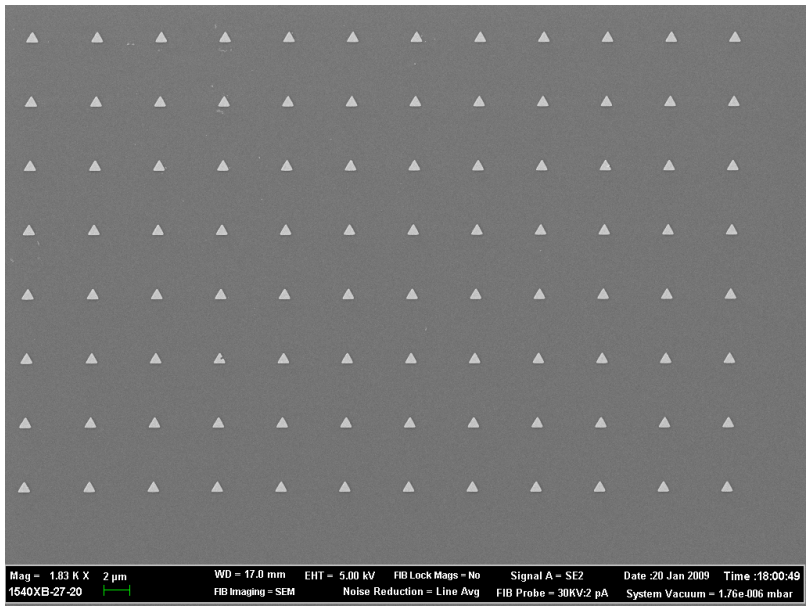
Dewetting to coalesce into crystals

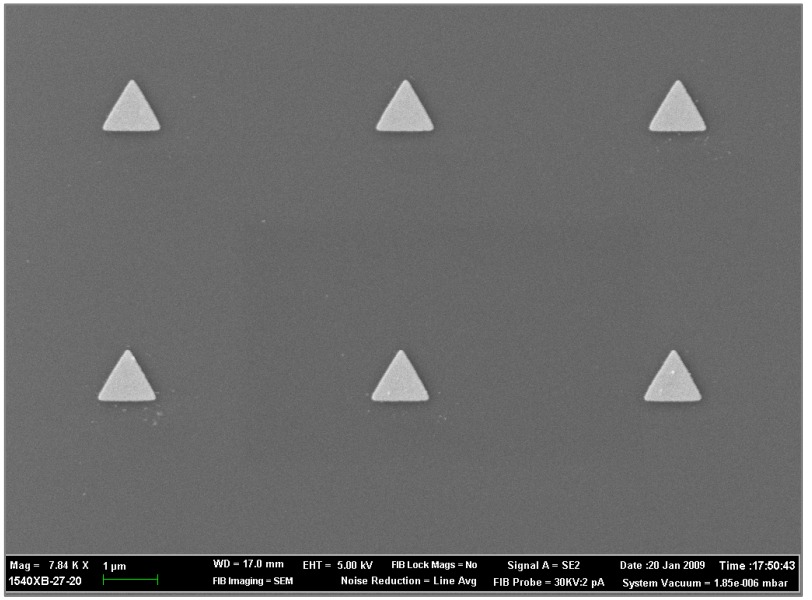
Garth Williams thesis (2005)



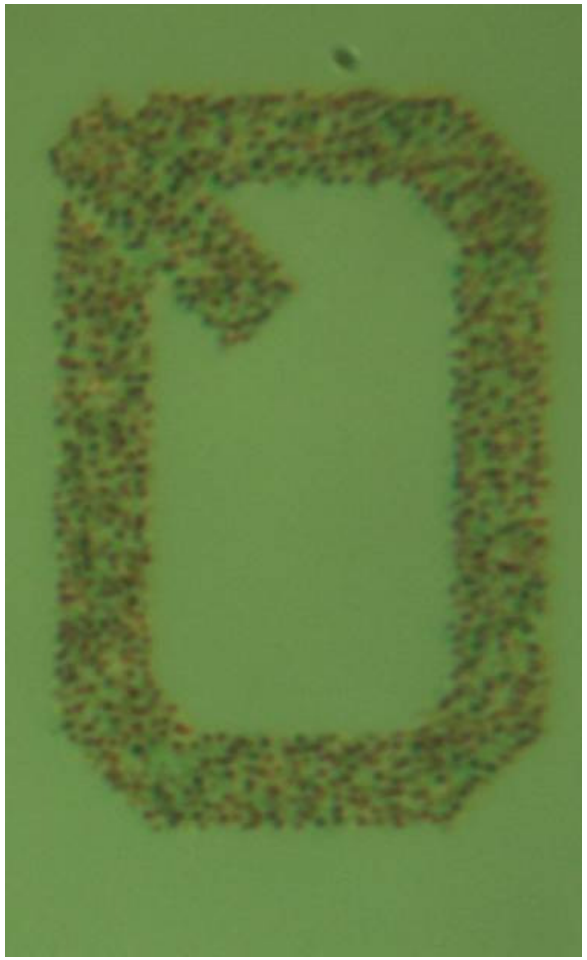
Patterned Au nanocrystal samples

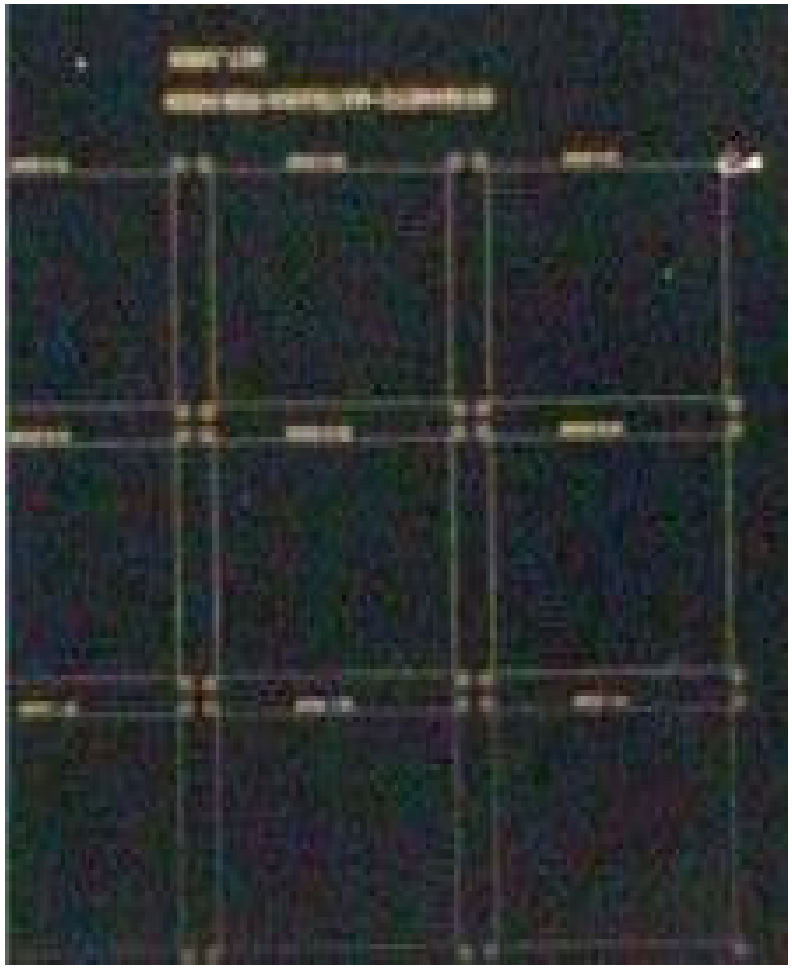
N. Shimamoto, Waseda University, Japan



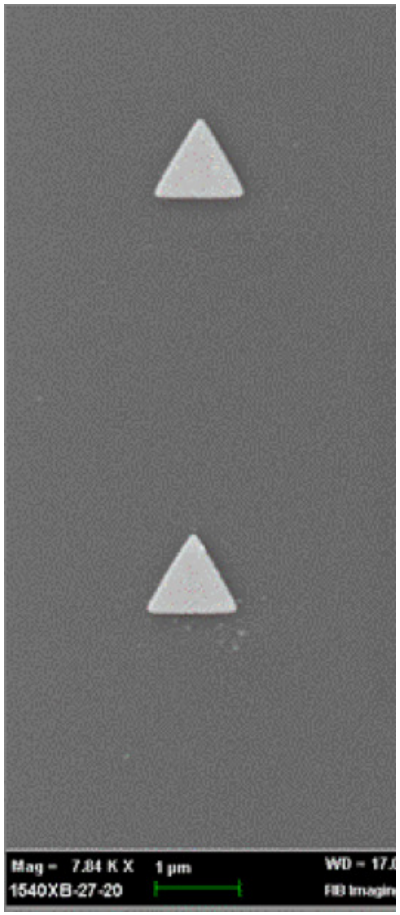


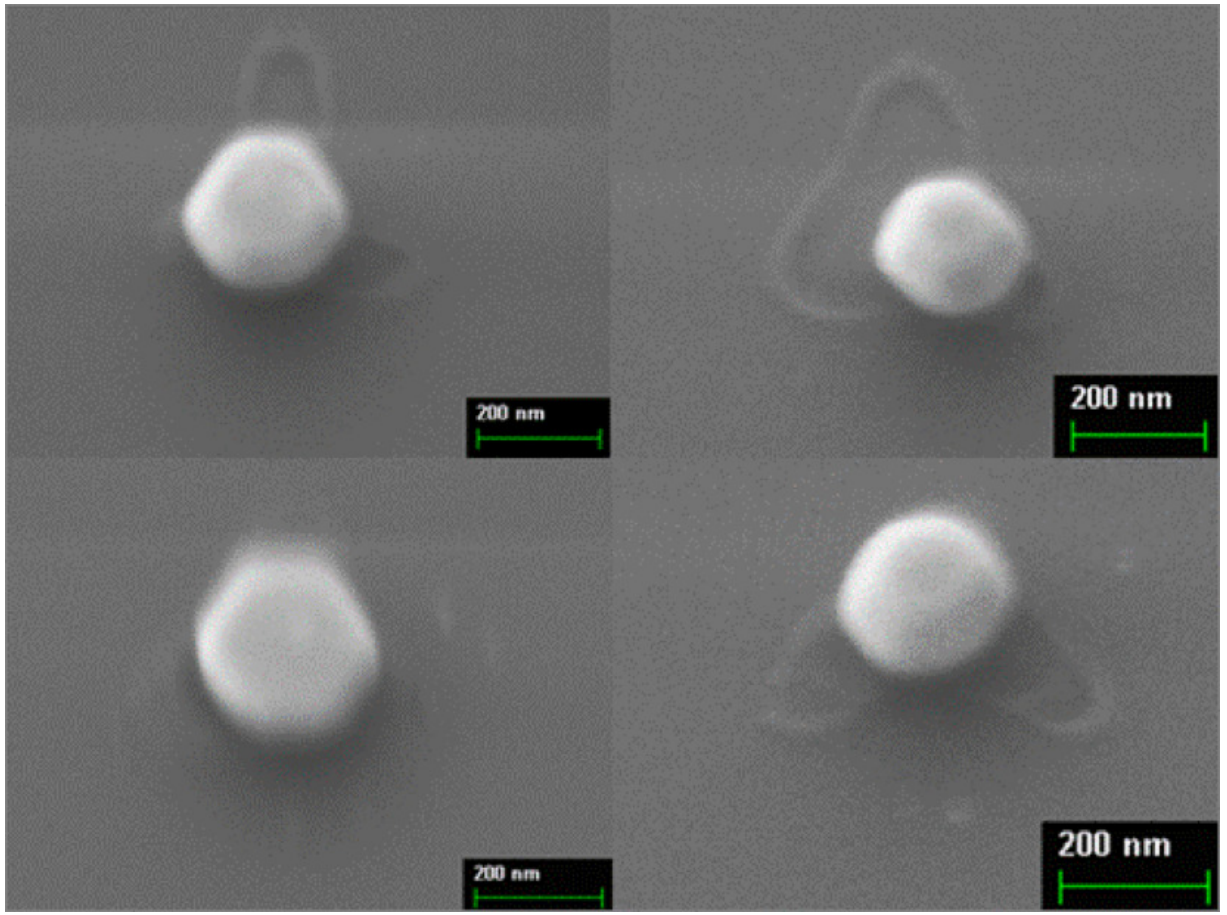
Annealing of Patterned Substrates



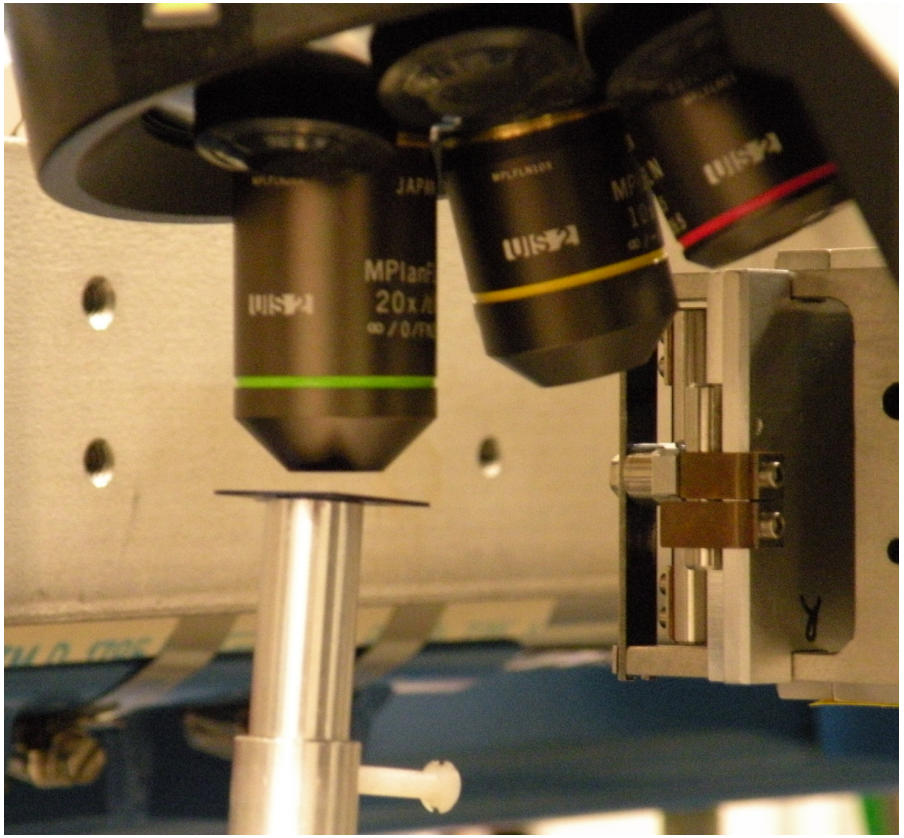


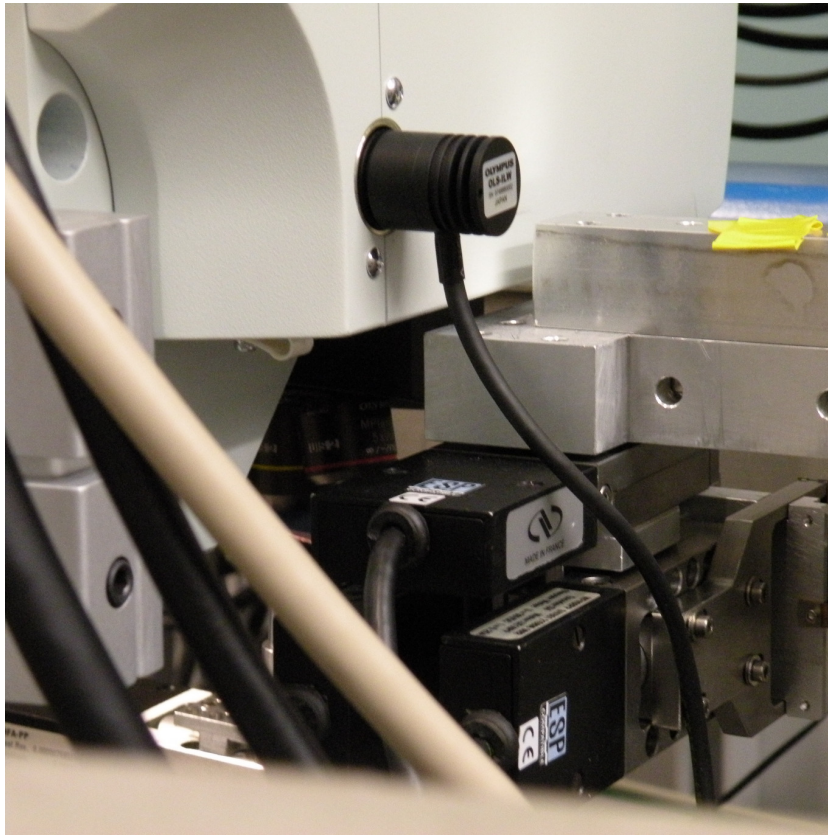
Single Au nanocrystal synthesis





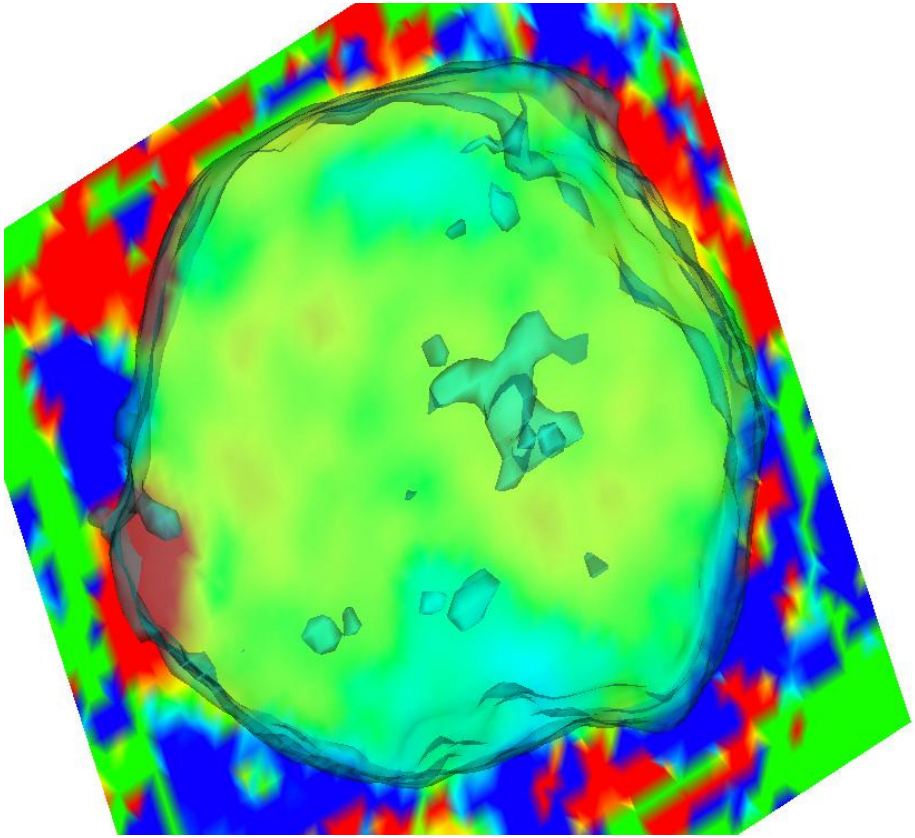
Confocal Alignment Microscope

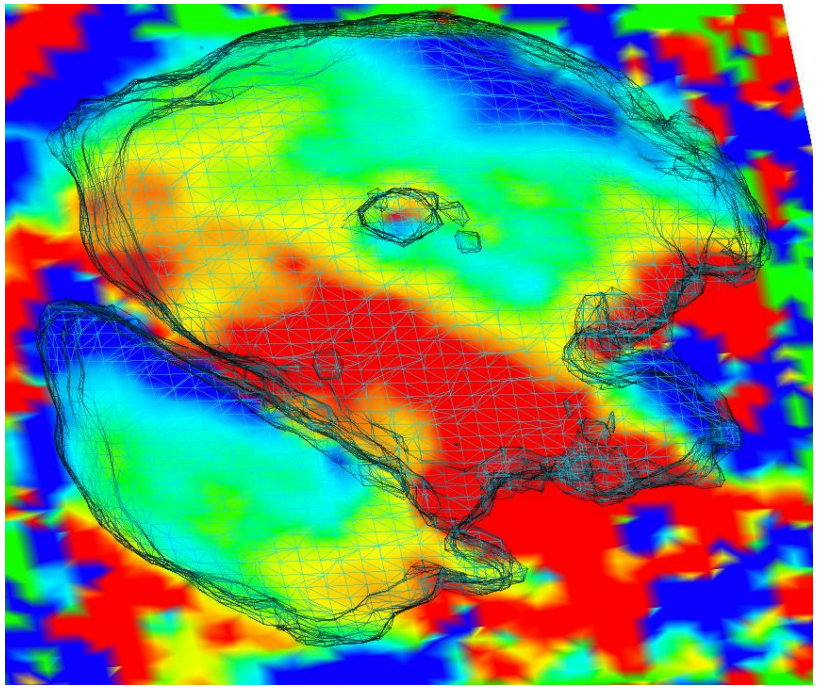


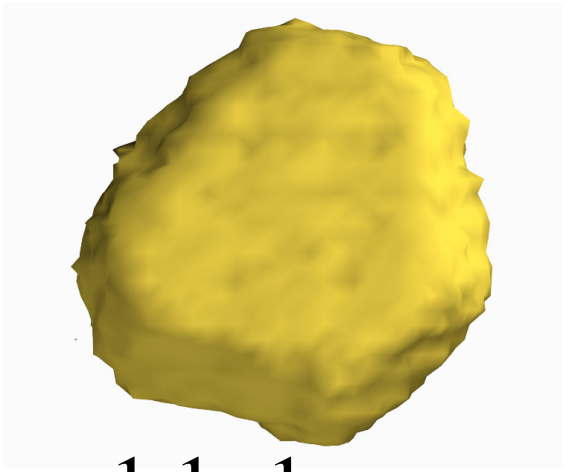


Two views of strain in Au NC

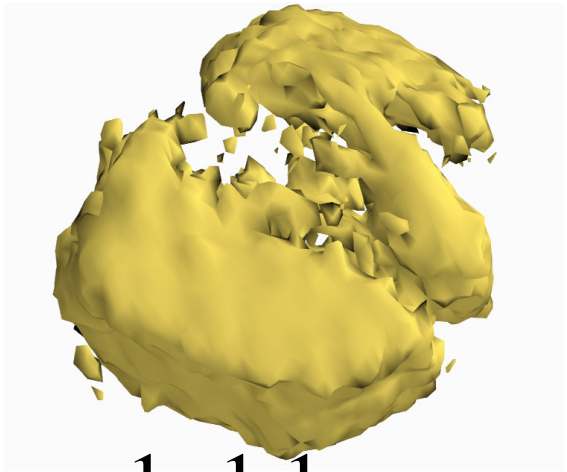
Au409B-52 (11-1) and Au409B-60 (200)







1,1,-1



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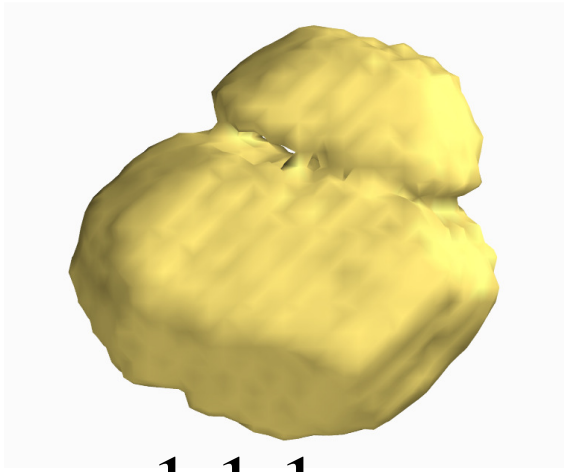
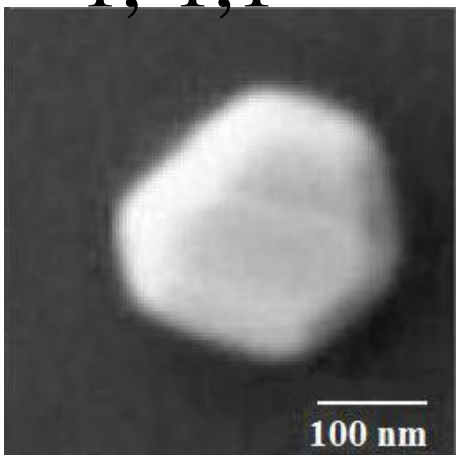
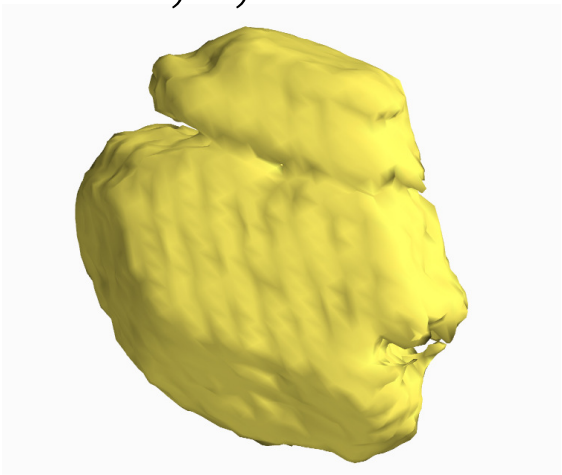
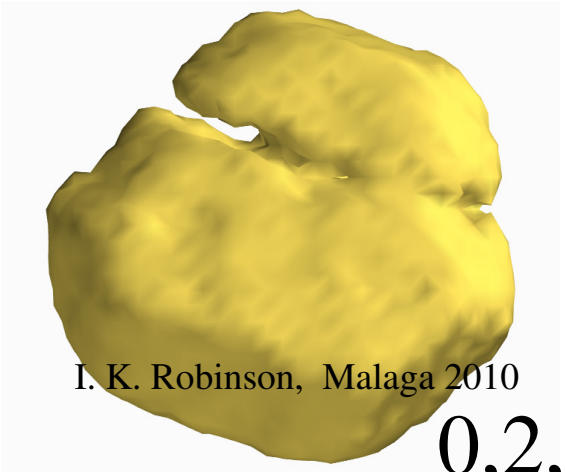


-1,1,1



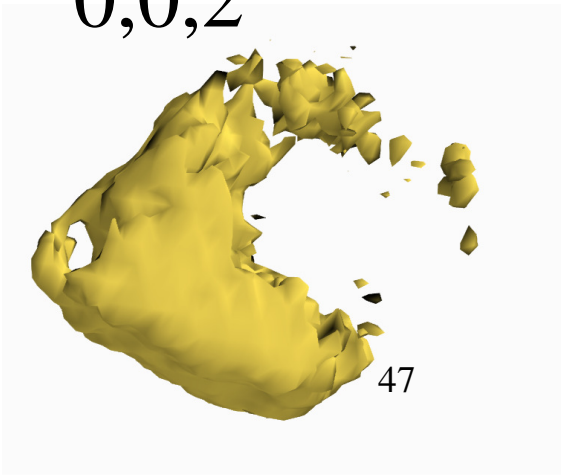
2,0,0





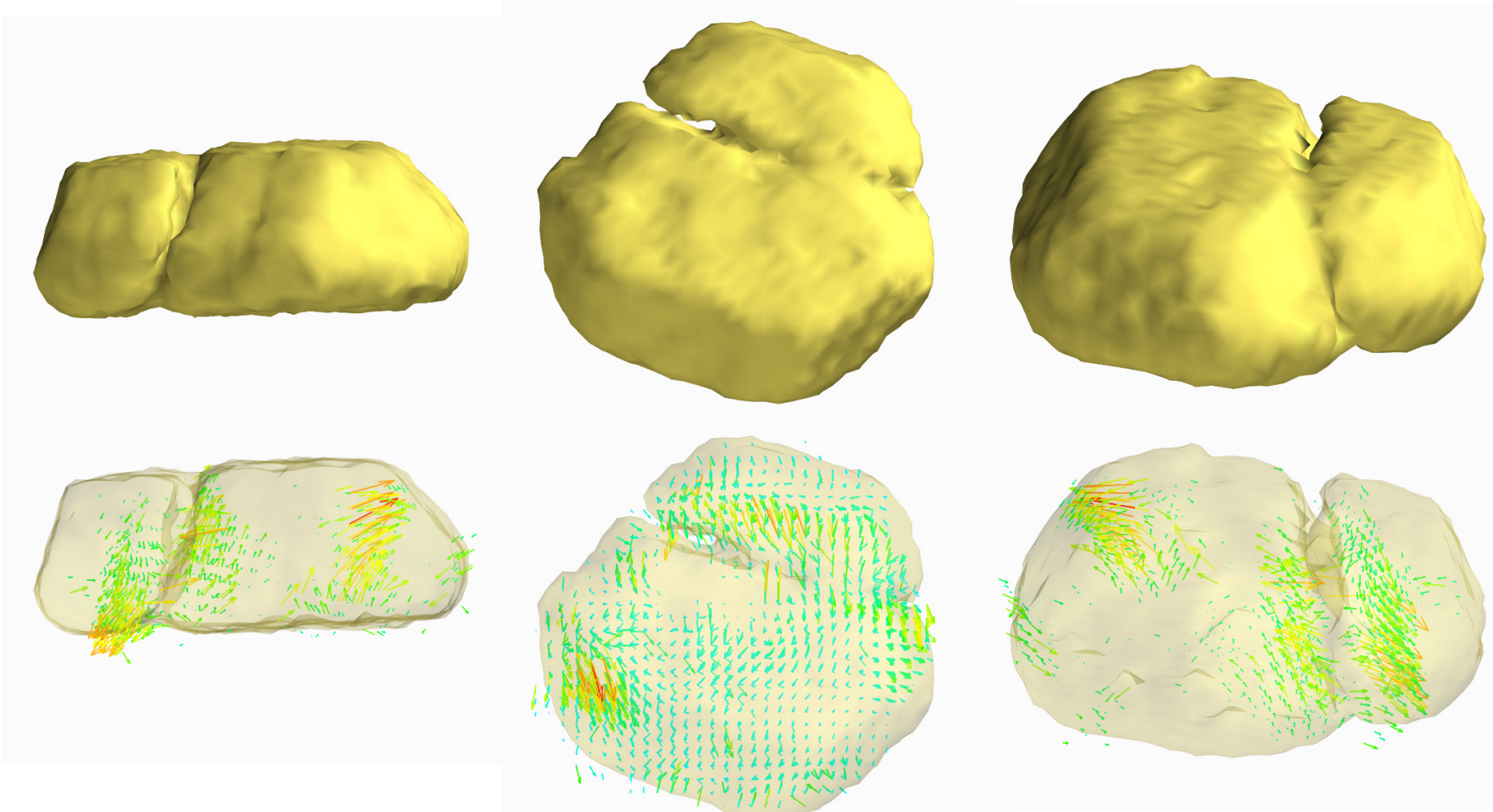
0,2,0

0,0,2



Vector displacement field

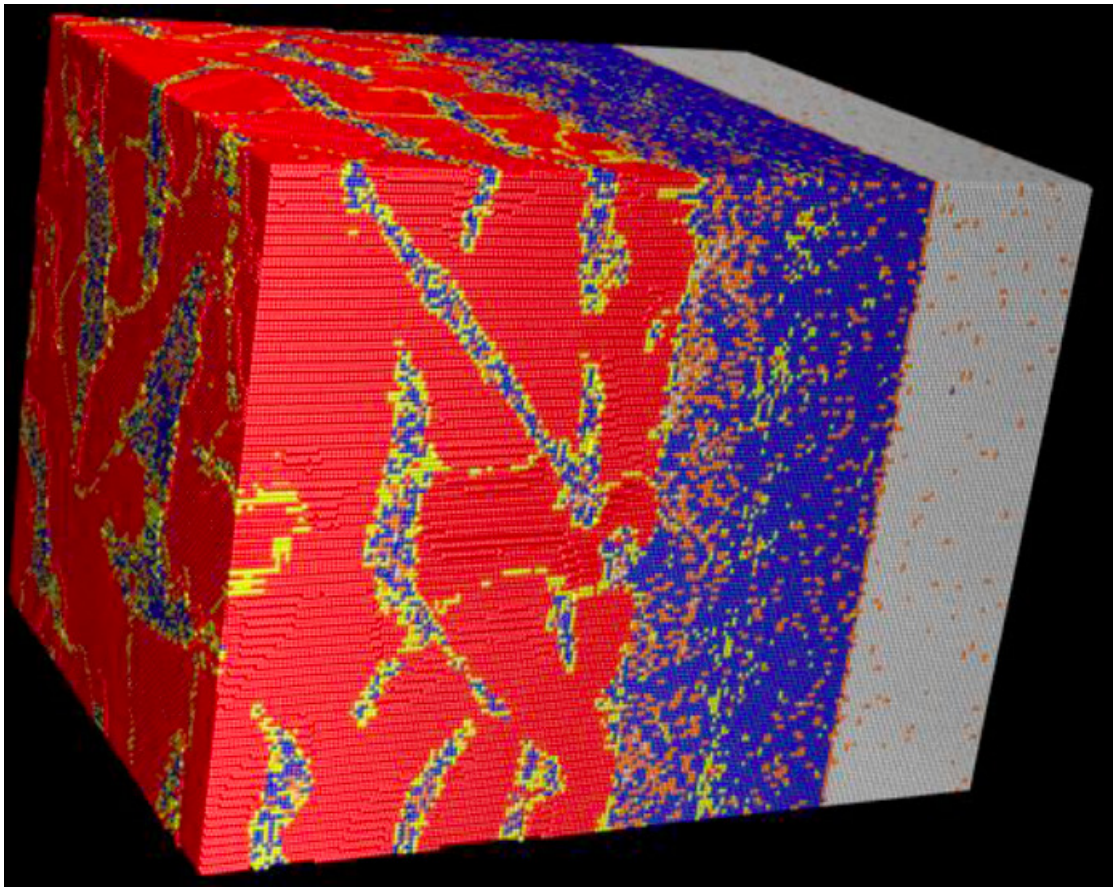
Merged reconstructions from (11-1) (020) and (-111)



MD simulation of Shock Wave

Damage in Fe along (001) direction

K Kadau, TC Germann, PS Lomdahl, and BL Holian. Science, 296 1681 2002



Charge Density Wave Dynamics?

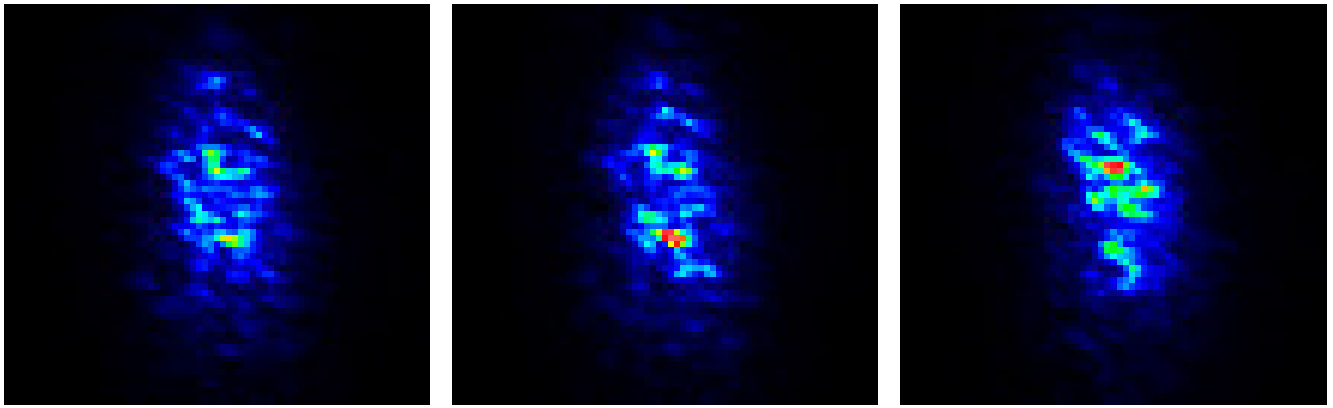
CDW peak ofTaS_2 crystal at room temperature

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

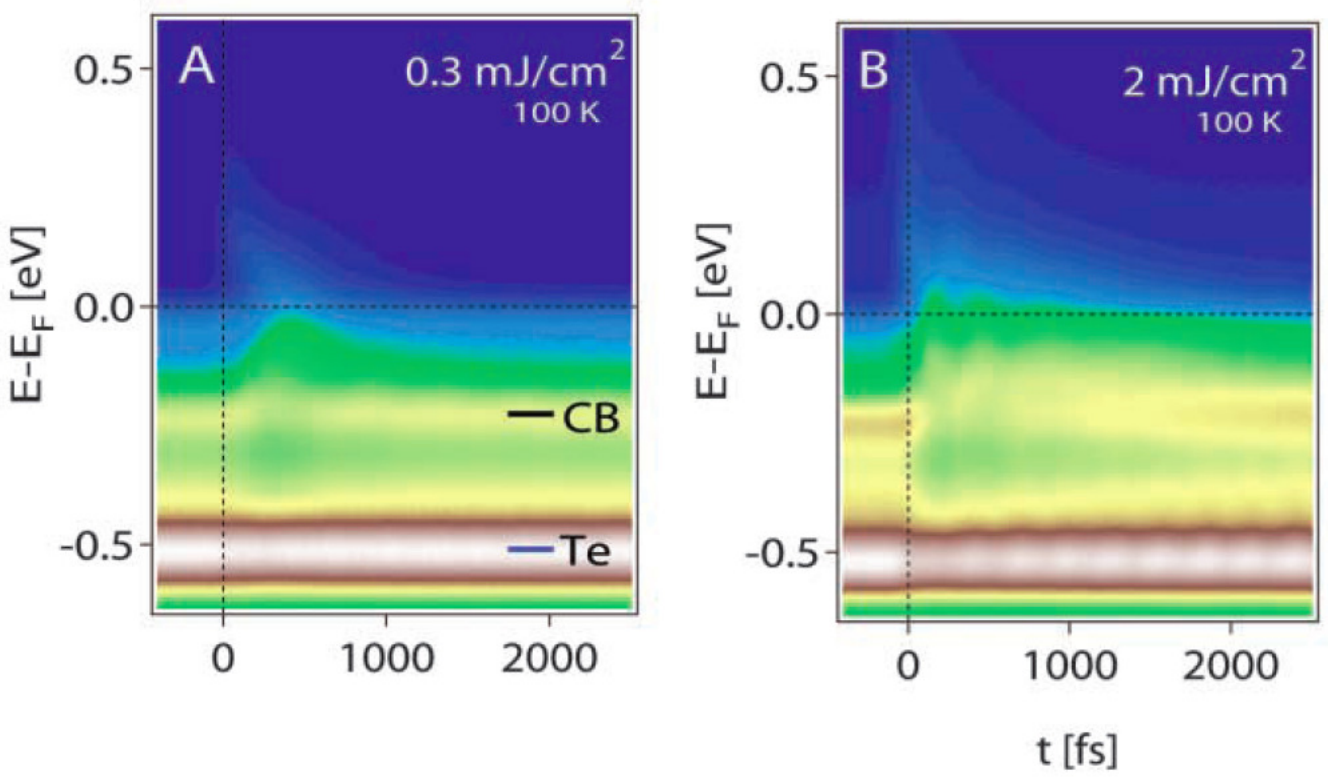


Charge Density Wave Dynamics

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

- Internal structure of Nanocrystals
- 3D imaging of faults in Nanowires
- Phasing by computation instead of lens
- Strain fields imaged from asymmetric patterns
- Plans for XFEL experiments