Confocal Microscope Alignment of Nanocrystals for Coherent Diffraction Imaging

Ian Robinson
Ross Harder
Moyu Watari
Steven Leake
Marcus Newton
Loren Beitra

London Centre for Nanotechnology
Diamond Light Source

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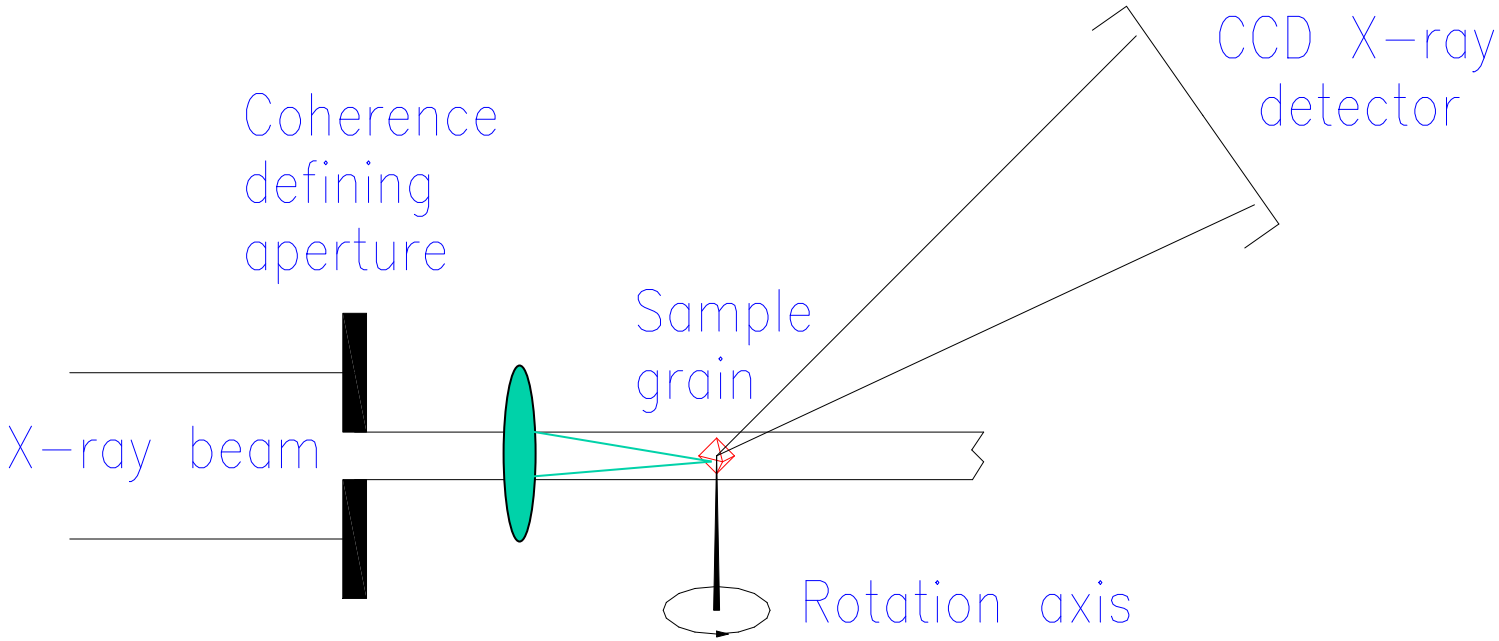
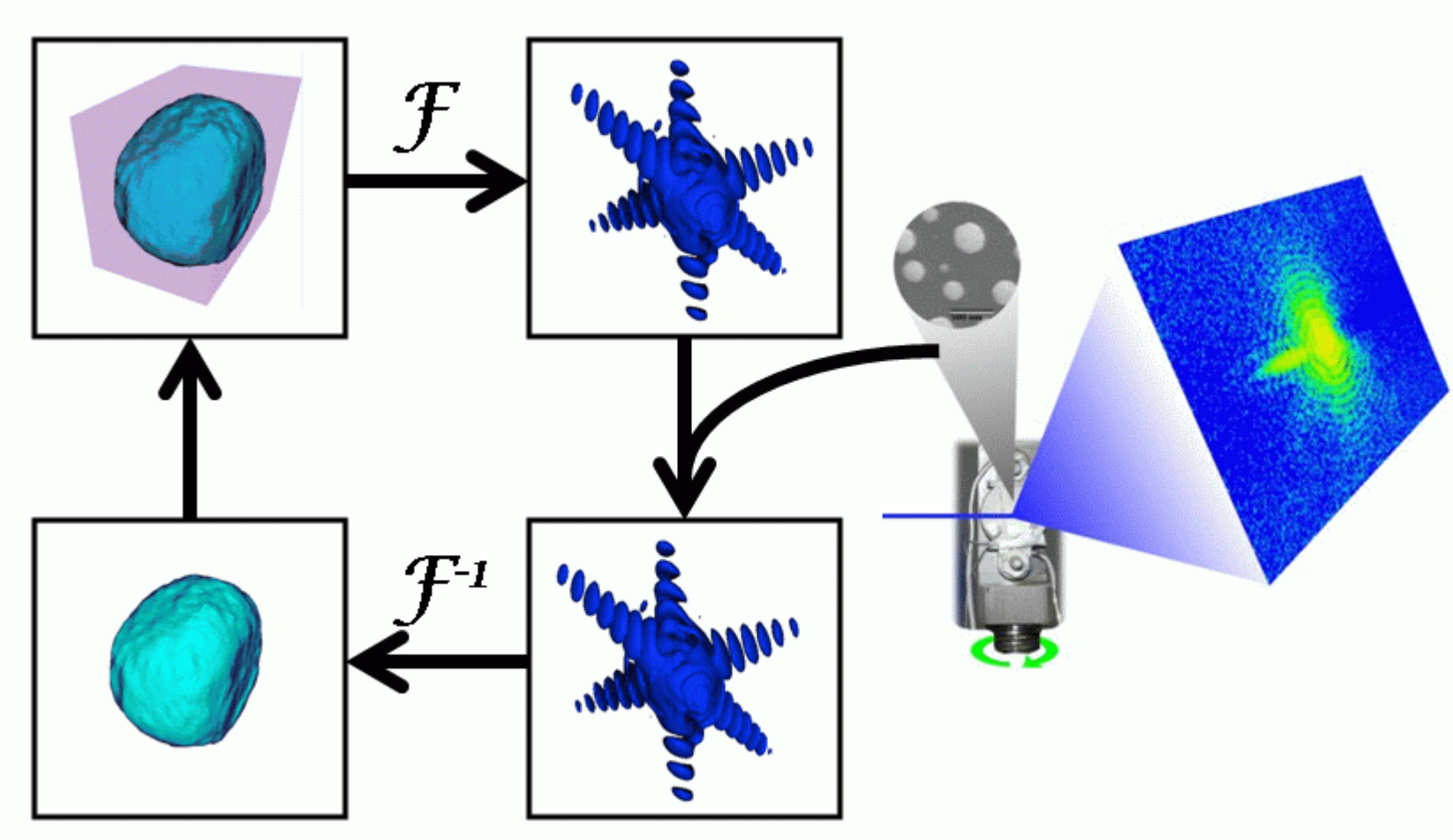
Outline

- Coherent x-ray diffraction
- Coherence solves the phase problem
- Exploration of crystal strain in ZnO
- Effects of longitudinal coherence
- Confocal microscope at 34-ID-C
- Twin domains in Au nanocrystals

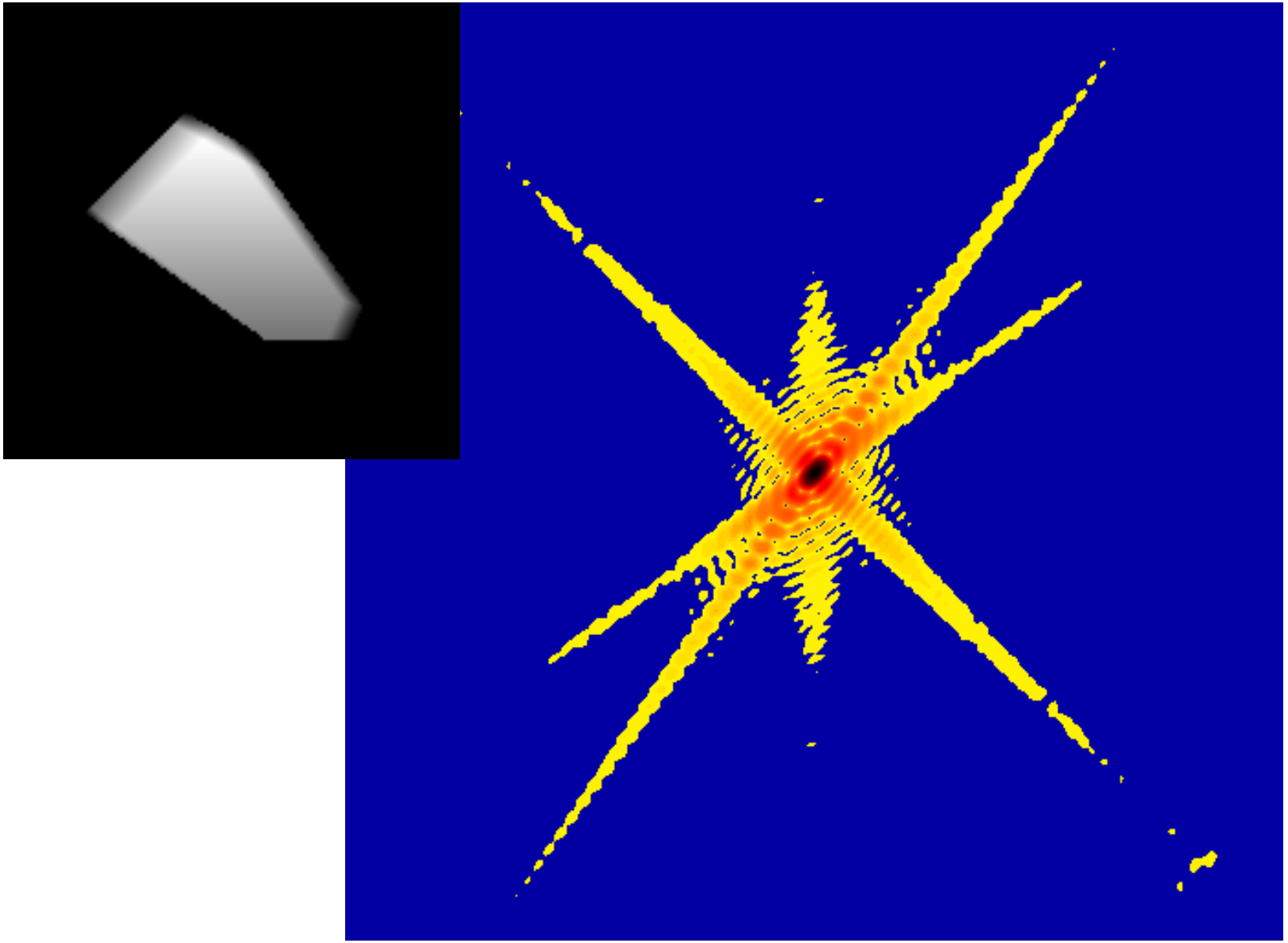
Lensless X-ray Microscope, 2003

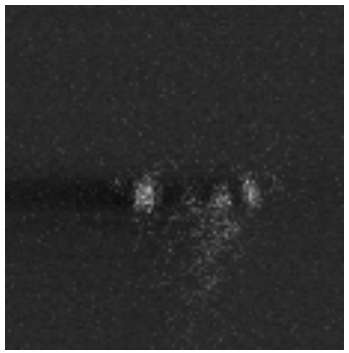


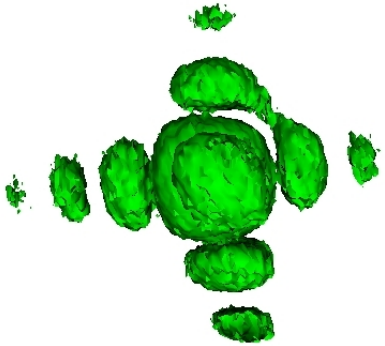
Generic "Error Reduction" method

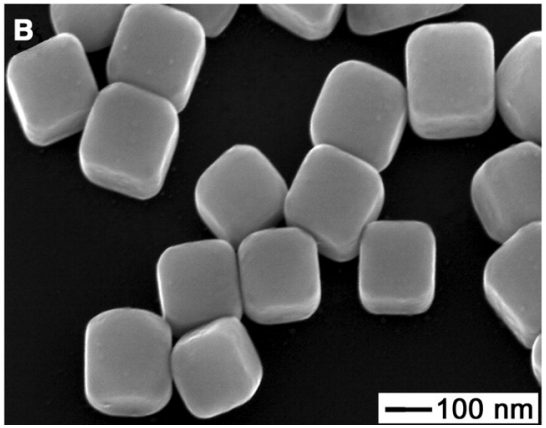


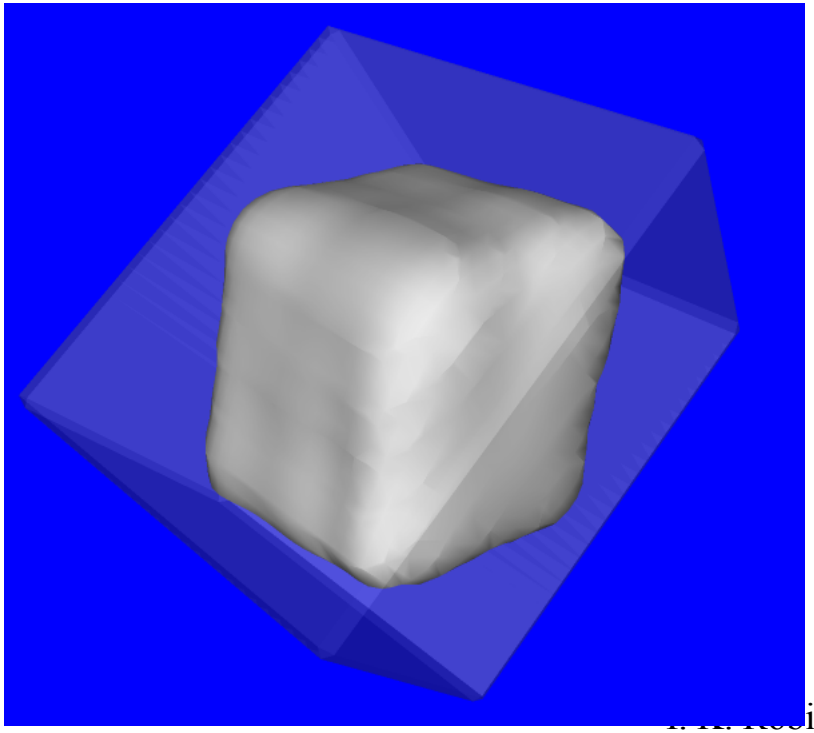
J. R. Fienup Appl. Opt. 21 2758 (1982)
R. W. Gerchberg and W. O. Saxton Optik 35 237 (1972)

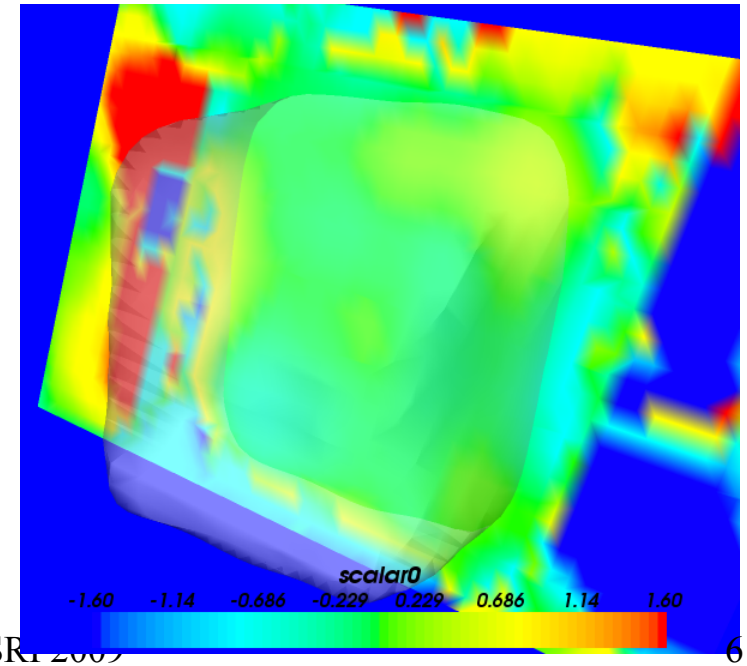




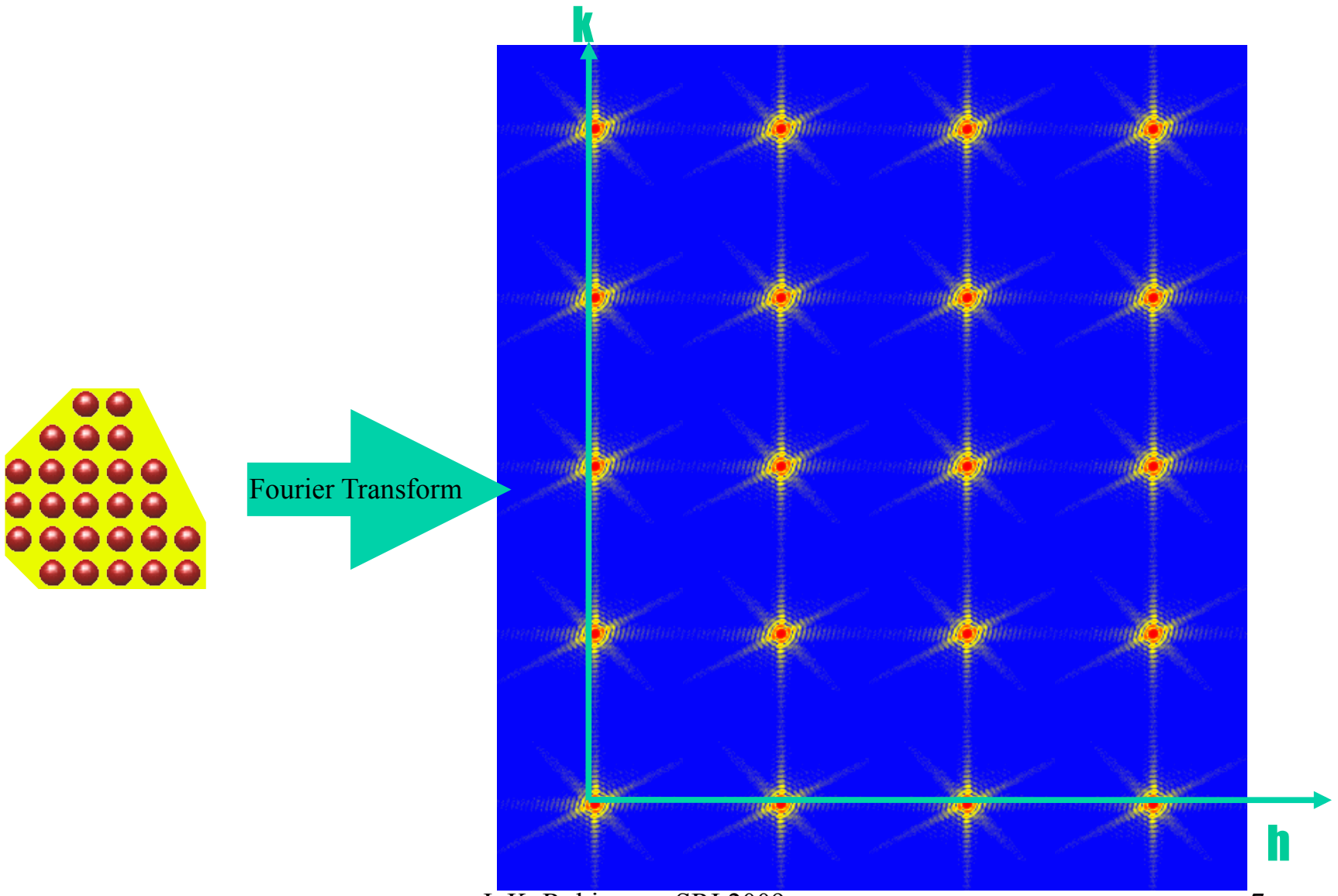



B
100 nm



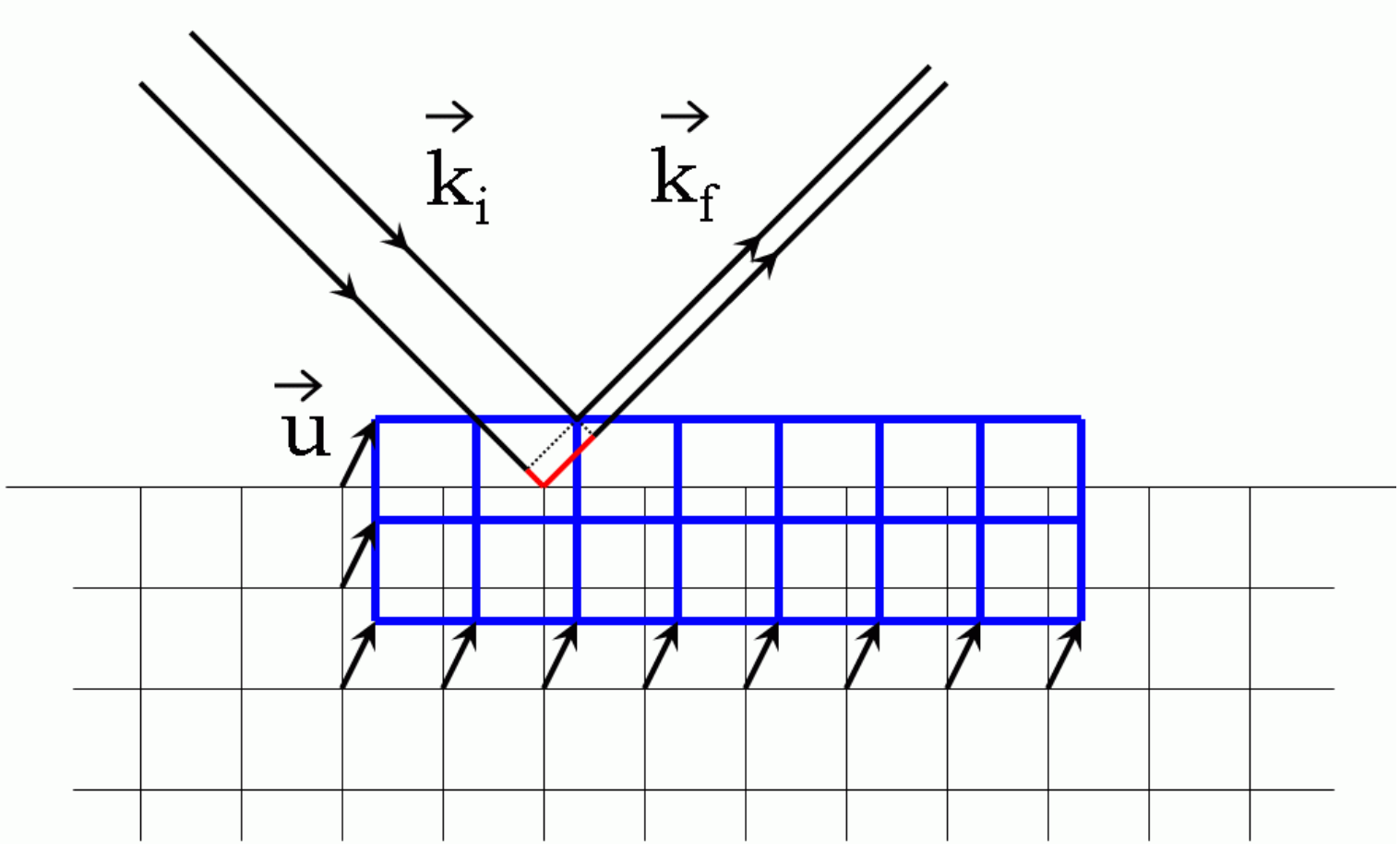

scalar0
-1.60 -1.14 -0.686 -0.229 0.229 0.686 1.14 1.60

Coherent Diffraction from Crystals



Sensitivity to strain

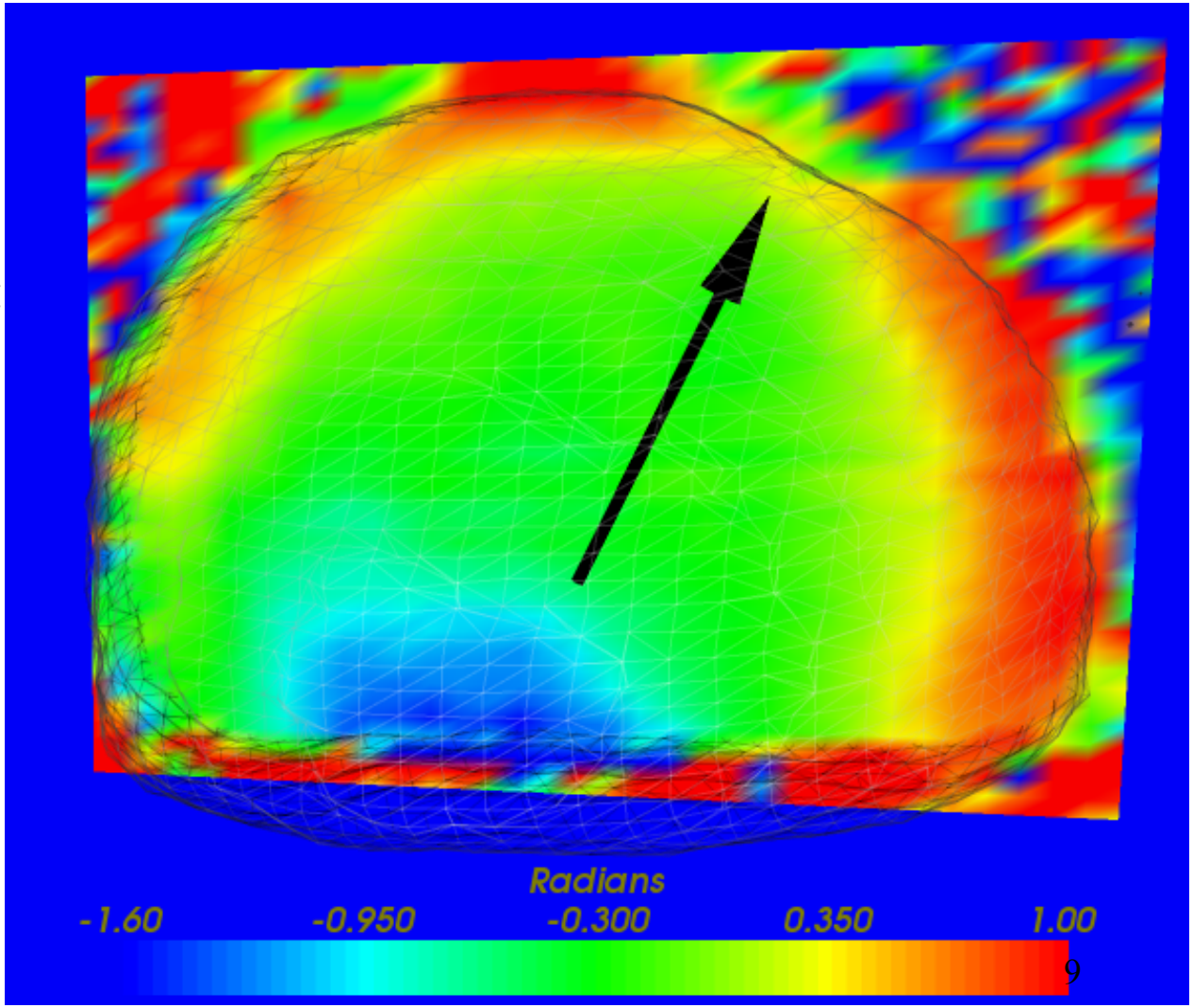
$$\Delta\varphi = \mathbf{k}_f \cdot \mathbf{u} - \mathbf{k}_i \cdot \mathbf{u} = \mathbf{Q} \cdot \mathbf{u}$$



Refraction corrected phase map

Max phase = 1.15rad
= 0.052nm

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

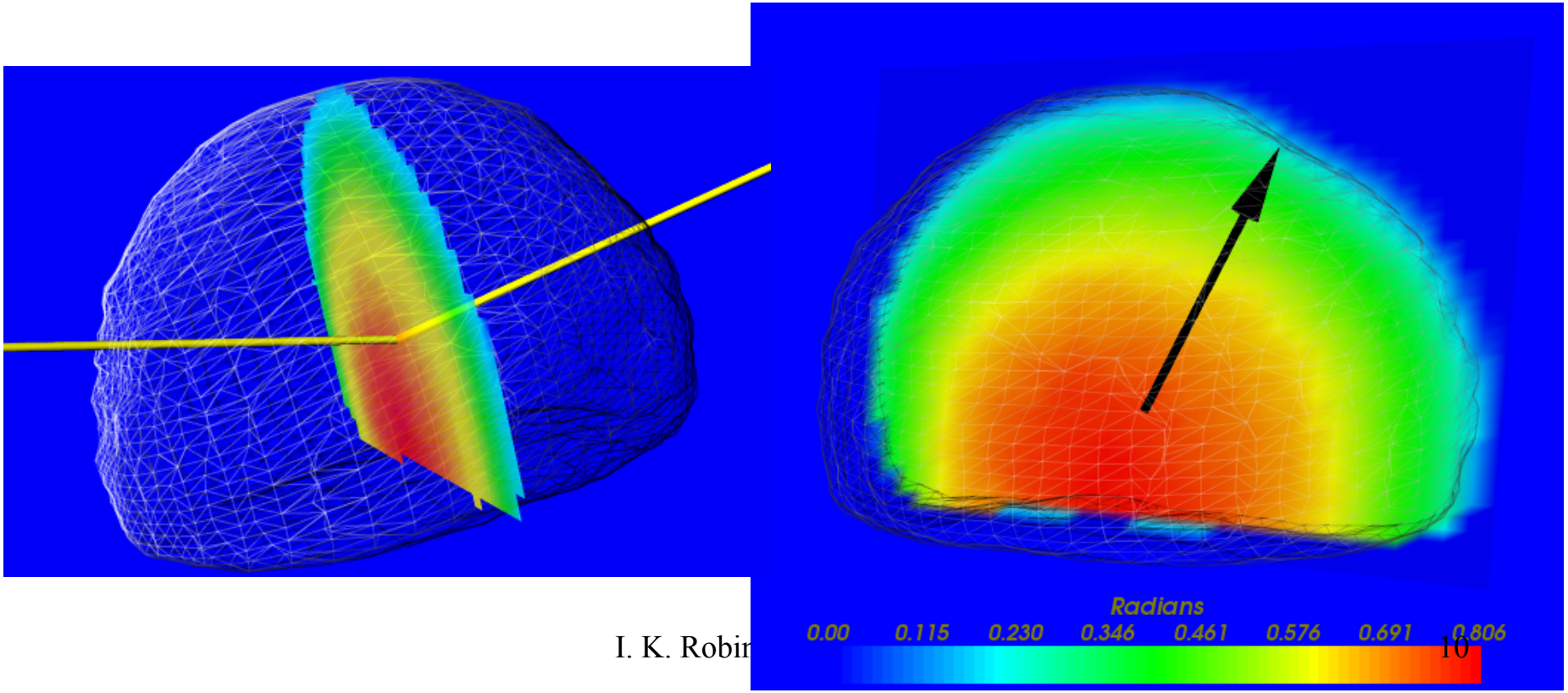


Refraction effects in Lead at 8.9keV

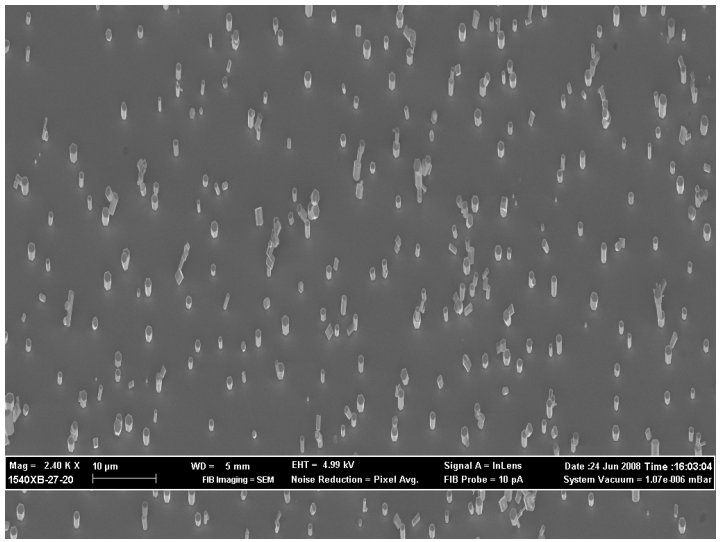
Phase accumulation due to refraction along scattering path

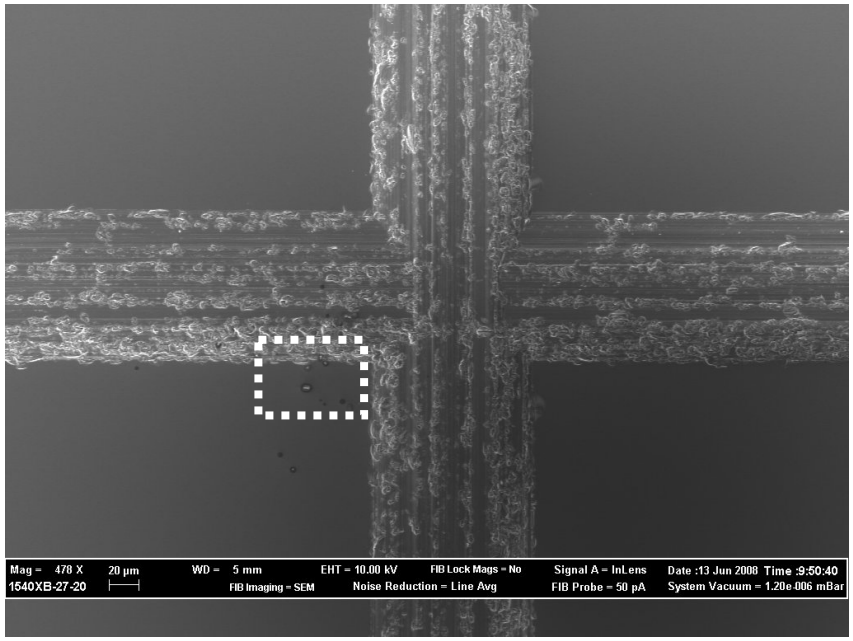
$$n=1-\delta+i\beta$$

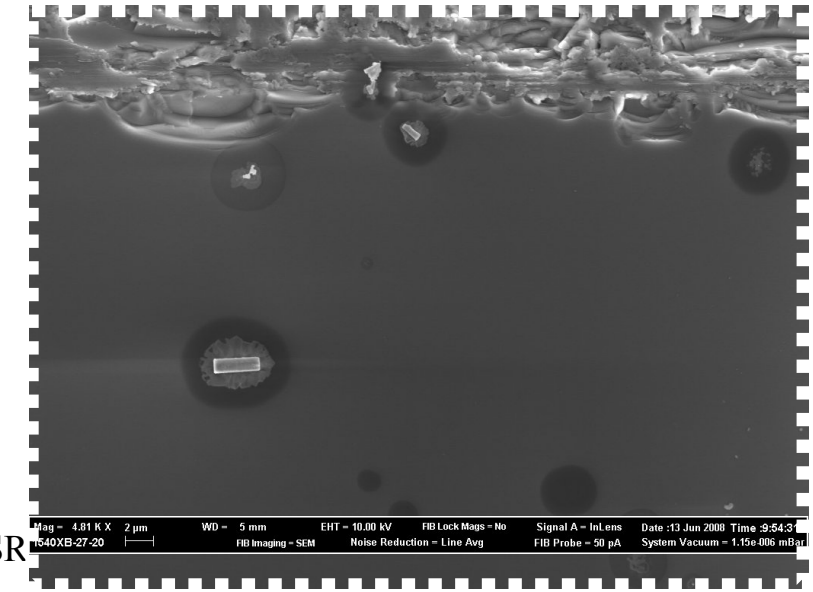
$$\delta=2.23\text{x}10^{-5}$$
$$\beta=2.19\text{x}10^{-6}$$



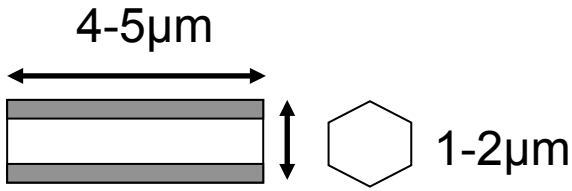
ZnO Sample Preparation







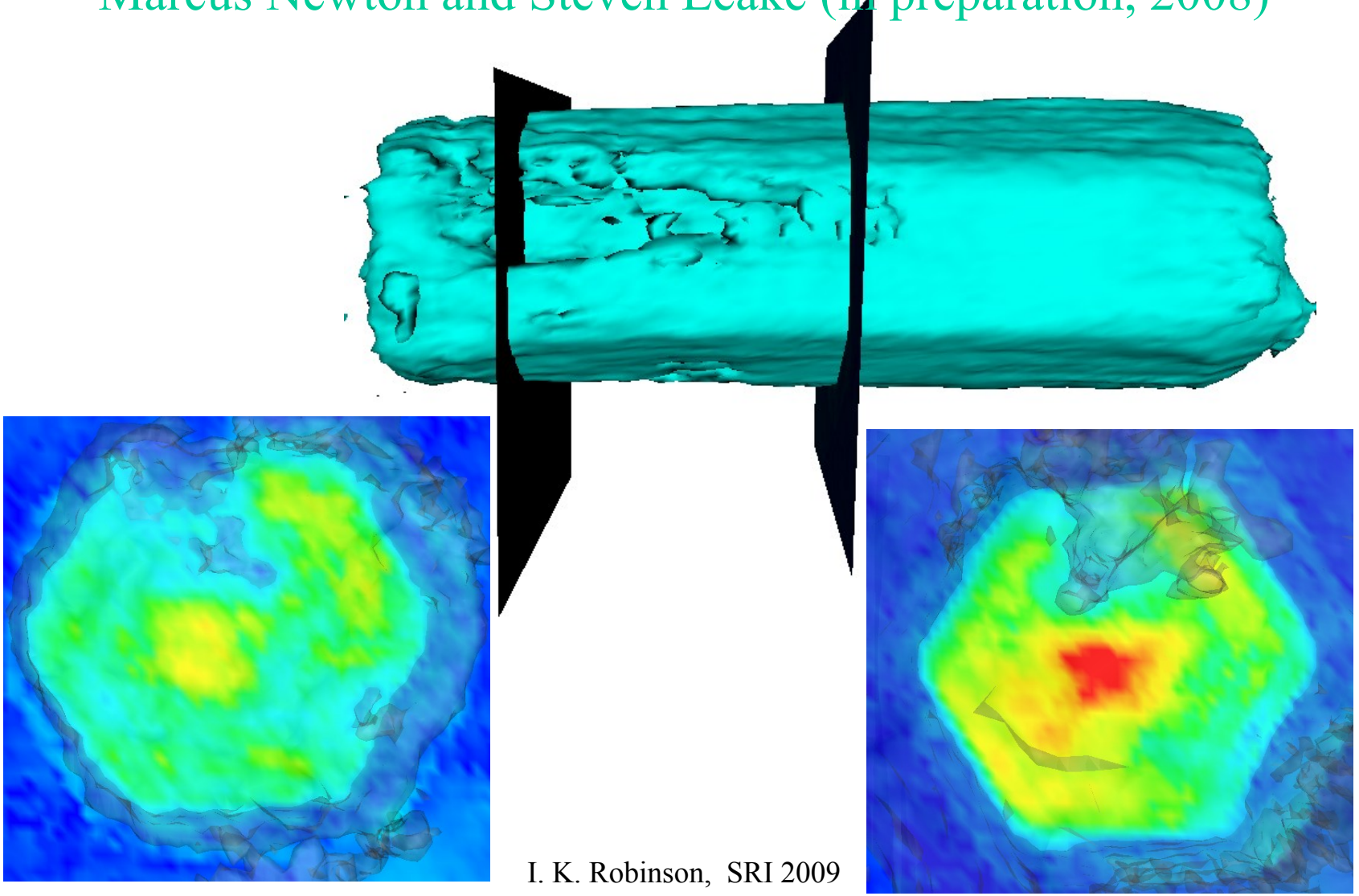
Dimensions:



I. K. Robinson, SR

Density sections ZnO-39 (010)

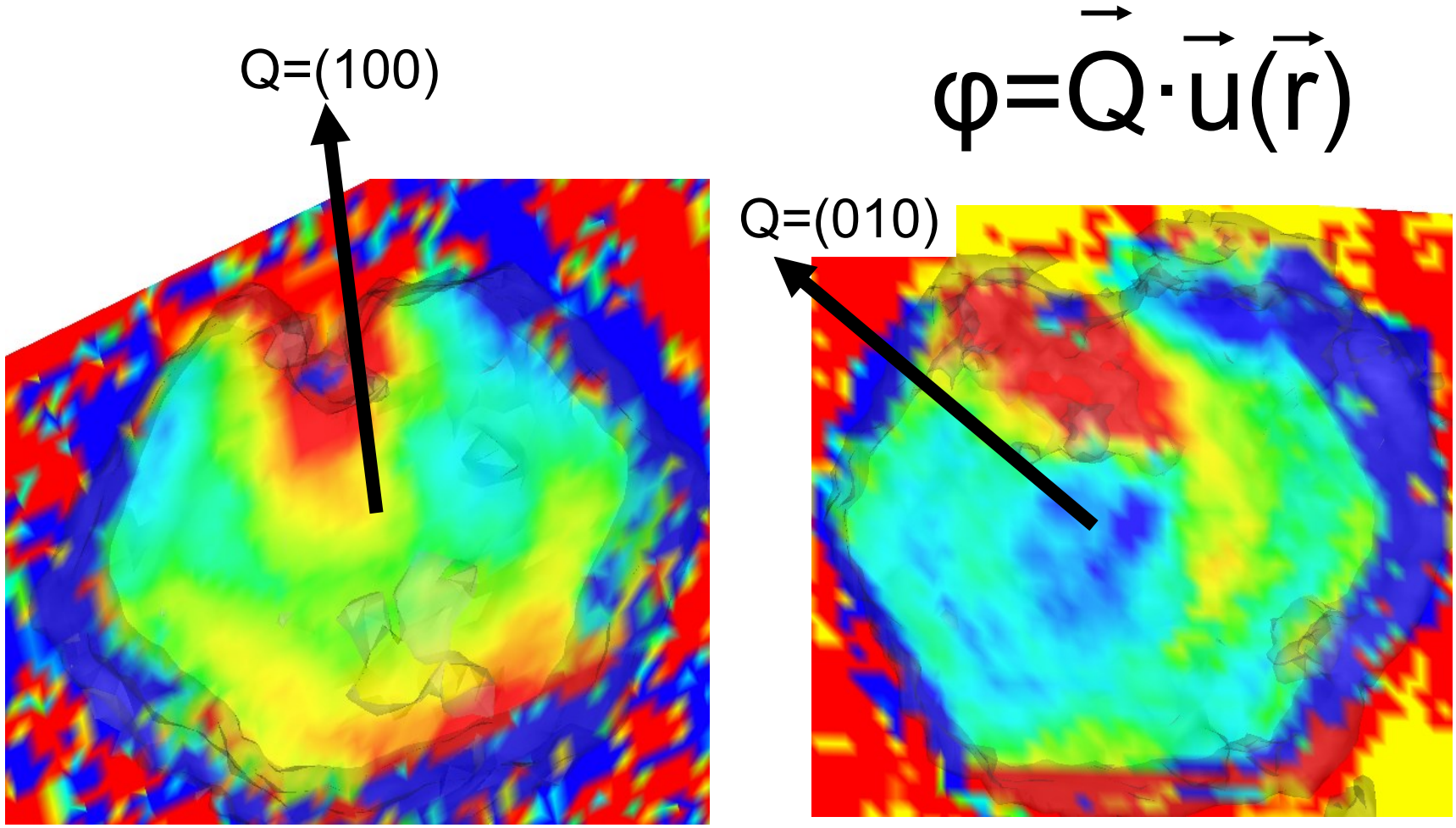
Marcus Newton and Steven Leake (in preparation, 2008)



I. K. Robinson, SRI 2009

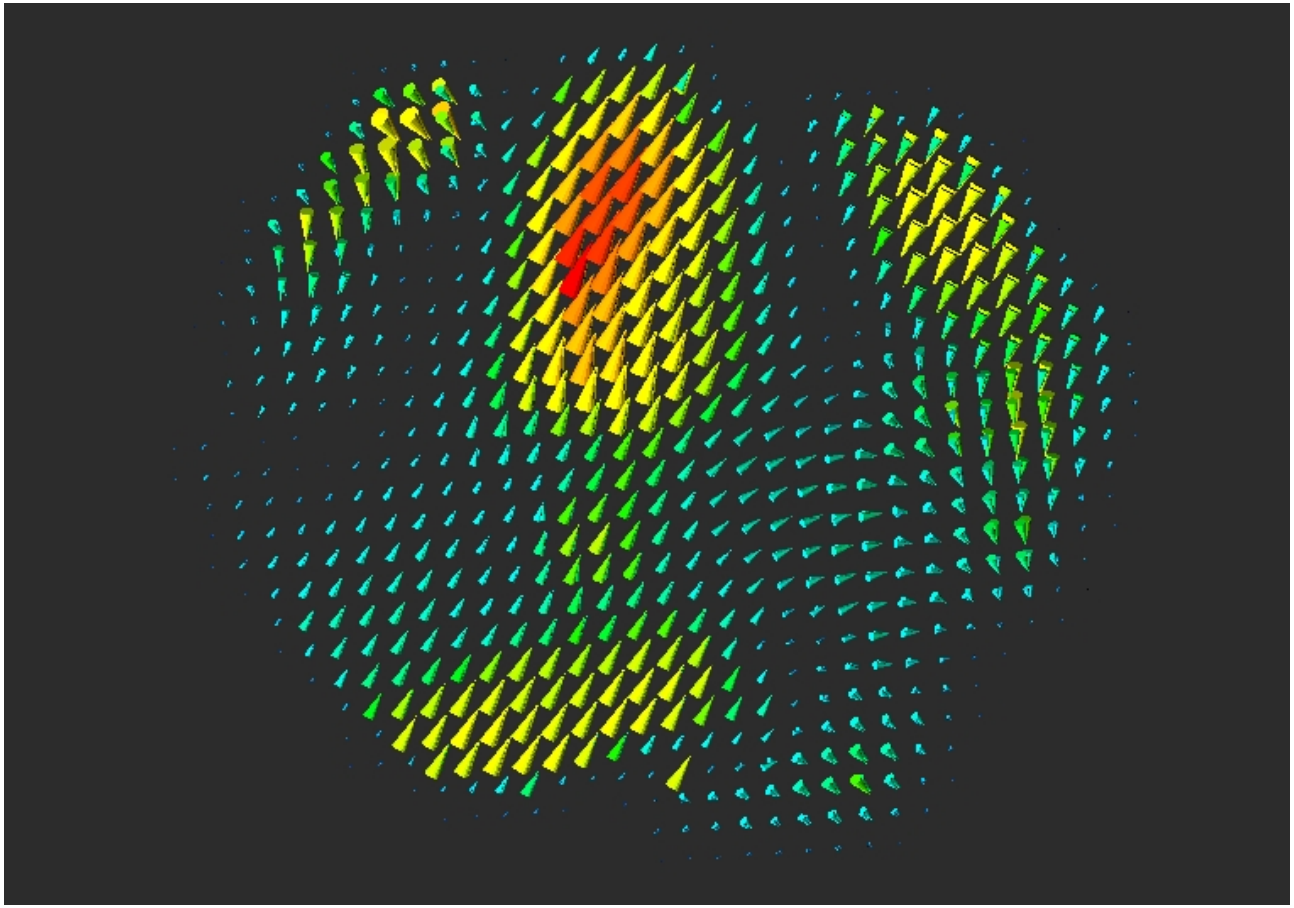
Phase maps from 2 Bragg peaks

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

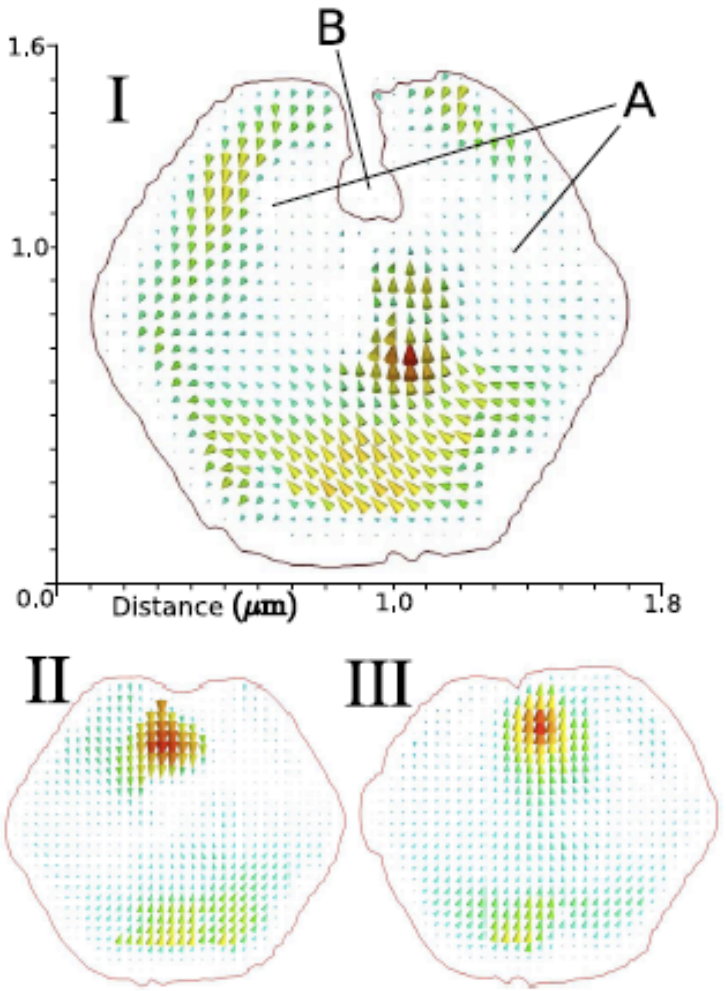


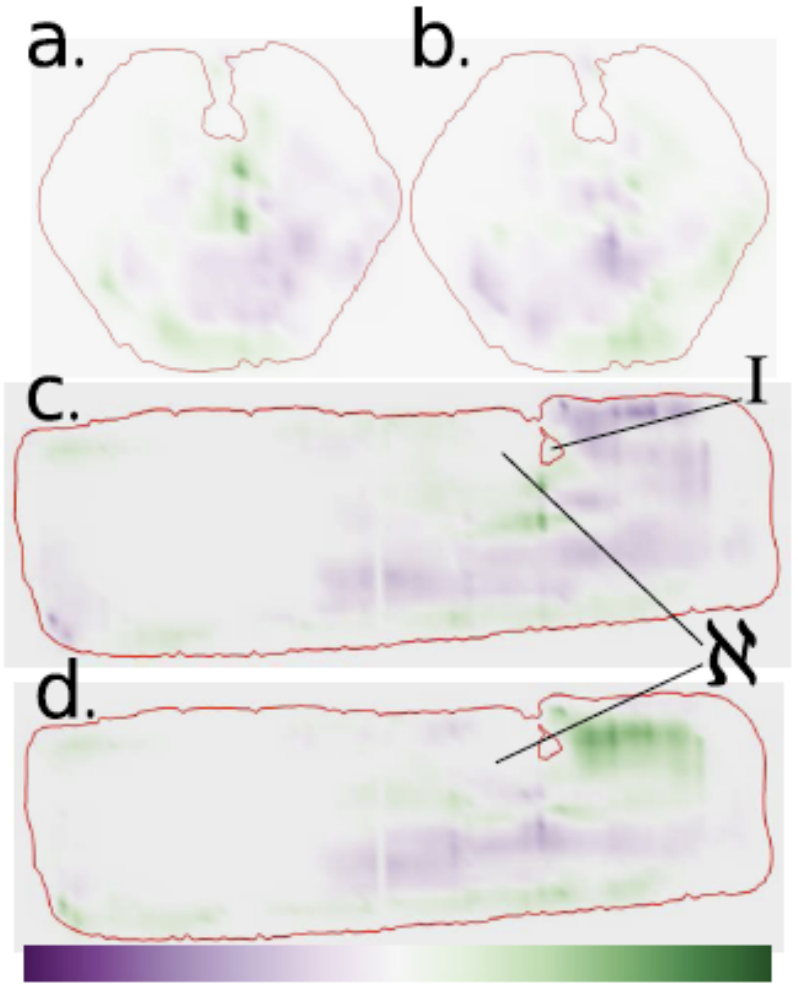
2D vector field of displacements

Marcus Newton, UCL, Jan 2009

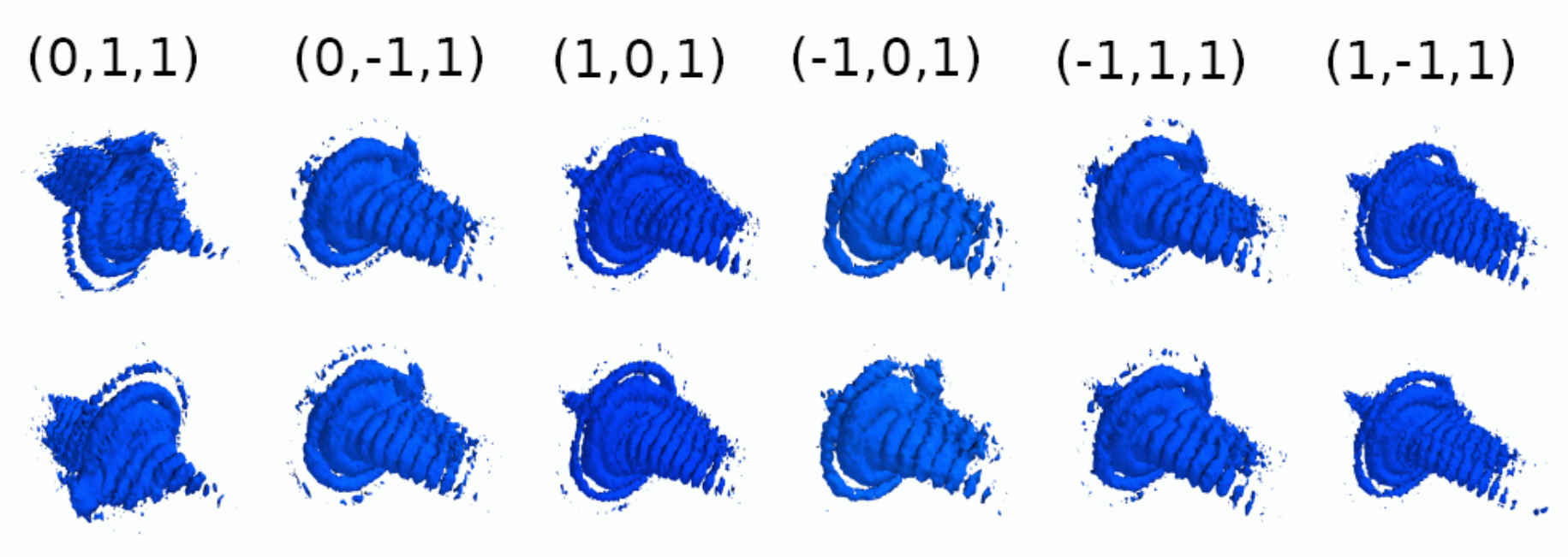


Strain and Rotation fields

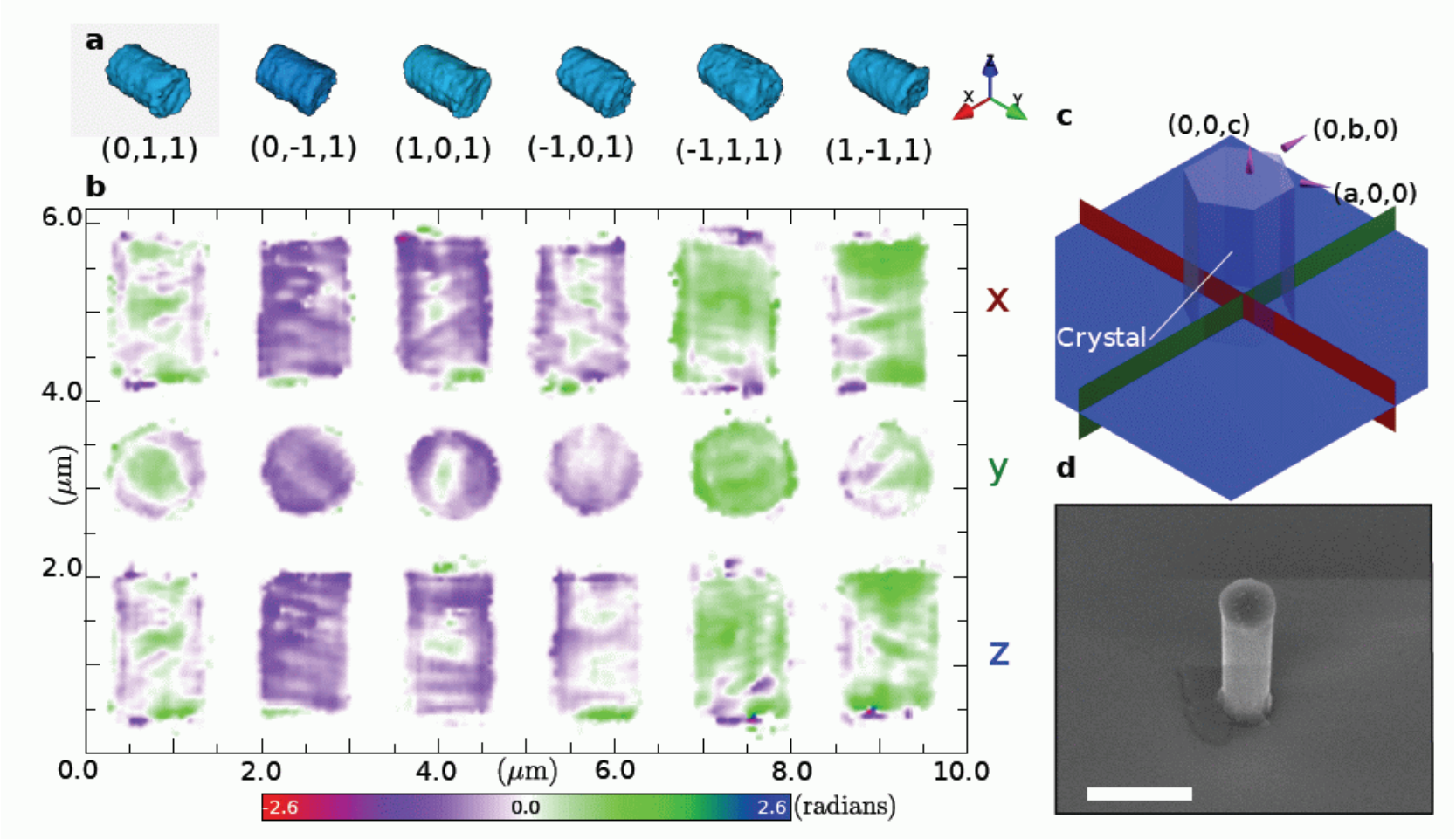




Extension to 6 Bragg Peaks

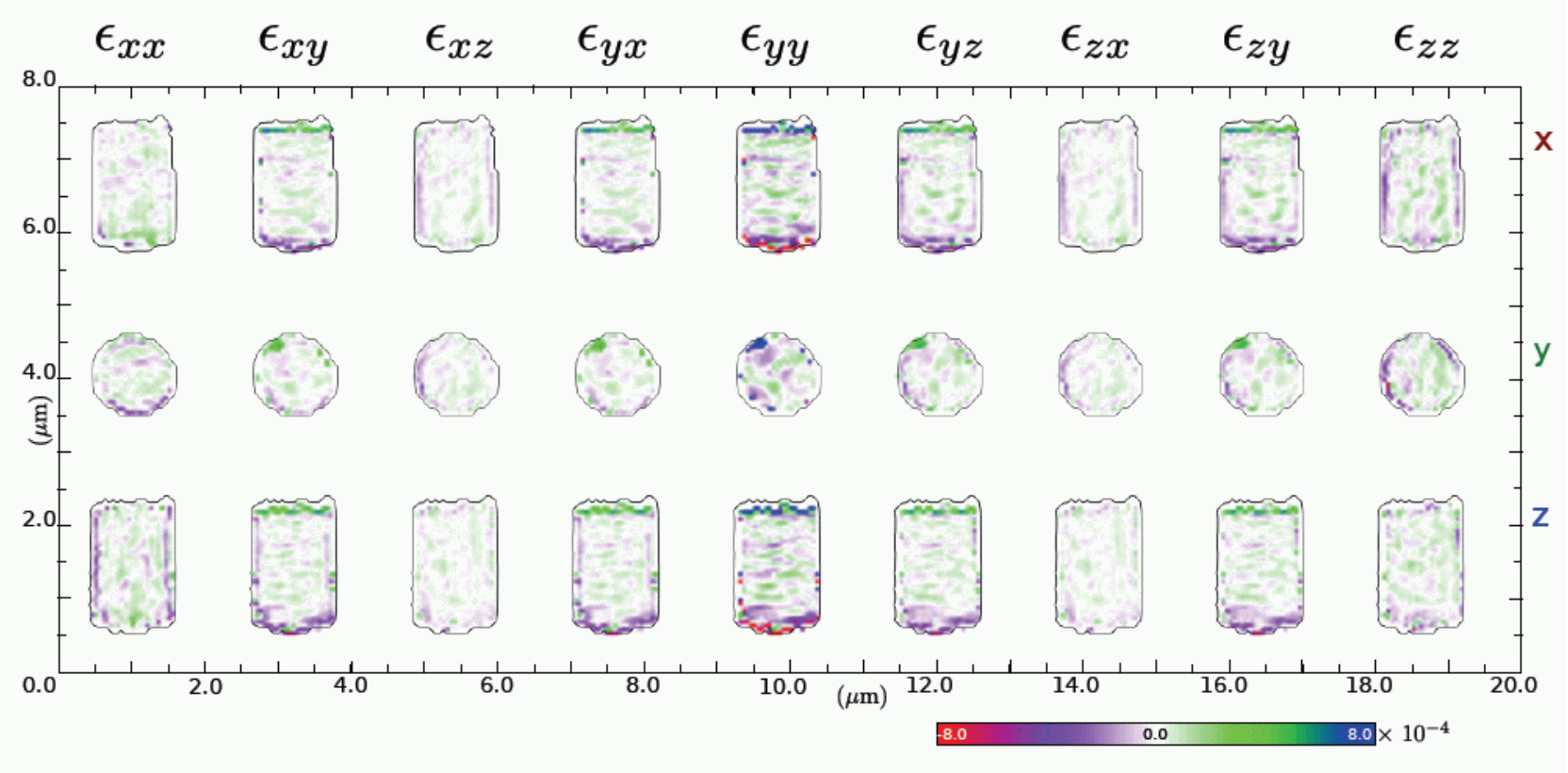


Extension to 6 Bragg Peaks

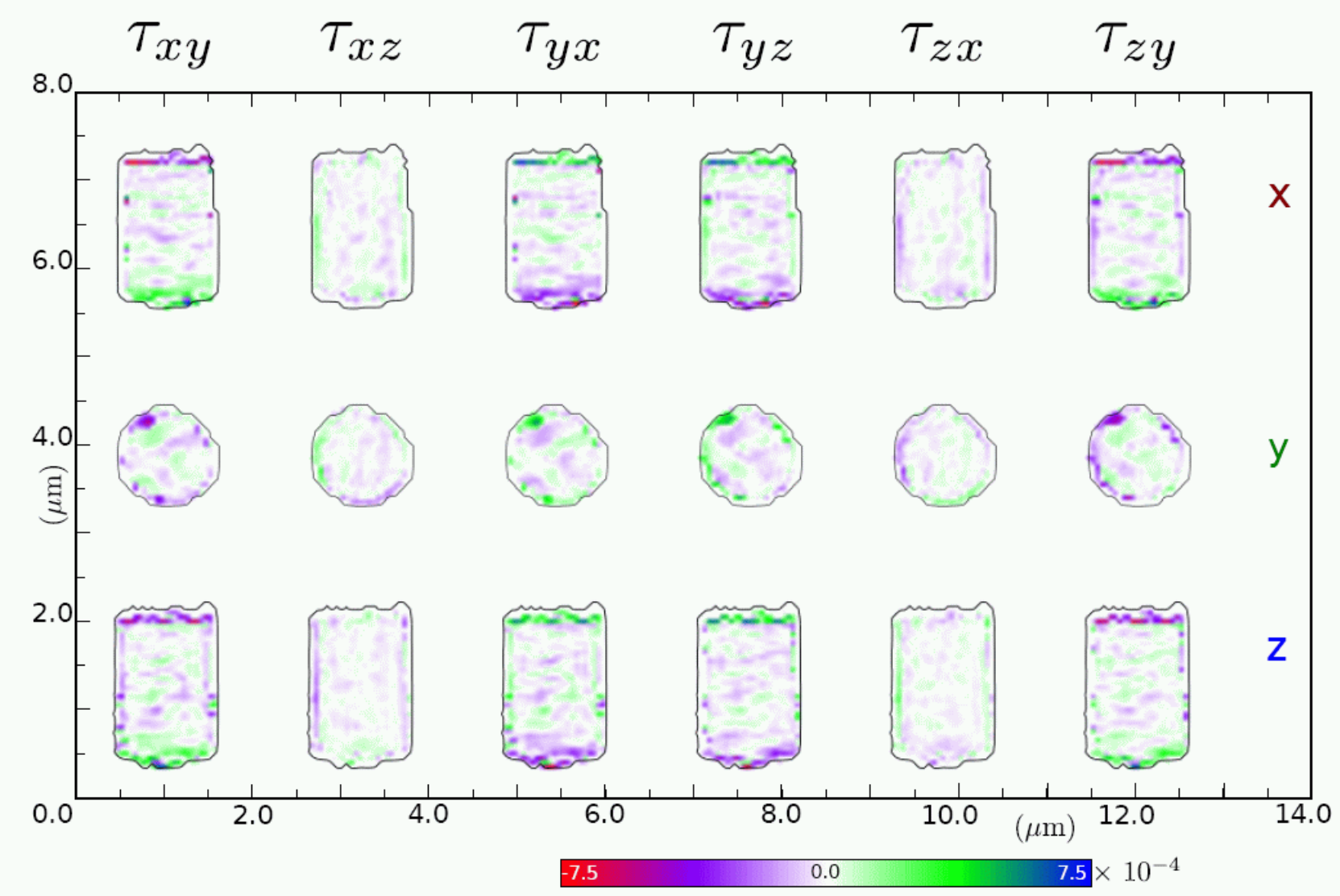


Full Strain Tensor

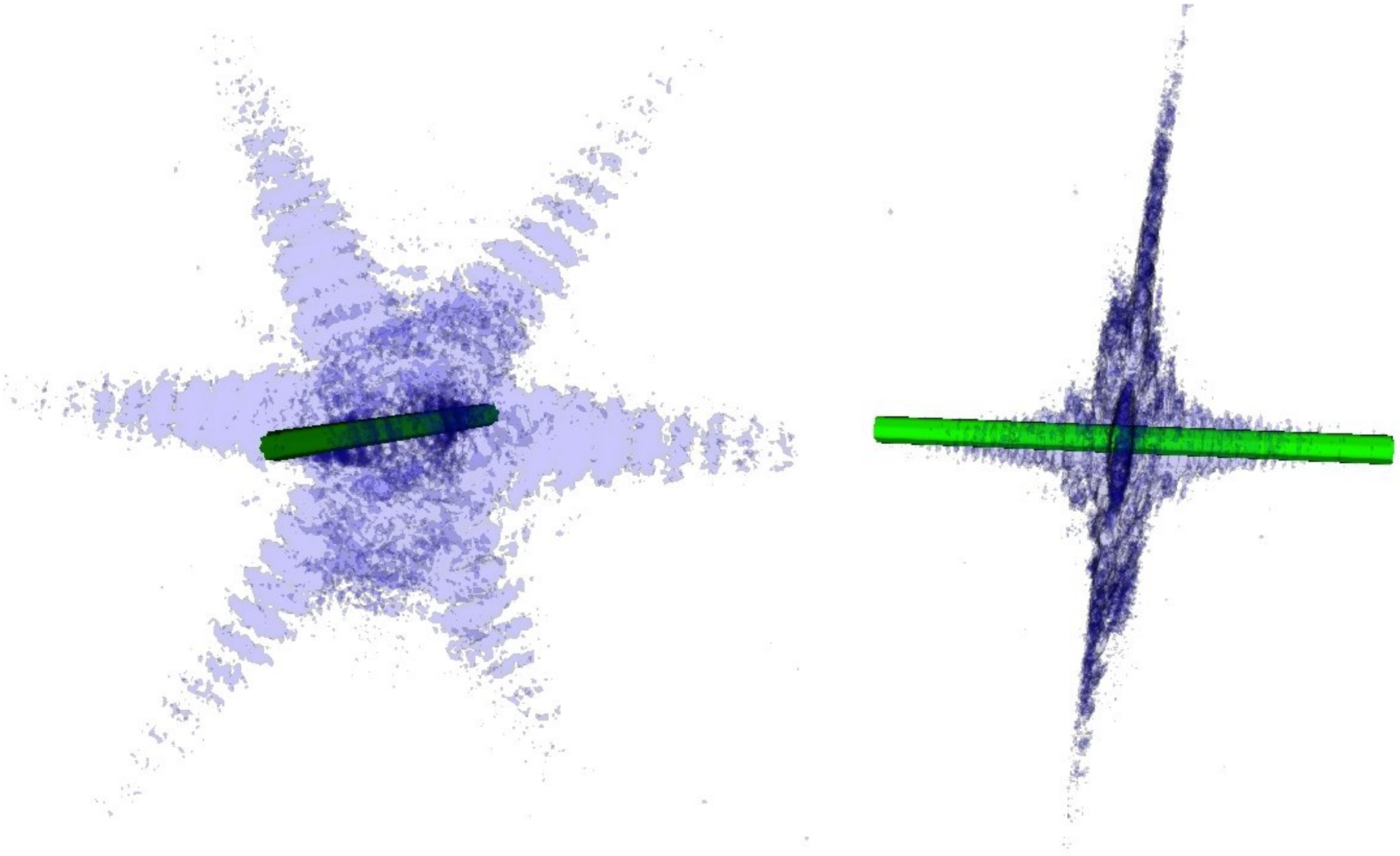
$$\epsilon_{ij} = \frac{1}{2}\left(\frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j}\right) \quad , \quad \tau_{ij} = \left(\frac{\partial u_j}{\partial x_i} - \frac{\partial u_i}{\partial x_j}\right)$$

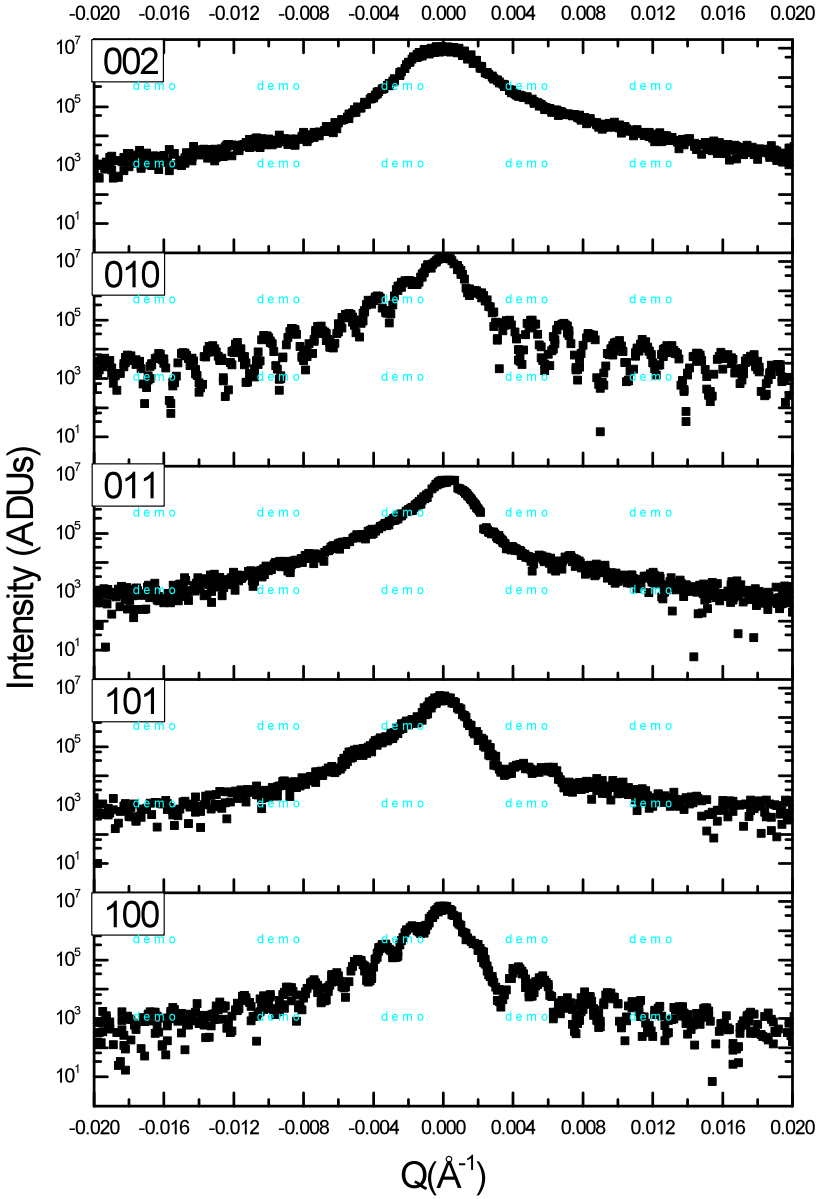


ZnO Rigid-body Rotations



How to extract the contrast data





Five Bragg peaks

002 no fringe visibility

010 & 100 good fringe visibility

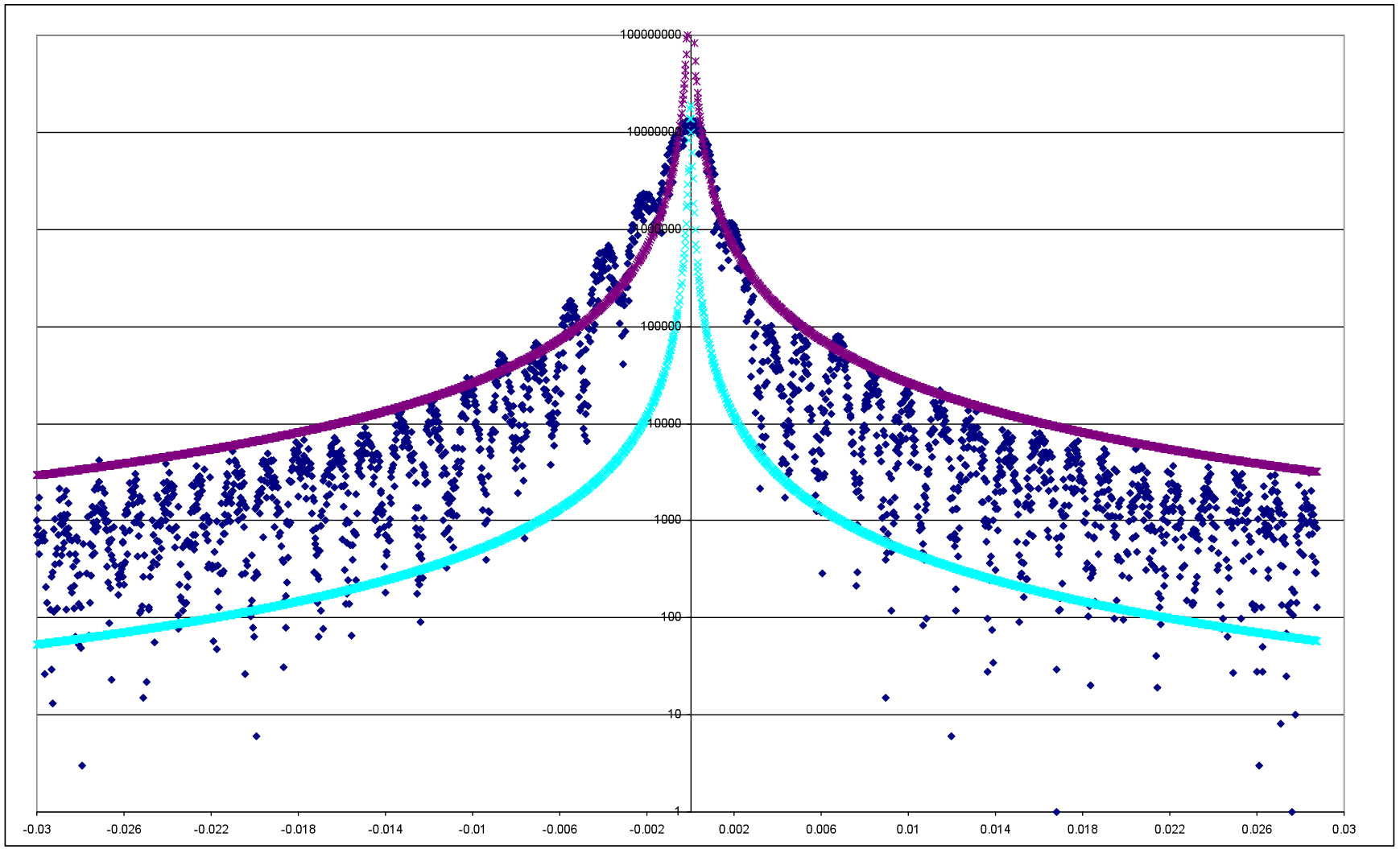
101 & 011 diminished fringe visibility
but fringes still evident

010:011 & 101:100
show complementary fringes
but not between each other

Error in coordinate transform ruled out

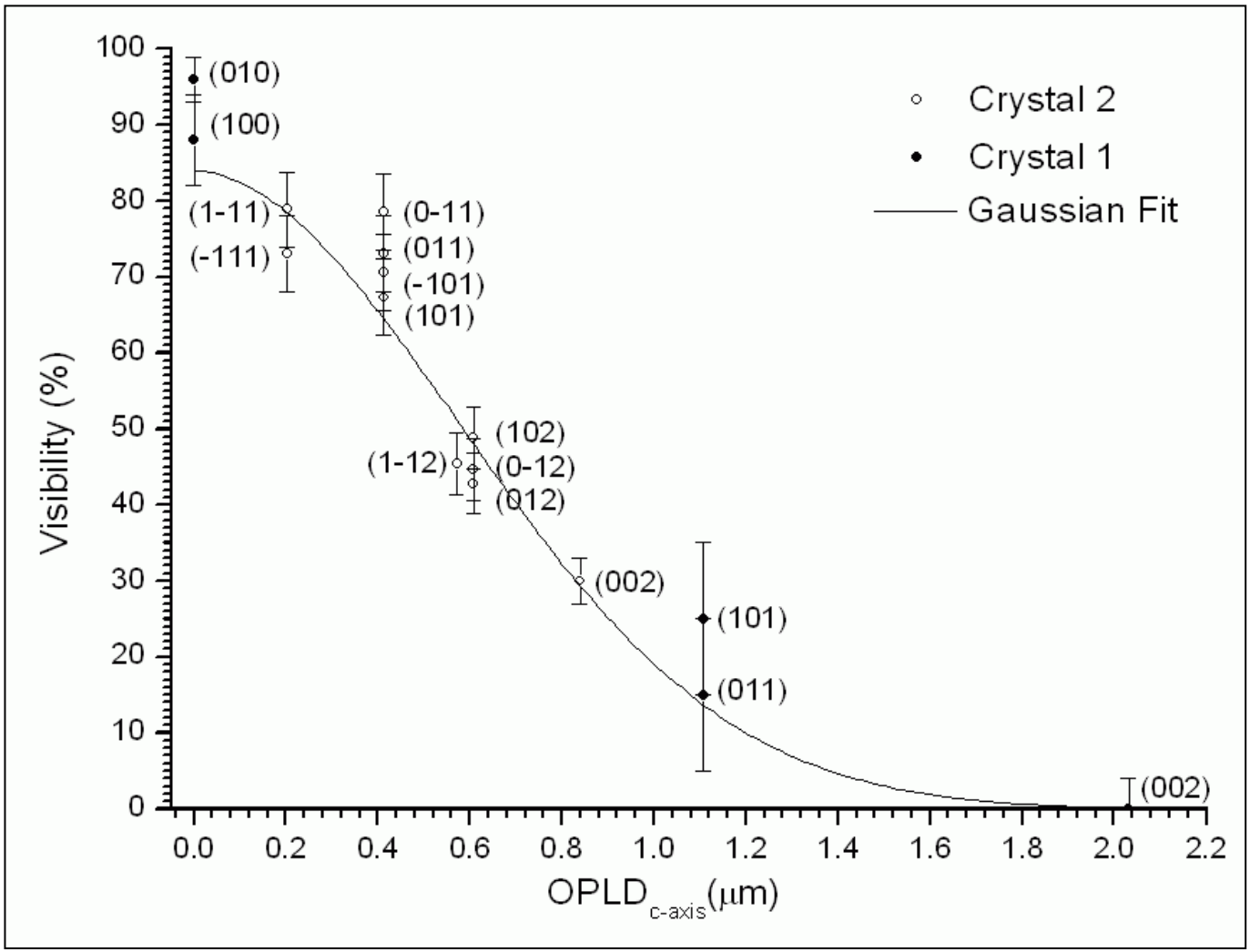
010 and 100 reflections fringe spacing
difference ~ 20%

Fringe Visibility 96±2% @010



Measured Longitudinal Coherence

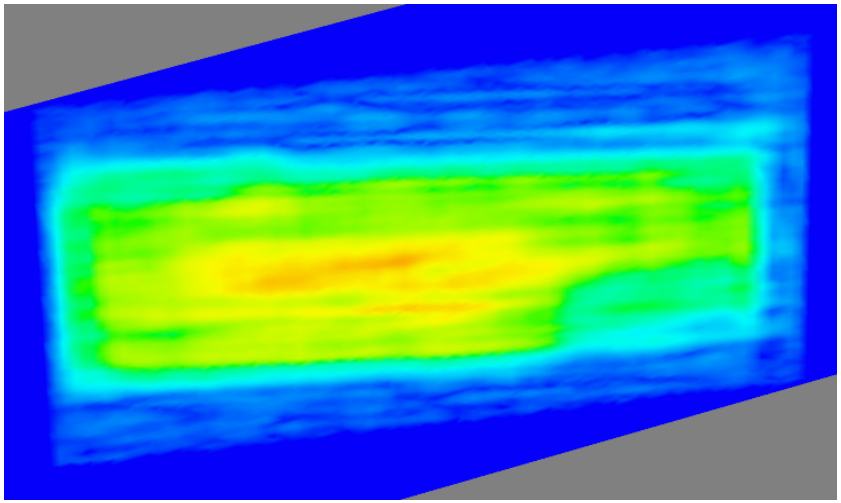
S. Leake, M. Newton, R. Harder and I. Robinson, Optics Express 17 15853 (2009)

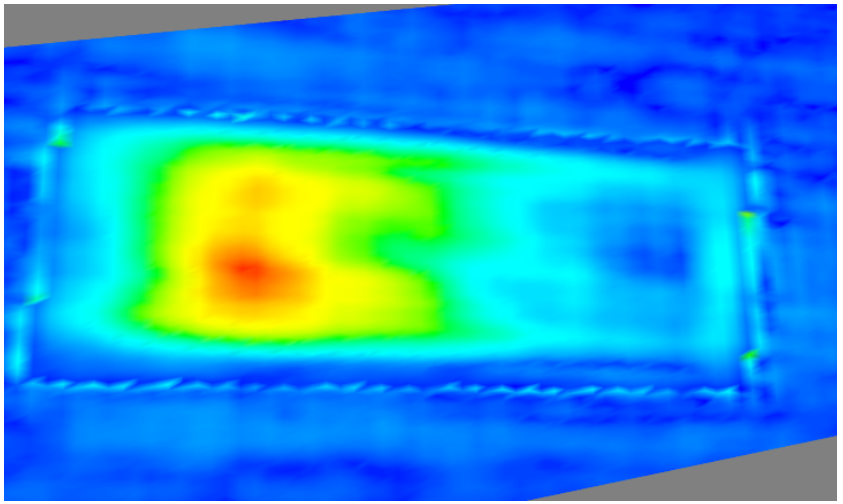


Density Section of Reconstruction using 100 and 101 reflections

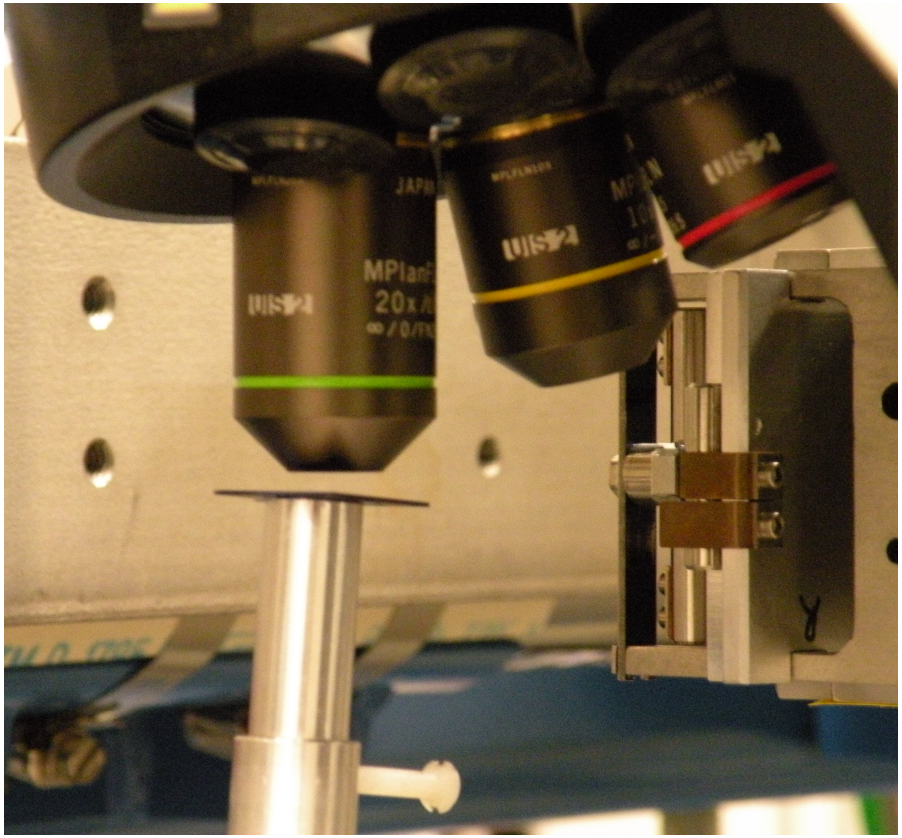
"hot spot" more developed for limited coherence

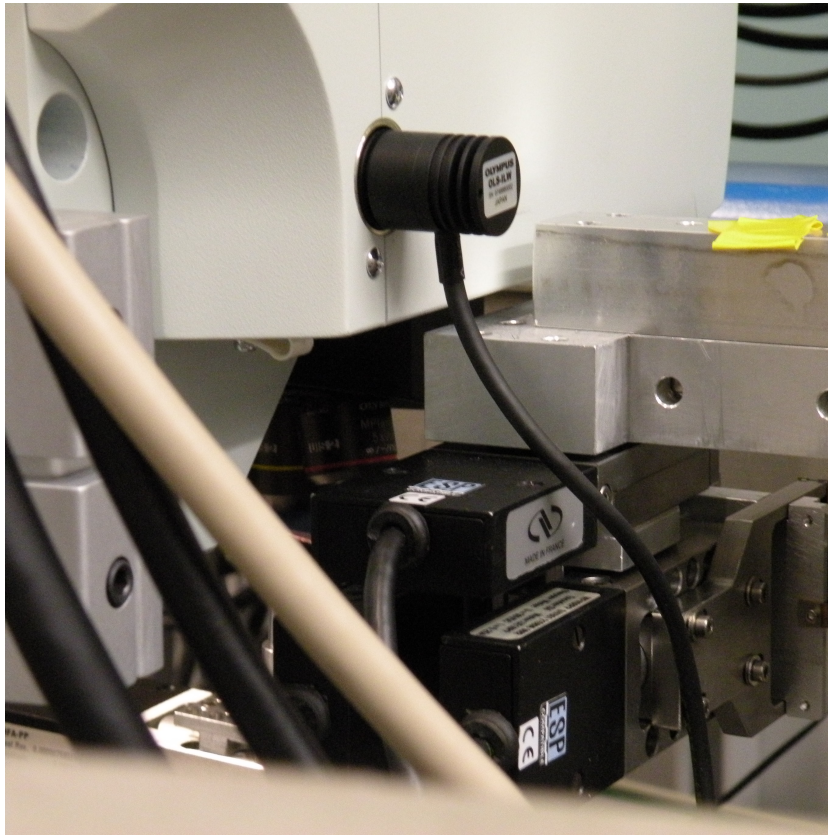
S. Leake, M. Newton, R. Harder and I. Robinson, Optics Express 17 15853 (2009)





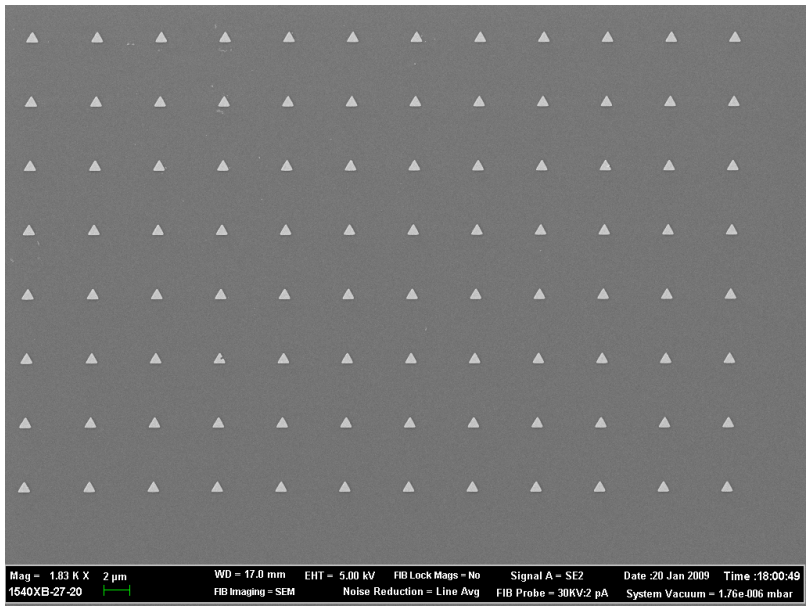
Confocal Alignment Microscope

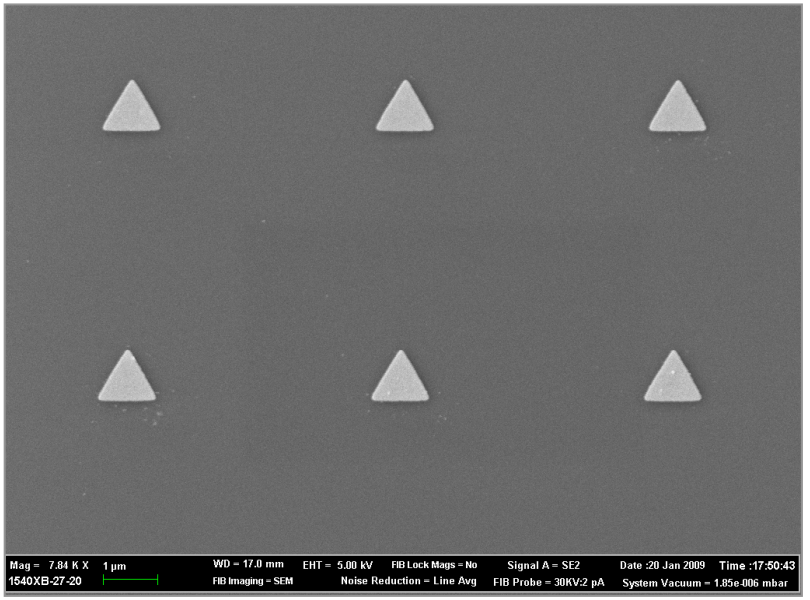




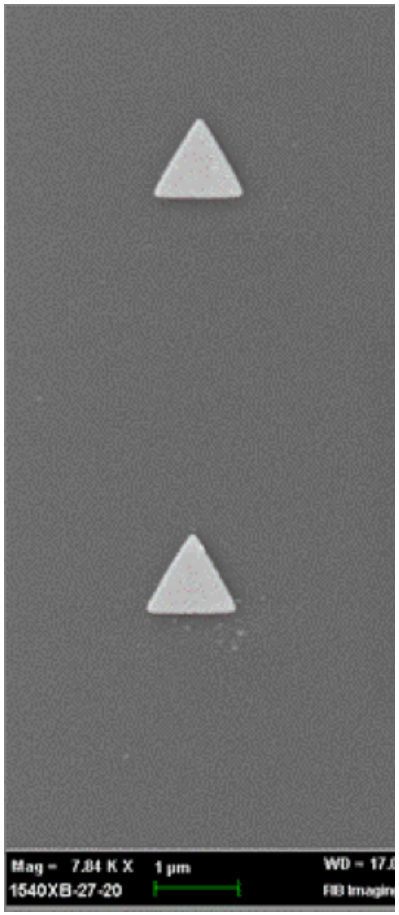
Patterned Au nanocrystal samples

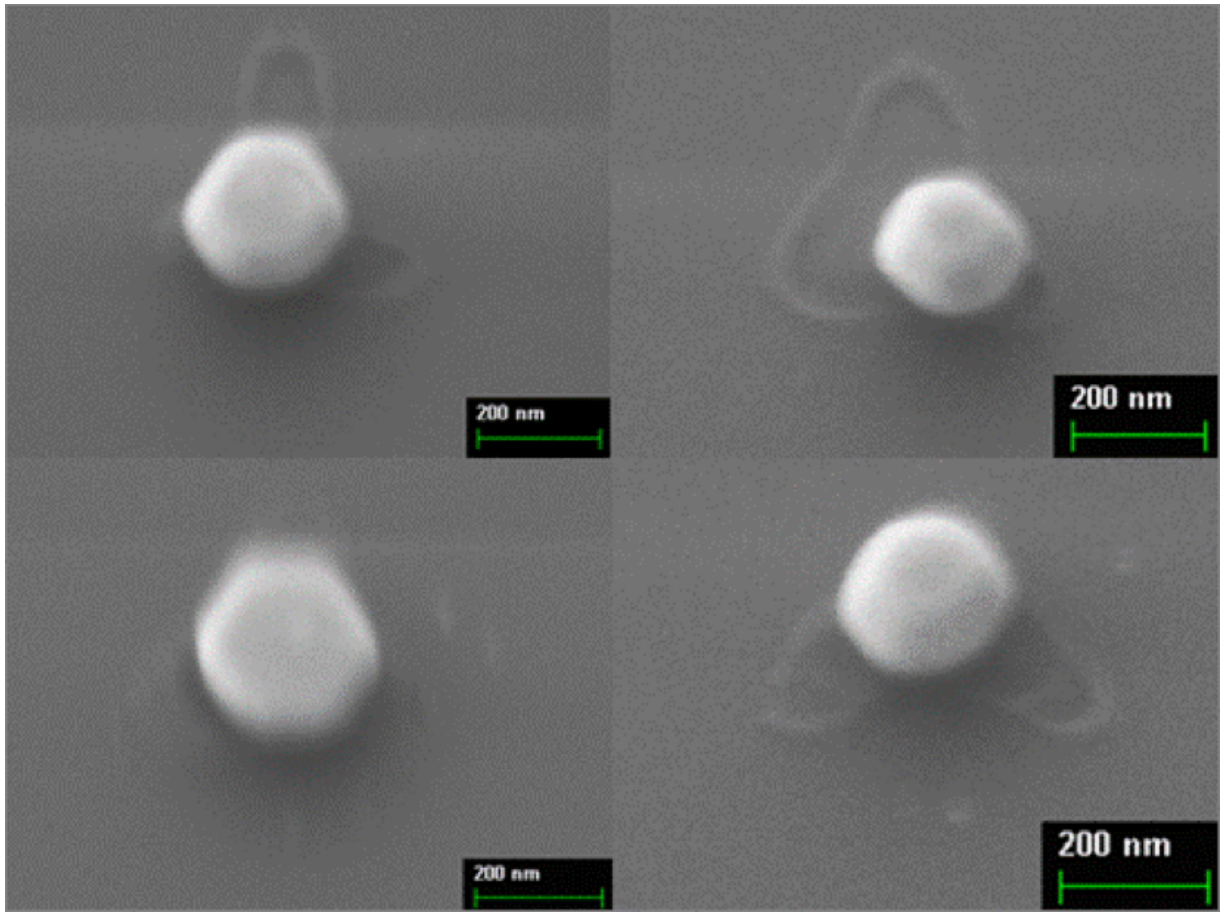
N. Shimamoto, Waseda University, Japan



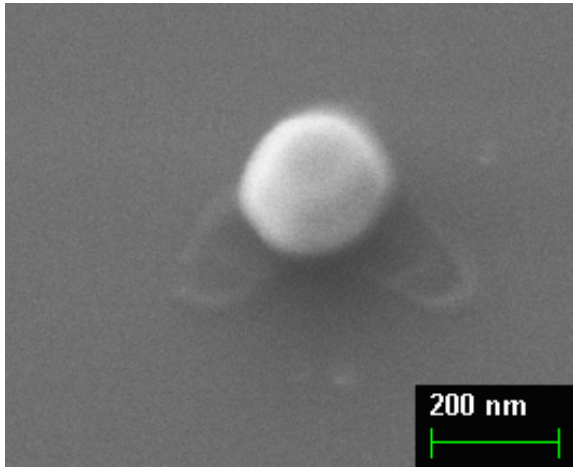


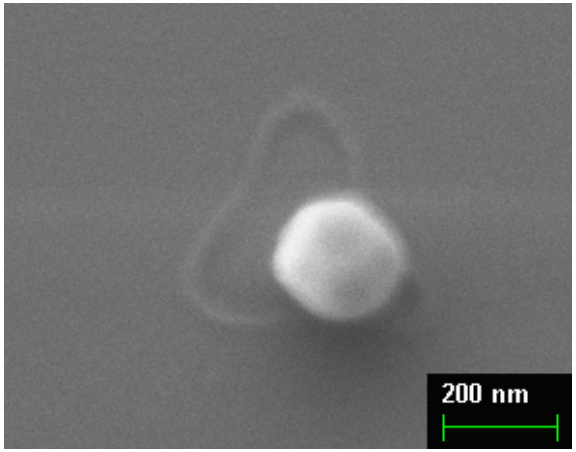
Single Au nanocrystal synthesis

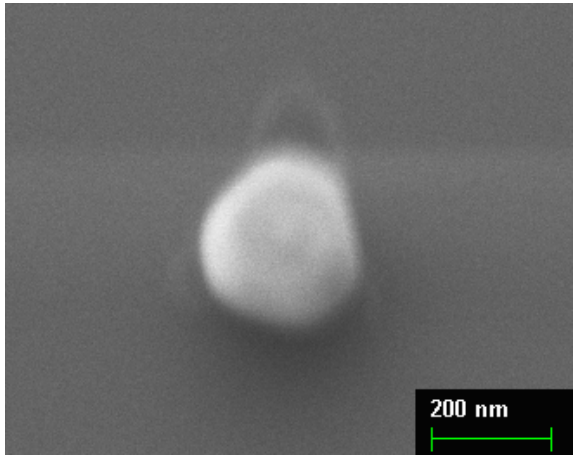


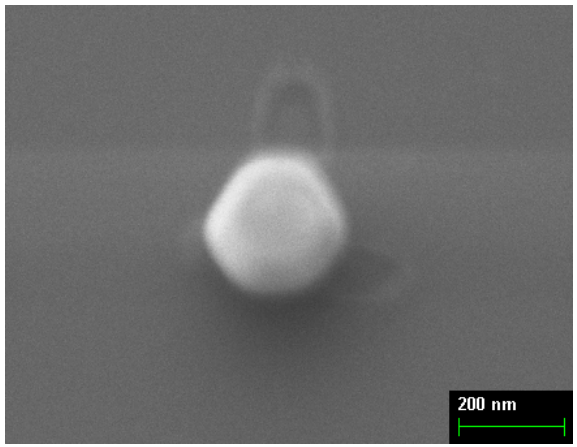


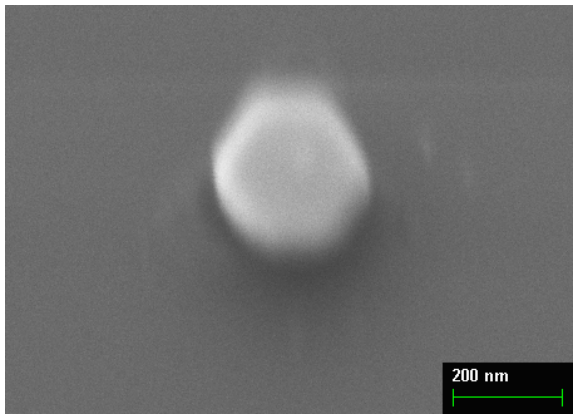
SEM images of Crystals after 950C anneal for 8hrs

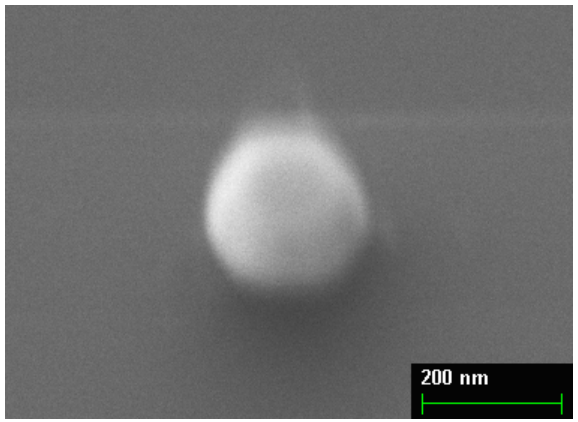


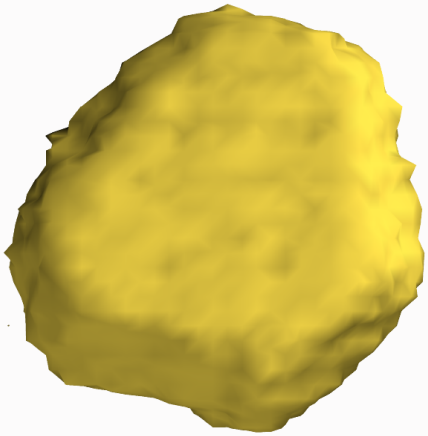












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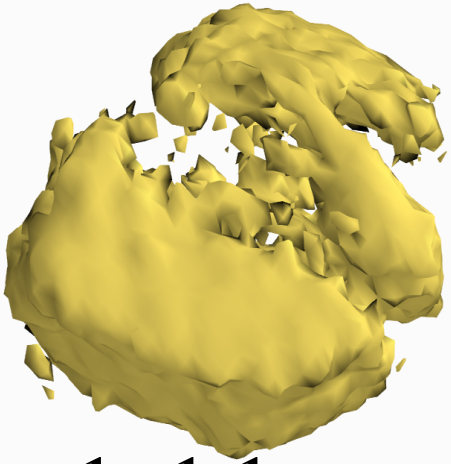

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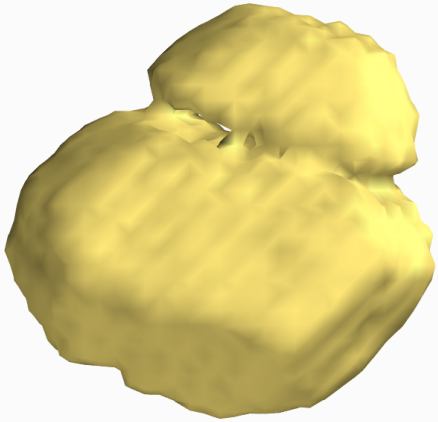

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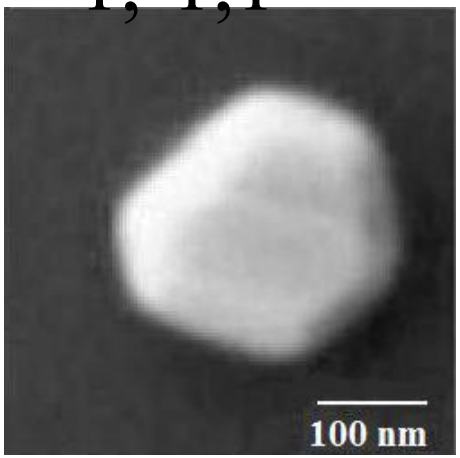
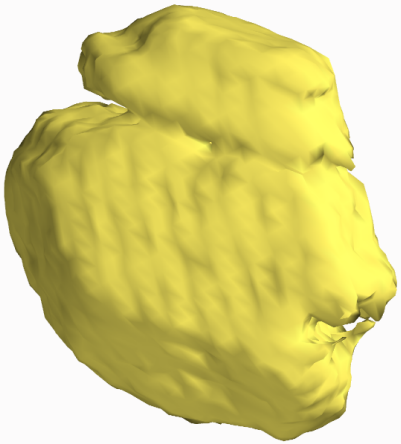
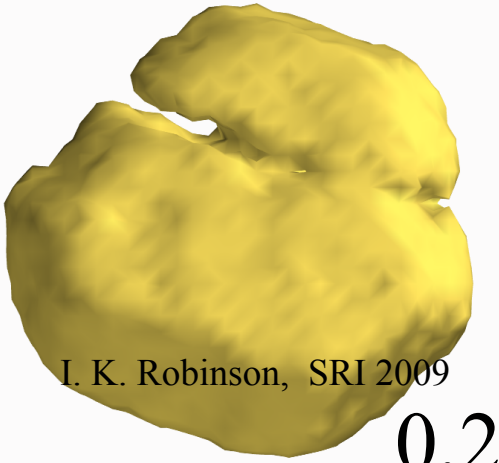


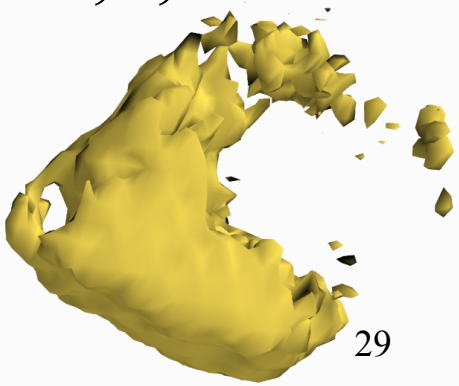
2,0,0

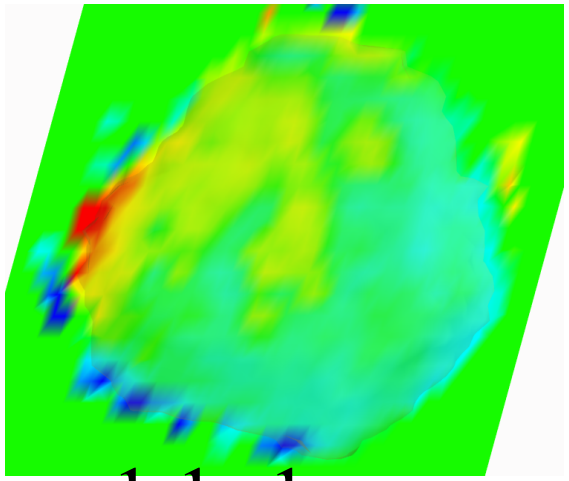




0,2,0

0,0,2





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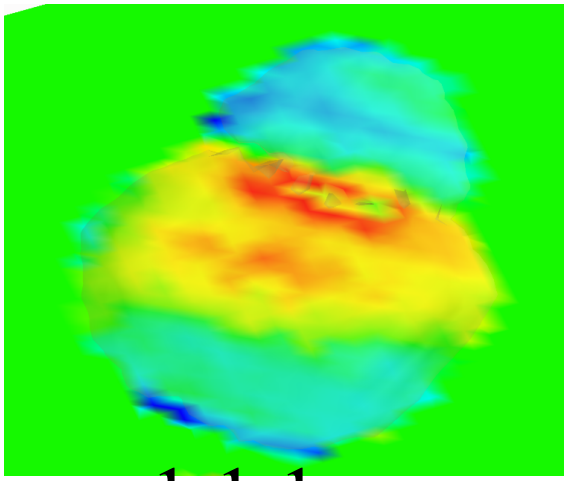

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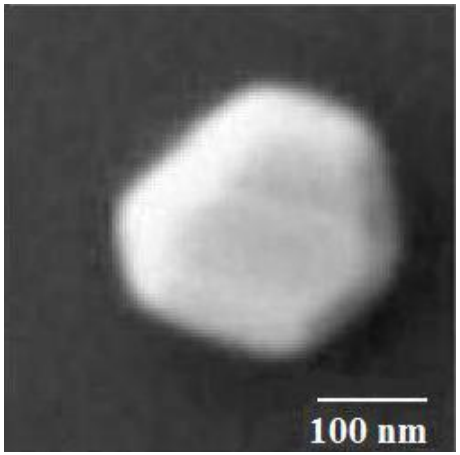
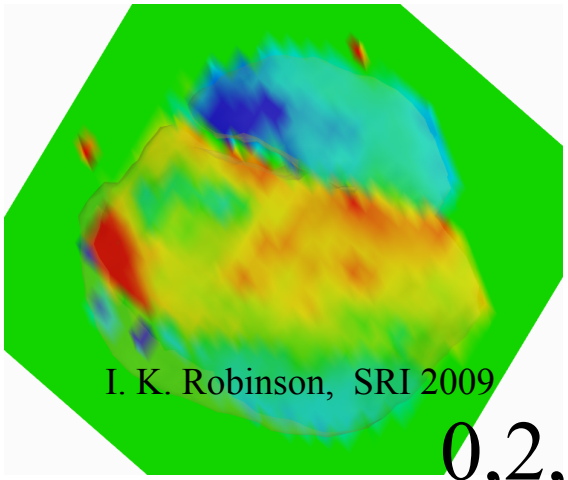
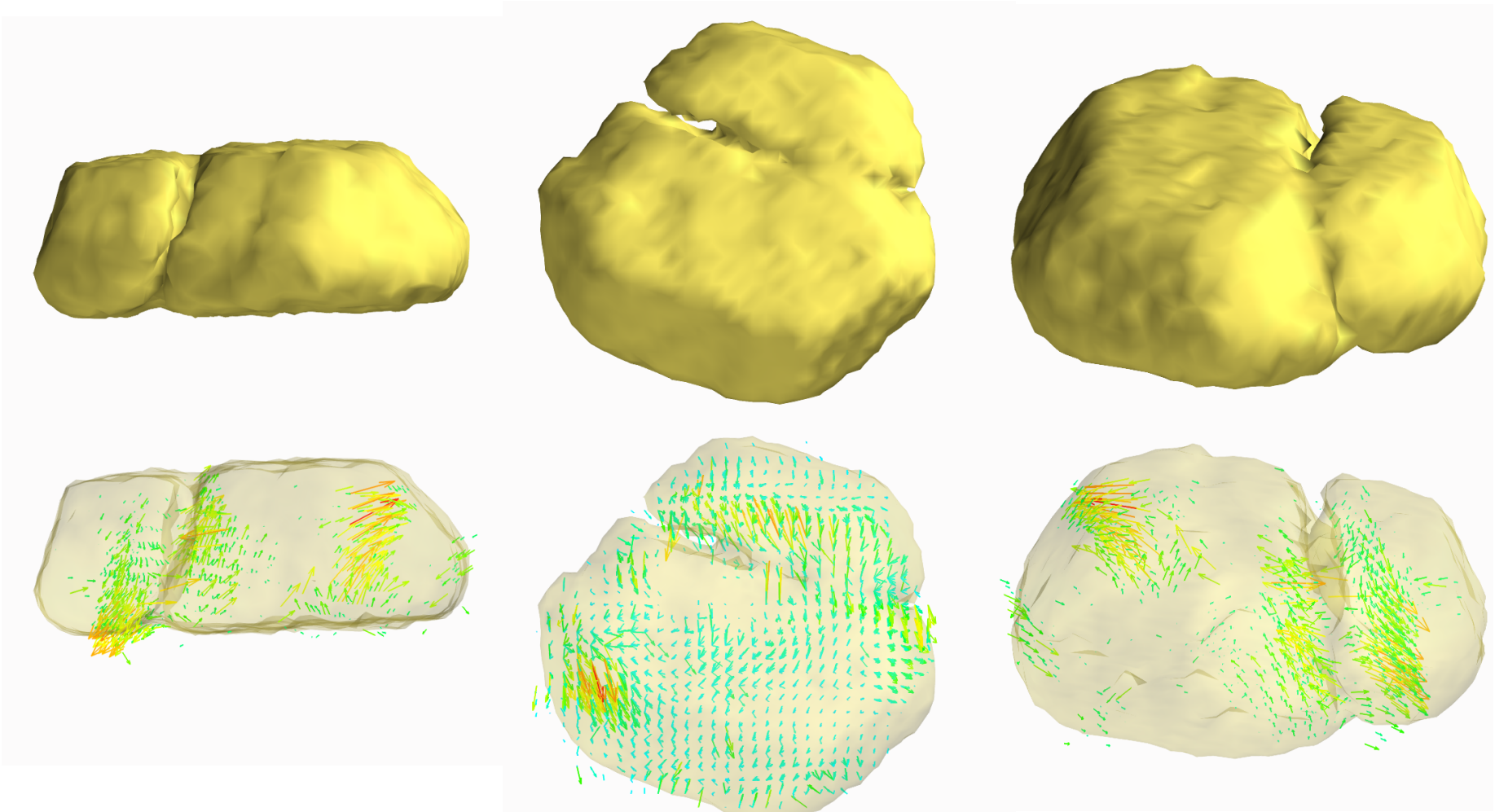




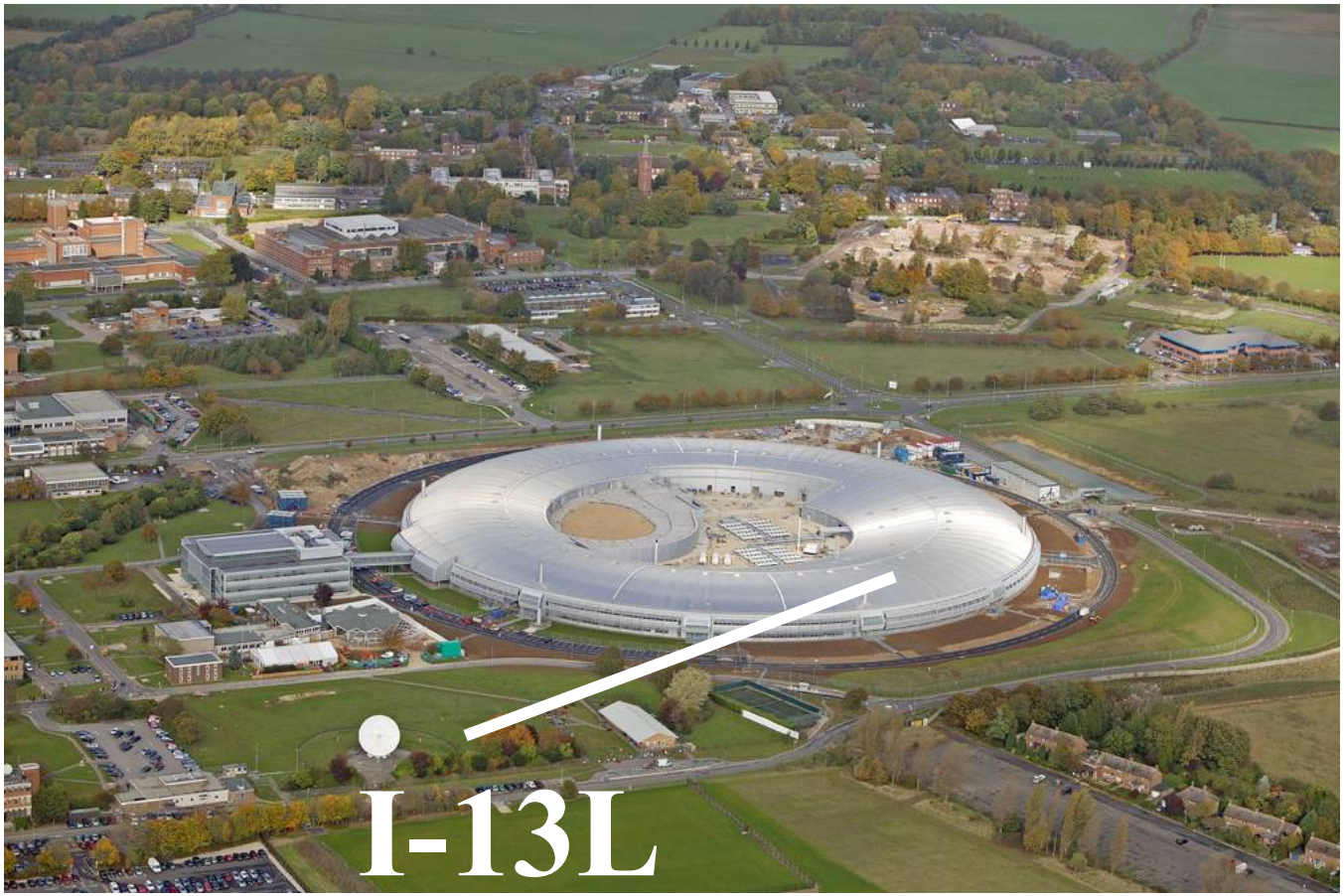
0,2,0

Vector displacement field

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



Diamond Light Source (RAL)



Conclusions

- Internal structure of Au and ZnO Nanocrystals
- Phasing by computation instead of lens
- Strain fields imaged from asymmetric patterns
- Coherence mapped with multiple Bragg peaks
- Full strain tensor requires multiple Bragg peaks
- Confocal microscope solves sphere of confusion