

Application of Coherent X-ray Diffraction imaging to Domain Structures

Ian Robinson

Ross Harder

Steven Leake

Marcus Newton

Richard Bean

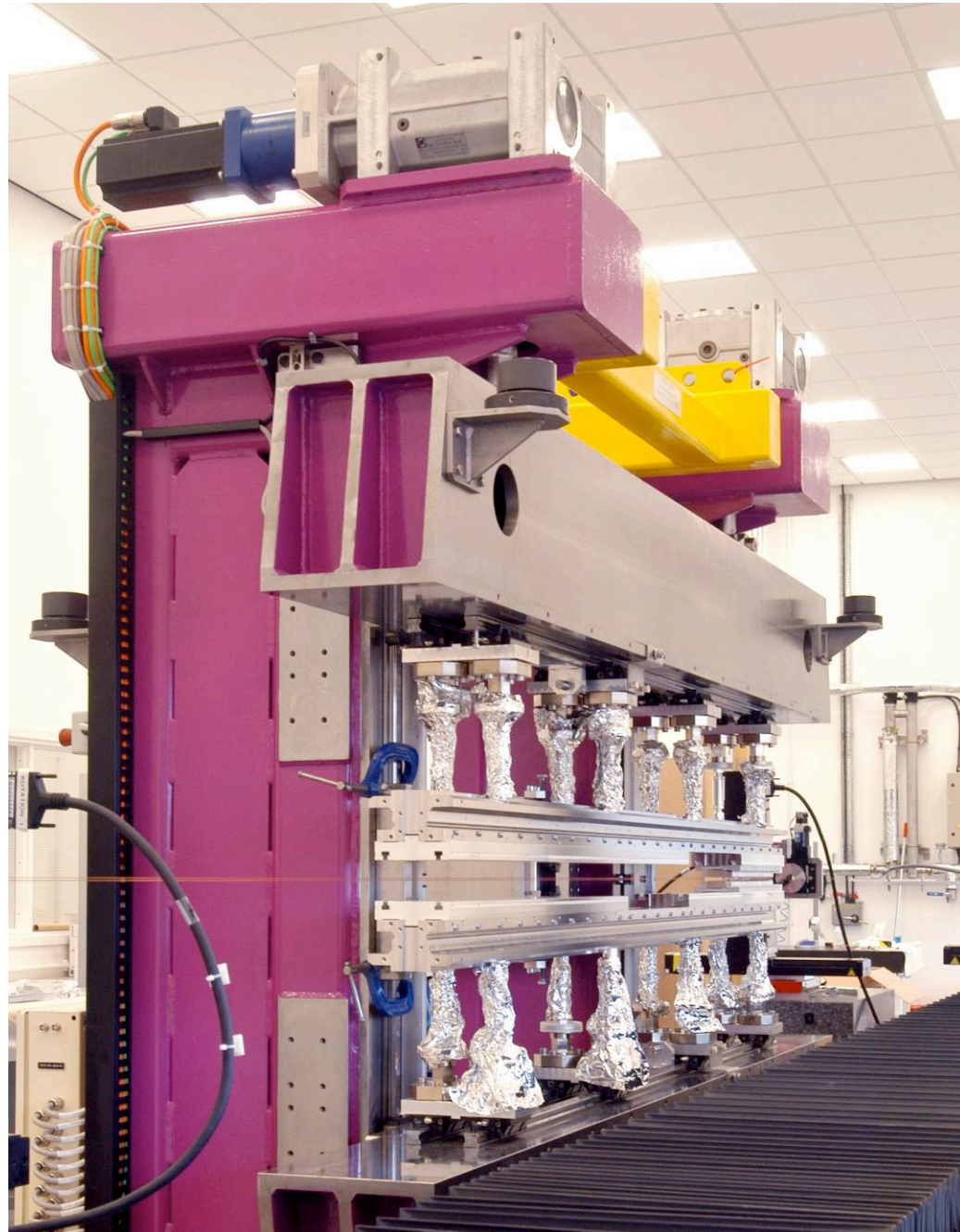
London Centre for Nanotechnology
Diamond Light Source

CFEL Seminar
Hamburg
February 2009

Outline

- Coherent X-ray Diffraction imaging of small crystals and strain fields
- Partial coherence effects
- Domain speckle patterns
- Ptychography
- Preparations for XFEL

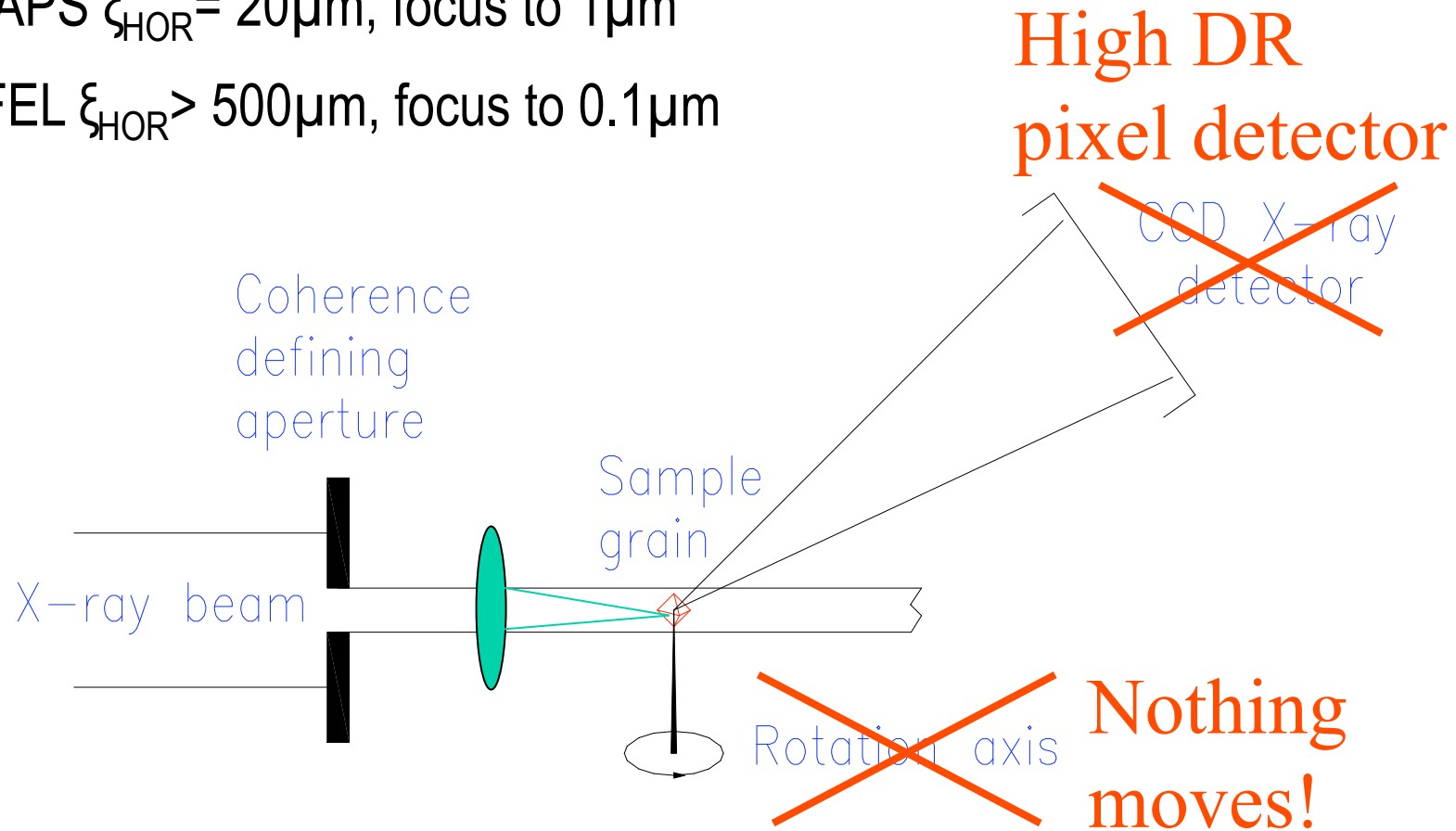
Diamond
in-vacuum
X-ray
Undulator

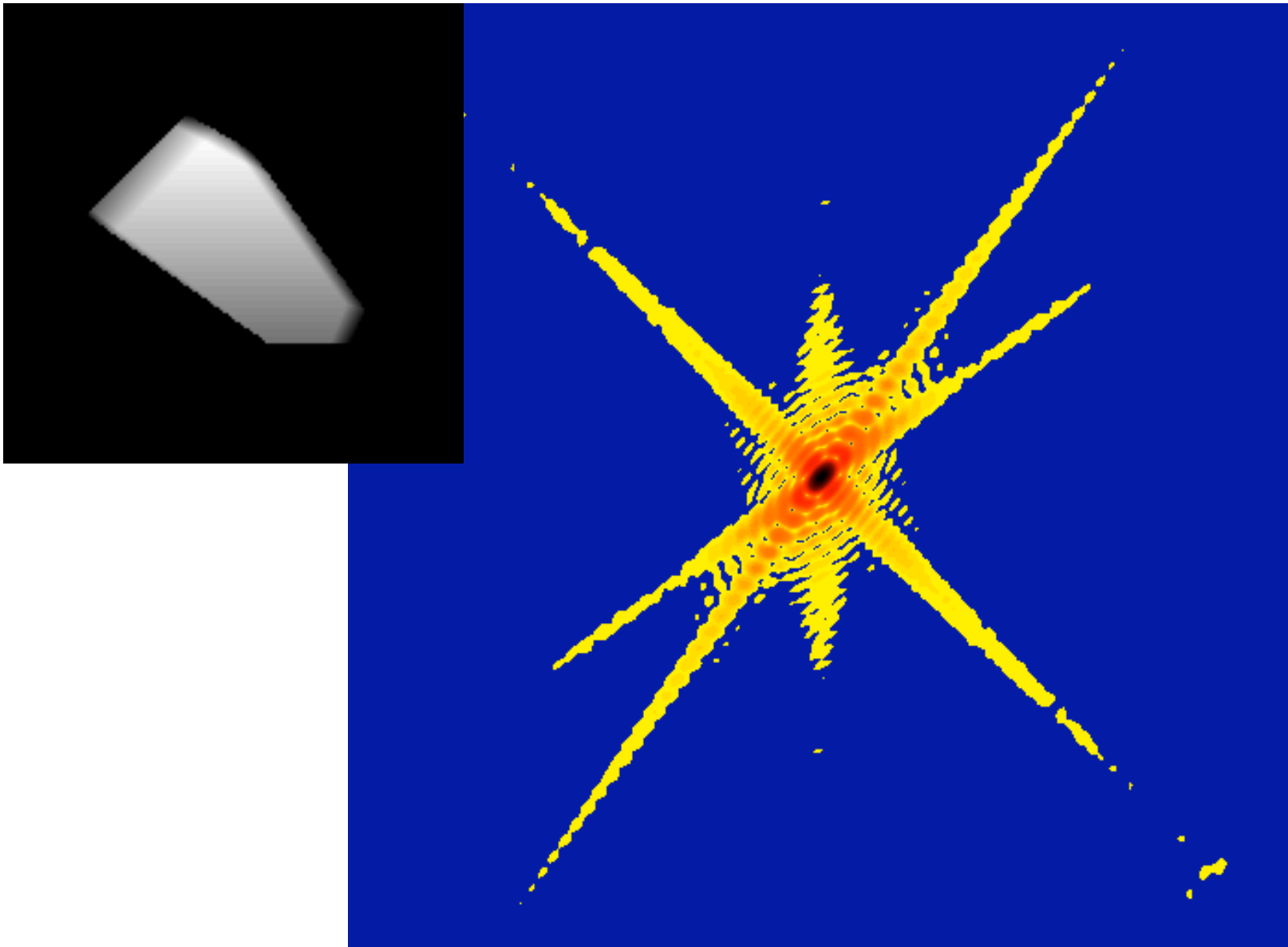


Coherent X-ray Diffraction Imaging

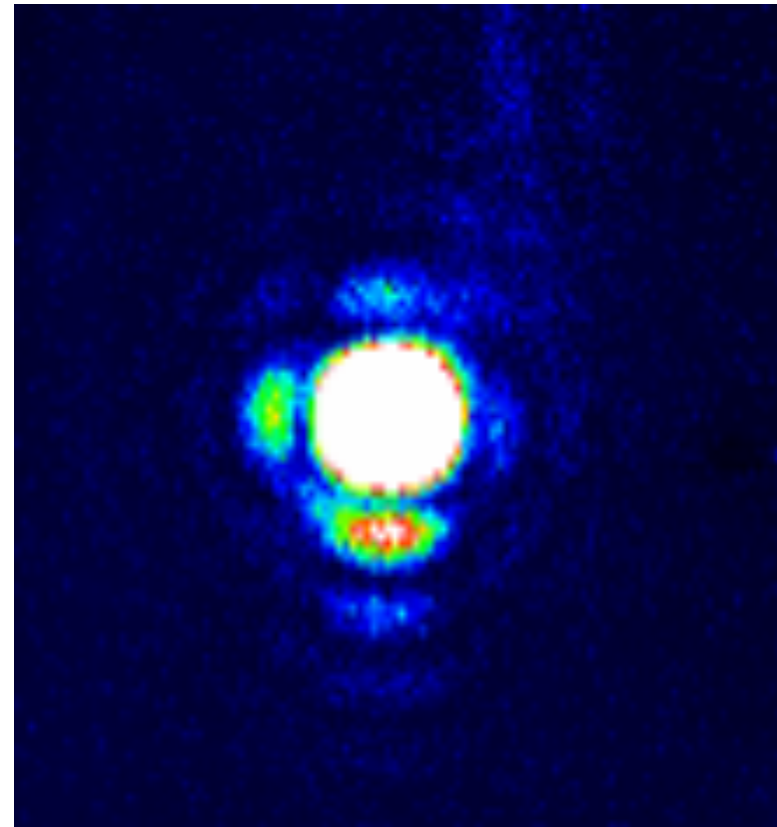
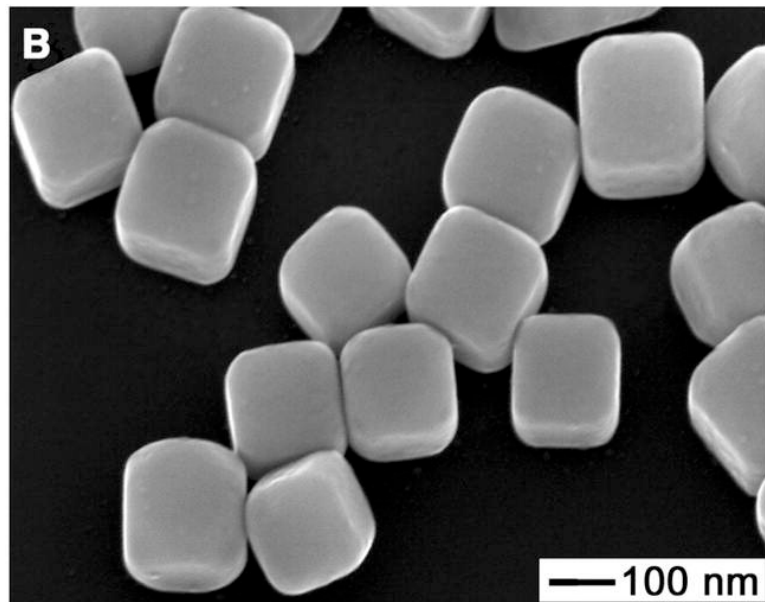
APS $\xi_{\text{HOR}} = 20\mu\text{m}$, focus to $1\mu\text{m}$

XFEL $\xi_{\text{HOR}} > 500\mu\text{m}$, focus to $0.1\mu\text{m}$



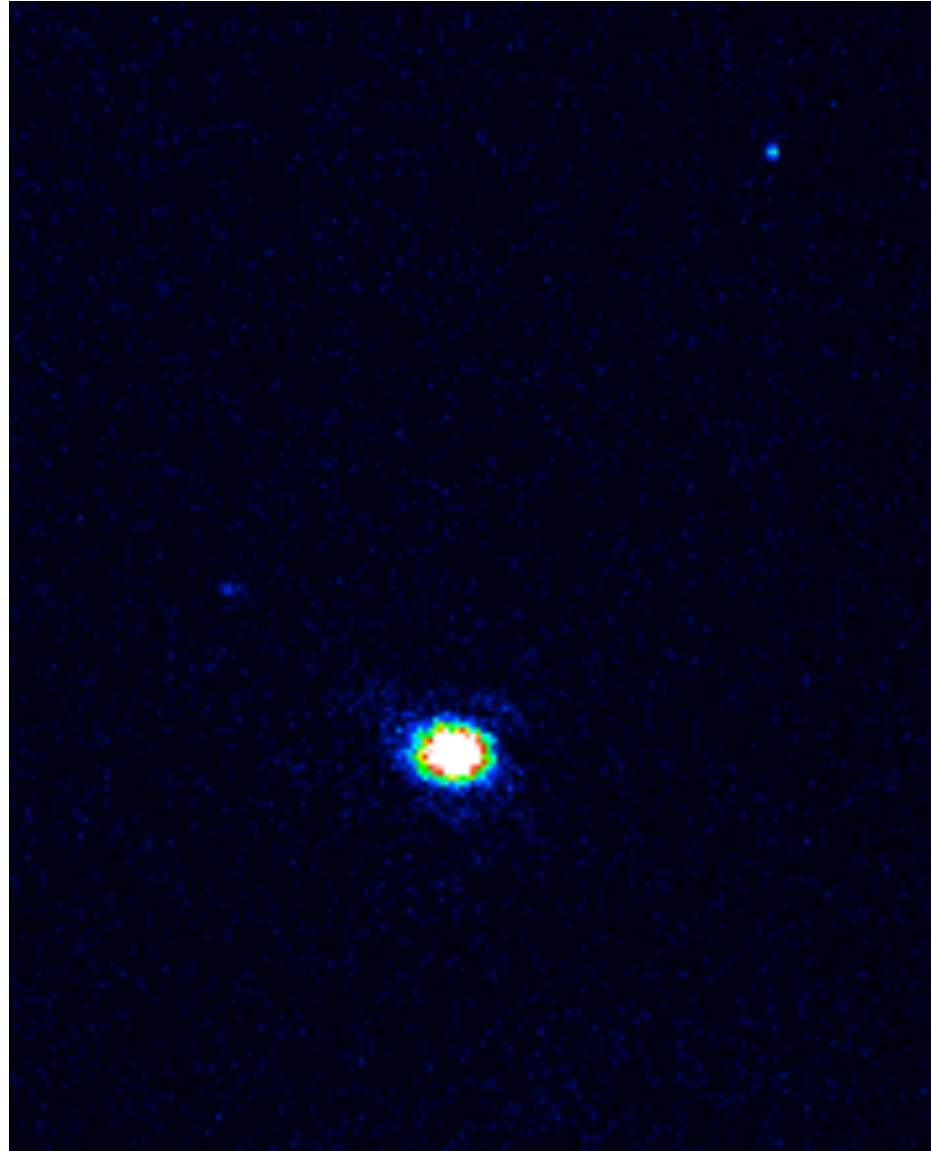


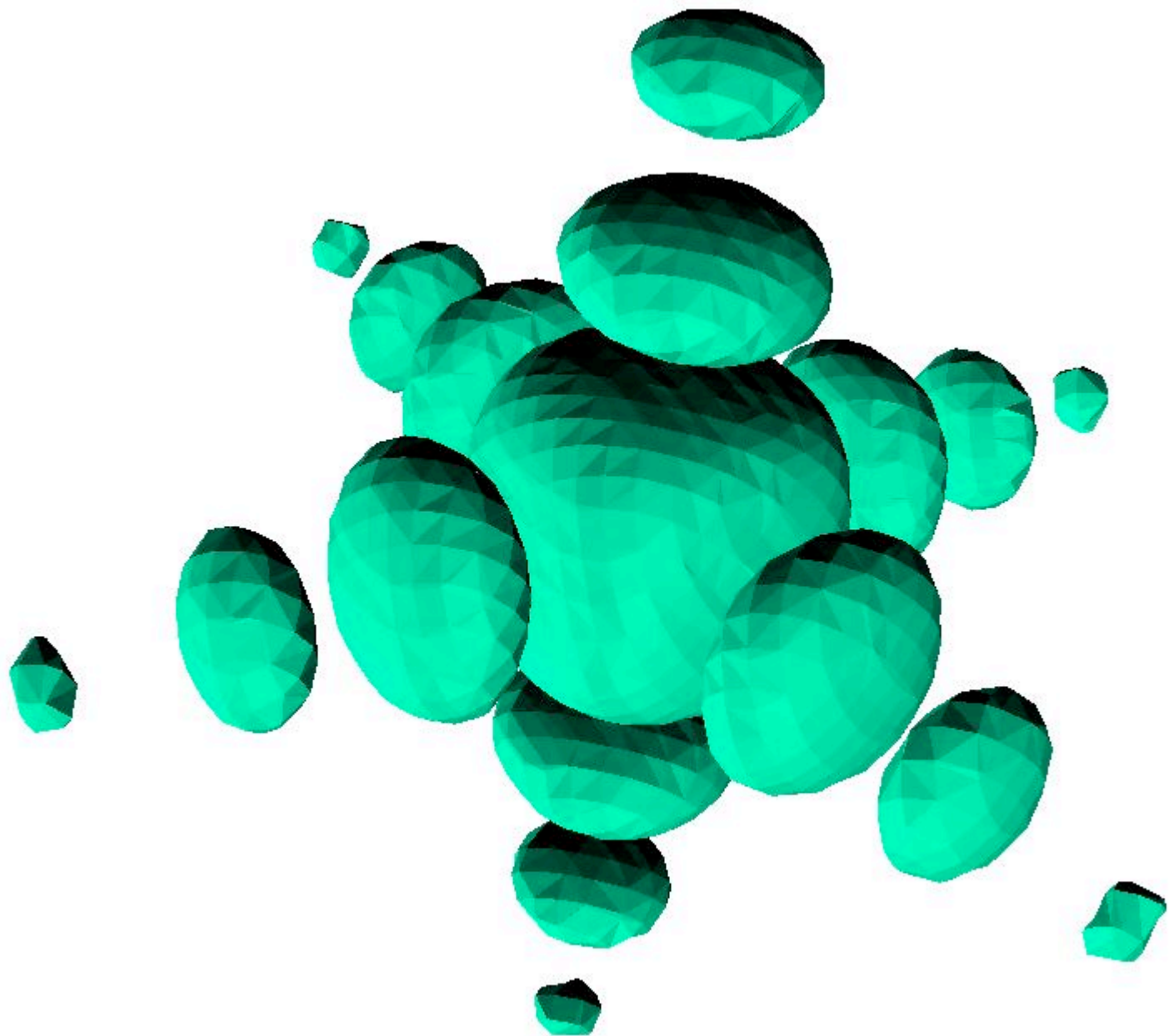
Chemically Synthesized Silver Nanocubes



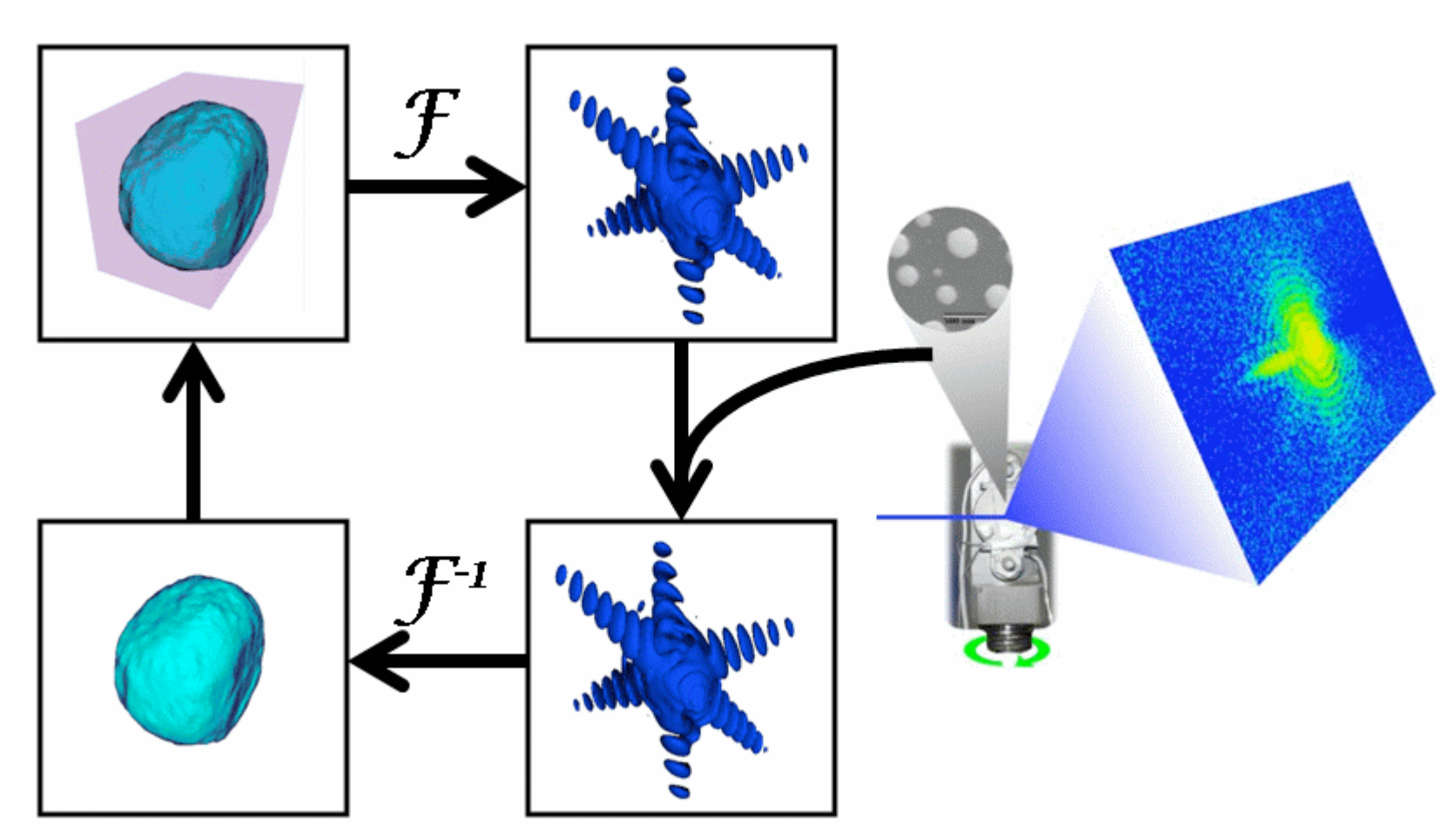
Yugang Sun and Younan Xia,
Science 298 2177 (2003)

Rocking
scan of Ag
cubes with
 0.01° steps





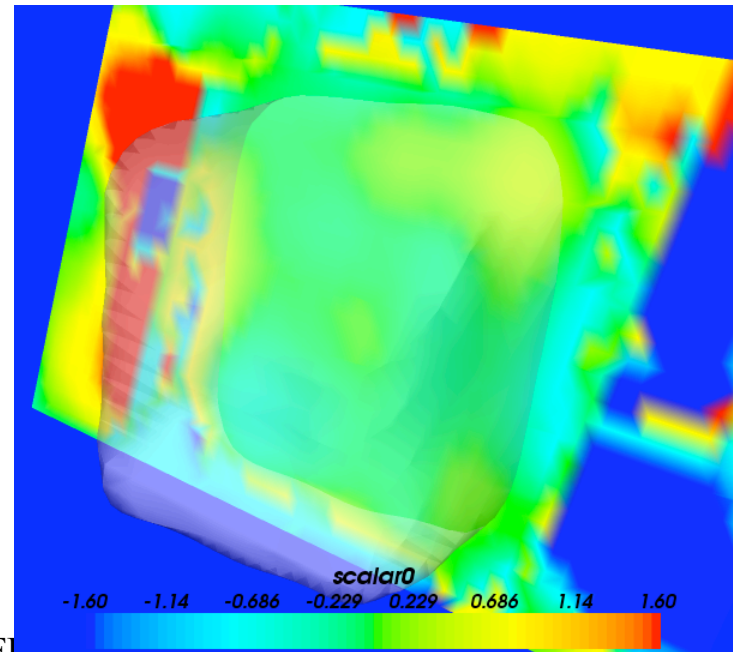
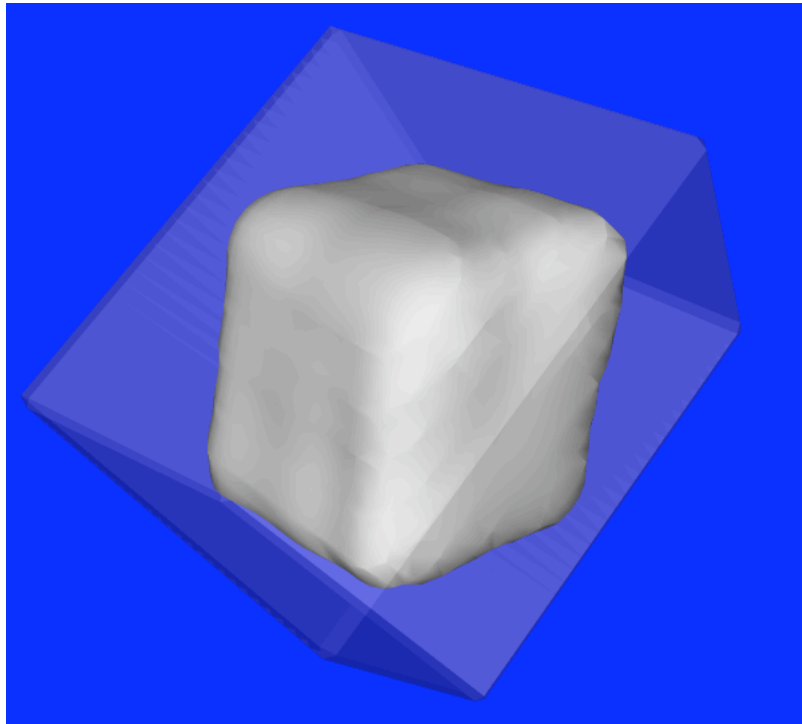
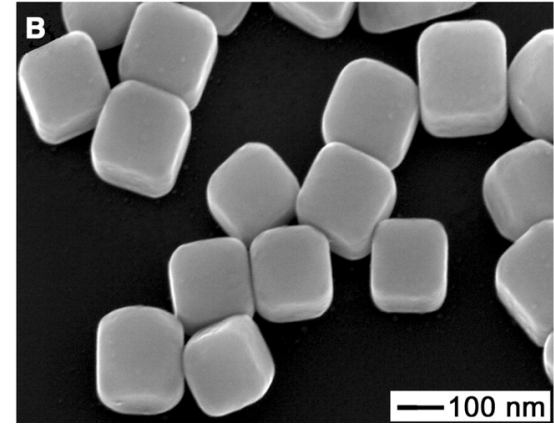
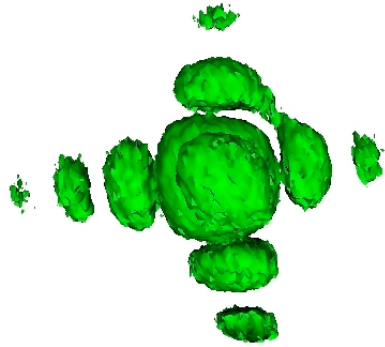
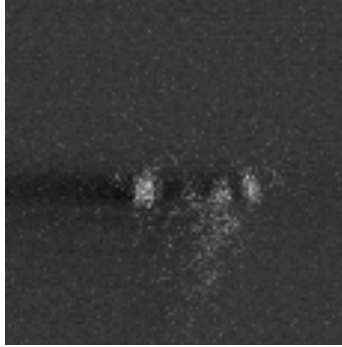
Generic “Error Reduction” method



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

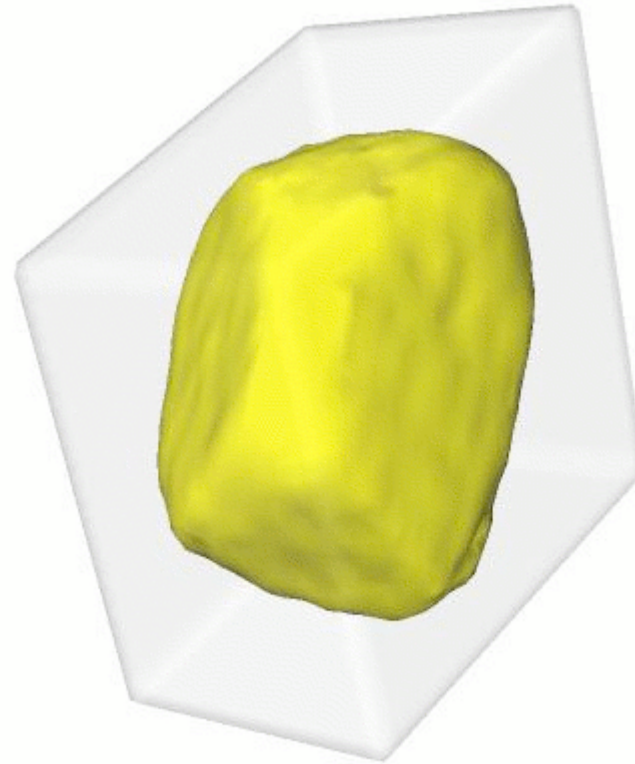
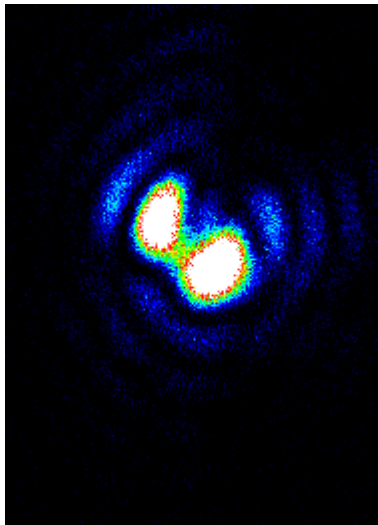
R. W. Gerchberg and W. O. Saxton *Optik* 35 237 (1972)

I. K. Robinson, CFEL 2009

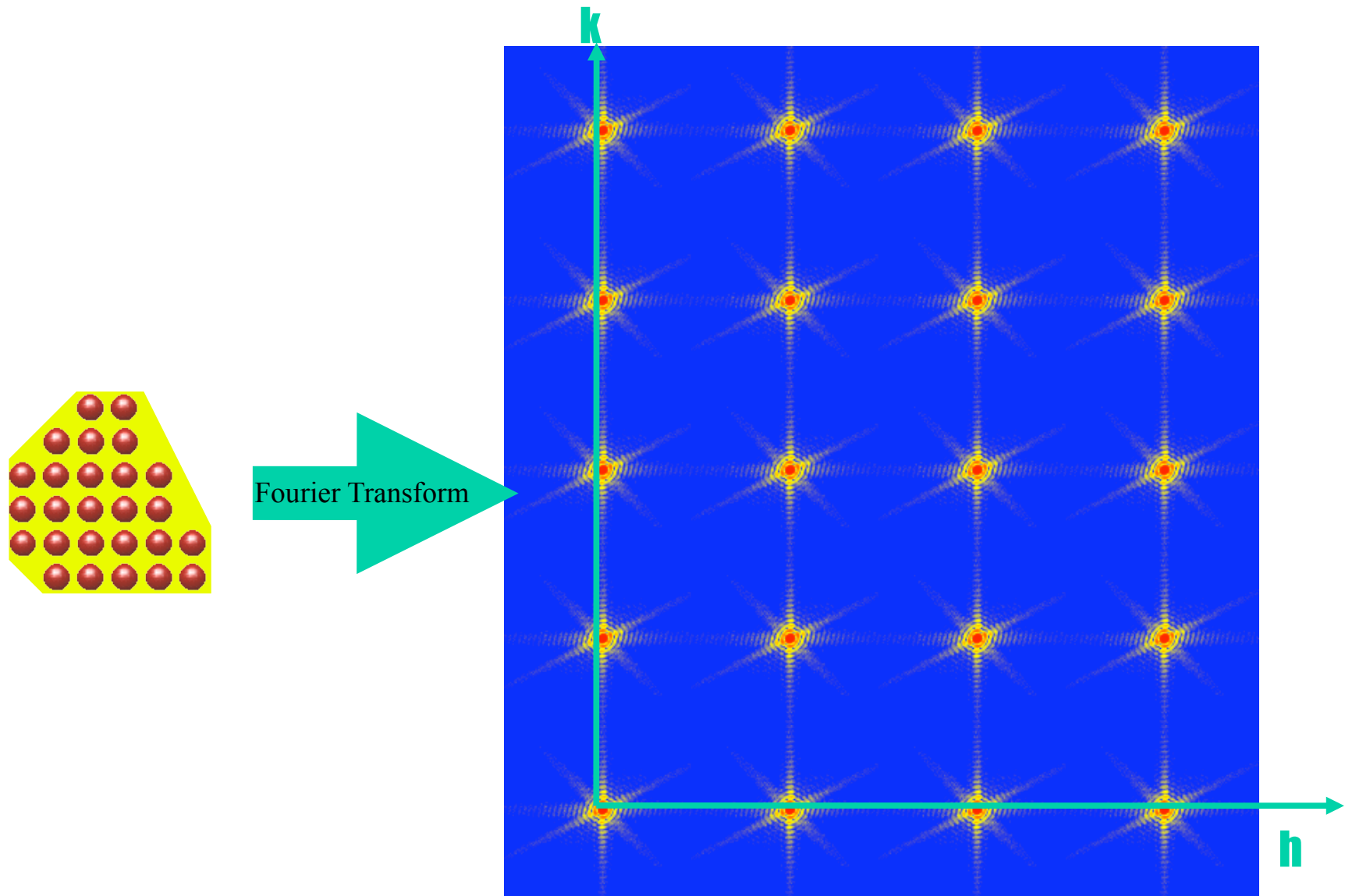


Gold nanocrystal reconstruction

showing support used for 20 HIO followed by 10 ER

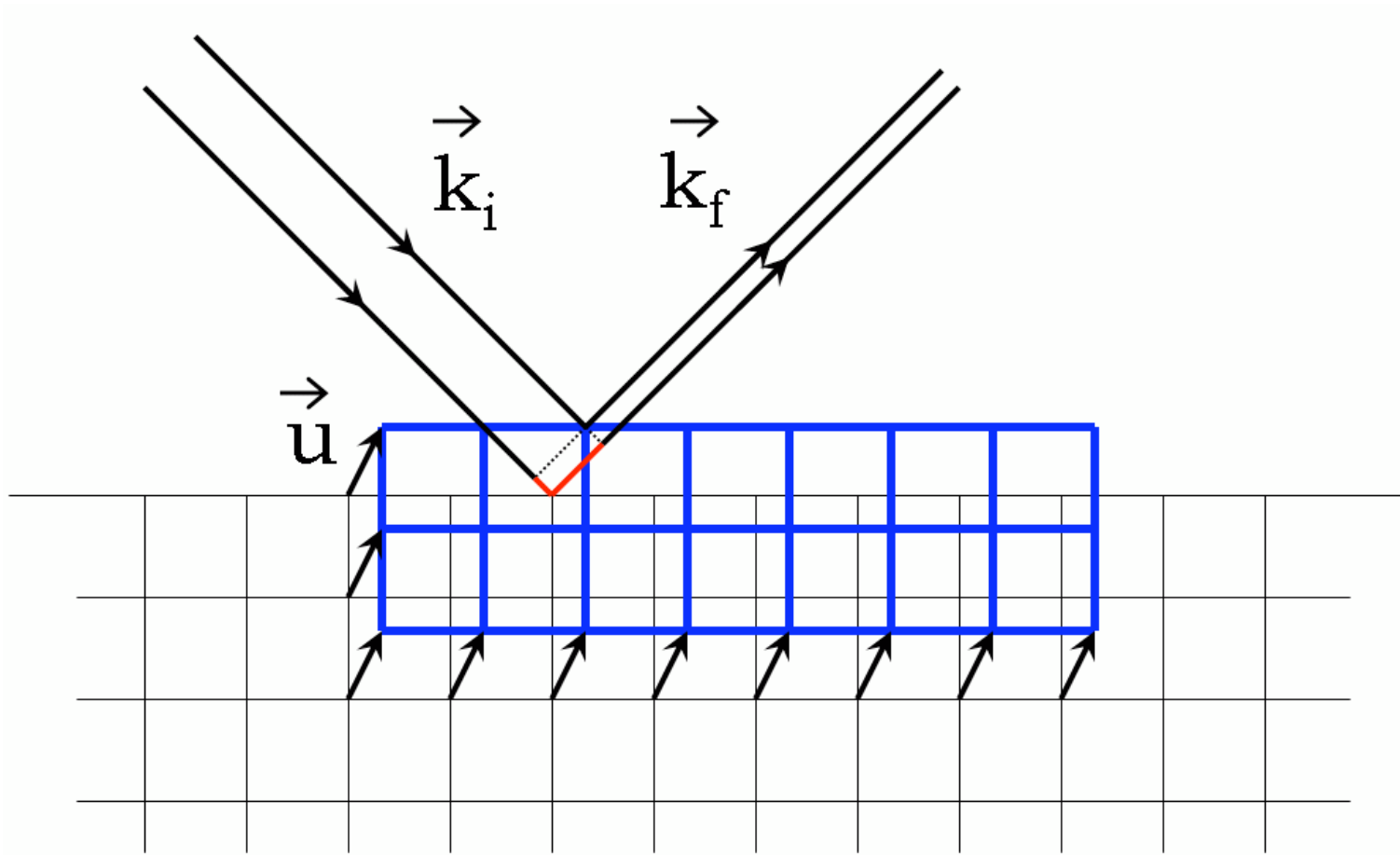


Coherent Diffraction from Crystals



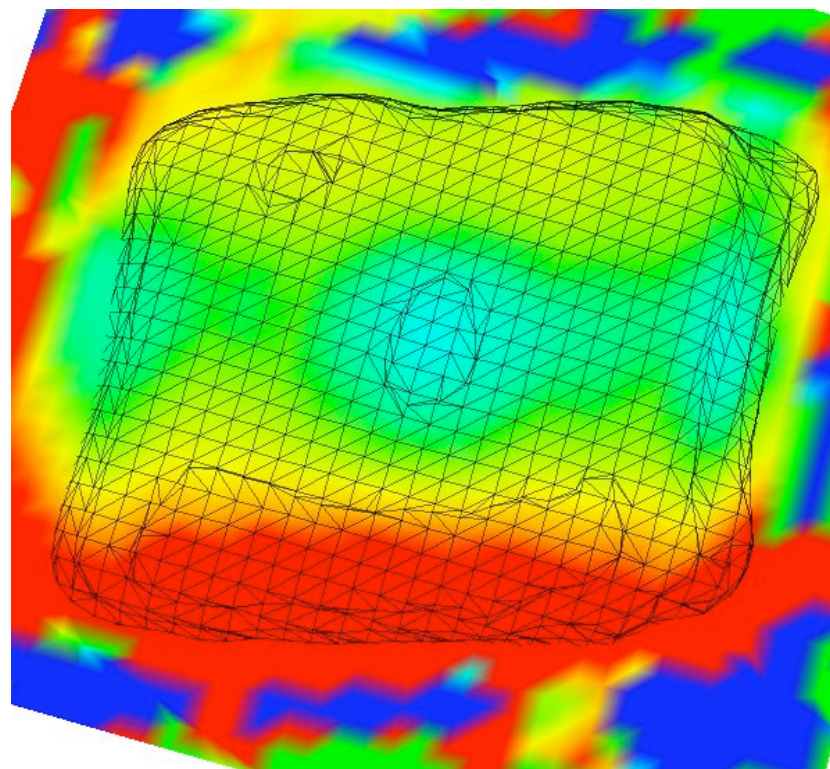
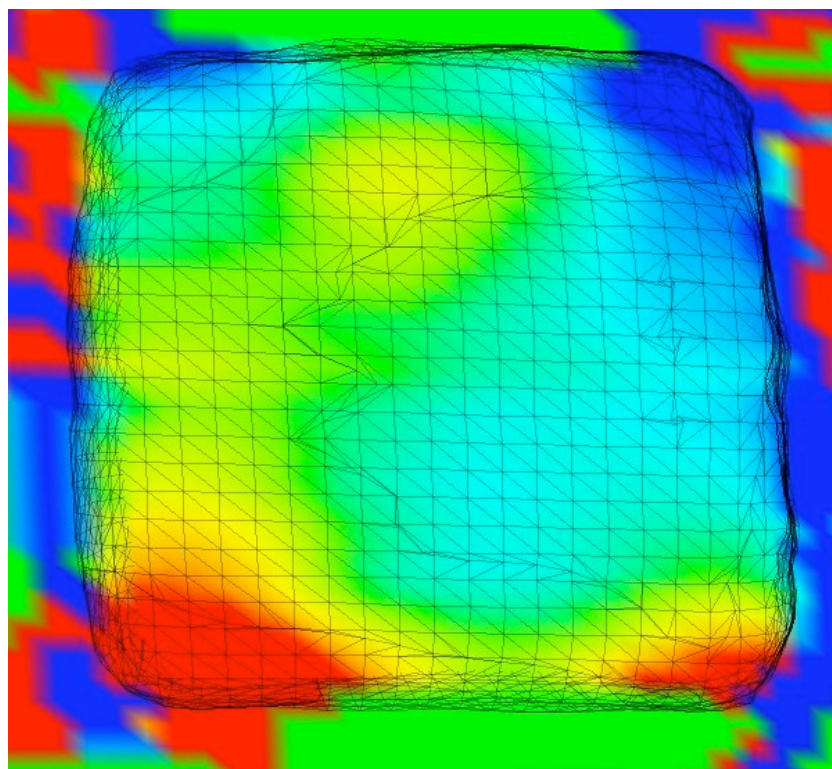
Sensitivity to strain

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



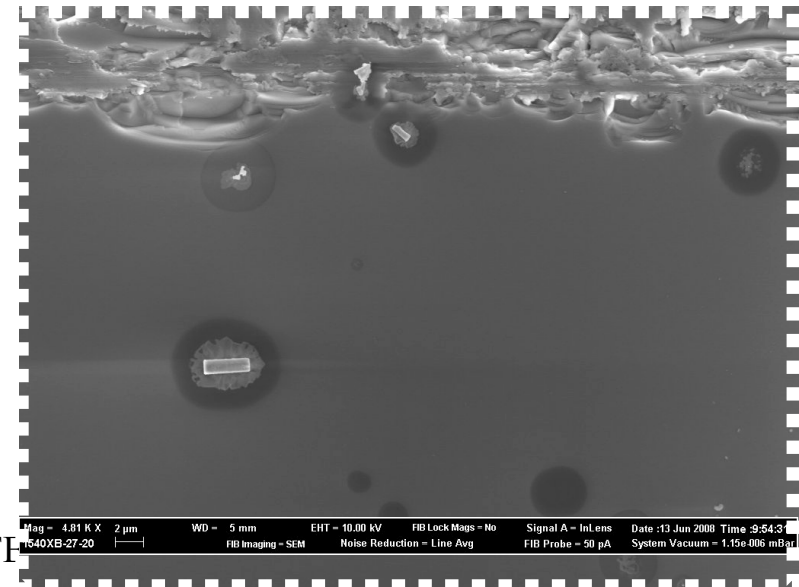
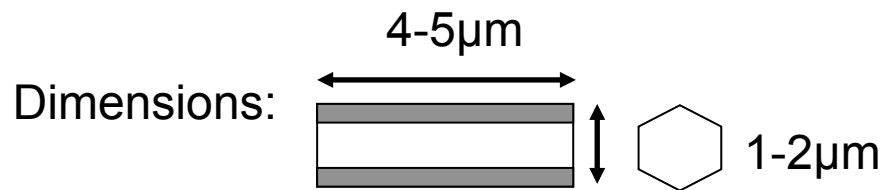
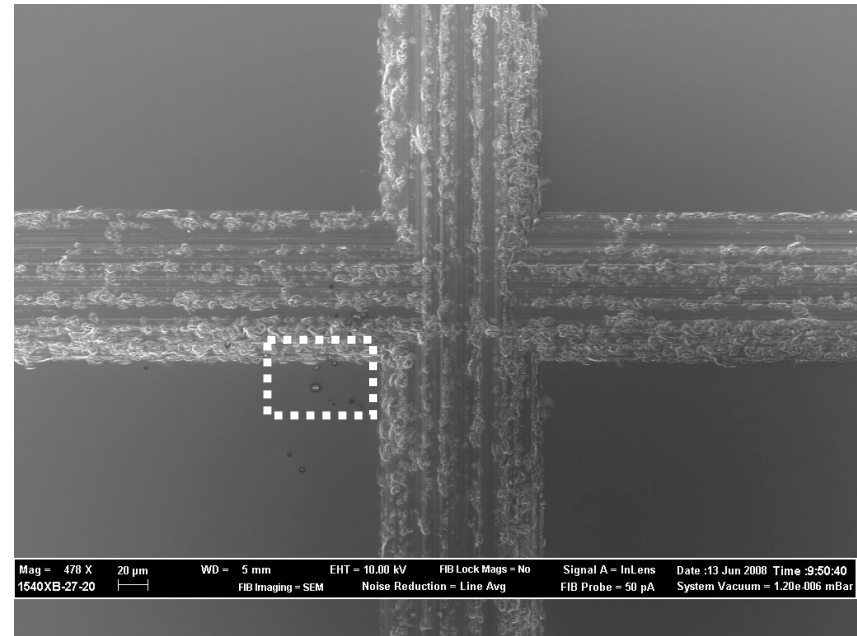
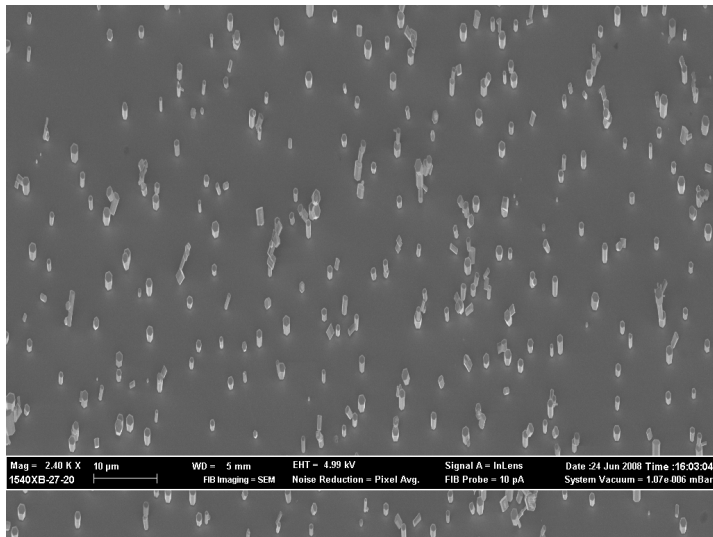
Contact strain of Zeolite ZSM-5

with Hyunjung Kim and K. B. Yoon at Sogang University



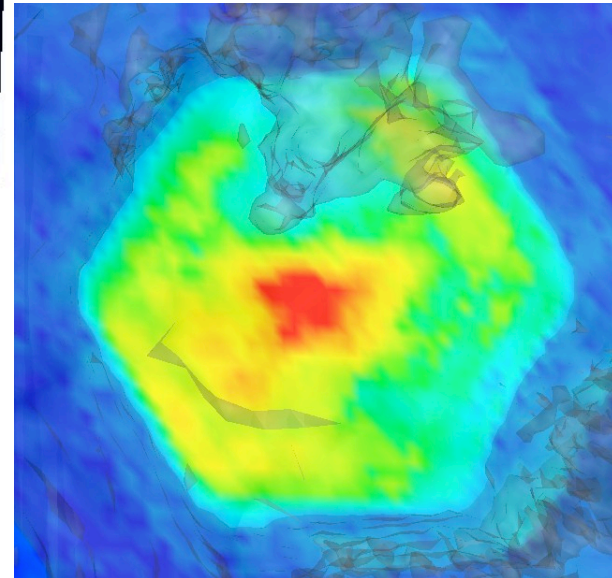
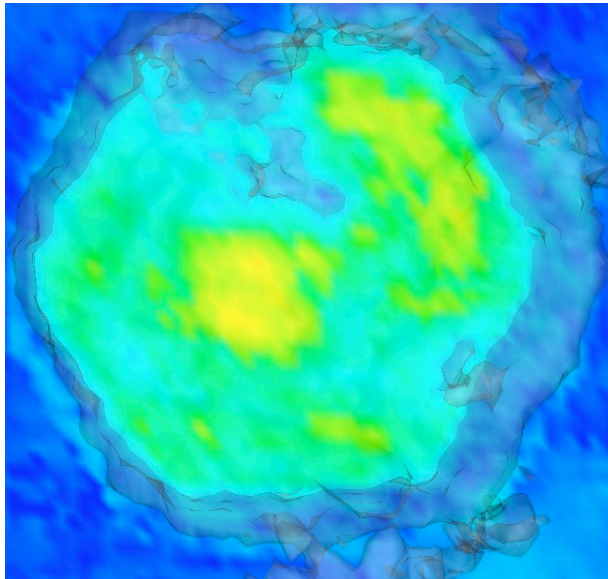
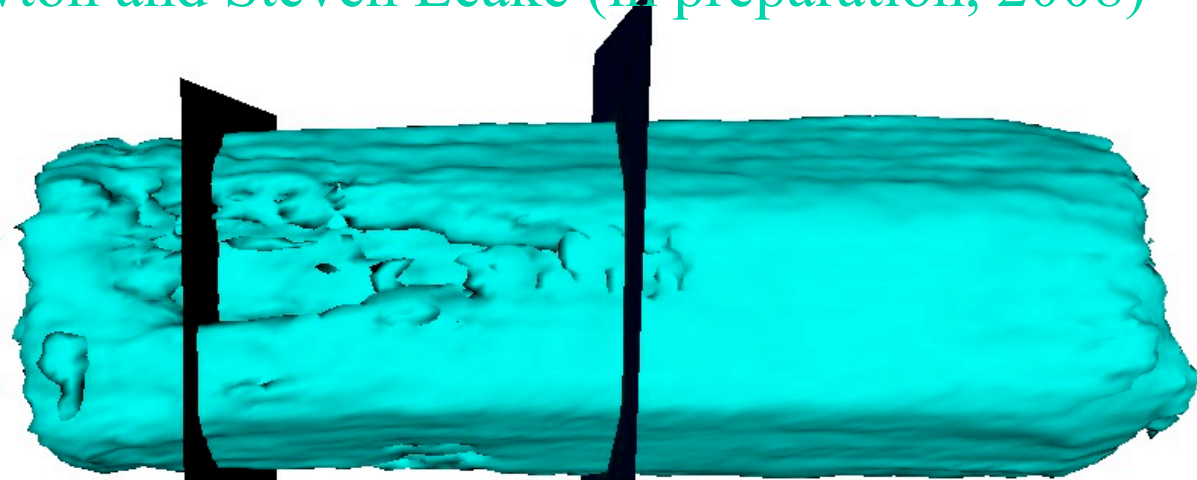
← 4μm →

ZnO Sample Preparation



Density sections ZnO-39 (010)

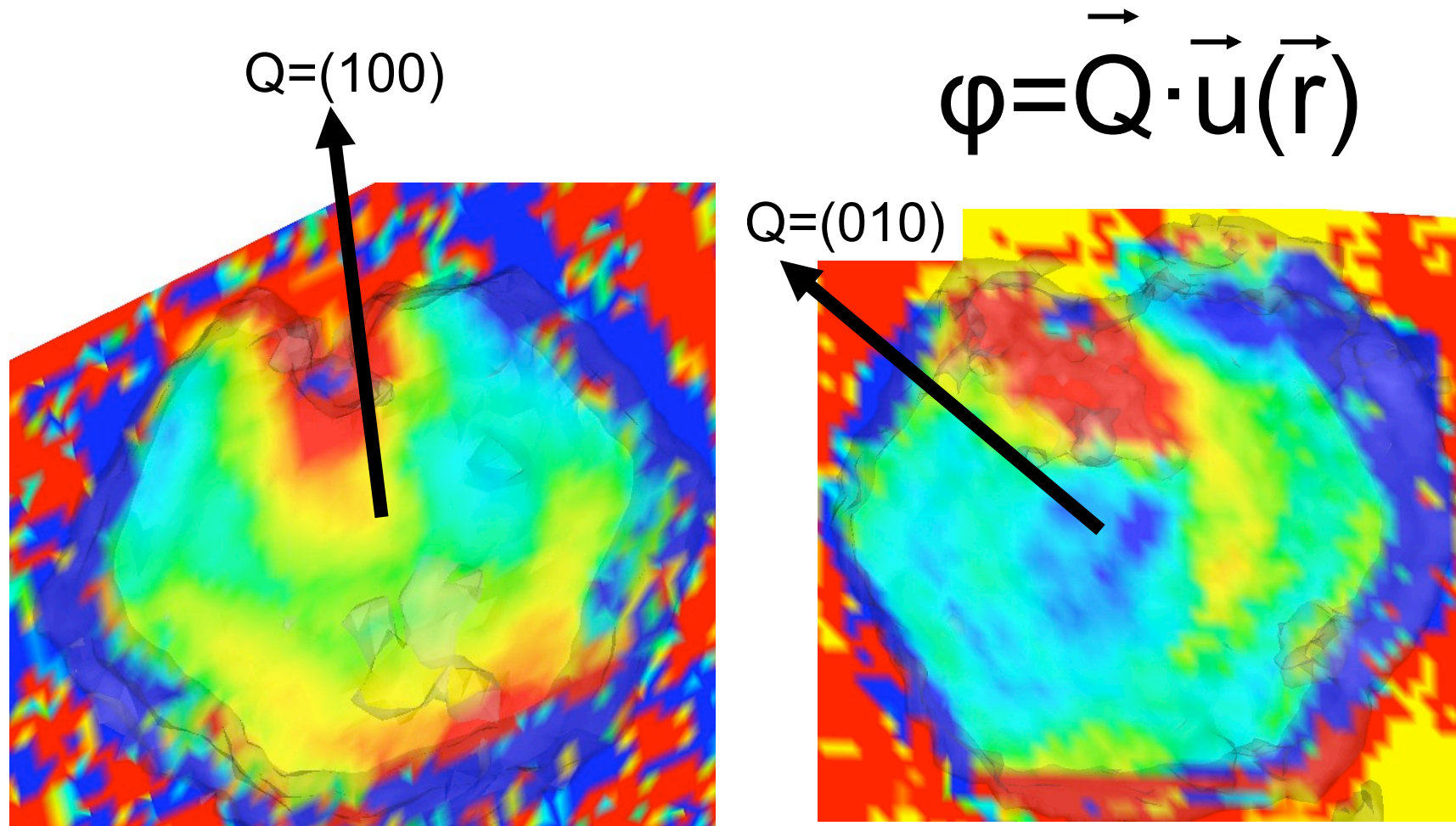
Marcus Newton and Steven Leake (in preparation, 2008)



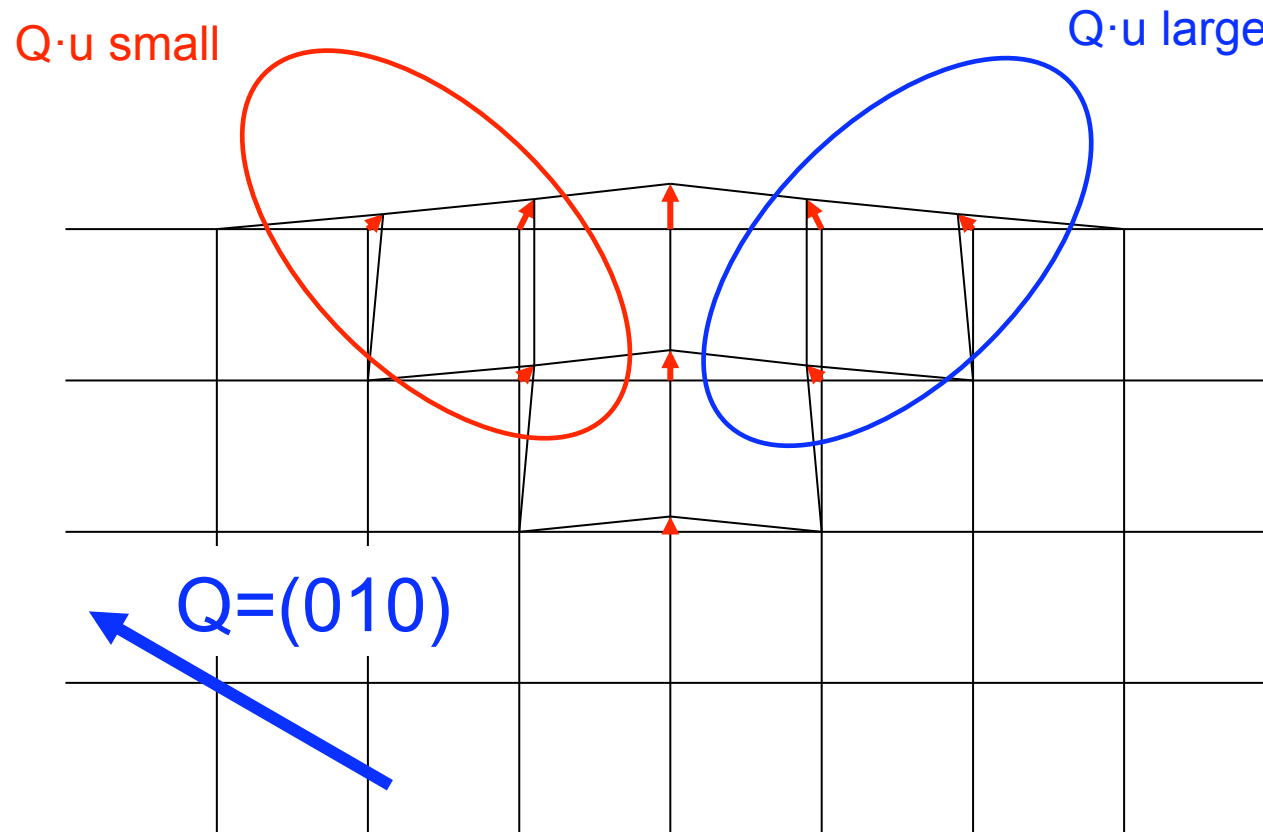
I. K. Robinson, CFEL 2009

Phase maps from 2 Bragg peaks

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

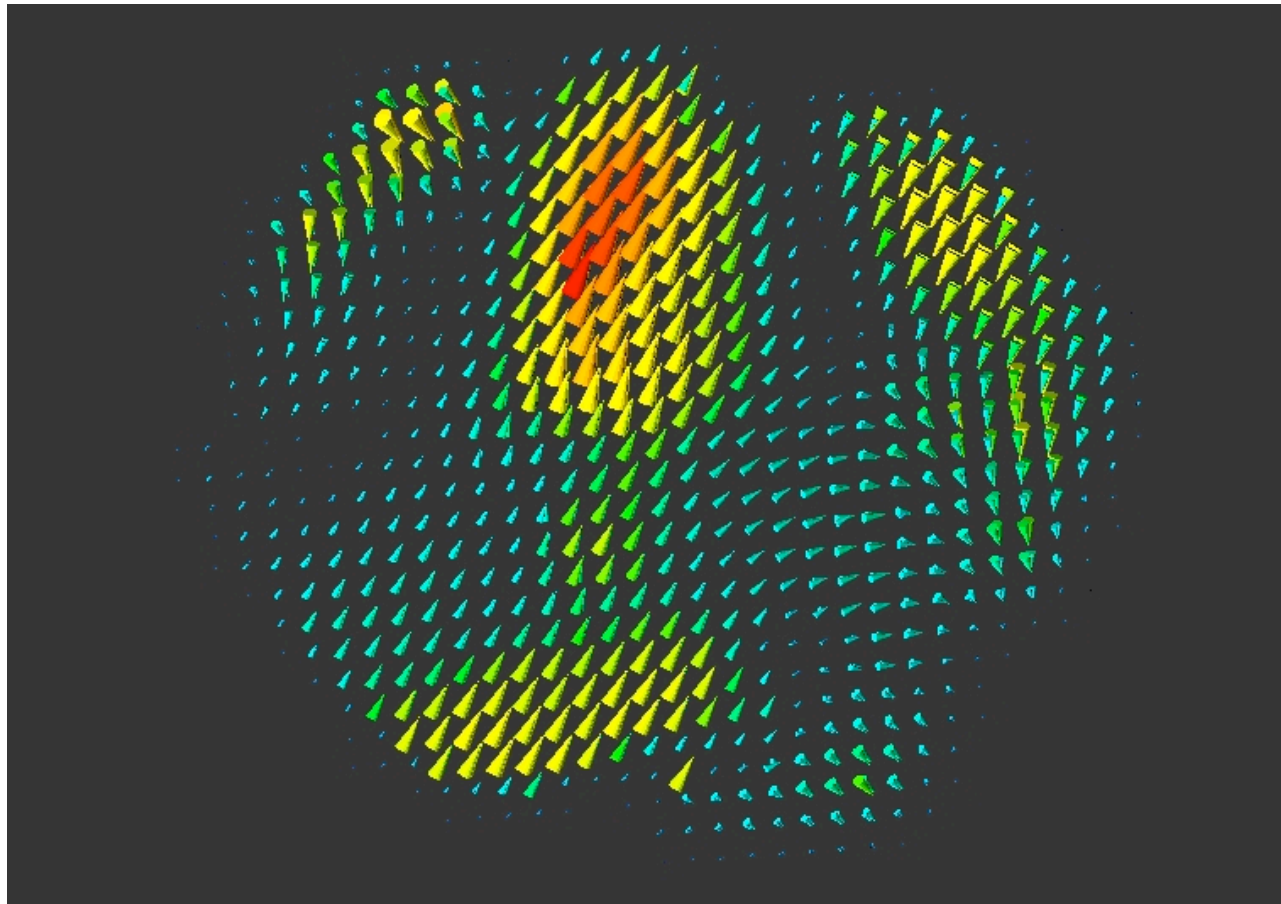


Typical displacement field

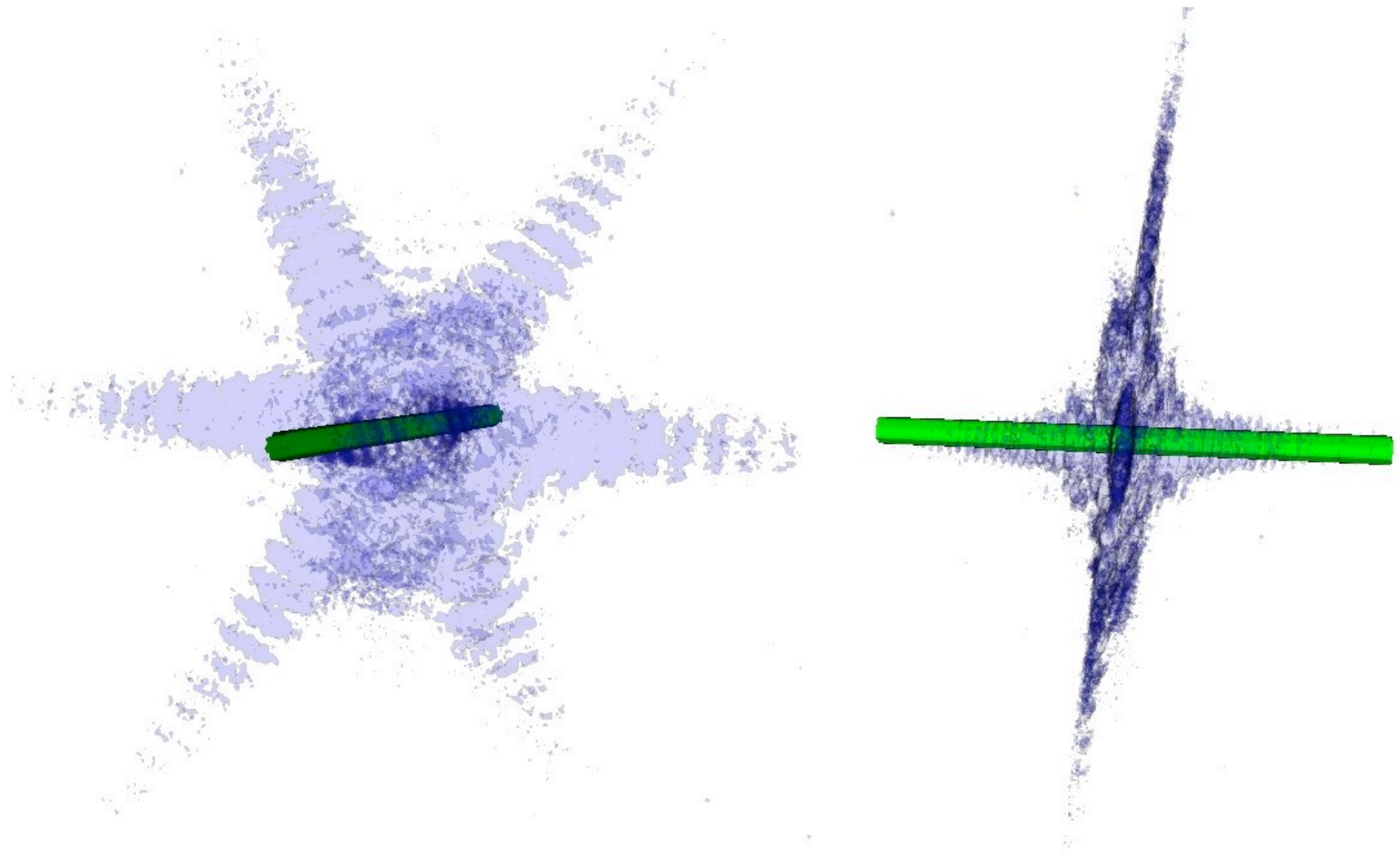


2D vector field of displacements

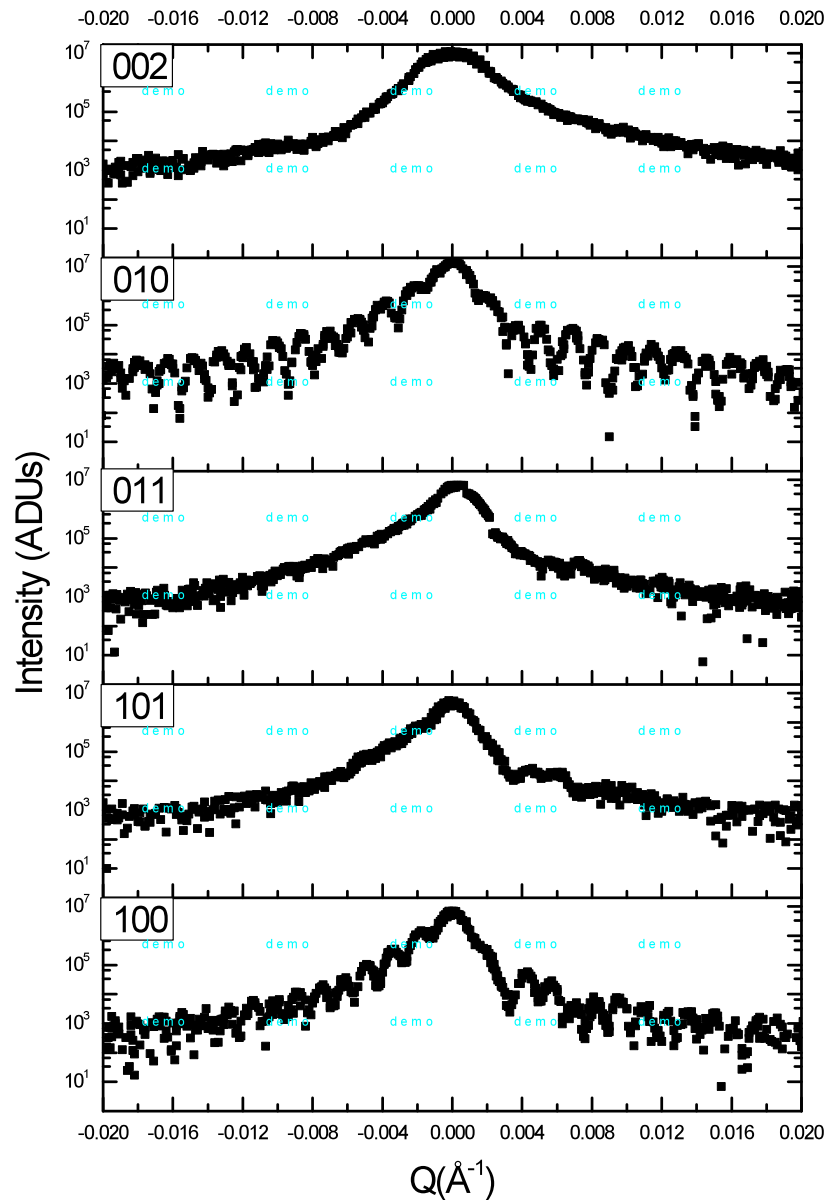
Marcus Newton, UCL, Jan 2009



How to extract the contrast data



Five Bragg peaks



002 no fringe visibility

010 & 100 good fringe visibility

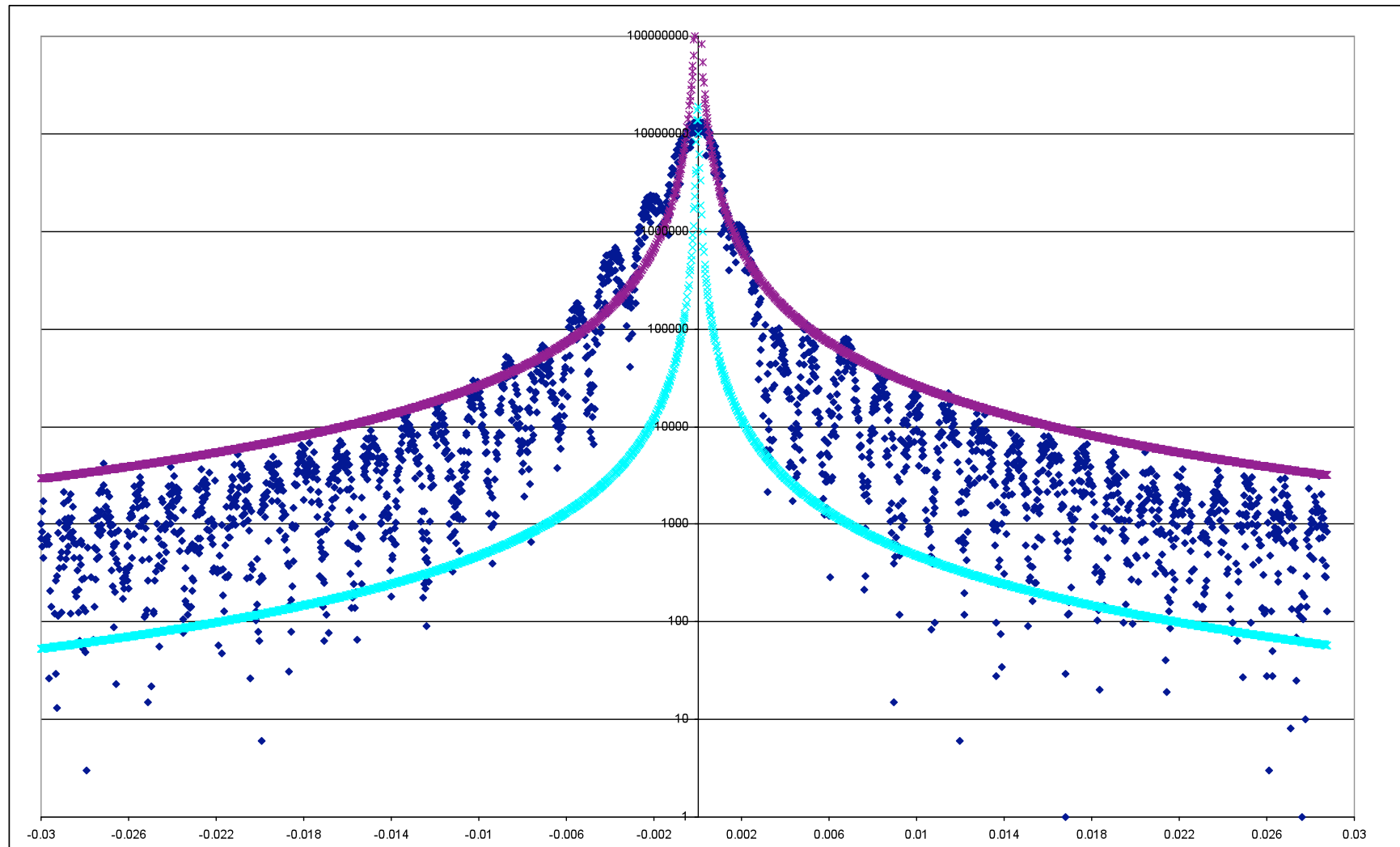
101 & 011 diminished fringe visibility
but fringes still evident

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

Error in coordinate transform ruled out

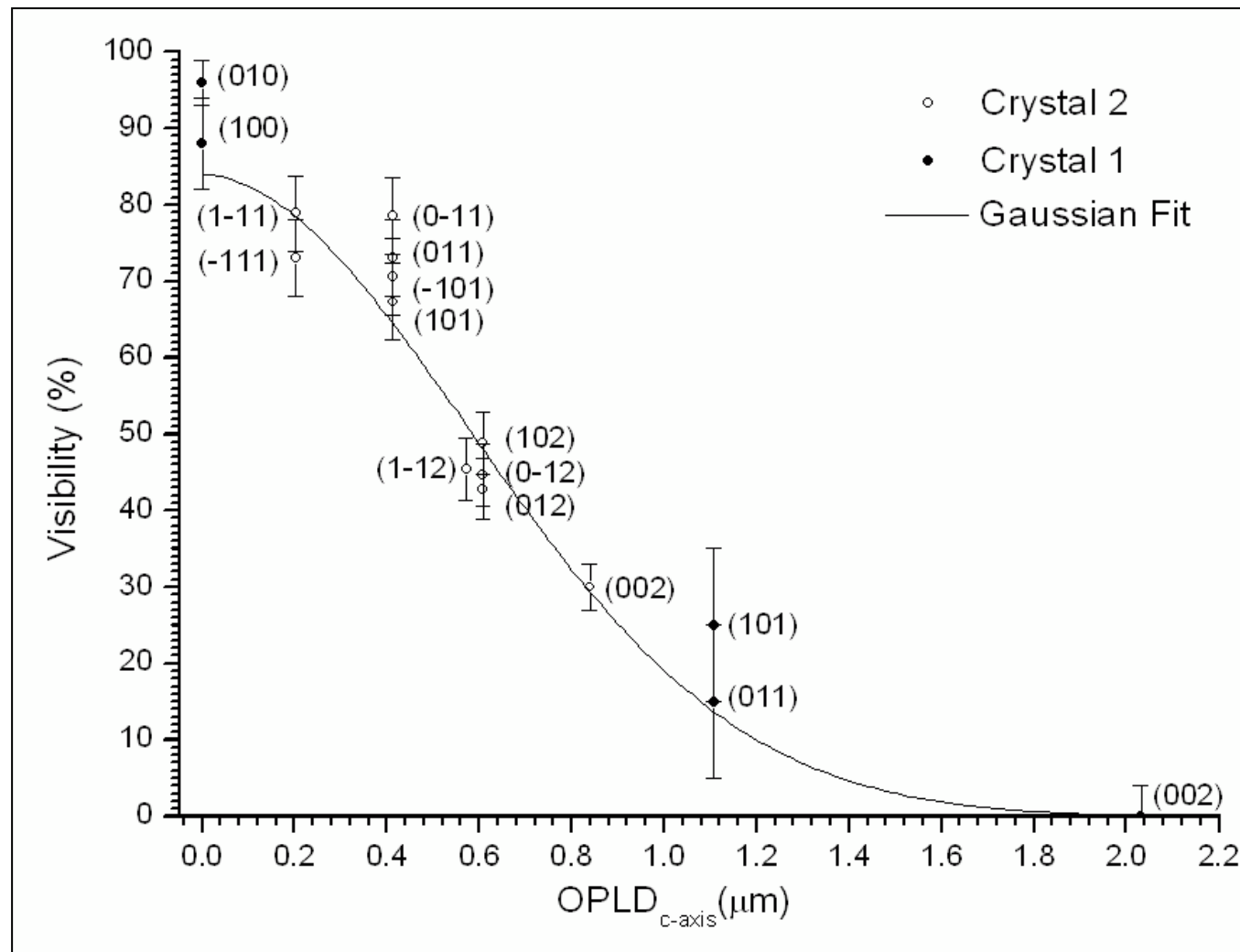
010 and 100 reflections fringe spacing
difference $\sim 20\%$

Fringe Visibility $96 \pm 2\%$ @010



Measured Longitudinal Coherence

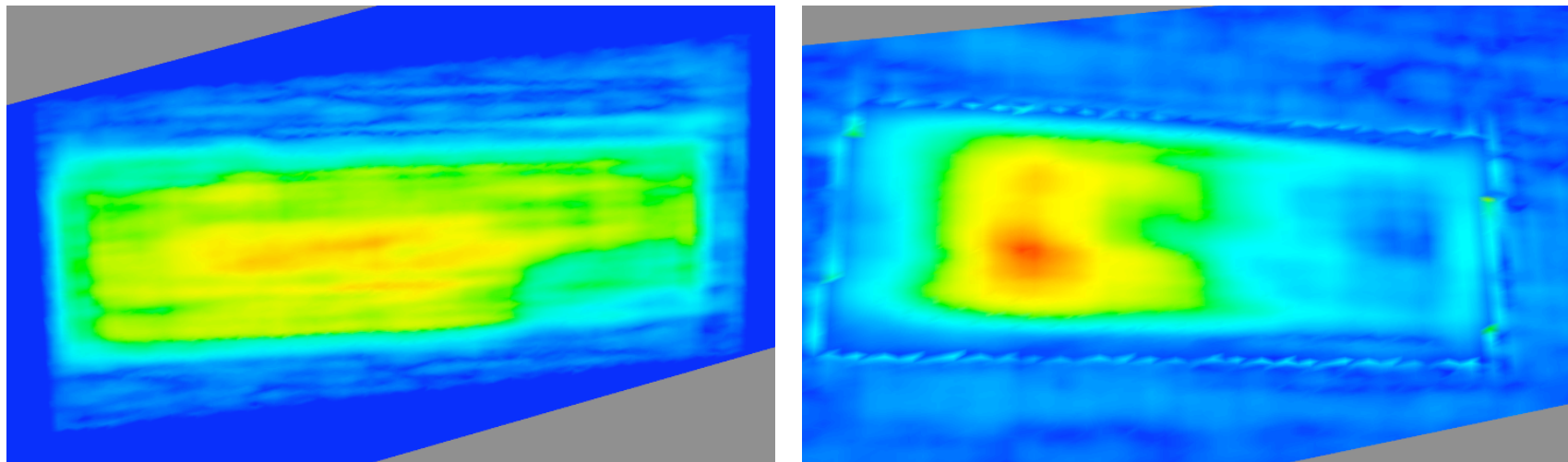
Steven Leake, unpublished, Dec 2008



I. K. Robinson, CFEL 2009

Density Section of Reconstruction using 100 and 101 reflections

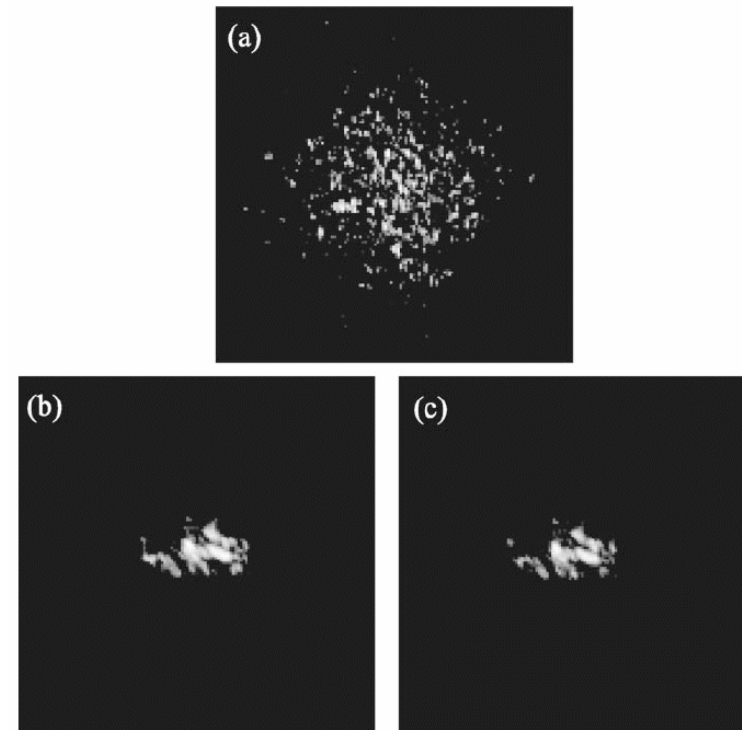
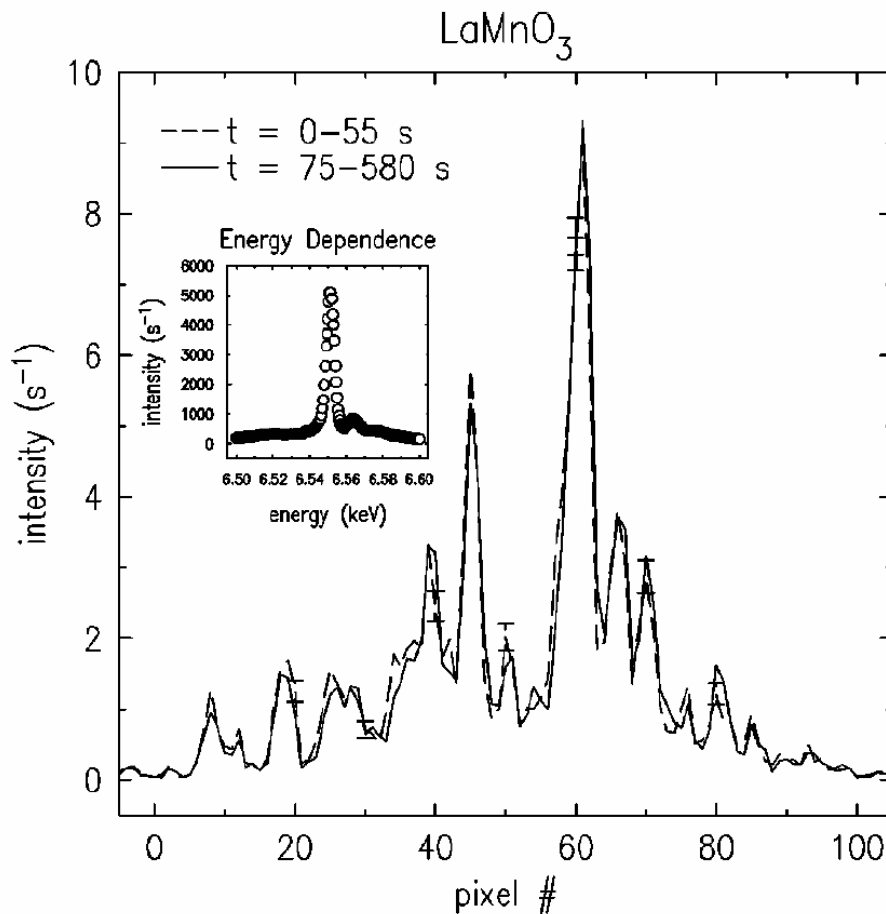
“hot spot” more developed for limited coherence
Steven Leake, unpublished, Dec 2008



LaMnO₃ and Pr_{0.6}Ca_{0.4}MnO₃ speckle

C. S. Nelson, J. P. Hill, Doon Gibbs, F. Yakhou, F. Livet, Y. Tomioka, T. Kimura and Y. Tokura, PRB 66 134412 (2002)

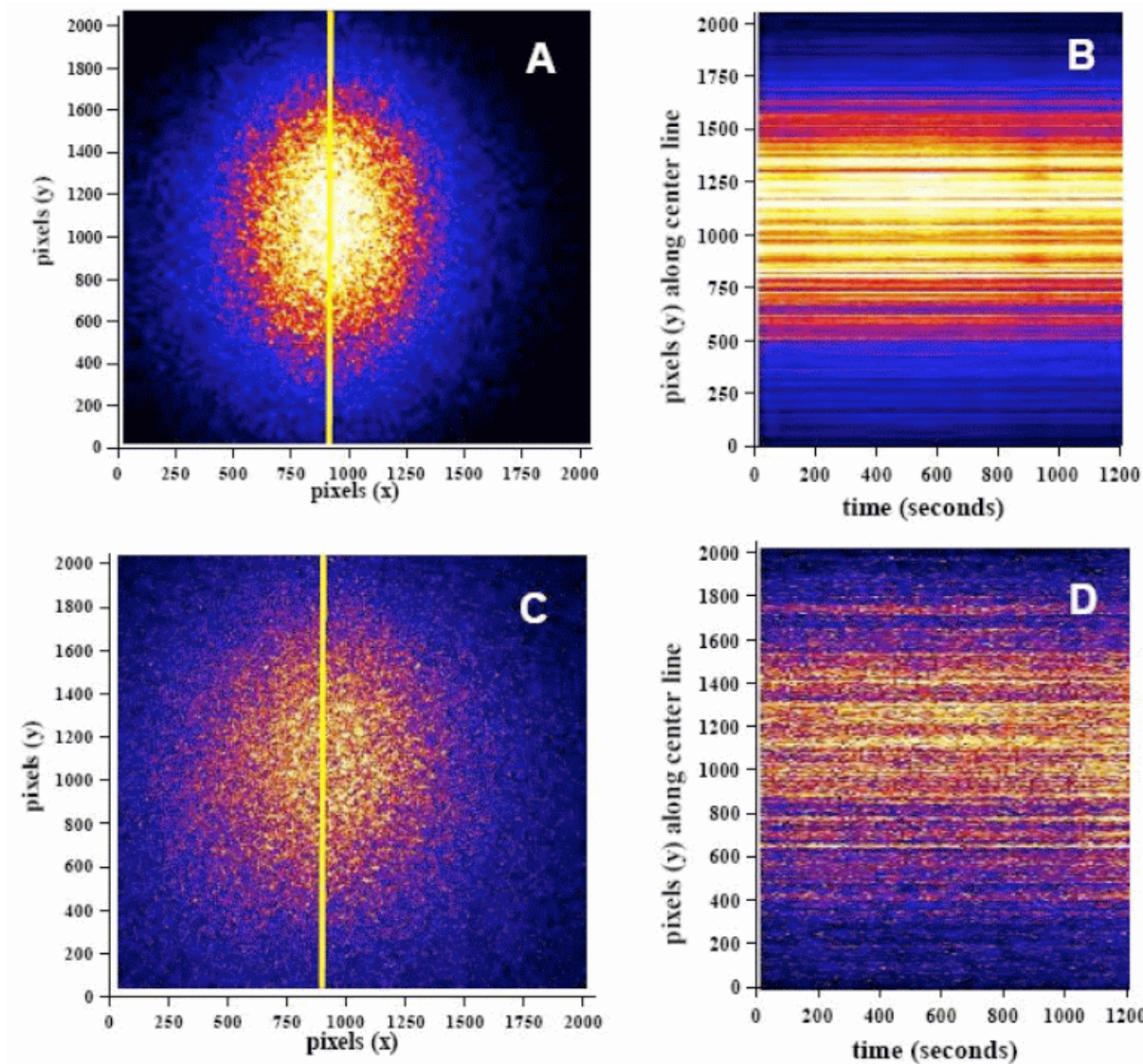
Pr_{0.6}Ca_{0.4}MnO₃, T = 150 K



. Images of orbital (a) and charge (b), (c) order

$\text{Pr}_{0.5}\text{Ca}_{0.5}\text{MnO}_3$ at MnL_{III} edge (650 eV)

J. J. Turner et al, New Journal of Physics 10 053023 (2008)

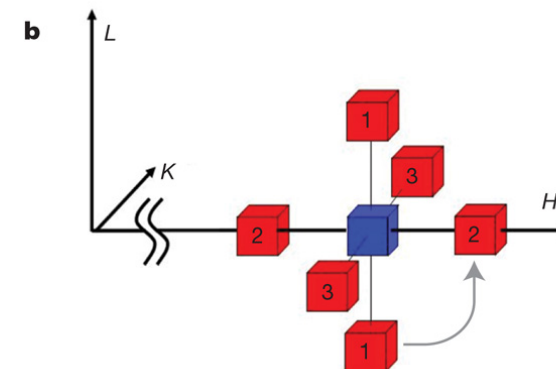
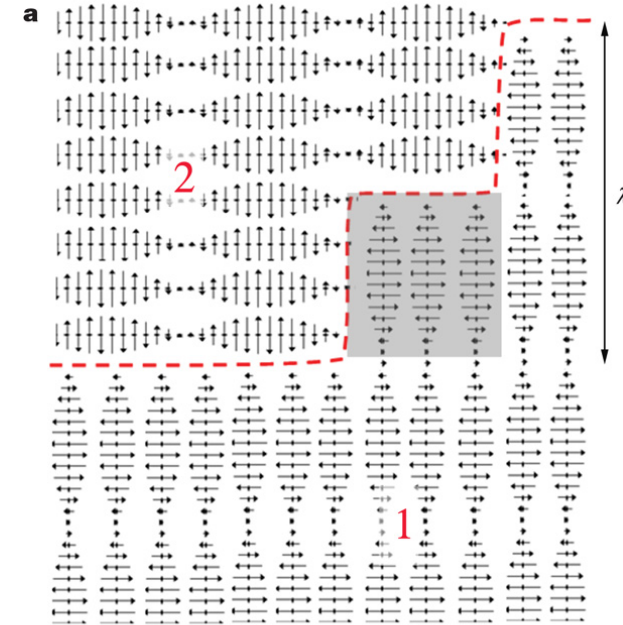
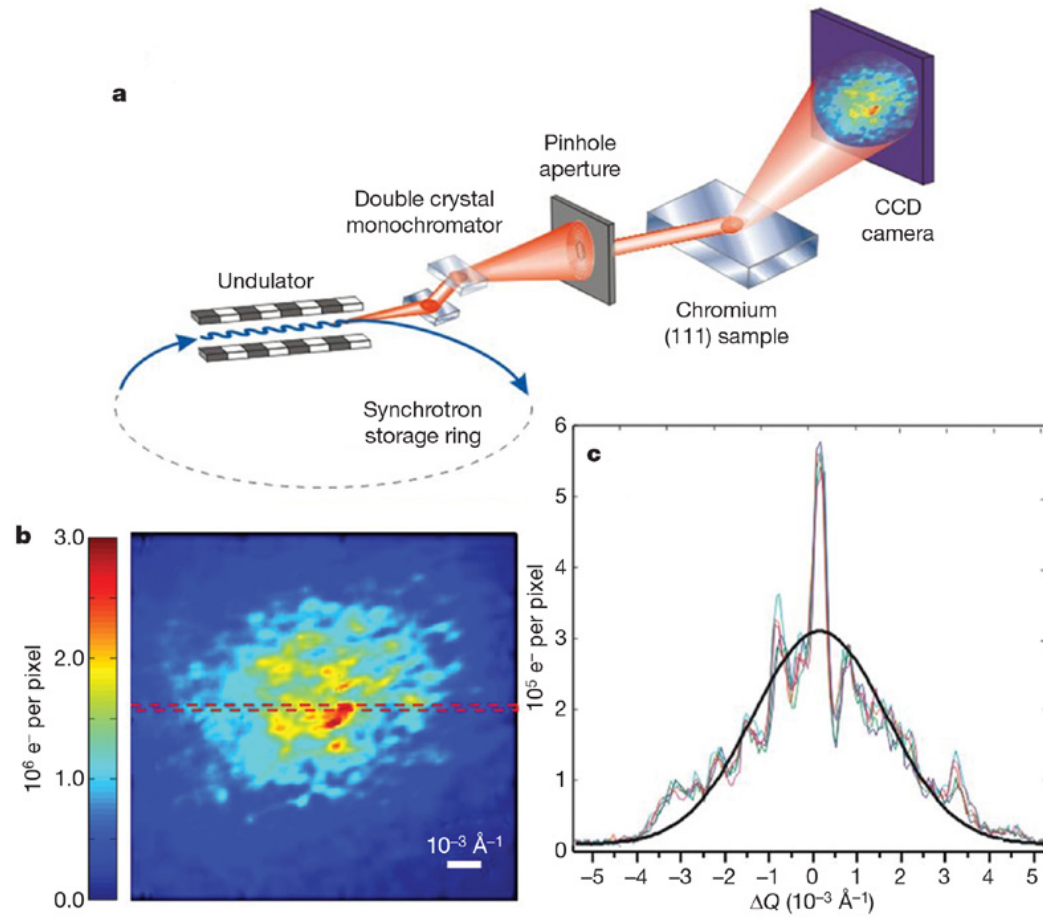


$(0, \frac{1}{2}, 0)$
Orbital ordered
T=205K

$(0, \frac{1}{2}, 0)$
Near phase
transition
T=232K

Antiferromagnetic Domains in Cr

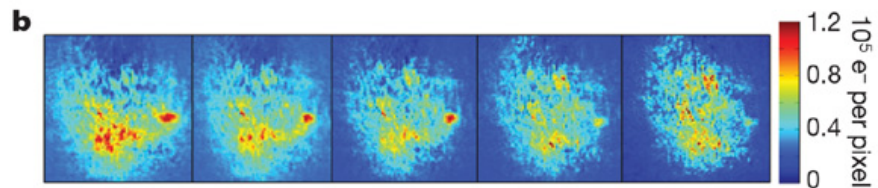
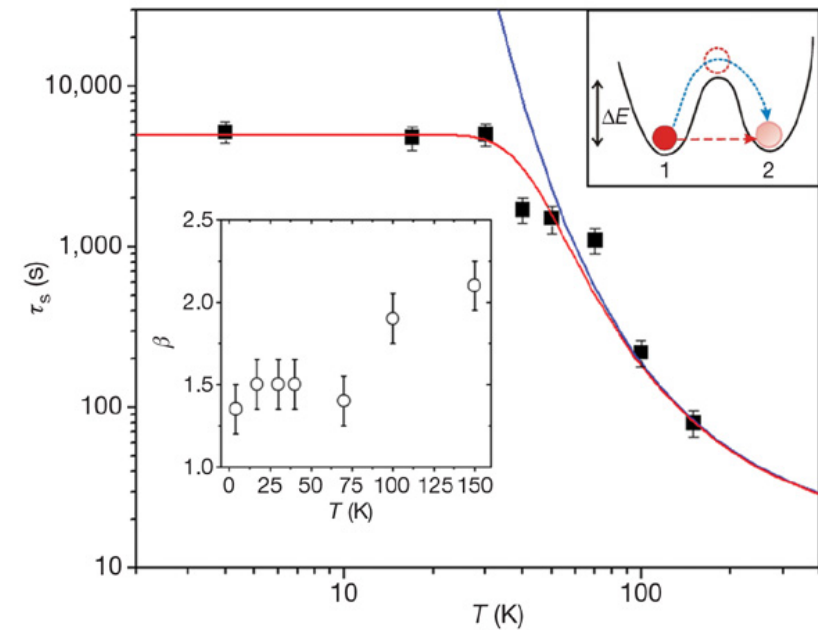
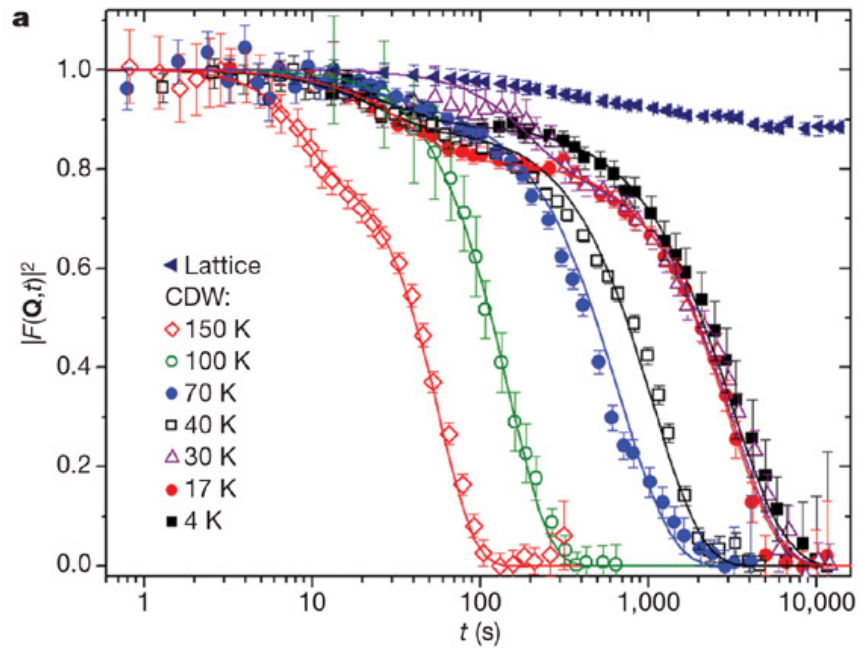
O. Shpyrko et al, Nature 447 68 (2007)



I. K. Robinson, CFEL 2009

XPCS of Domain Fluctuations in Cr

O. Shpyrko et al, Nature 447 68 (2007)



FeAl antiphase domains (001)

Lorenz Stadler, PhD dissertation, TU Wien (2005)

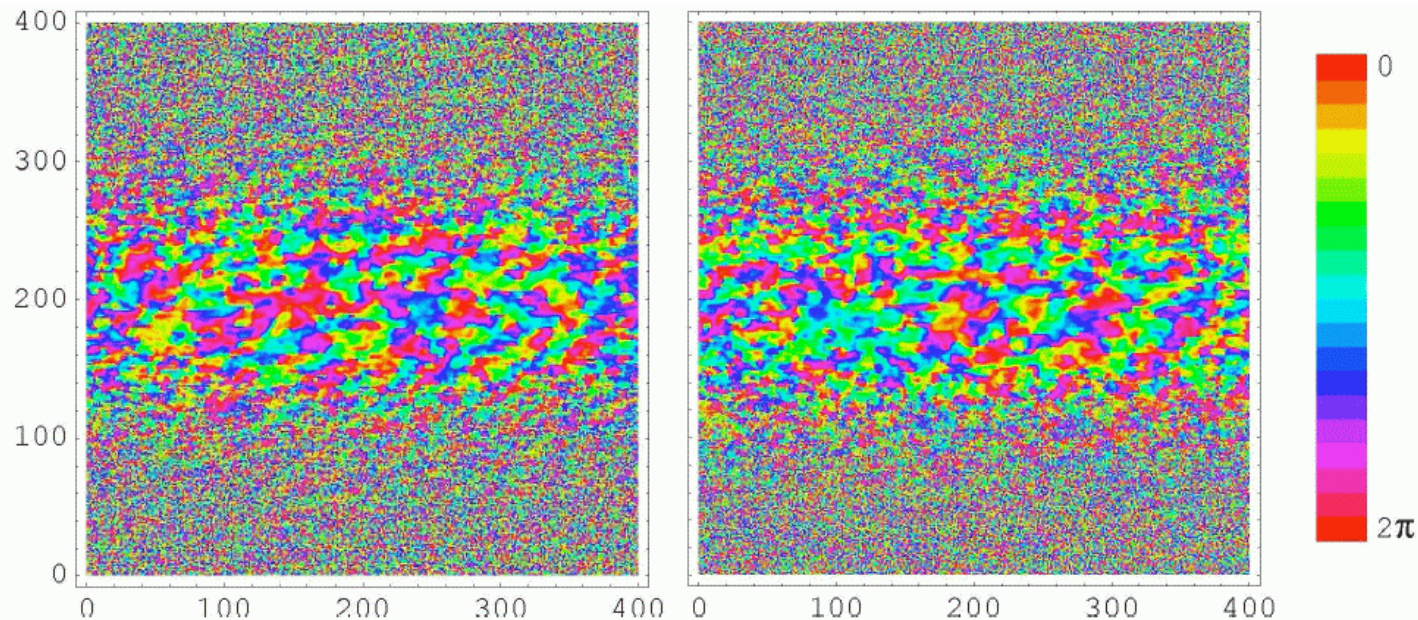
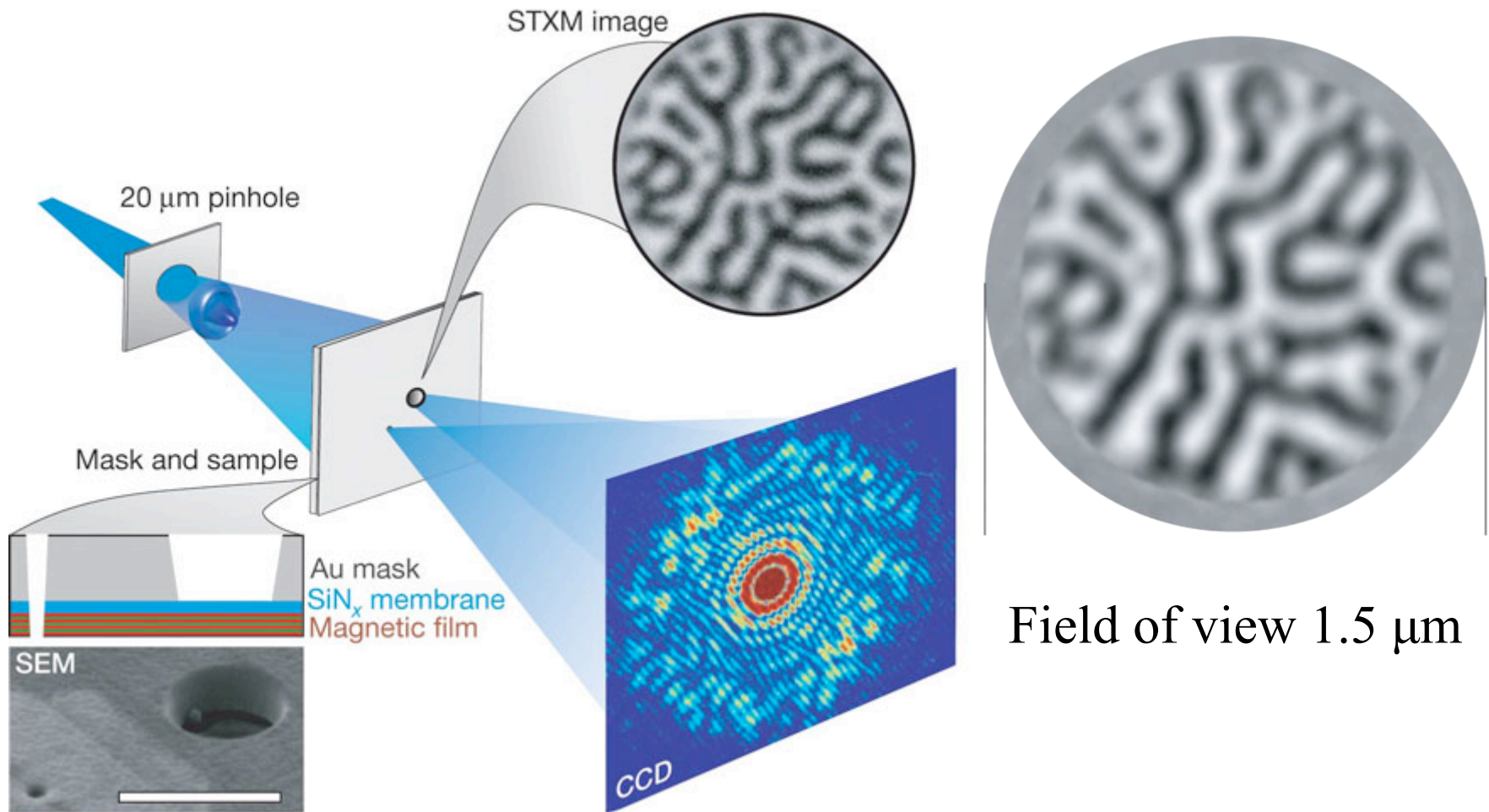


Figure 7.11: Typical reconstructed phases from runs with different combinations of algorithms and supports derived from the 2D Gaussian fit of the illumination function. Numbers in brackets denote how many iterations of the particular algorithm were done each cycle. Graphs on the left are from reconstruc-

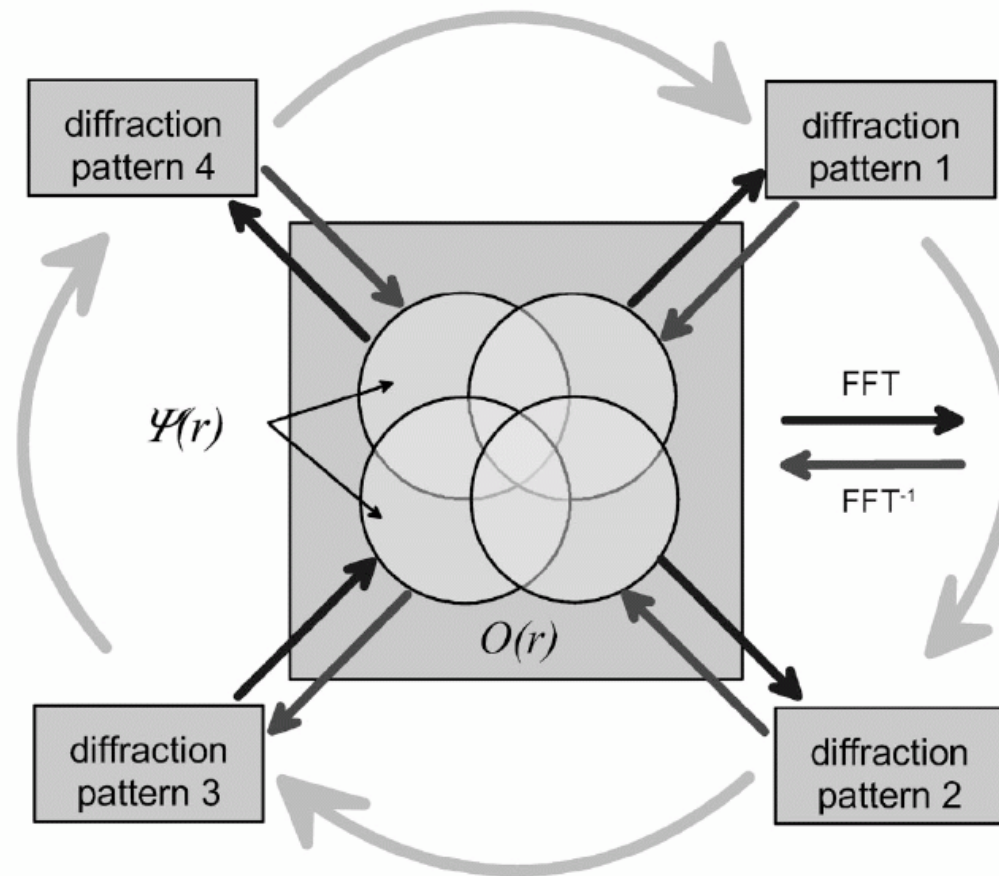
X-ray Holography of Pt/CoML Domains

S. Eisebitt et al. Nature 432 885 (2004)



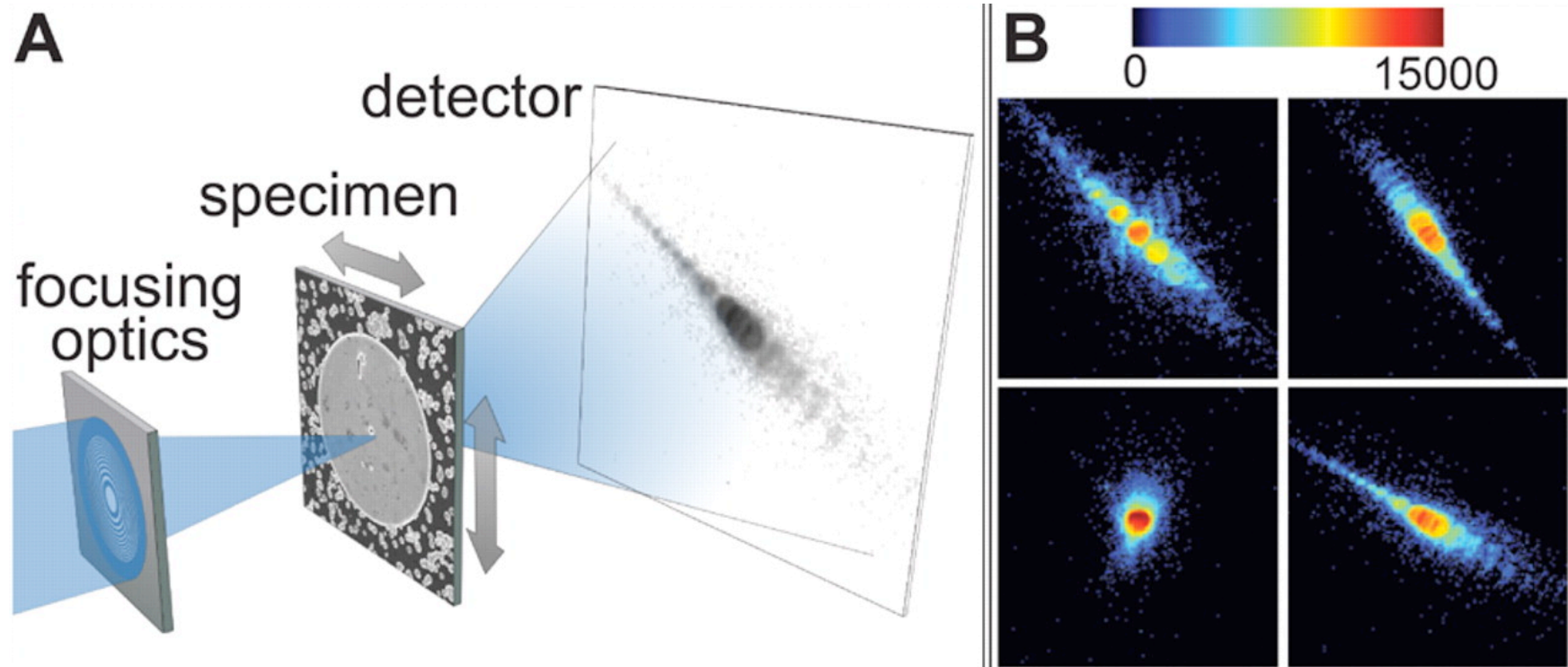
X-ray Ptychography

J. Rodenburg et al, PRL 98, 034801 (2007)



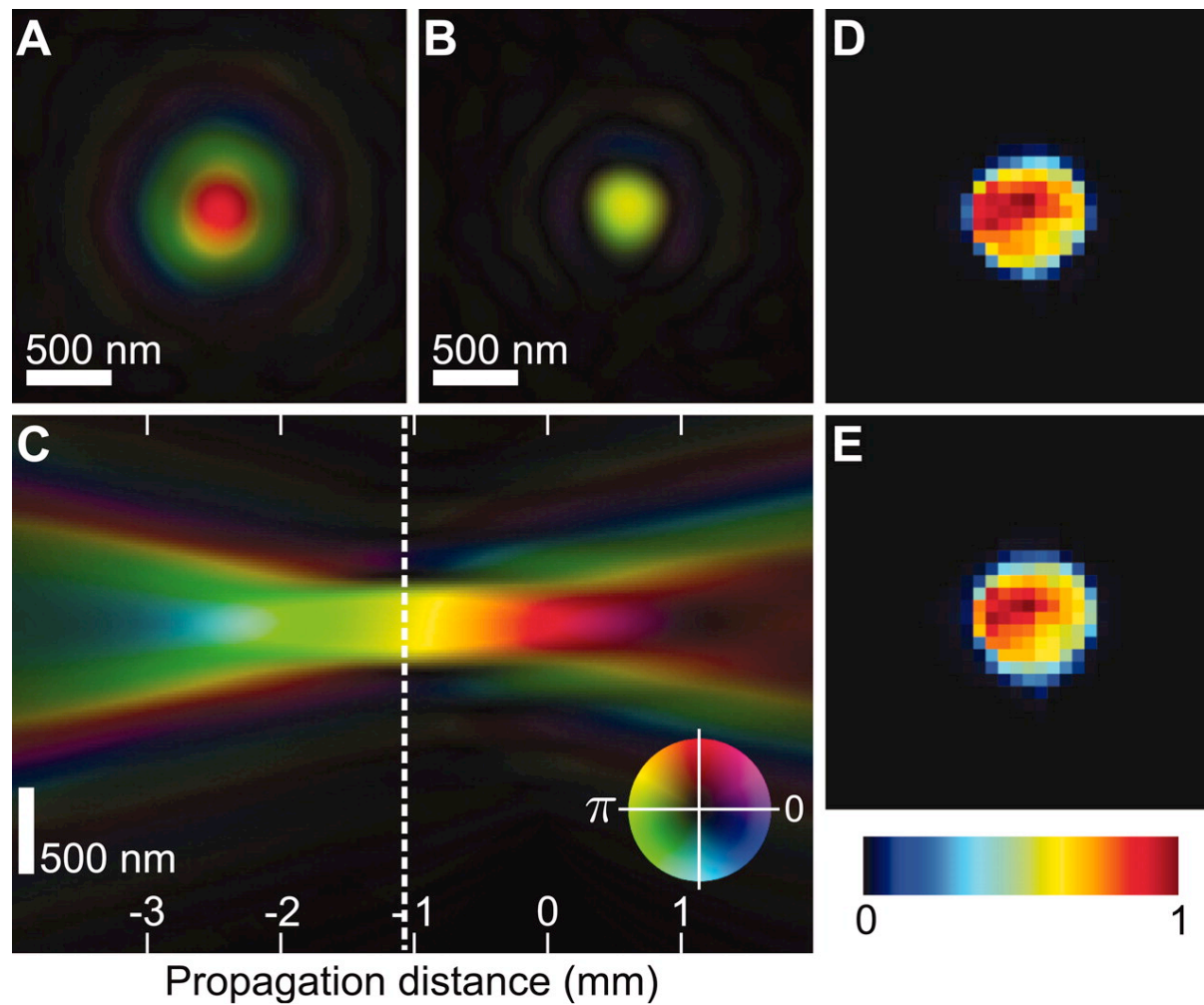
X-ray Ptychography

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



Reconstruction of Probe

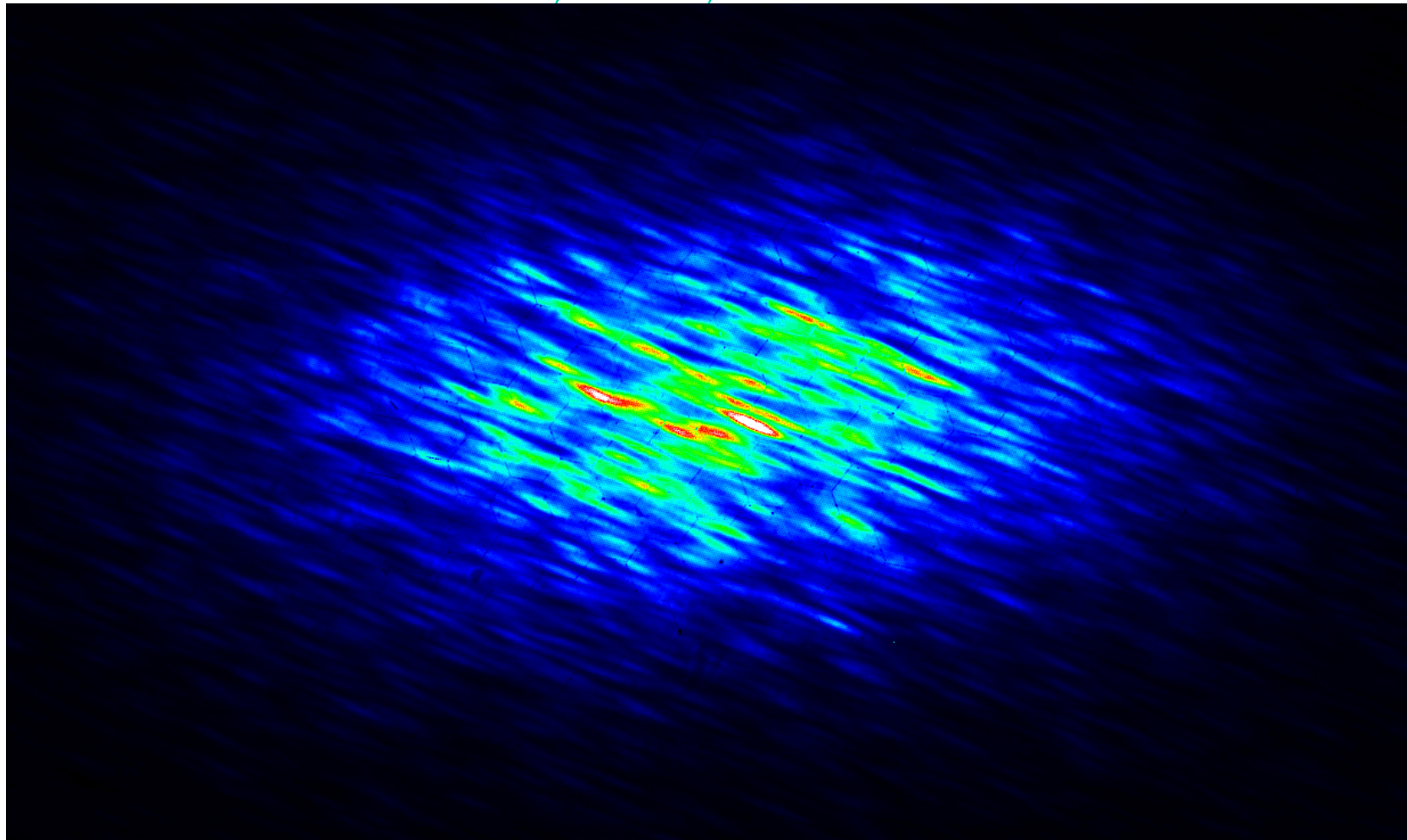
P. Thibault et al, Science 321 379 (2008)



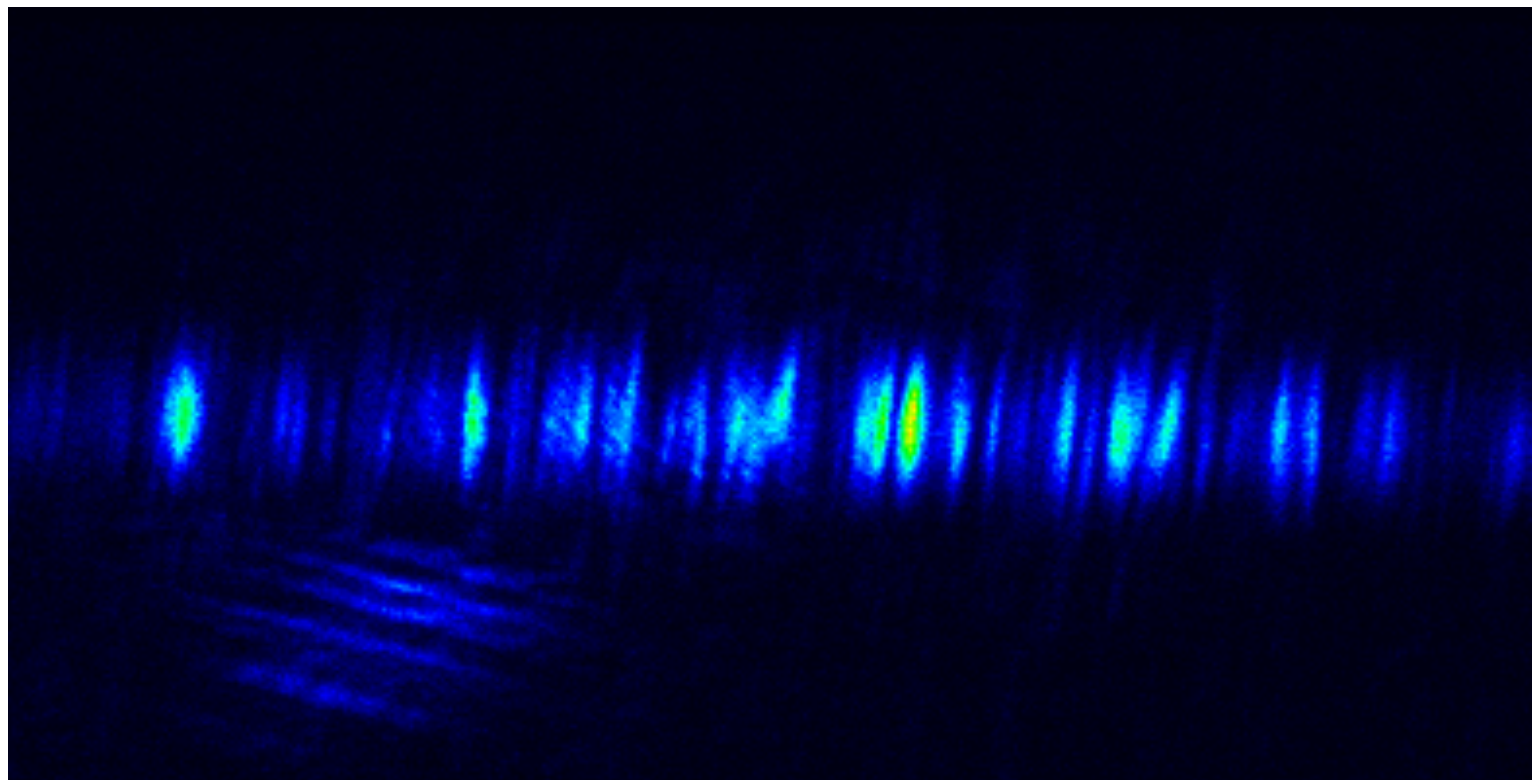
Niobium (110) Thin Film Grains

1 μm steps across 3 μm beam of KB mirror focus

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

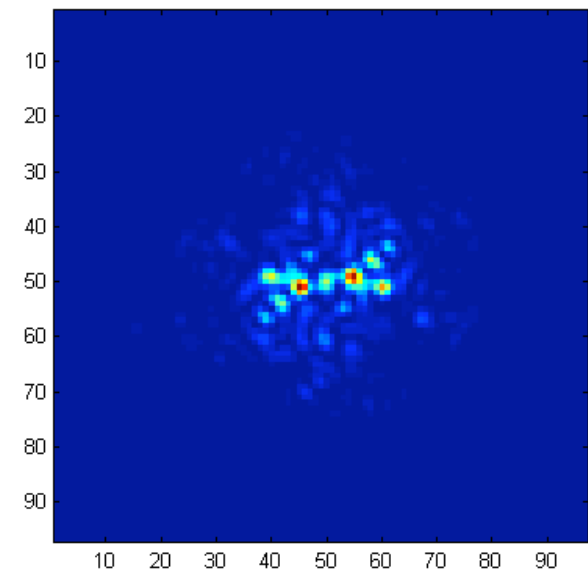
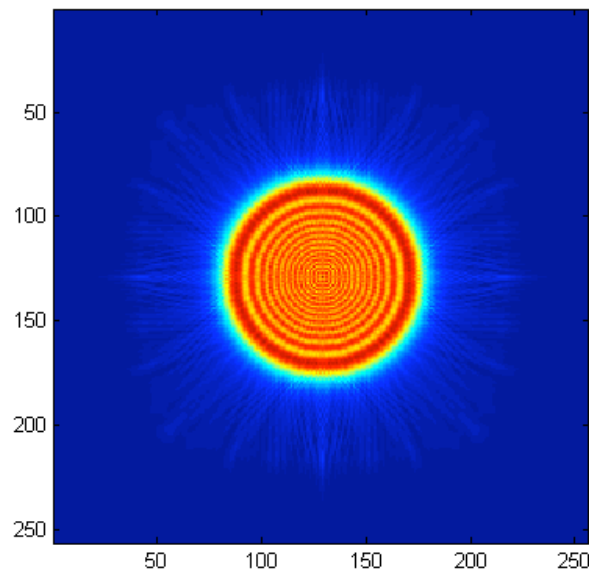
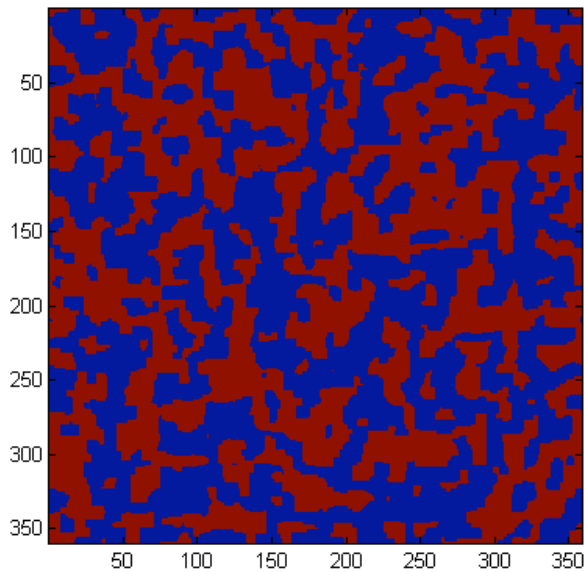


“Barcode” diffraction of GaAs nanowire



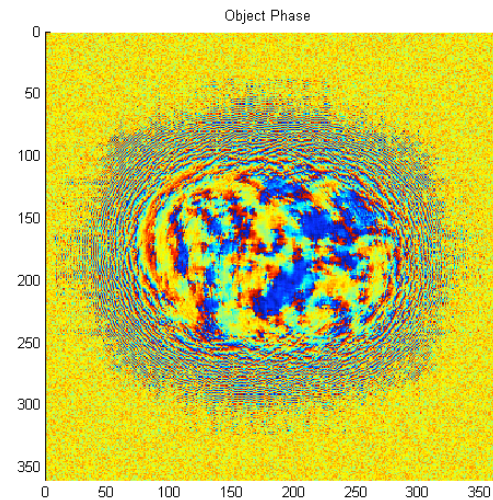
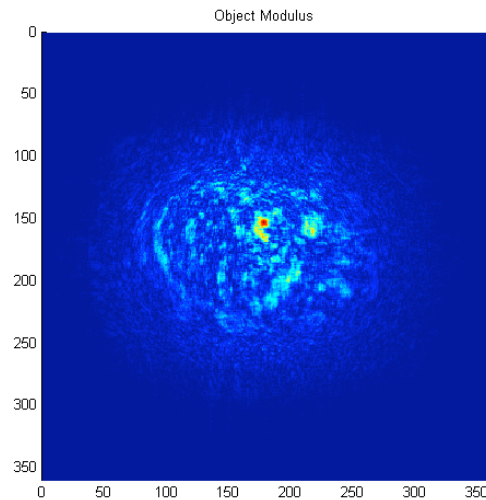
Ptychography phasing tests

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

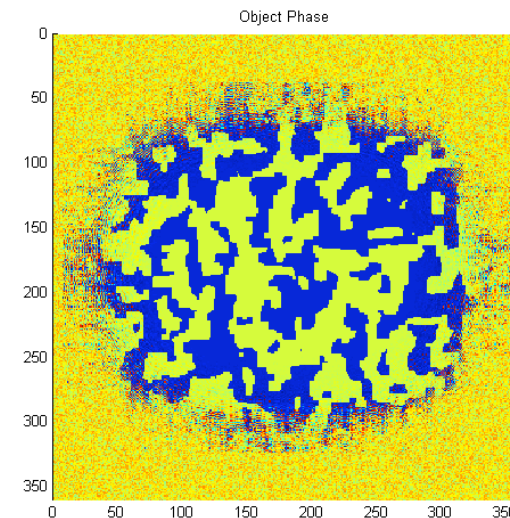
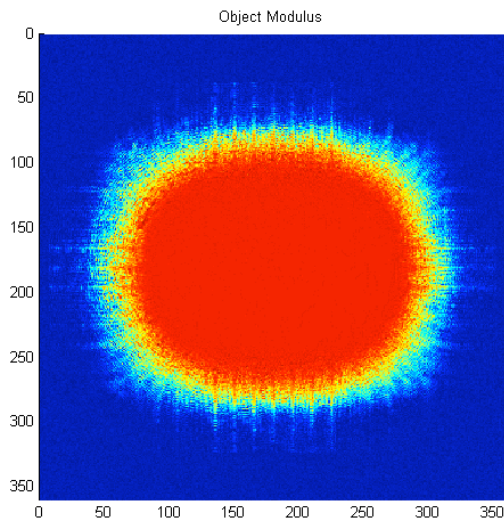


Ptychography phasing tests

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



Amplitude and phase after 1 iteration.

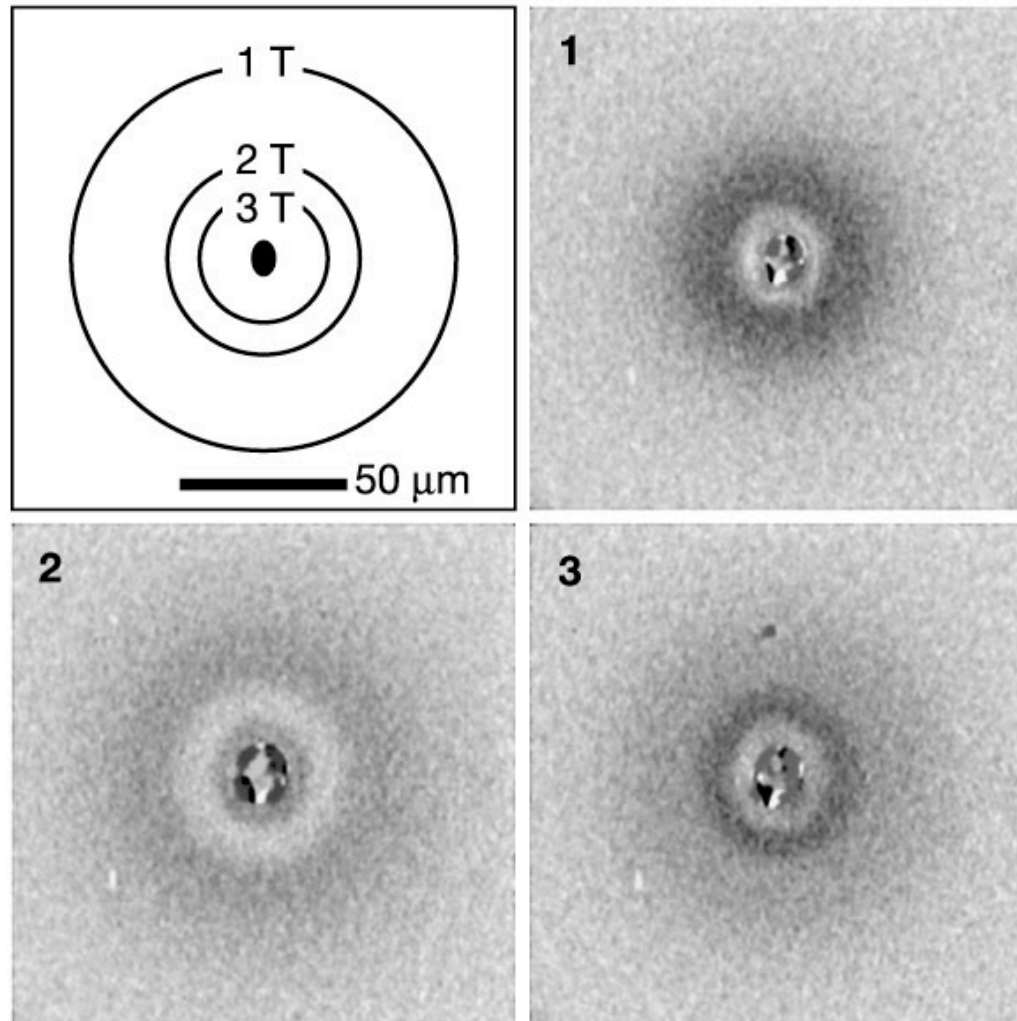


Amplitude and phase after 20 iterations.

Kerr microscopy after 28GeV SLAC pulses

14-nm perpendicular granular magnetic recording media (CoCrPt)

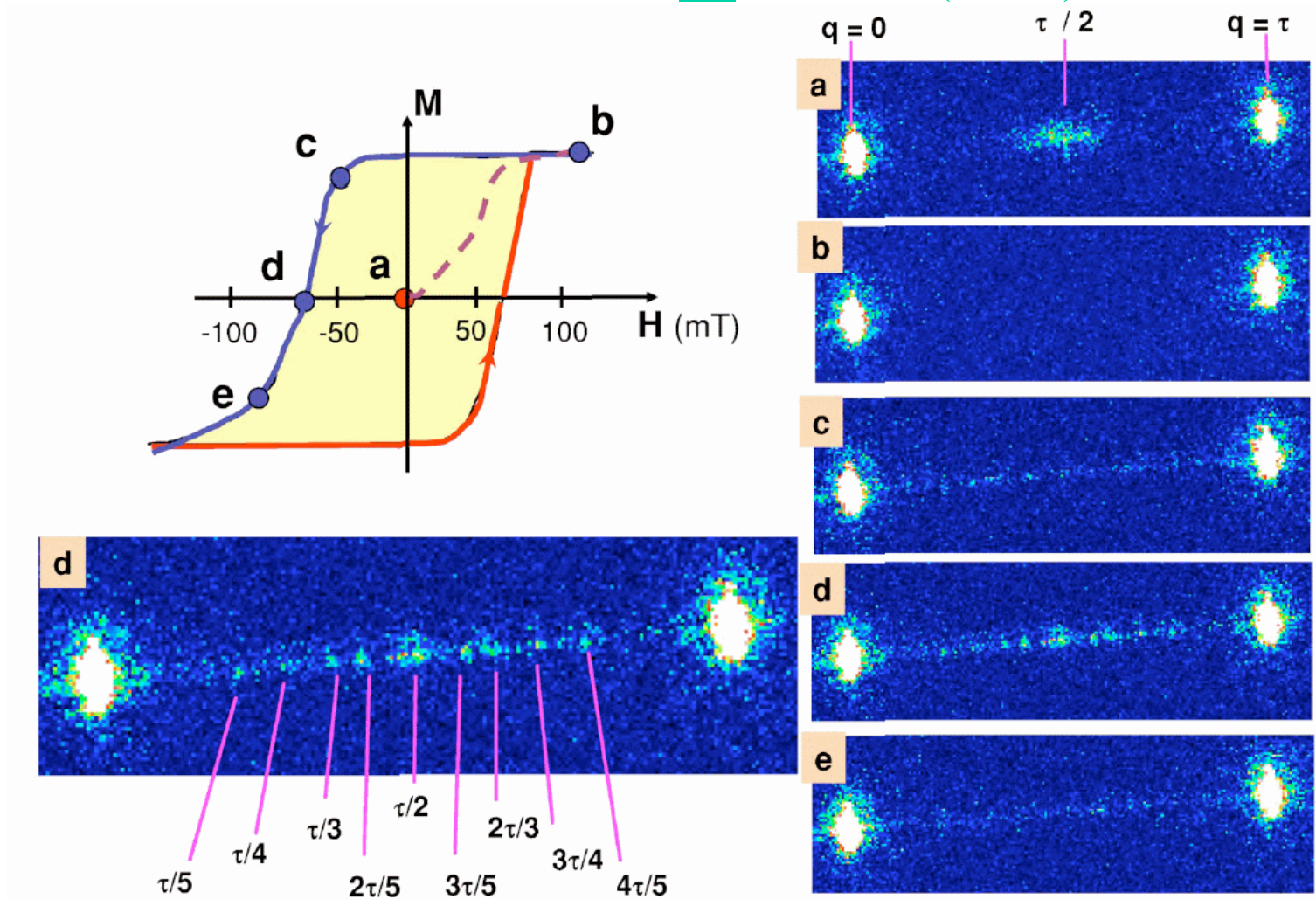
I. Tudosa et al, Nature 428 831 (2004)



number
of 2.3ps
pulses

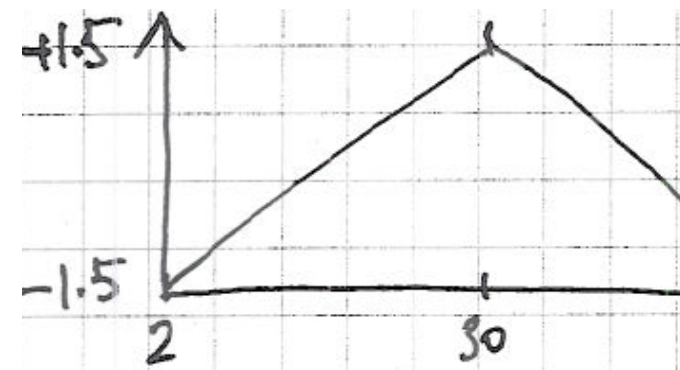
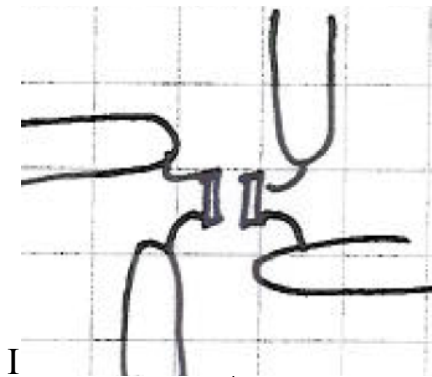
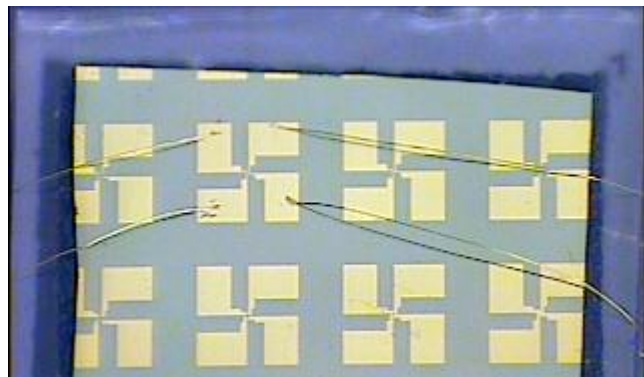
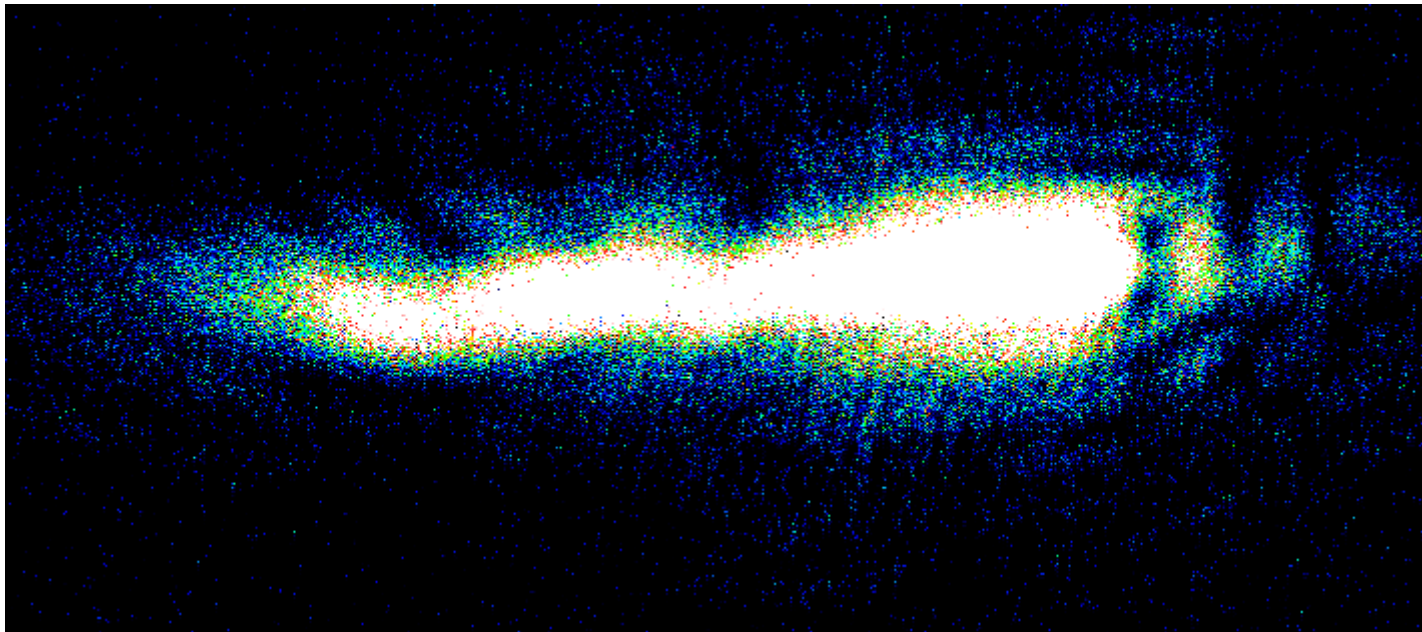
Co/ Pt multilayer line grating at 780eV

K. Chesnel et al, PRB 70 180402 (2004)



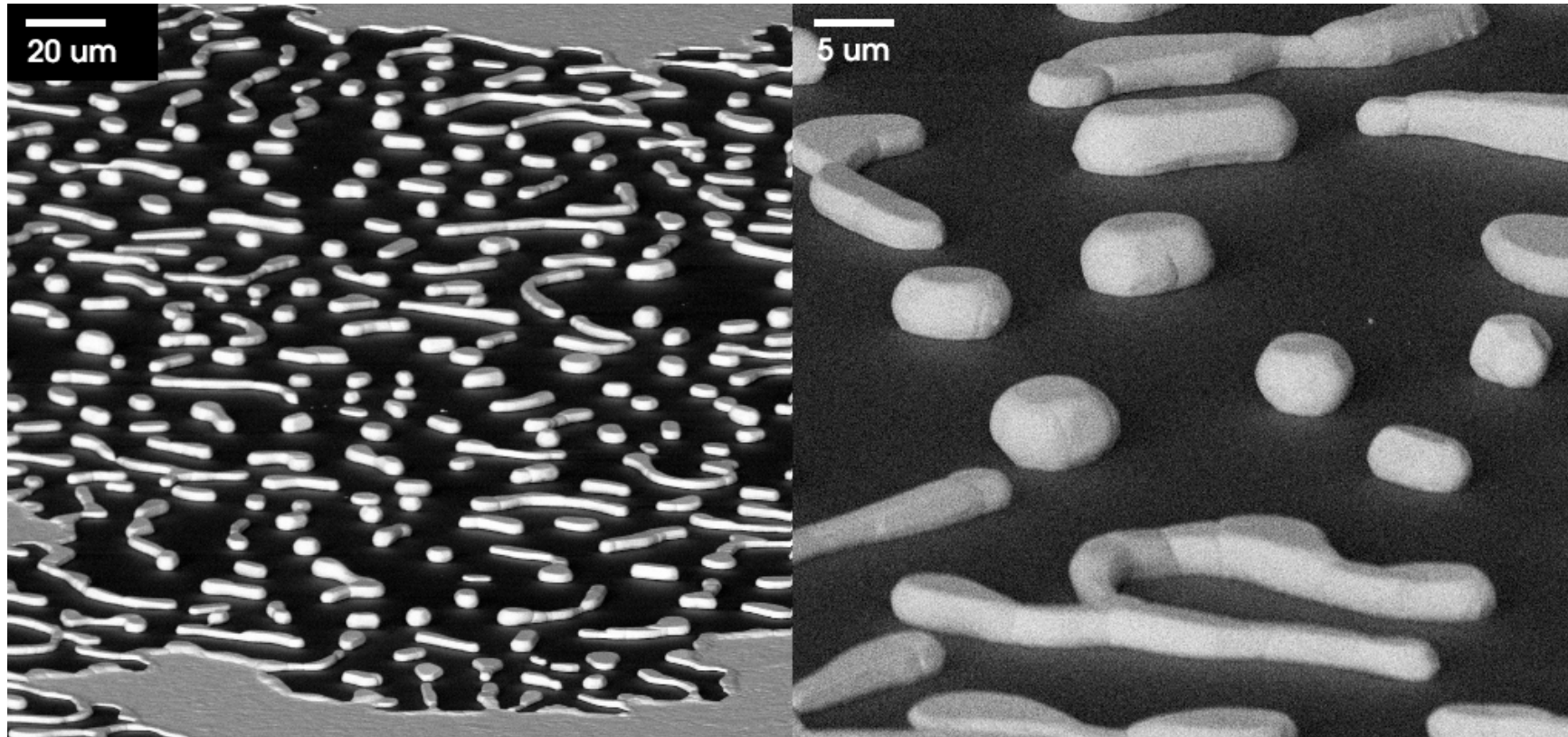
Apply Electric Field along ZnO NC

Marcus Newton. 34-ID-C zno808-18 Aug 2008

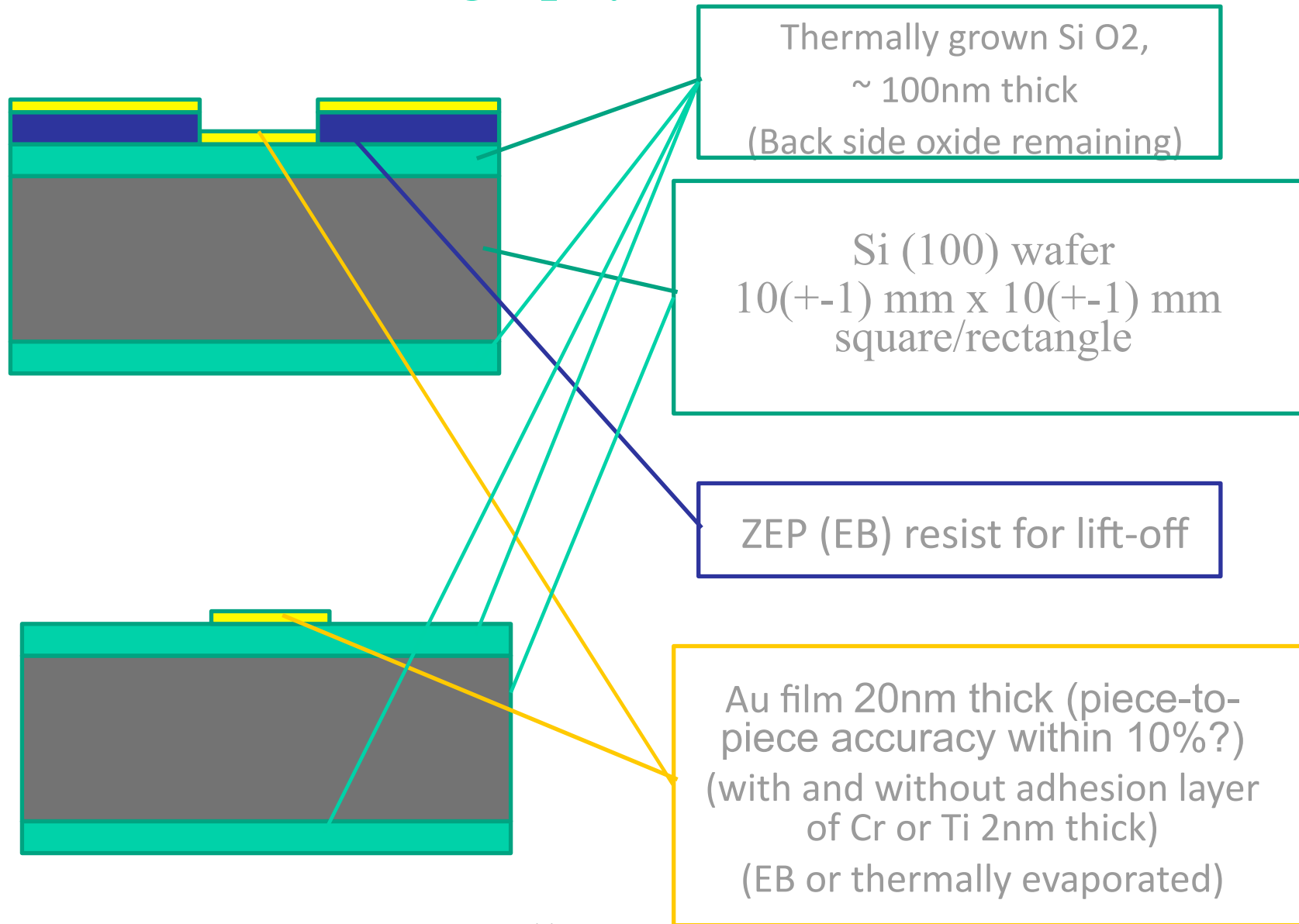


Dewetting to coalesce into crystals

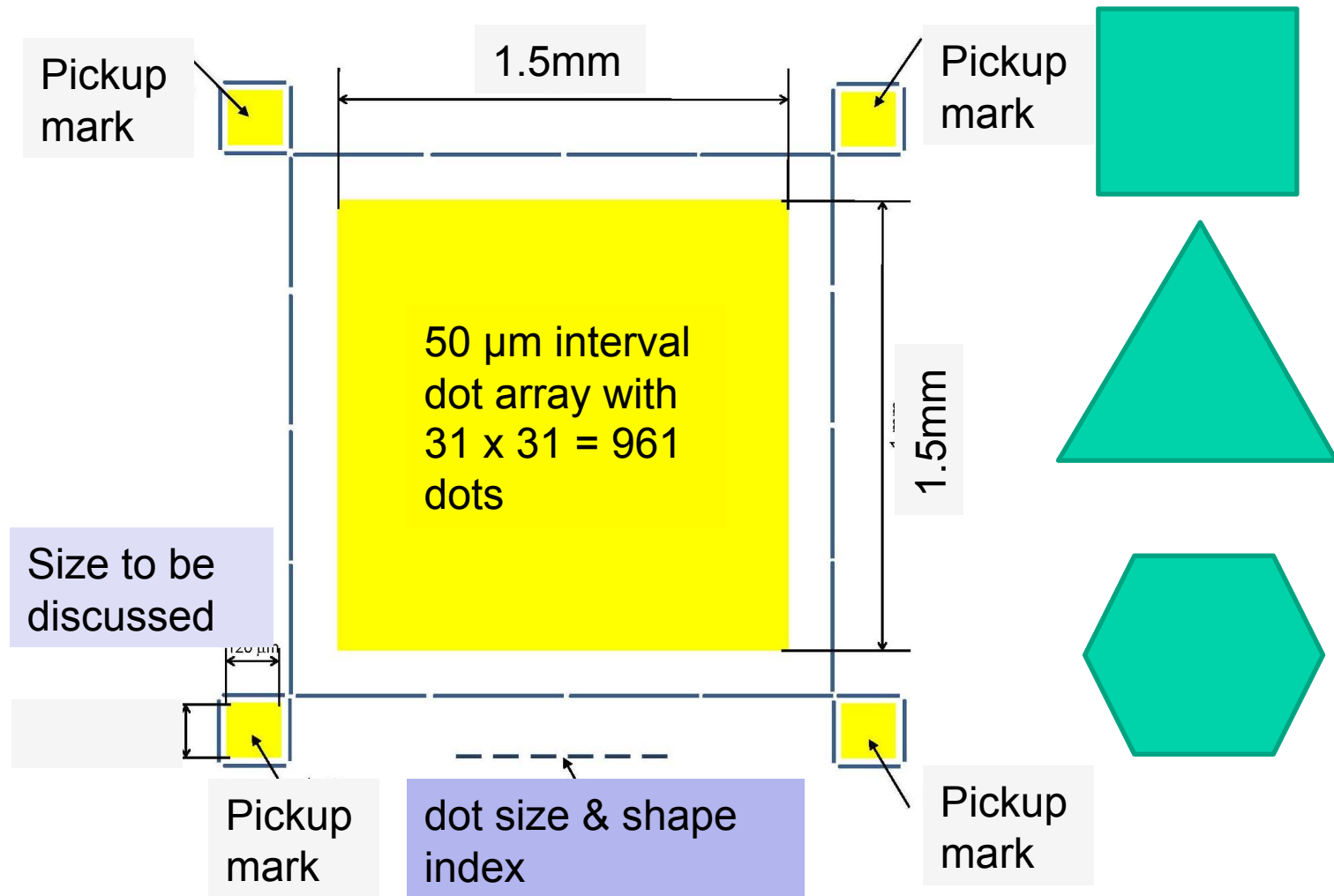
Garth Williams thesis (2005)



e-beam Lithography “Lift-off” method

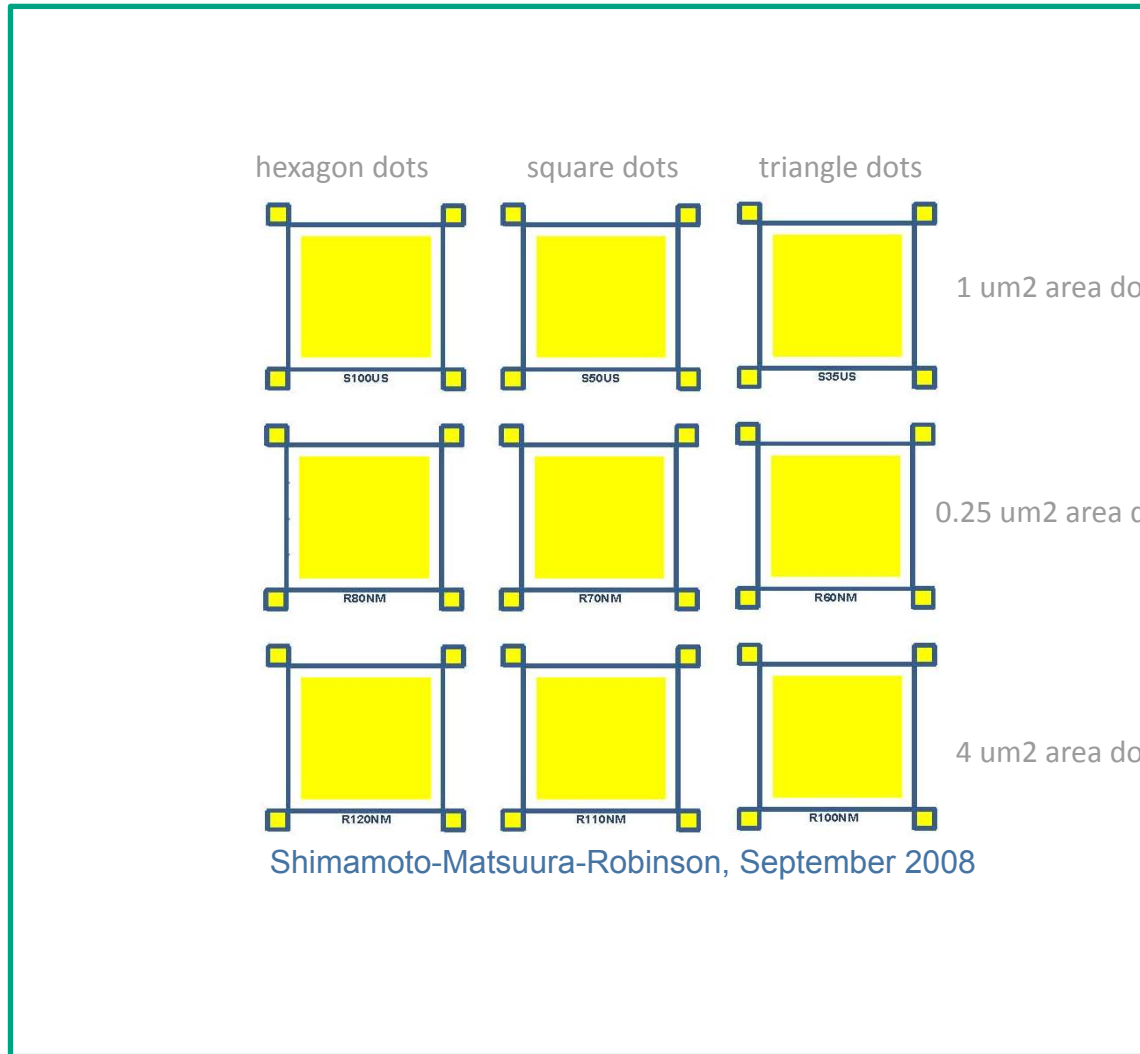


Top View of basic layout plan with pickup marks

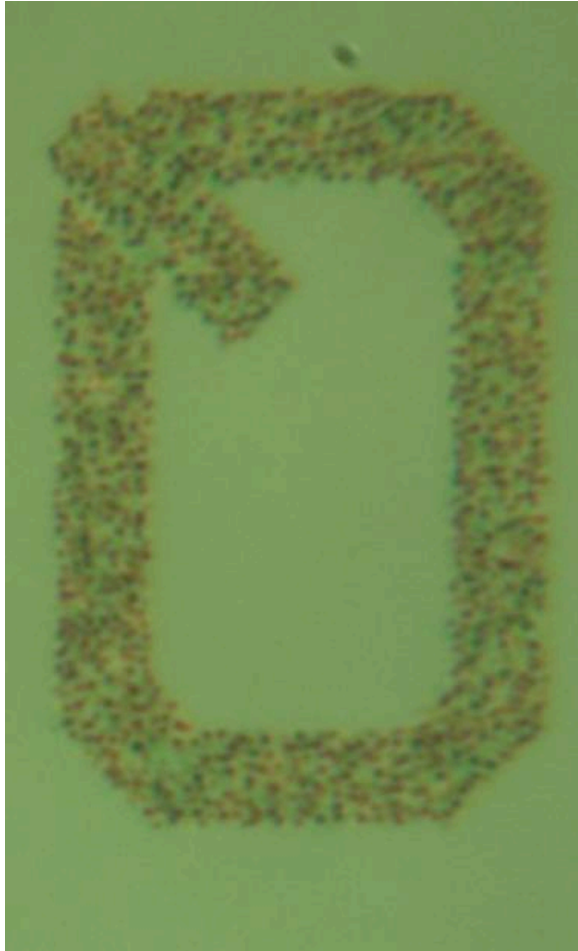


Top View of chip layout

S. Shimamoto (Waseda), T. Matsuura (UCL), Sept 2008



Annealing of Patterned Substrates



Conclusions

- Small crystal imaging
- Strains visible as real-space phase
- Domain imaging should work soon
- Magnetic domains should be visible as strain
- Ptychography reveals probe structure also
- Preparations under way for XFEL