Experience with X-ray Ptychography

- Ian Robinson
- Felisa Berenguer
- Richard Bean
- Graeme Morrison
- Bo Chen
- Fucai Zhang
- Nicolas Burdet
- Isaac Peterson
- Ana Diaz
- Manuel Guizar
- Ross Harder

London Centre for Nanotechnology
University College, London
Research Complex at Harwell

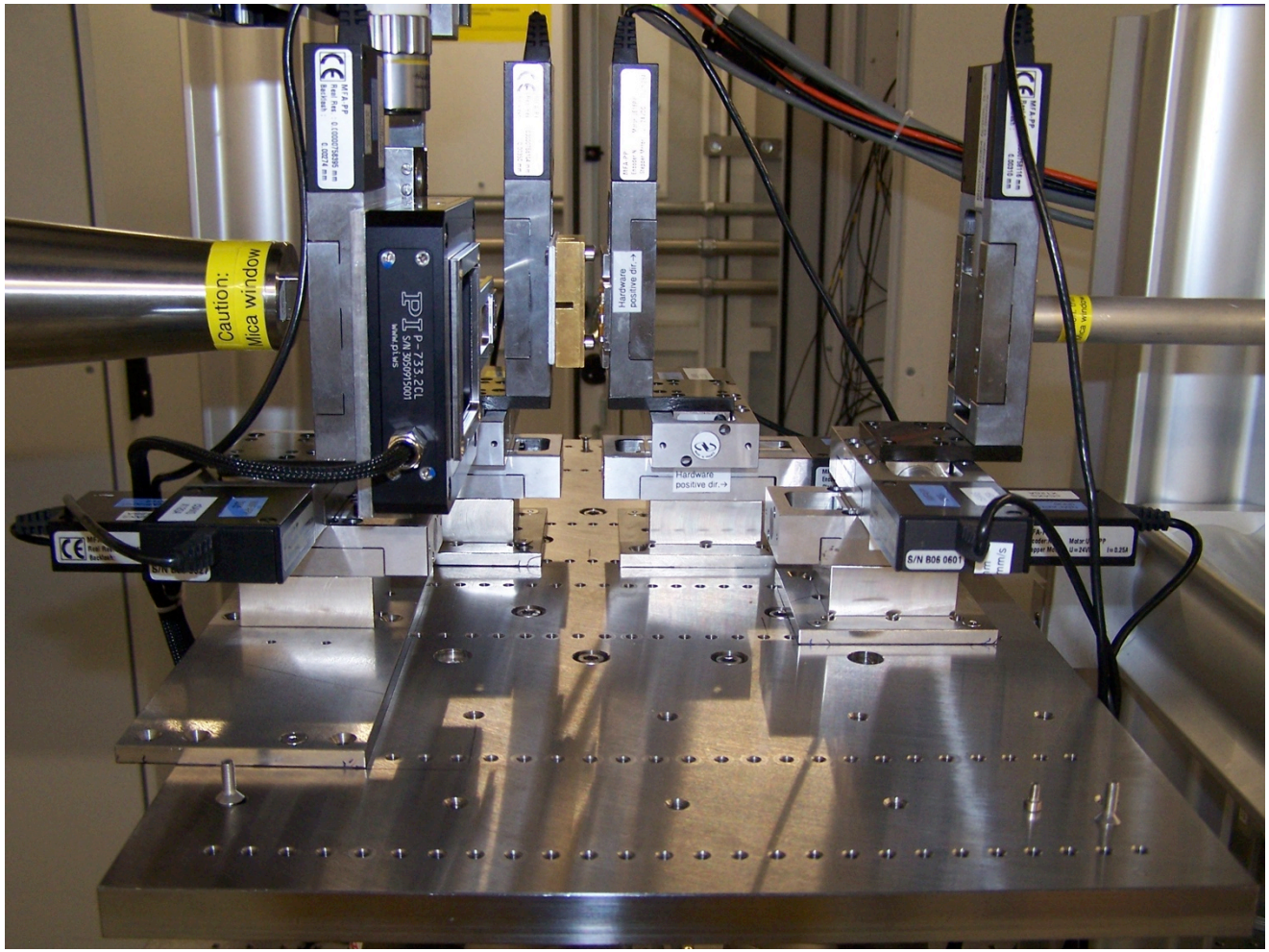
Swiss Light Source
Advanced Photon Source

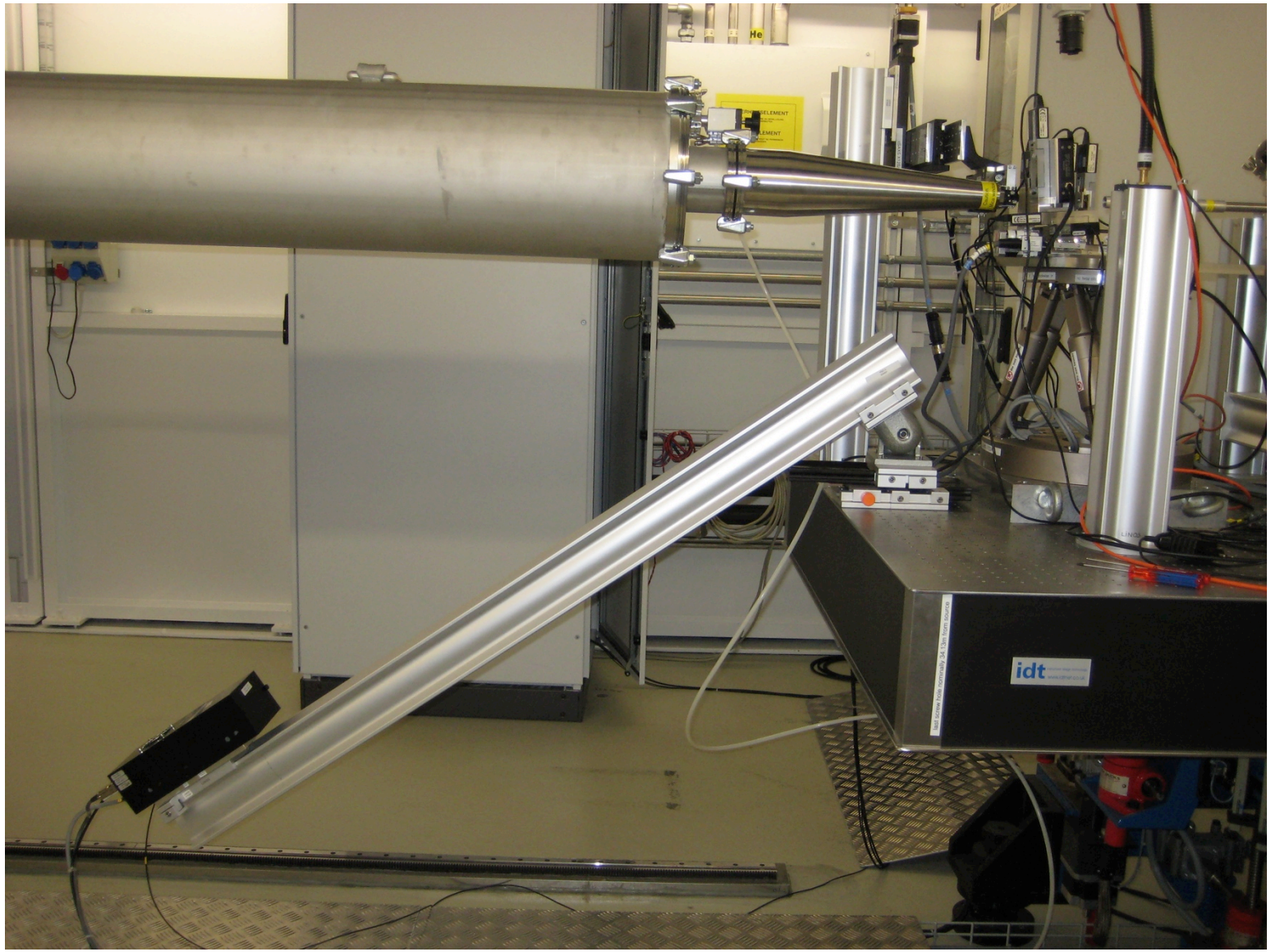
Sao Paulo School
July 2015

Lecture 2 Topics

I. Ptychography Setup
II. Propagation Uniqueness
III. Bragg Ptychography
IV. Collagen Imaging
V. Probe Diversity
VI. Position correction

Swiss Light Source cSAXS beamline

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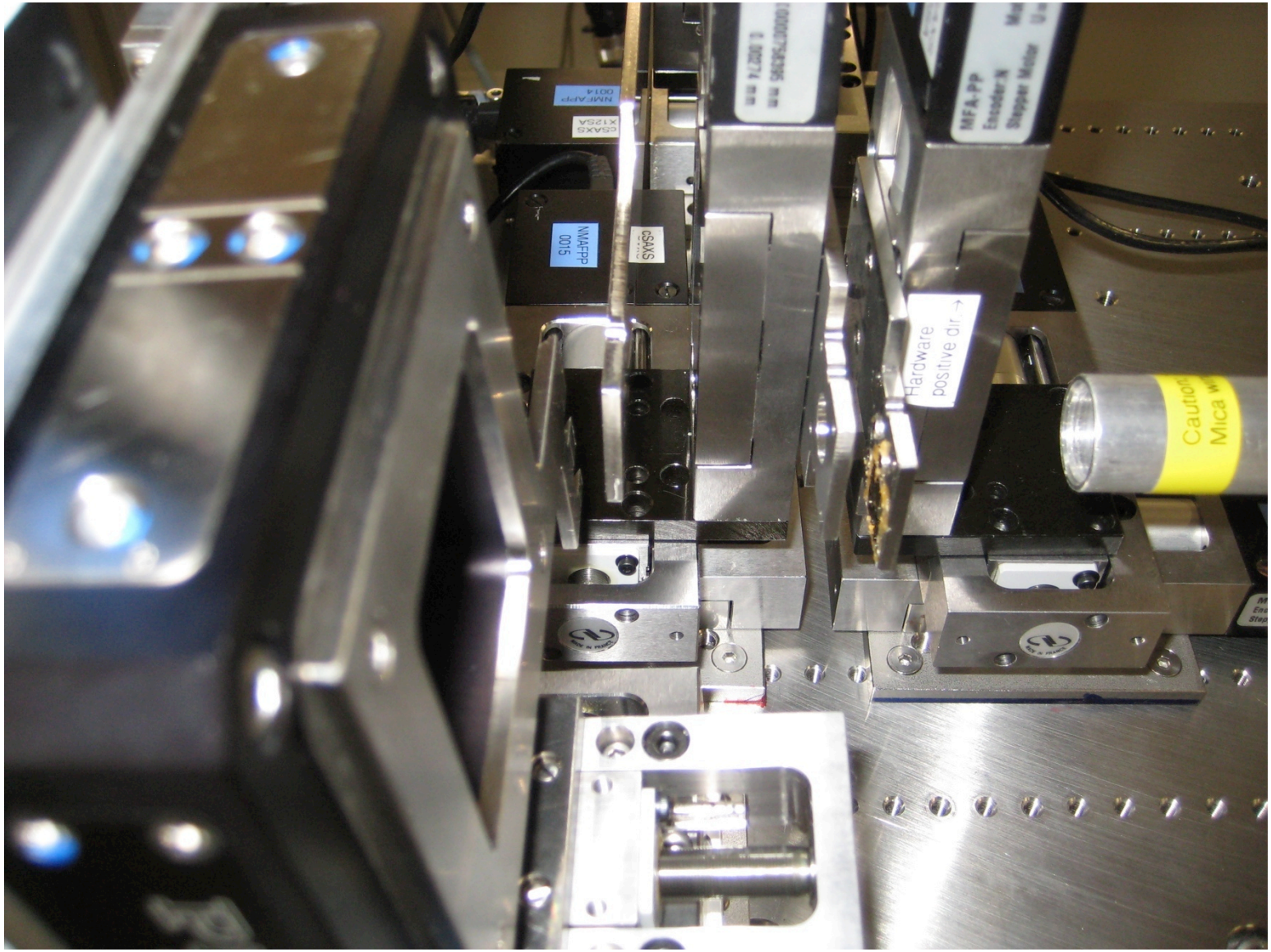
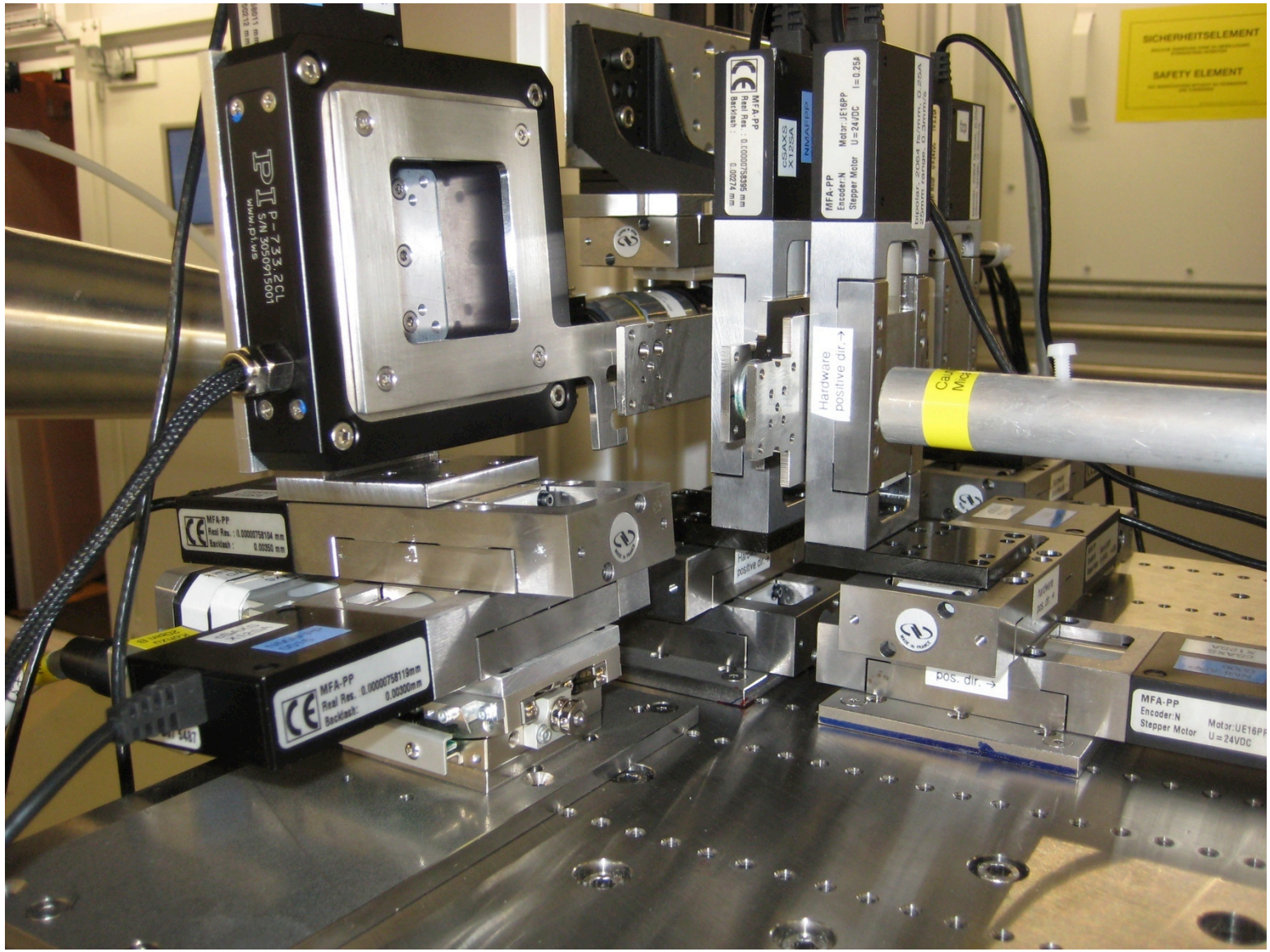
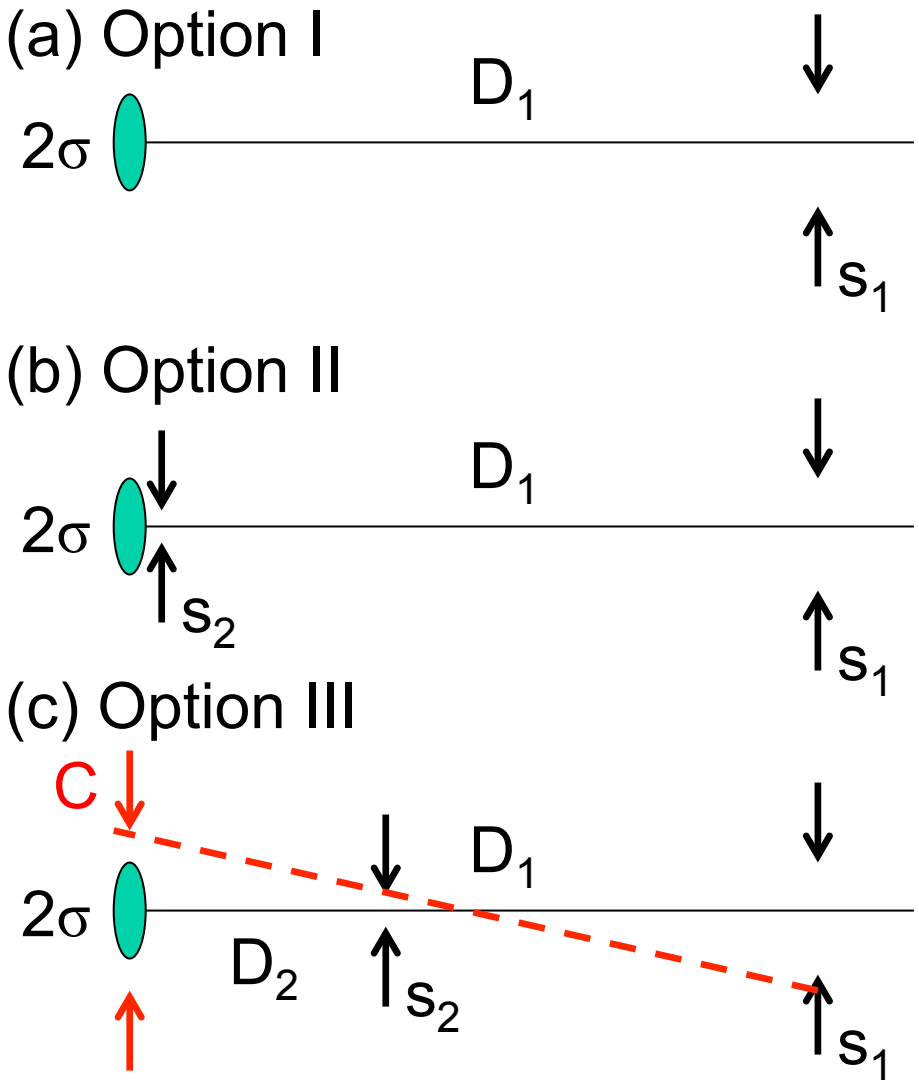
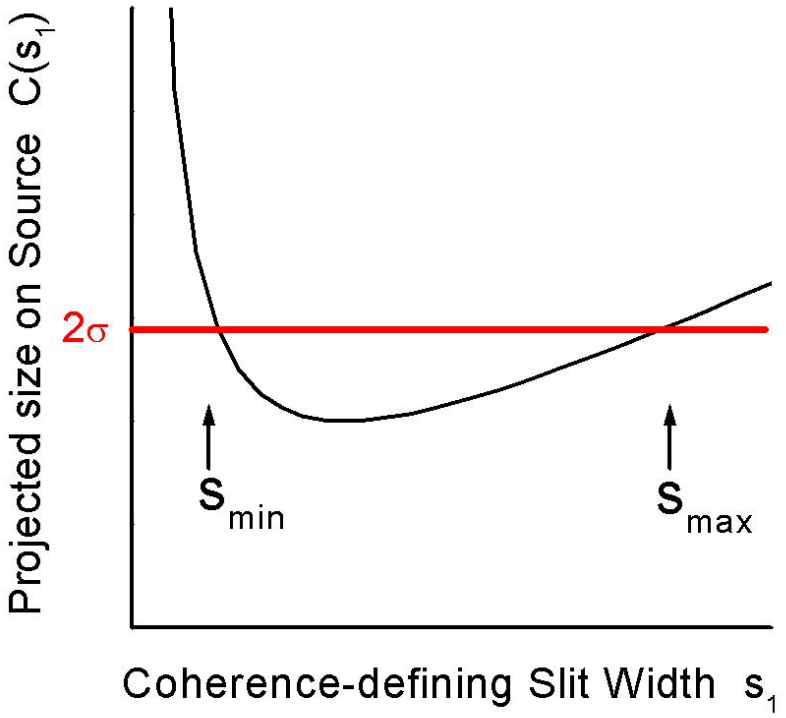

NMAFPP
0015
cSAXS
Hardware
positive dir →


SICHERHEITSELEMENT
SAFETY ELEMENT
PI
P-733.2CL
MFA-PP
Hardware positive dir.→
pos. dir.→
MFA-PP
Encoder:N
Stepper Motor
Motor:UE16PP
U=24VDC

Horizontal Secondary Source





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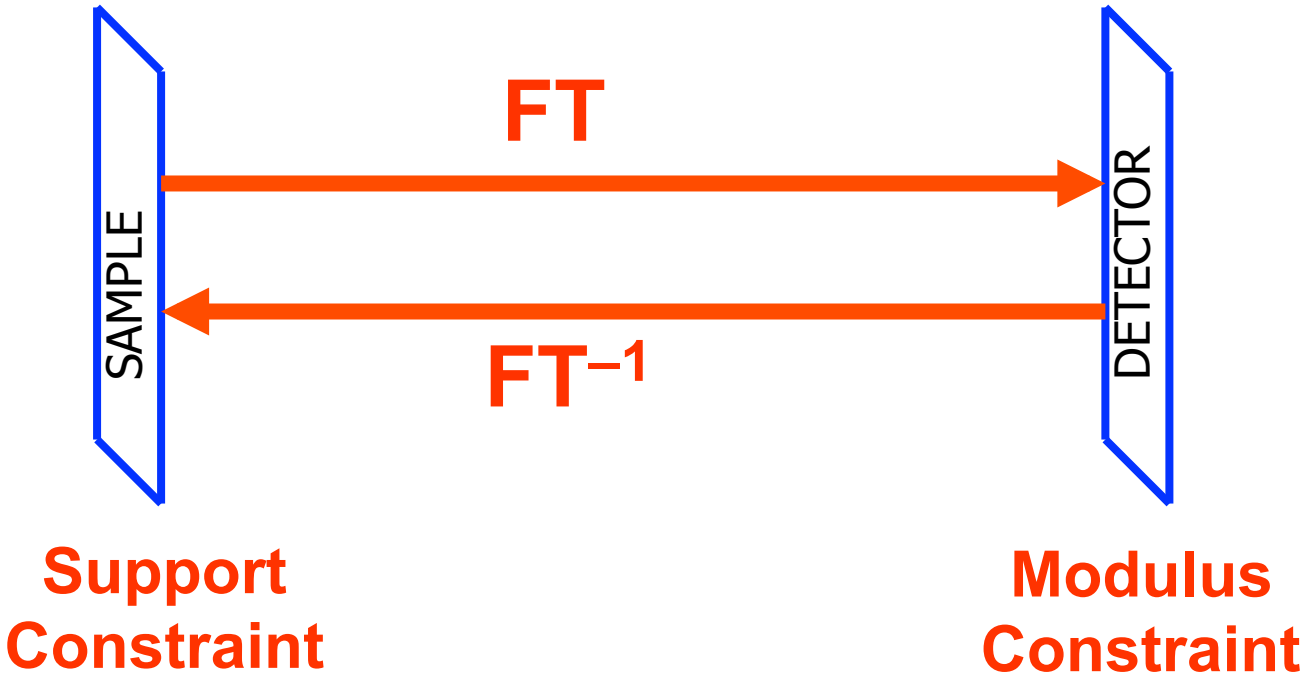
Free-space propagation

$$t'(\mathbf{r}') = \int t(\mathbf{r}) e^{ik(\mathbf{r}-\mathbf{r}')^2/2d} d\mathbf{r},$$

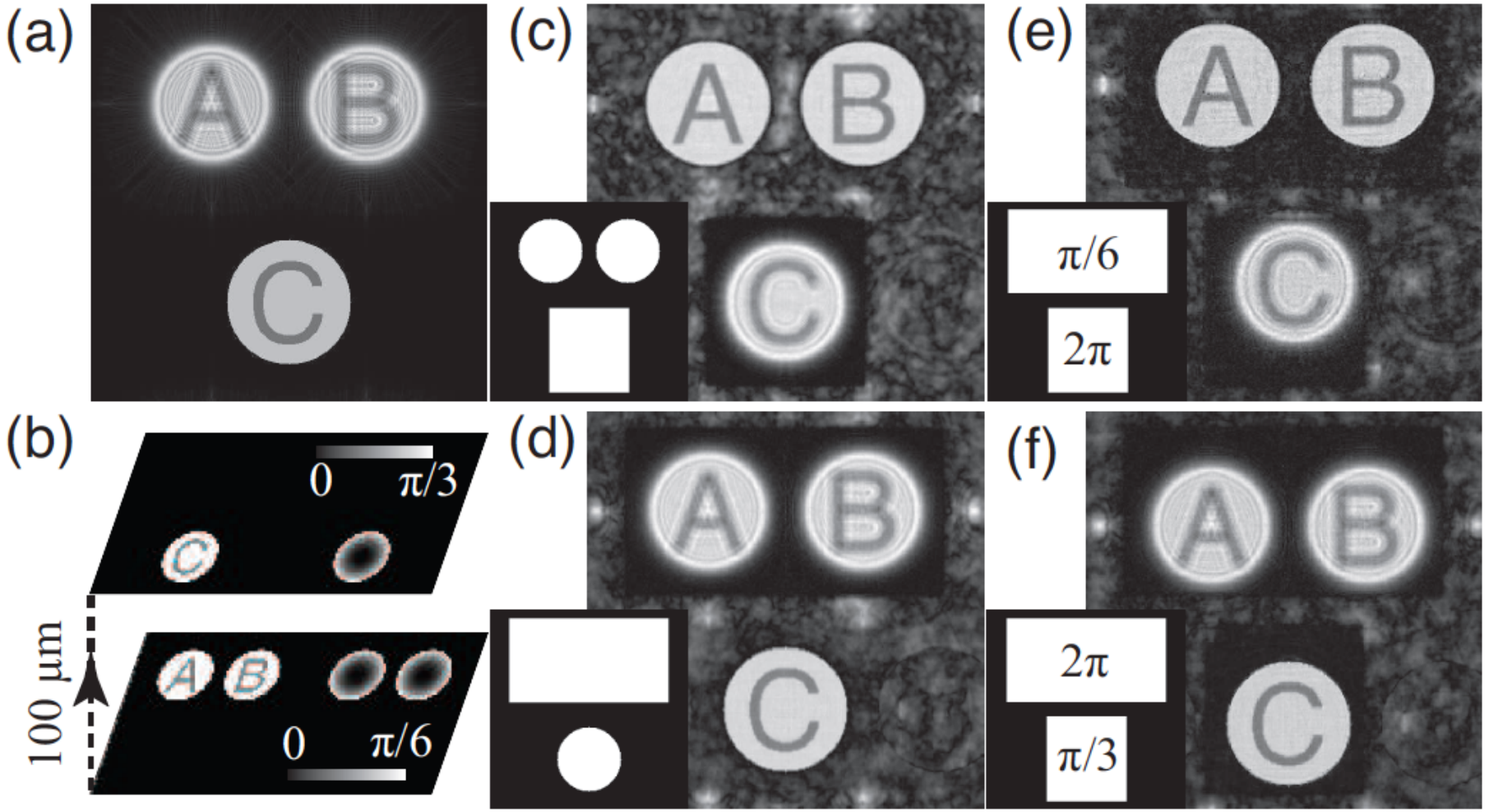
- Box -> box with fringes
- Real Gaussian -> complex *wider* Gaussian
- Real sharp object -> defocused complex object
- Propagated objects all have the same Fourier transform
- Inversion of far-field diffraction is non-unique

Coherent Diffractive Imaging
General 2-plane Method



2D reconstruction support tests

J. C. H. Spence, U. Weierstall and M. Howells, Phil. Trans. 360, 875 (2002)
Xiaojing Huang, et al, Physical Review B 83 224109 (2011)



Curvature cures Stagnation

Image and its twin have same Fourier transform

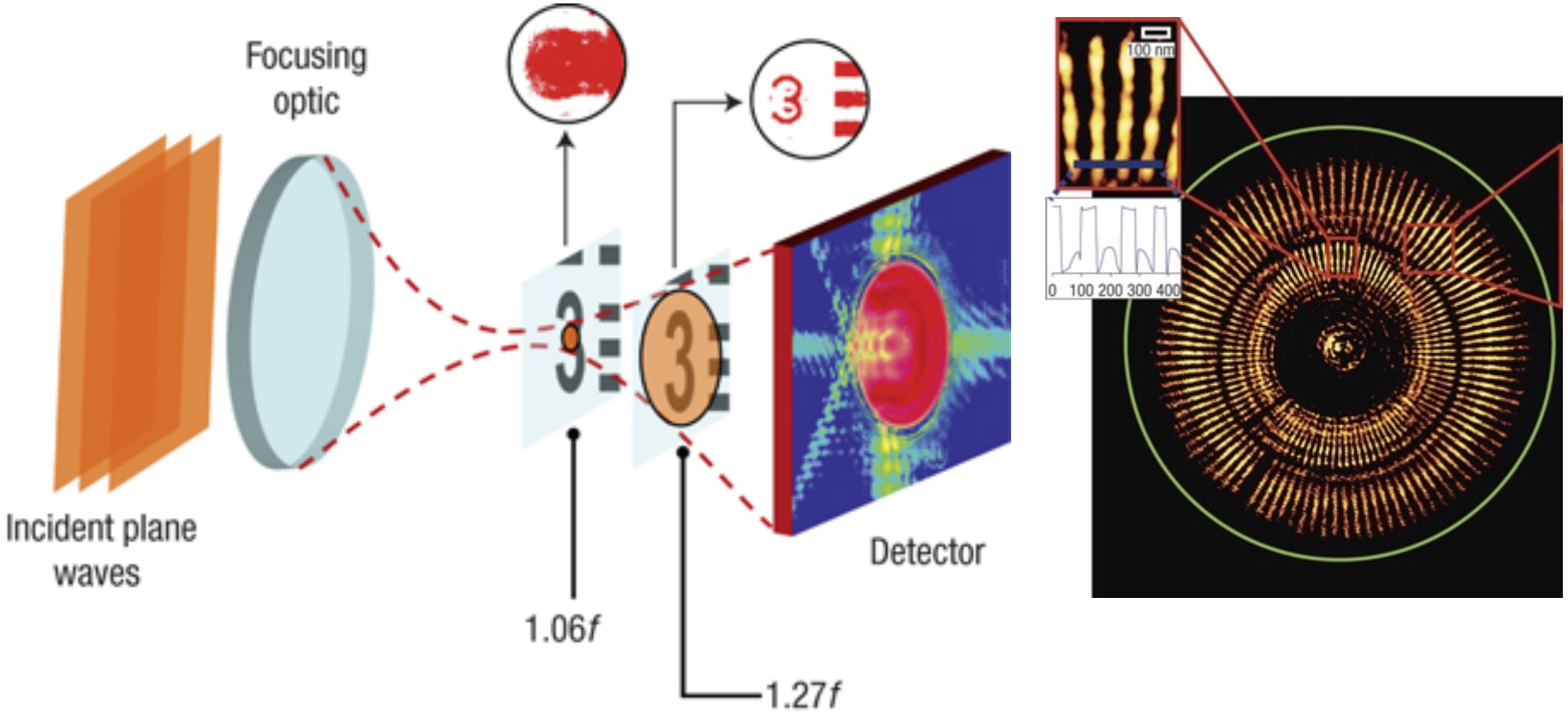
$$\rho(x) \qquad \rho^*(-x)$$

$$\rho(x)\exp(\frac{i\pi x^2}{\lambda D}) \qquad \rho^*(-x)\exp(\frac{-i\pi x^2}{\lambda D})$$

Known modulation (phase curvature) allows twins to be discriminated using support

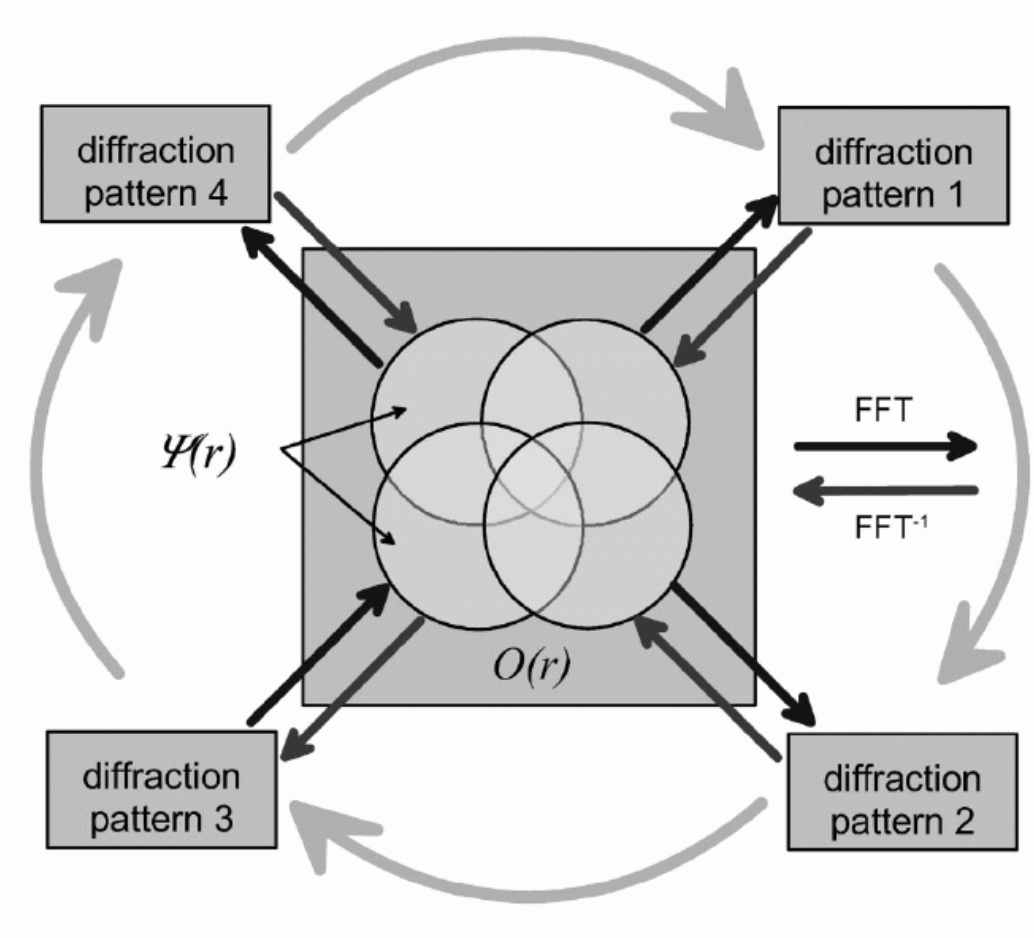
Keyhole coherent diffractive imaging

B. Abbey, K. A. Nugent, G. J. Williams, J. N. Clark, A. G. Peele, M. A. Pfeifer, M. de Jonge & I. McNulty, Nature Physics 4, 394 - 398 (2008)



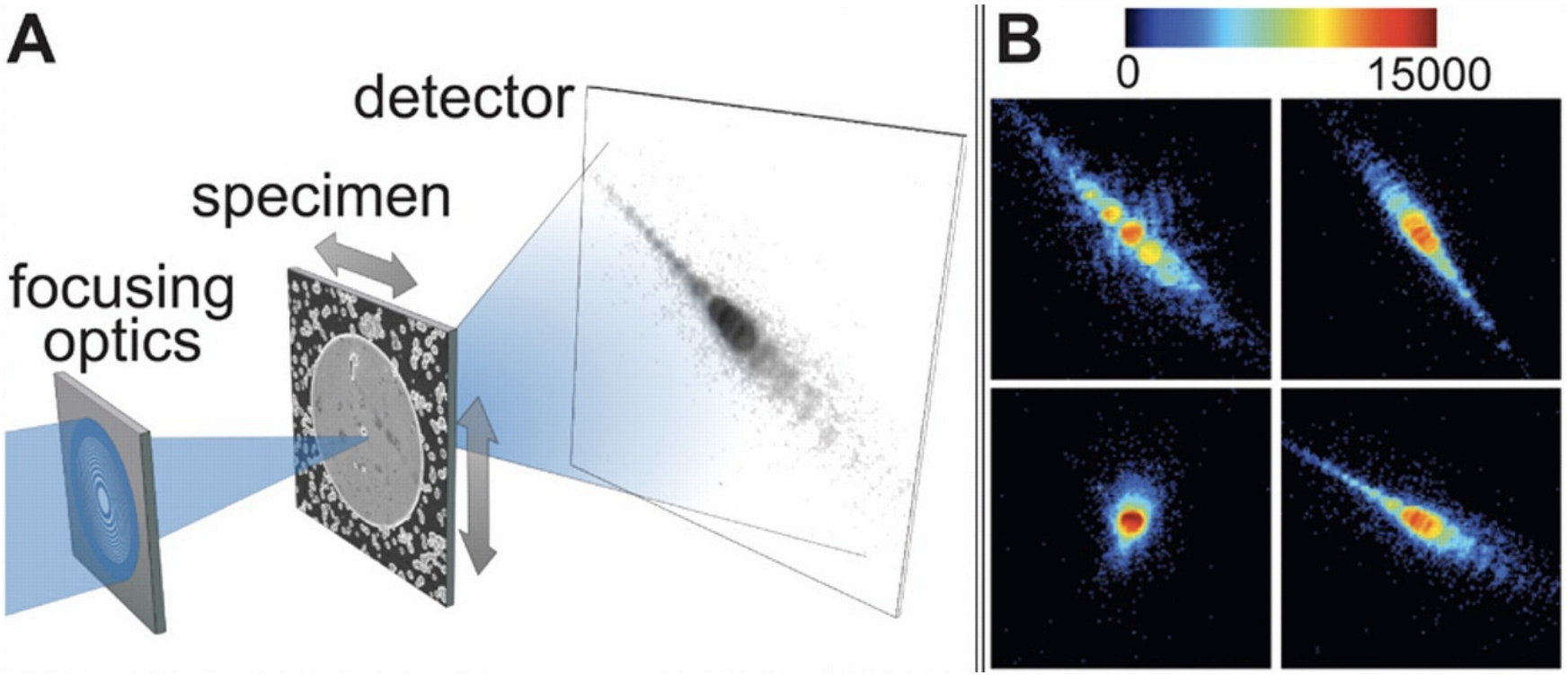
X-ray Ptychography

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



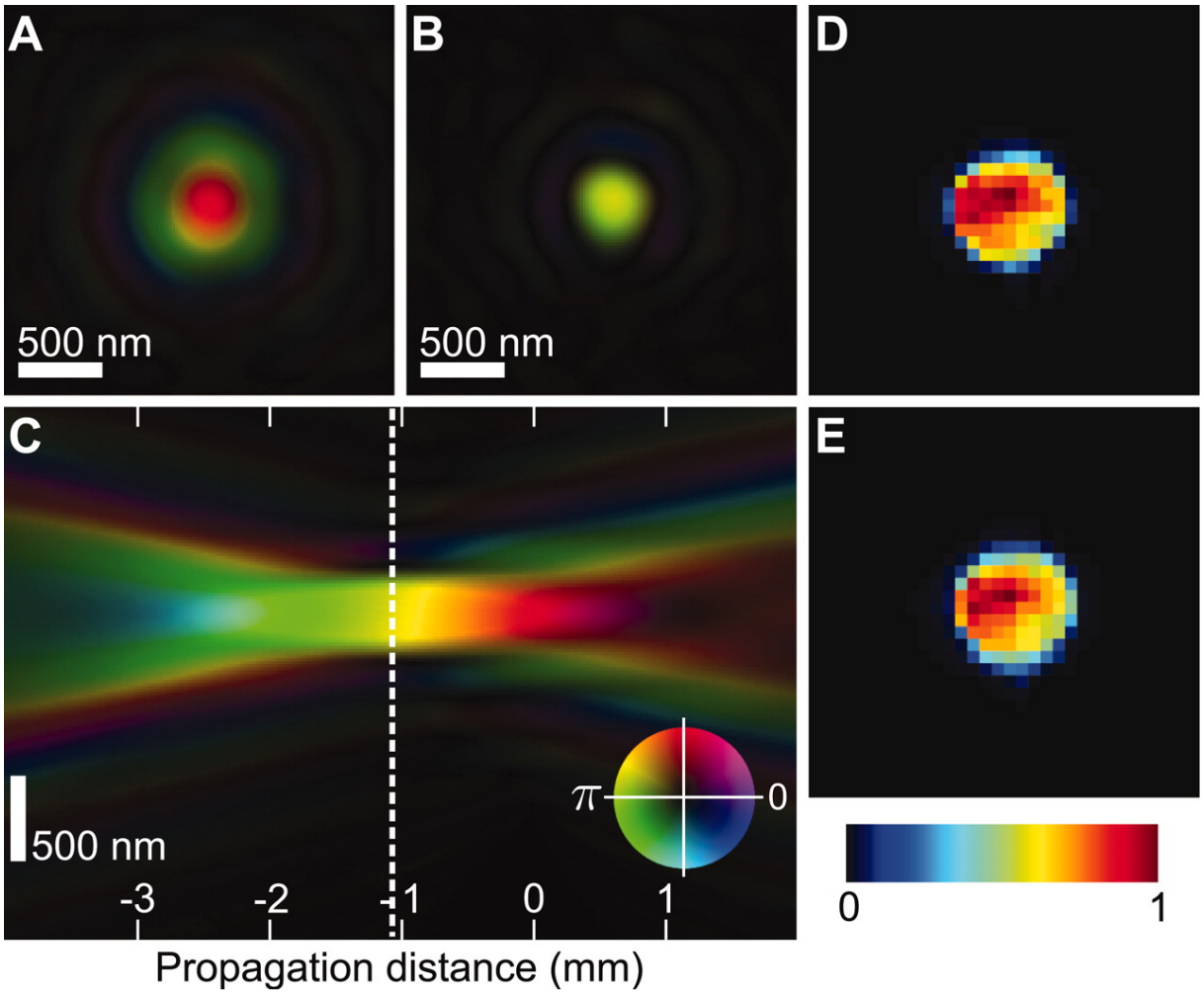
X-ray Ptychography

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



Reconstruction of Probe

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



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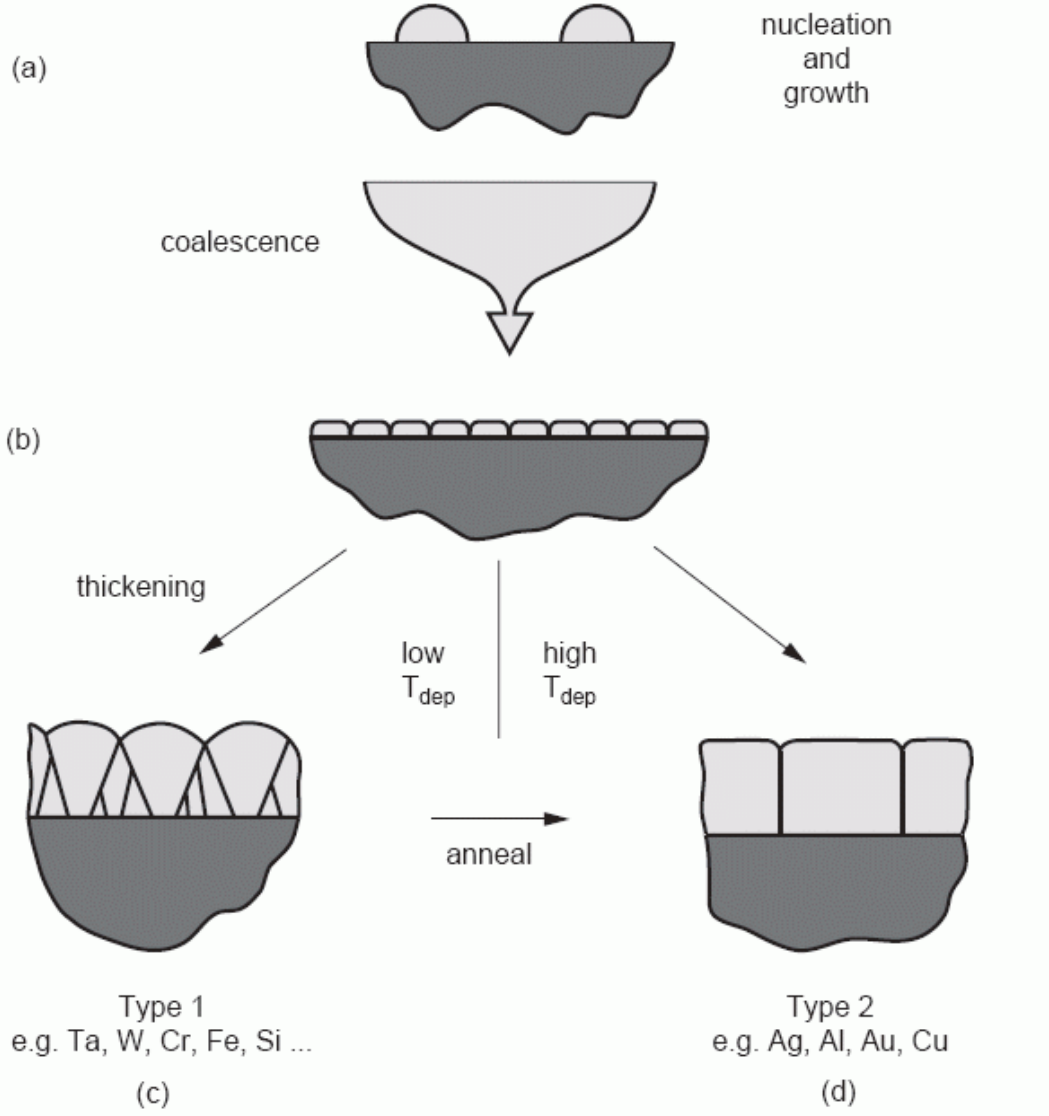
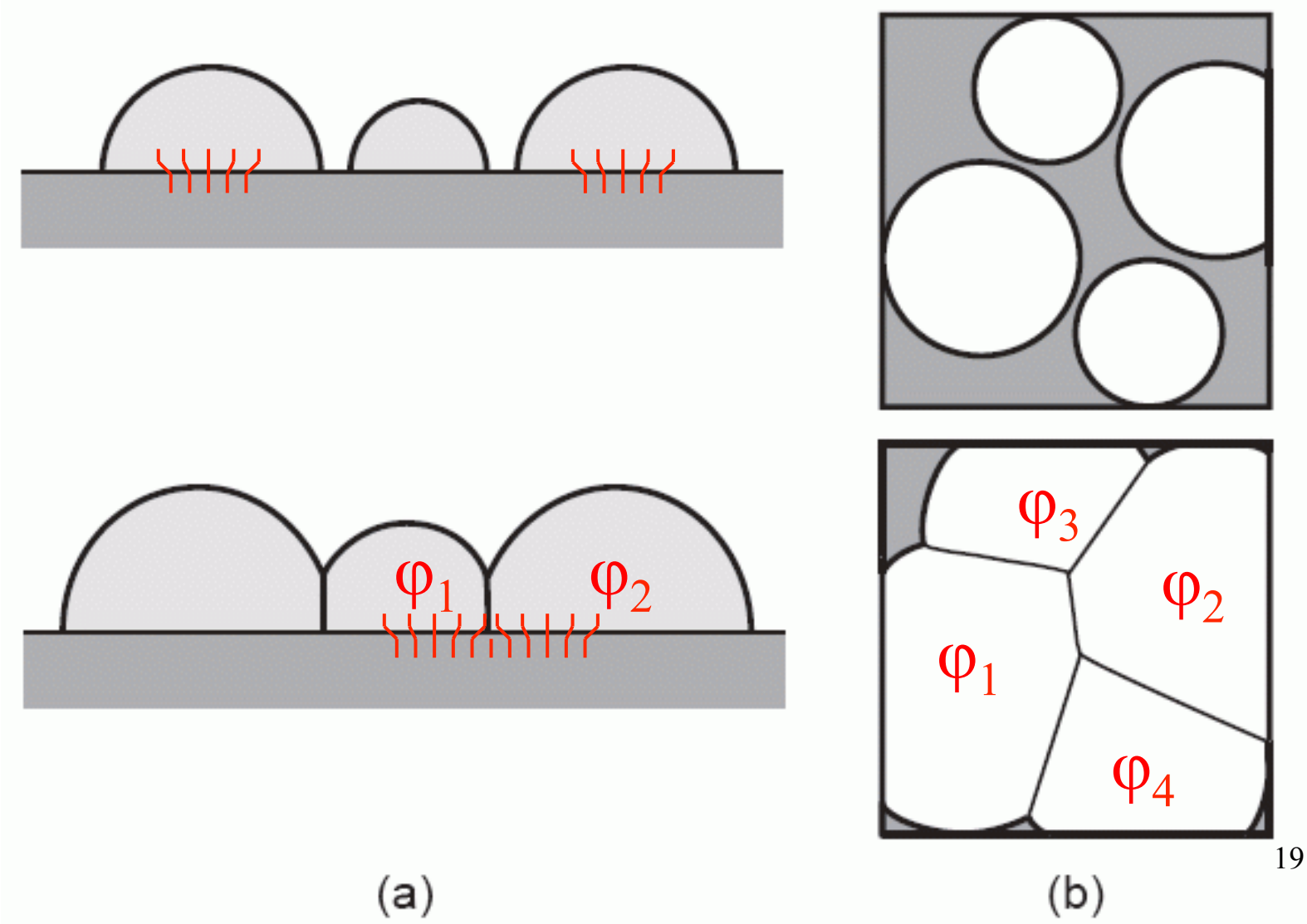
Thin film growth after deposition

C. V. Thompson, Annu. Rev. Mater. Sci. 2000. 30:159–90



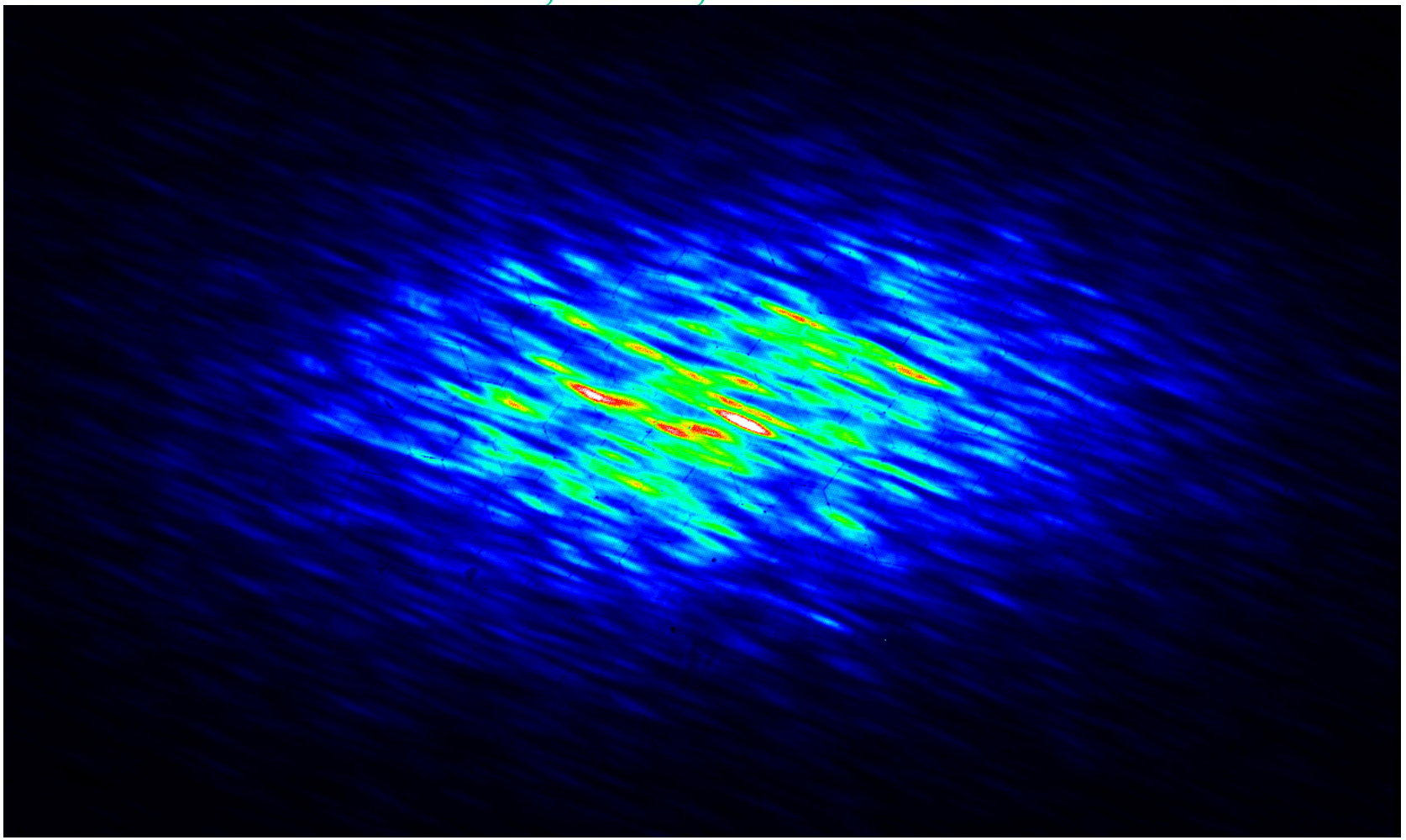
Epitaxial growth effects



Niobium (110) Thin Film Grains

1μm steps across 3μm beam of KB mirror focus

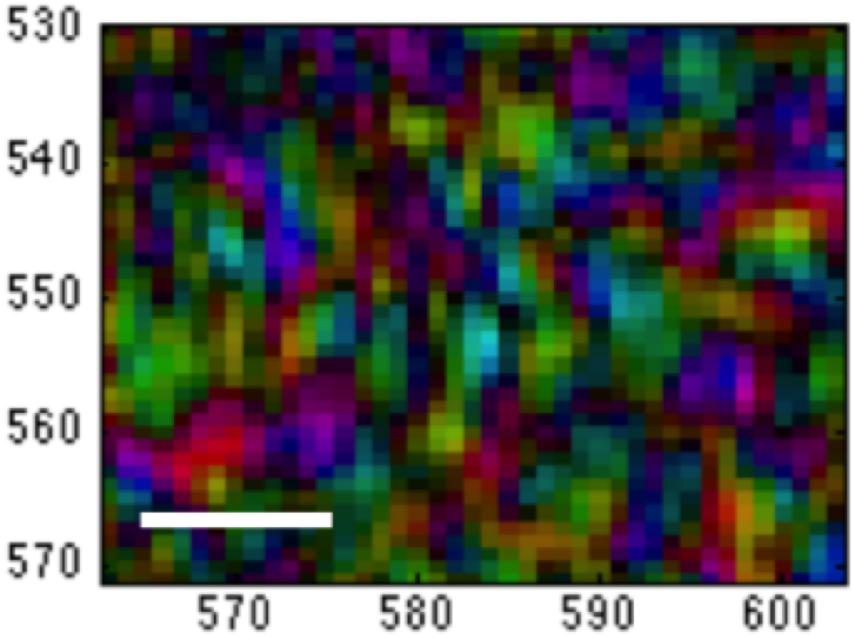
Richard Bean, I-16, Nb110-35 Jan 2009

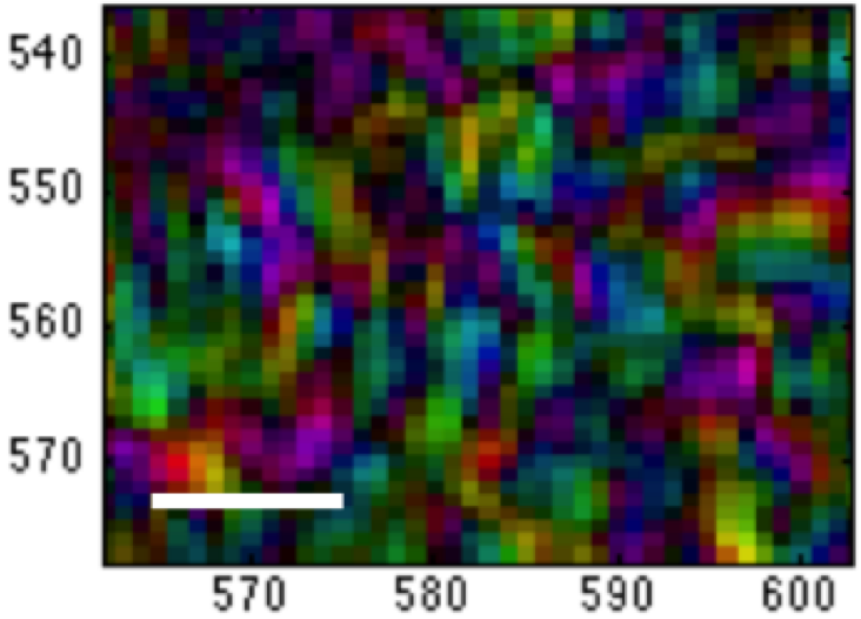


Reconstruction of Nb domains

Nicolas Burdet, PhD Thesis (2015)

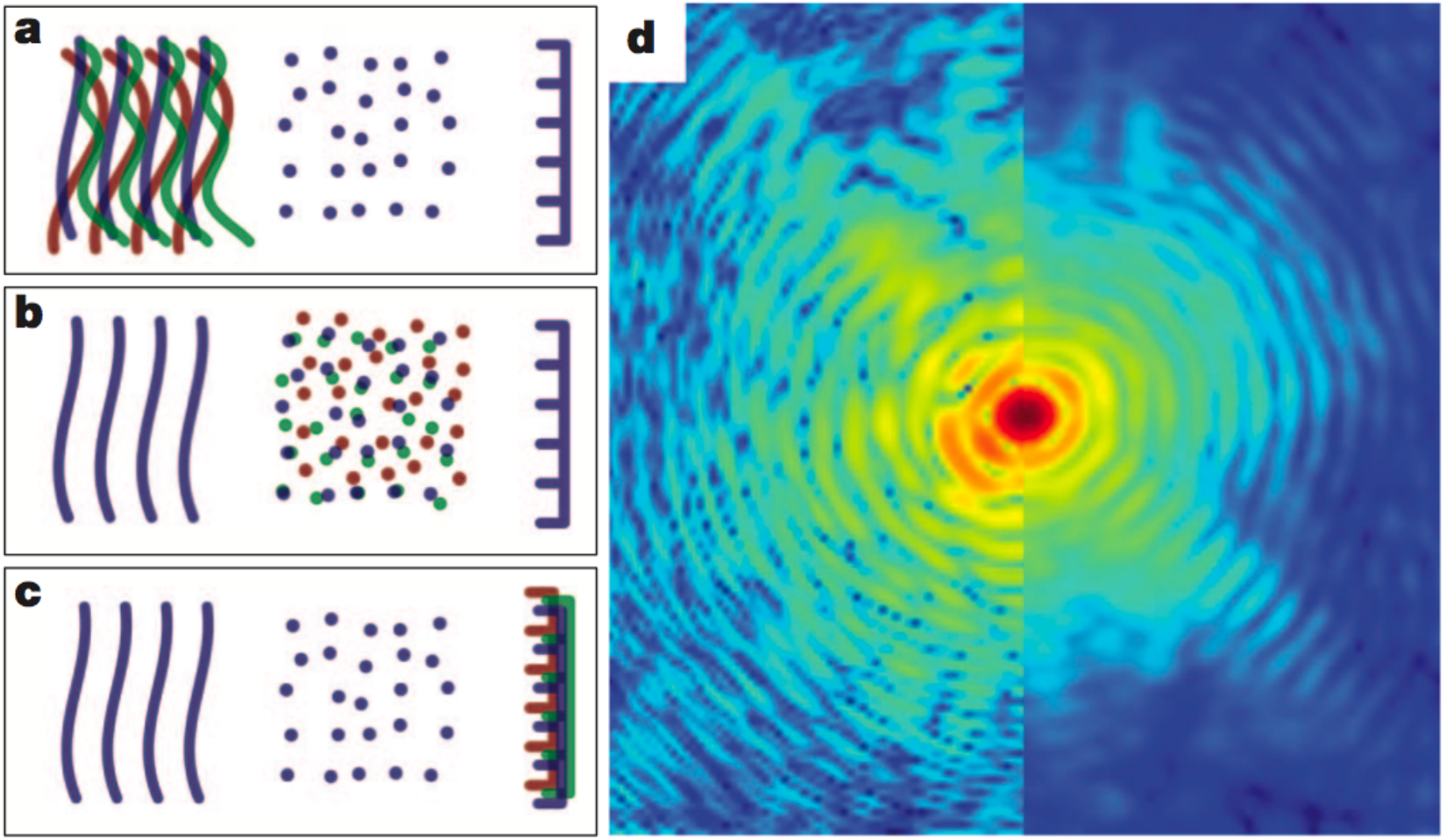
Scale bar = 150nm; multiple illumination modes





Modal Decomposition in Ptychography

Pierre Thibault & Andreas Menzel, Nature 494 68 (2013)



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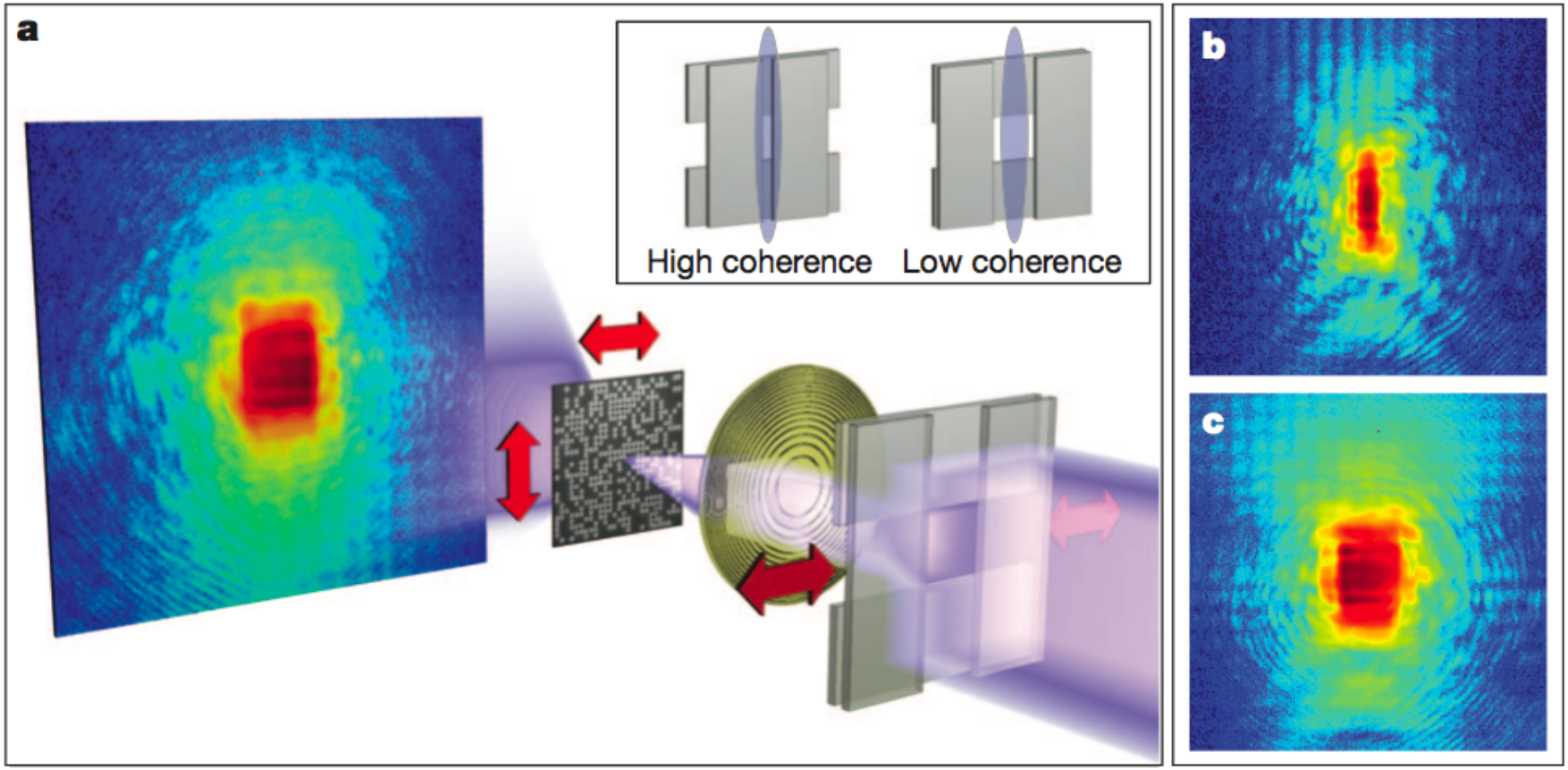
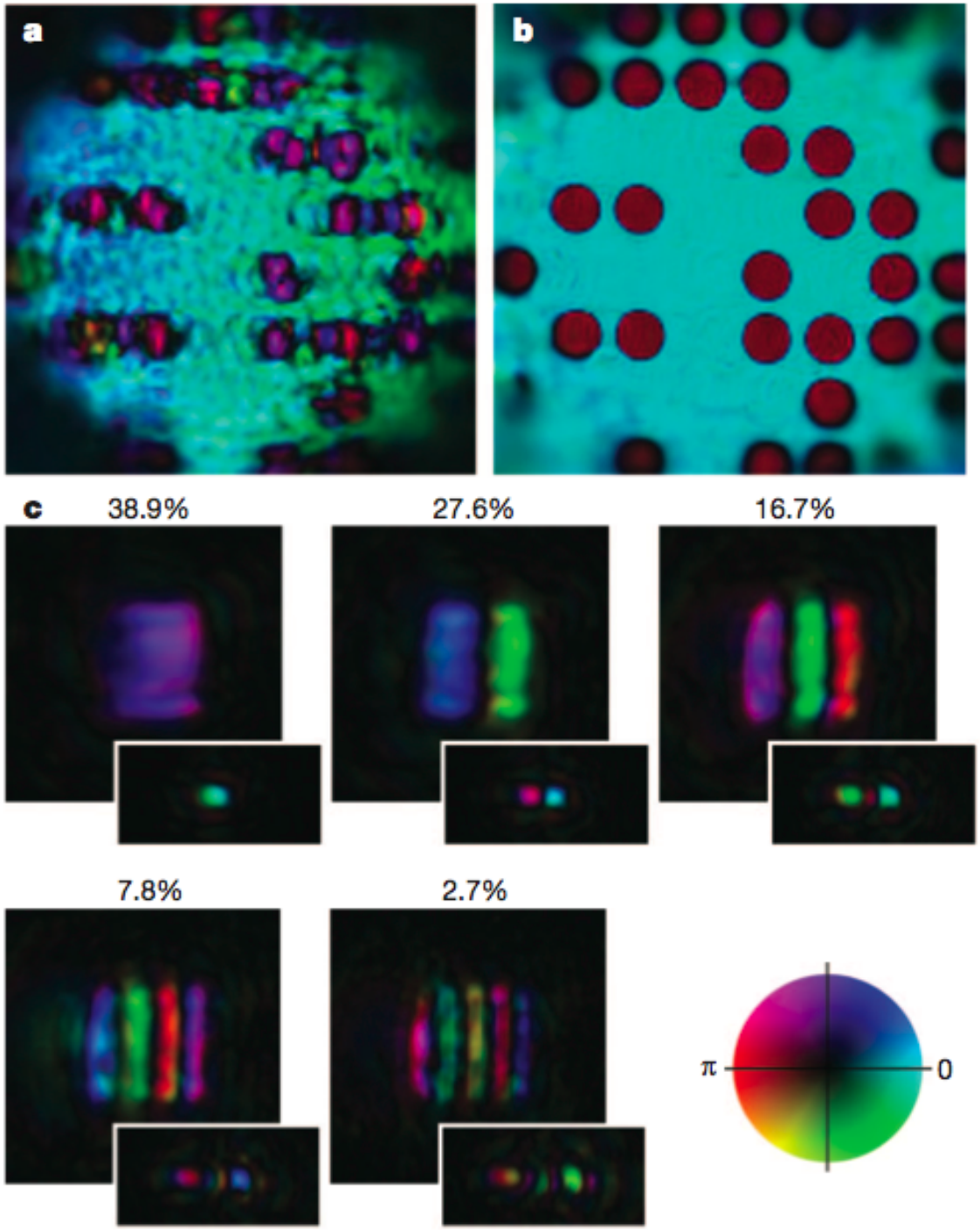
Pierre Thibault & Andreas Menzel, Nature 494 68 (2013)




a
b
c
38.9%
27.6%
16.7%
7.8%
2.7%
π
0

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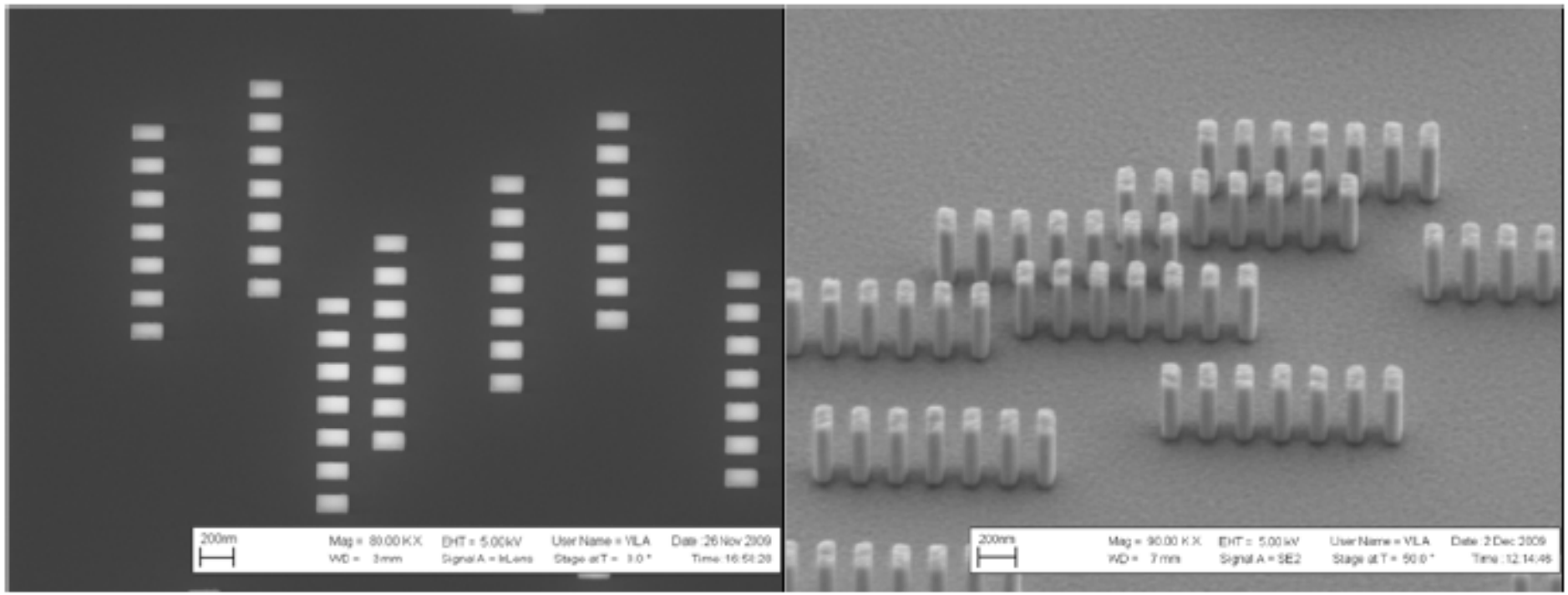
Collagen test object: ladder array

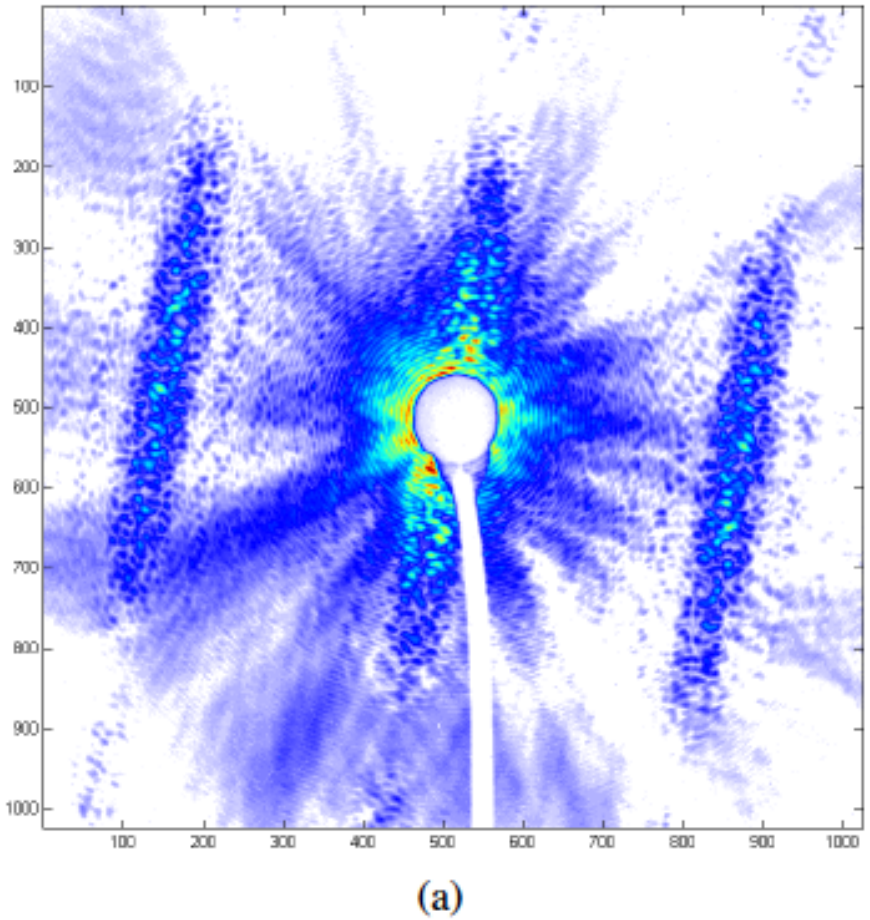
R. Bean and J. Vila-Comamala, PSI

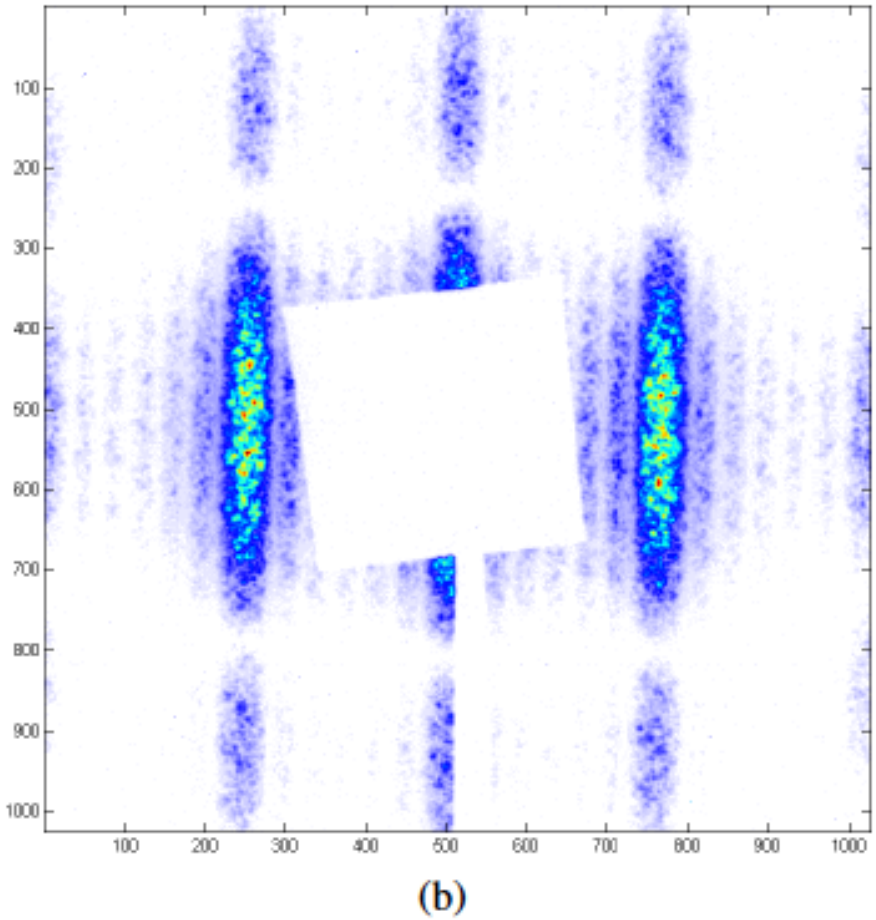


Bragg Ptychography: First Order Peak

Richard Bean, PhD Thesis 2012

Effect of clean-up pinhole

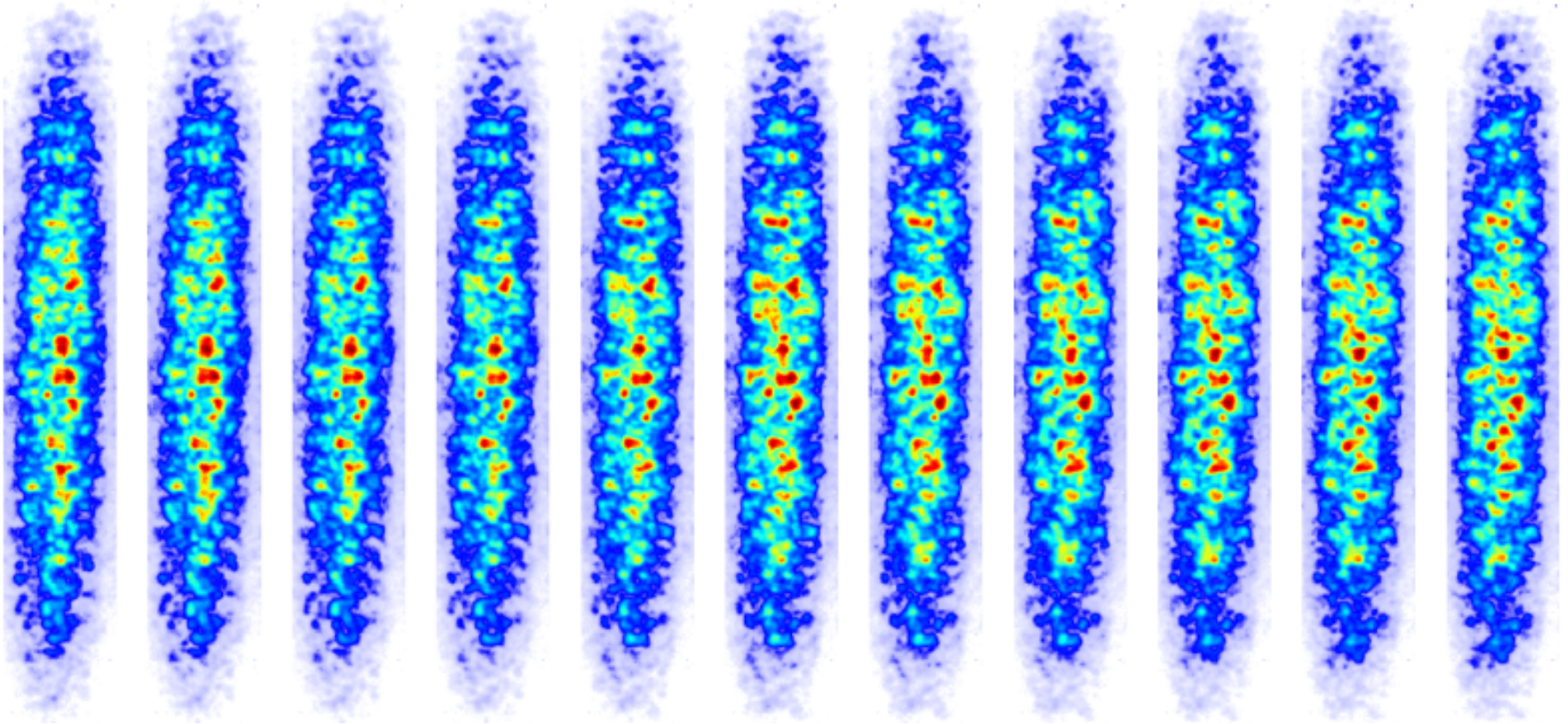




Bragg Ptychography: First Order Peak

Richard Bean, PhD Thesis 2012

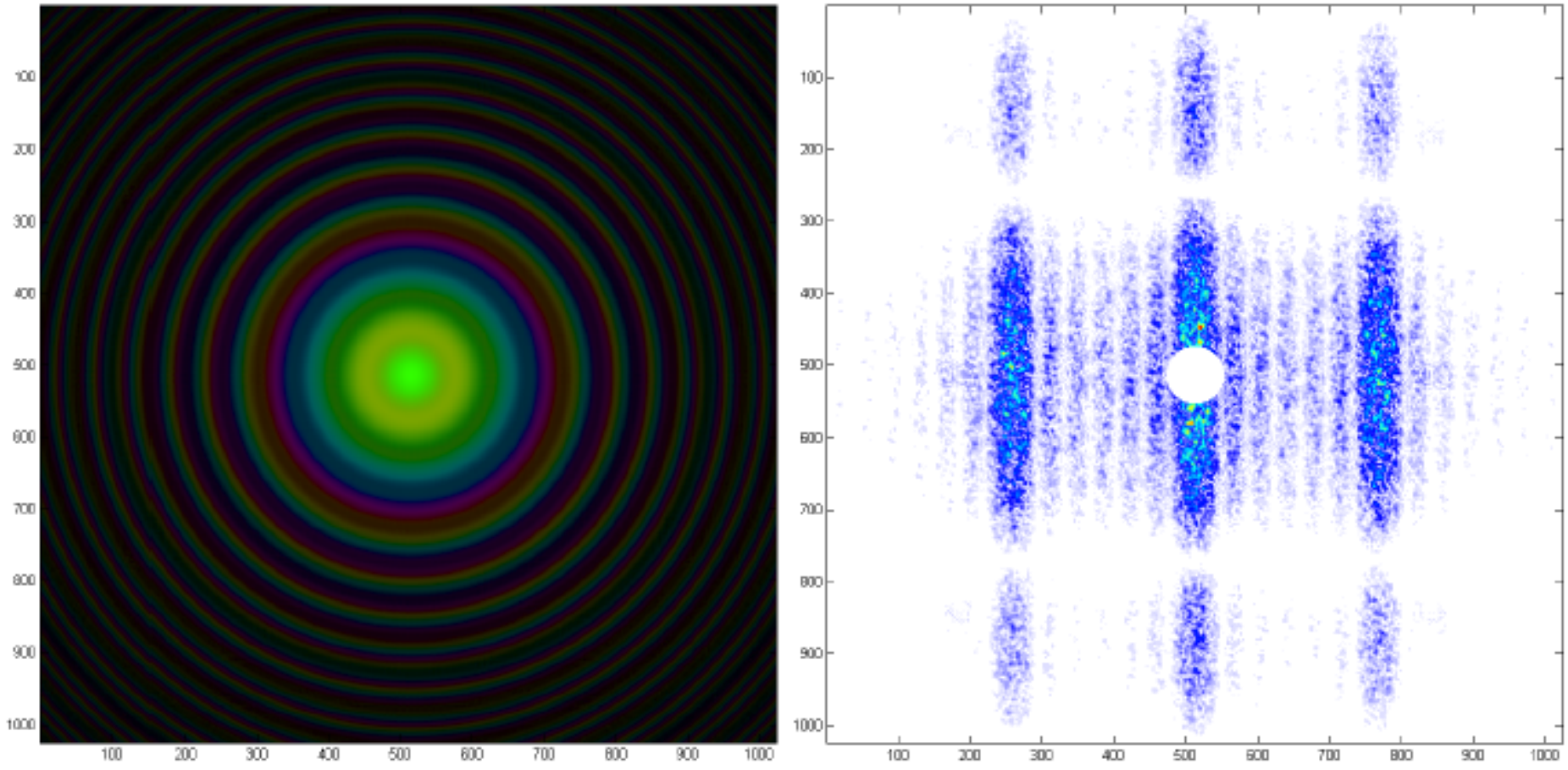
Measured ptychographic series



Bragg Ptychography: First Order Peak

Richard Bean, PhD Thesis 2012

Simulated probe and diffraction pattern

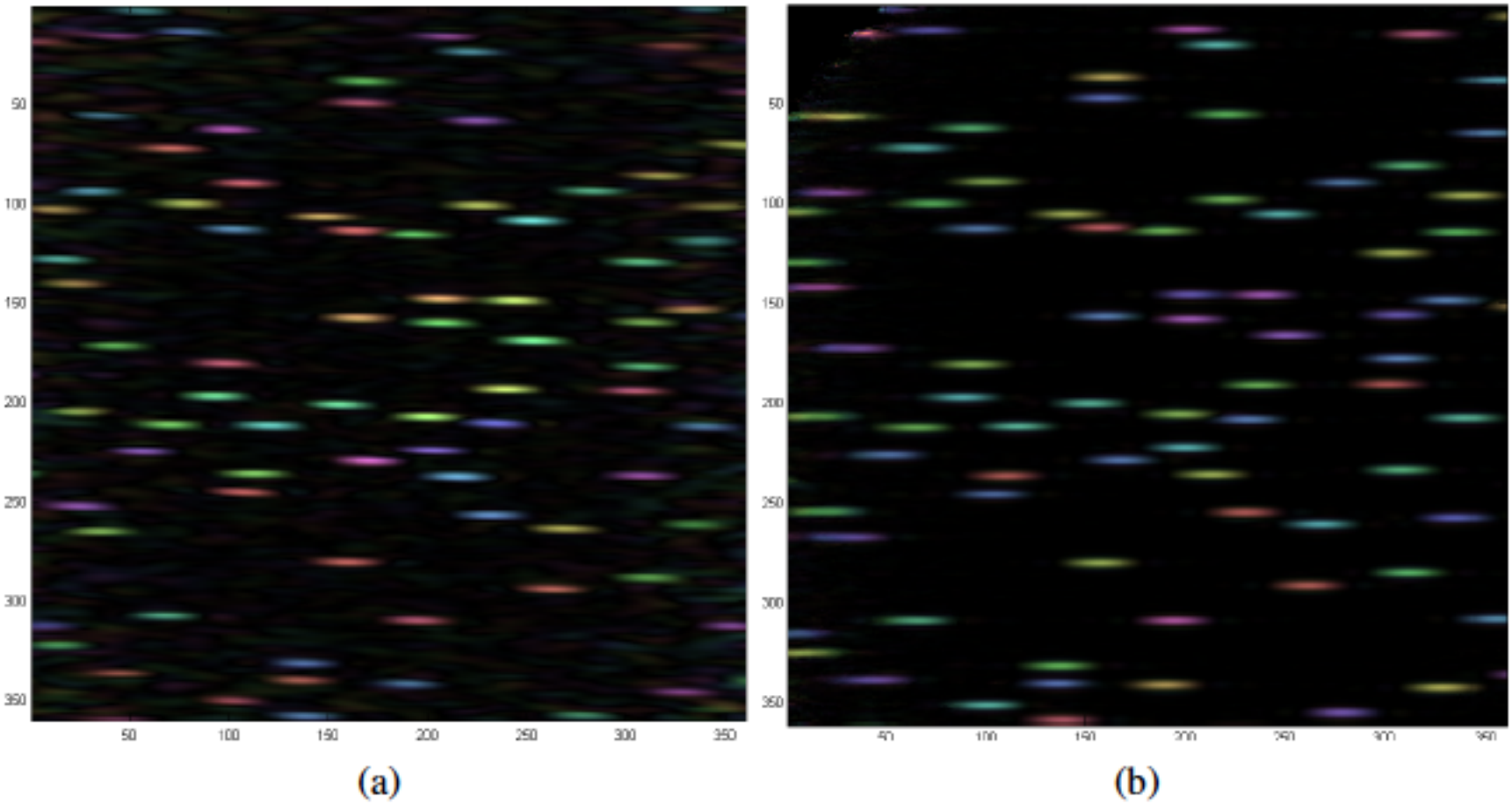


Bragg Ptychography: First Order Peak

Richard Bean, PhD Thesis 2012

Measured Object

Simulated Object

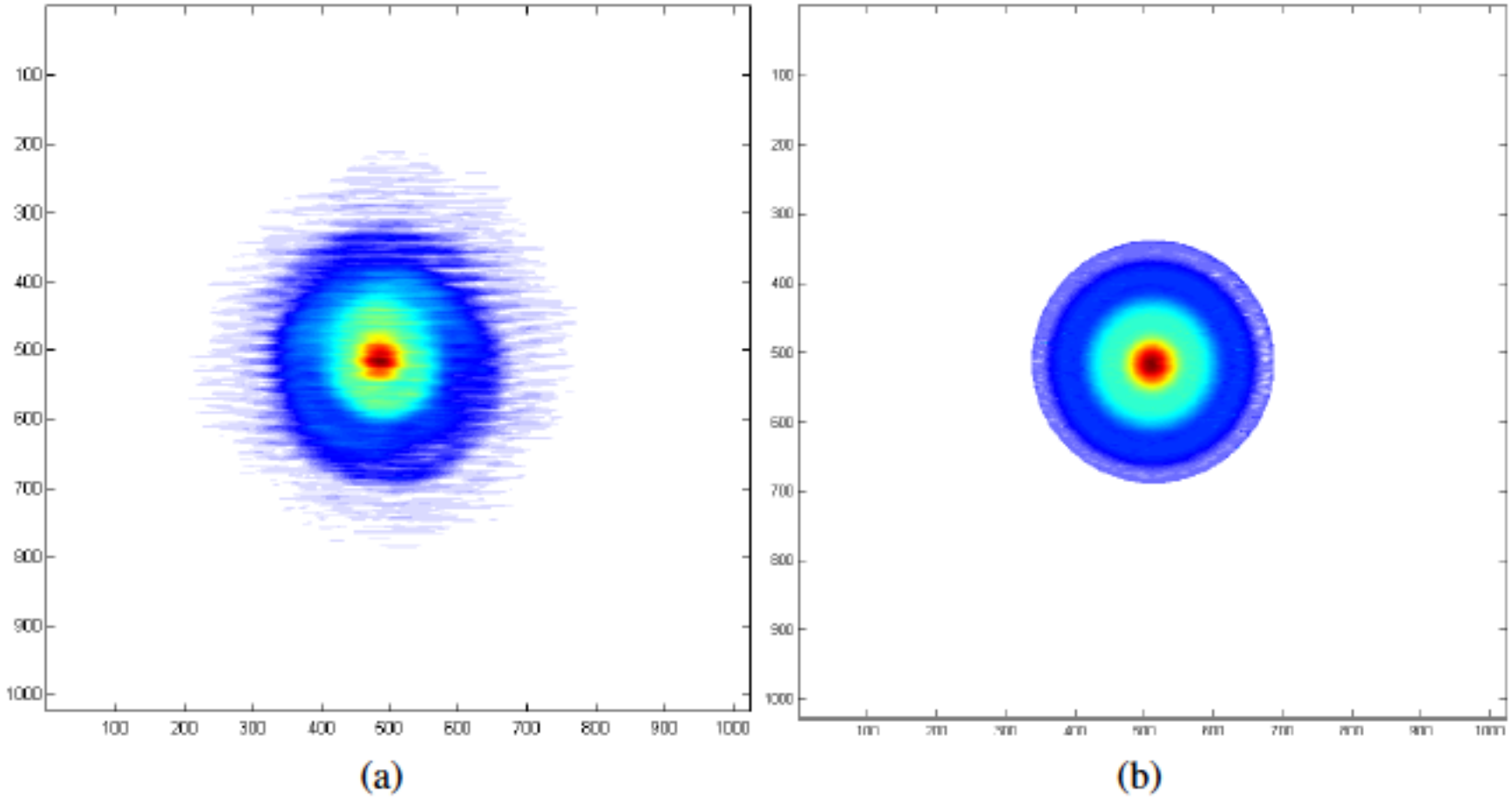


Bragg Ptychography: First Order Peak

Richard Bean, PhD Thesis 2012

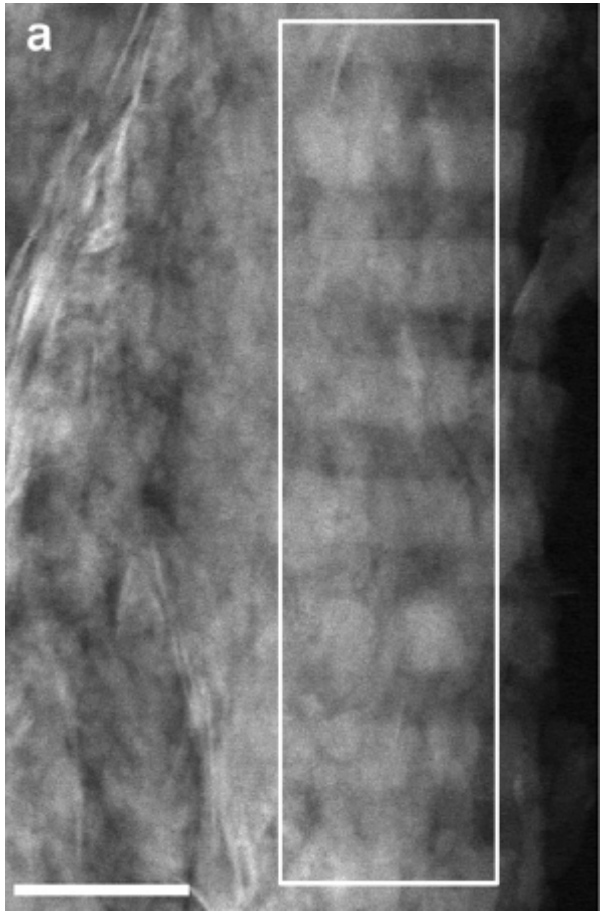
Measured Probe

Simulated Probe



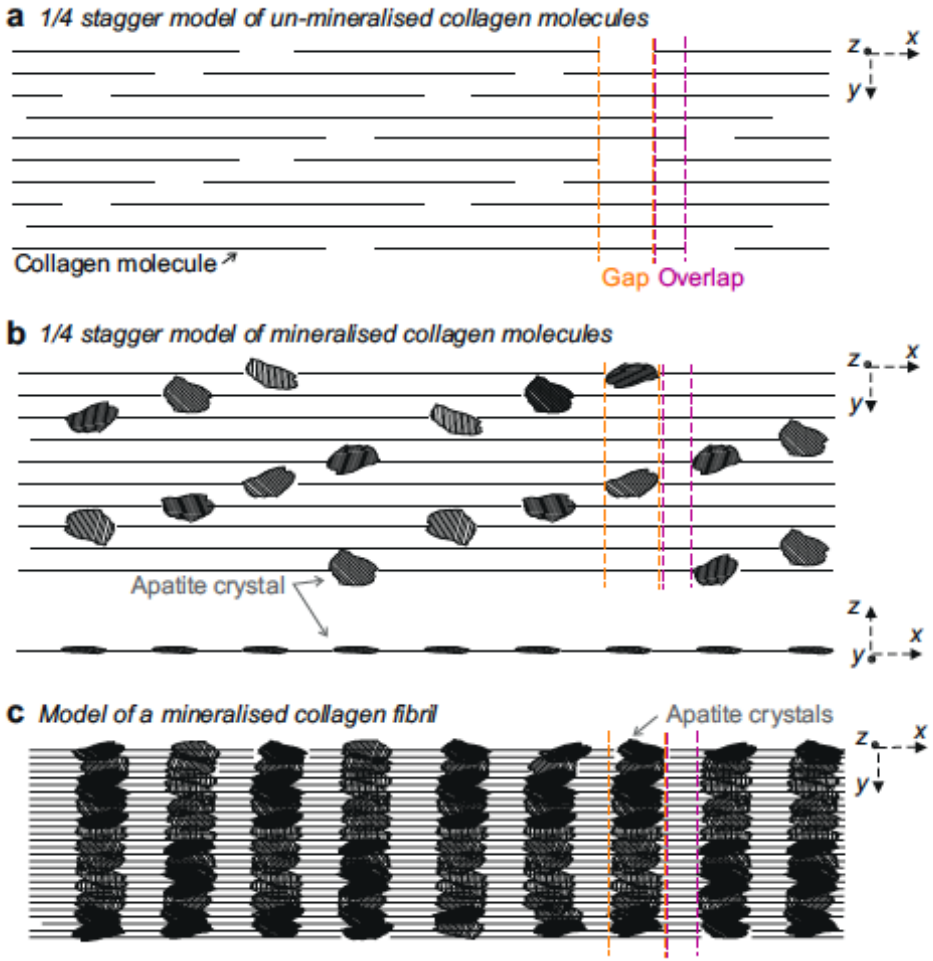
STEM biomineralisation, AFM

Mike Horton and Laurent Bozec

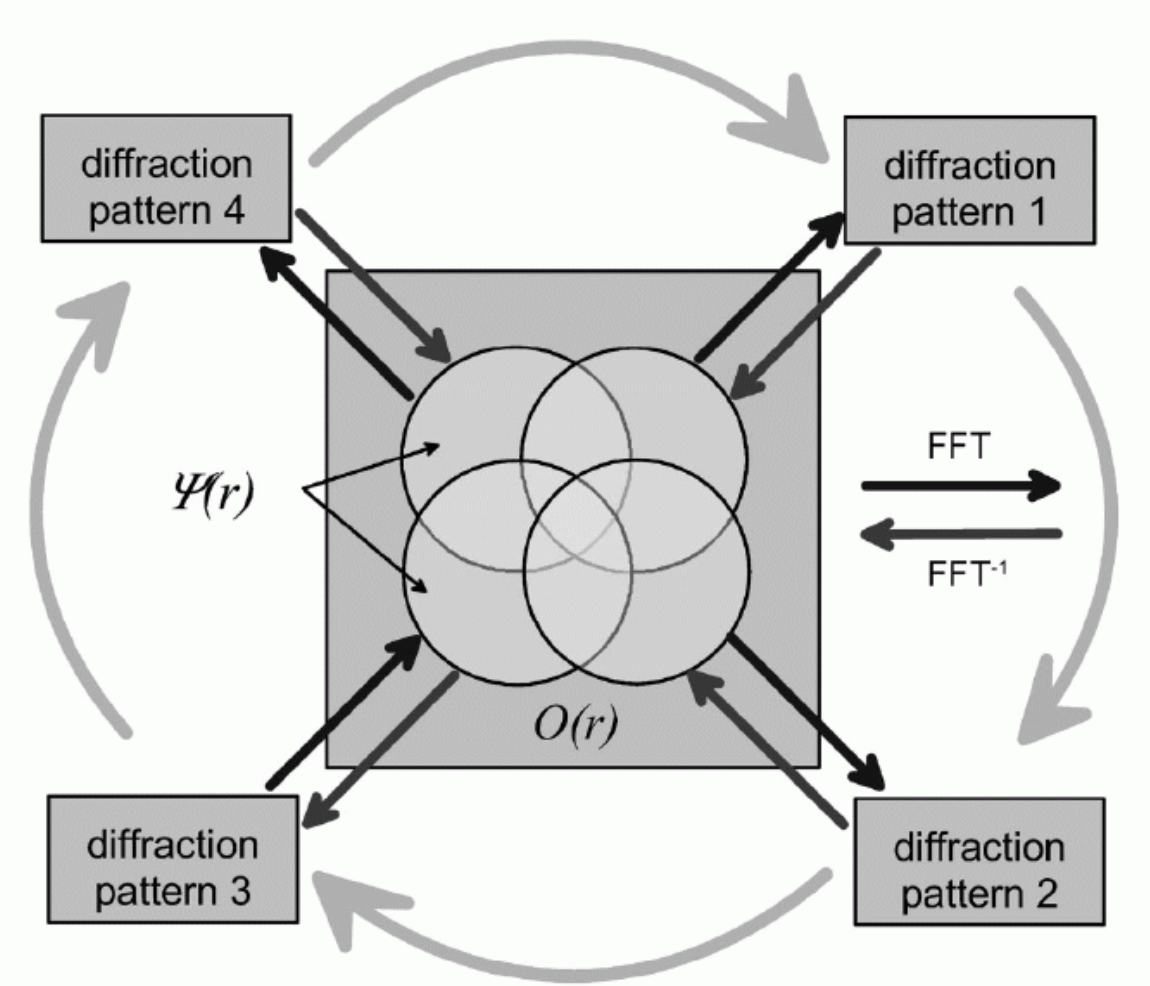


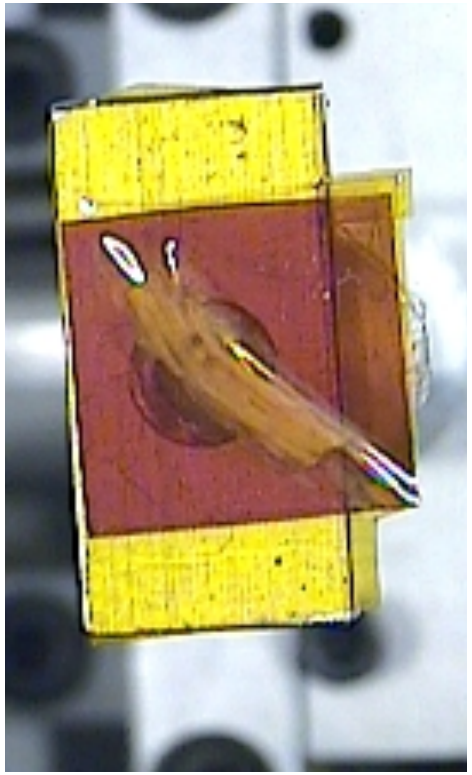
Biomineralisation Model

Jantou-Morris, V, Horton, MA, McComb, DW
Biomaterials 31 5275 (2010)



Collagen Ptychography

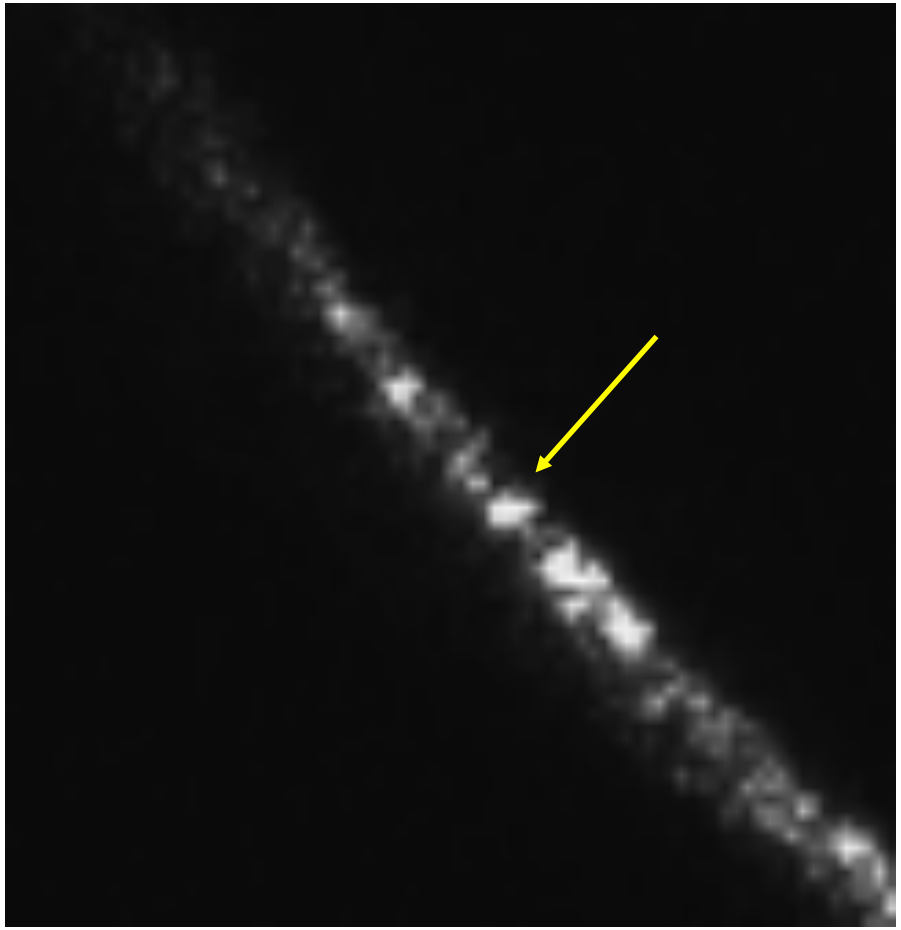




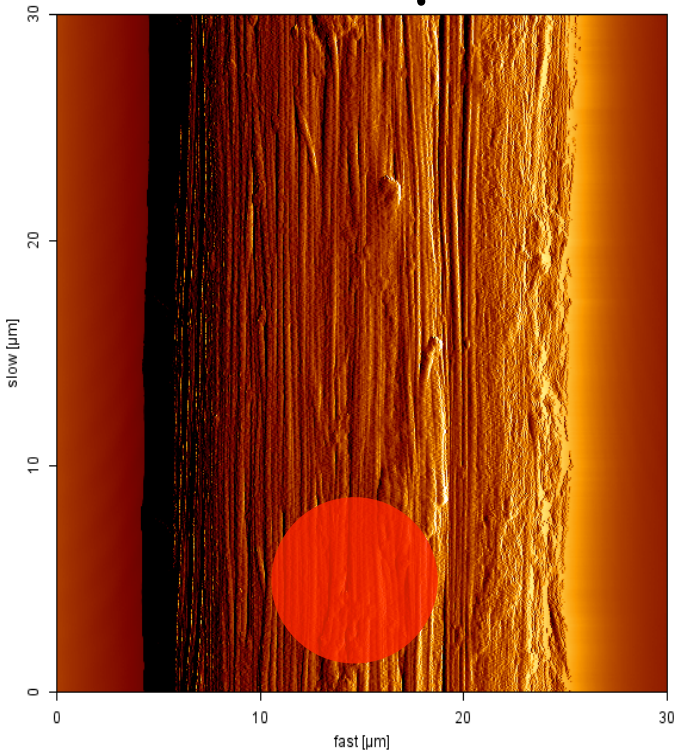
J. M. Rodenburg et al, Phys. Rev. Lett. 98 034801 (2007)

Collagen X-ray Ptychography

67nm meridional reflection



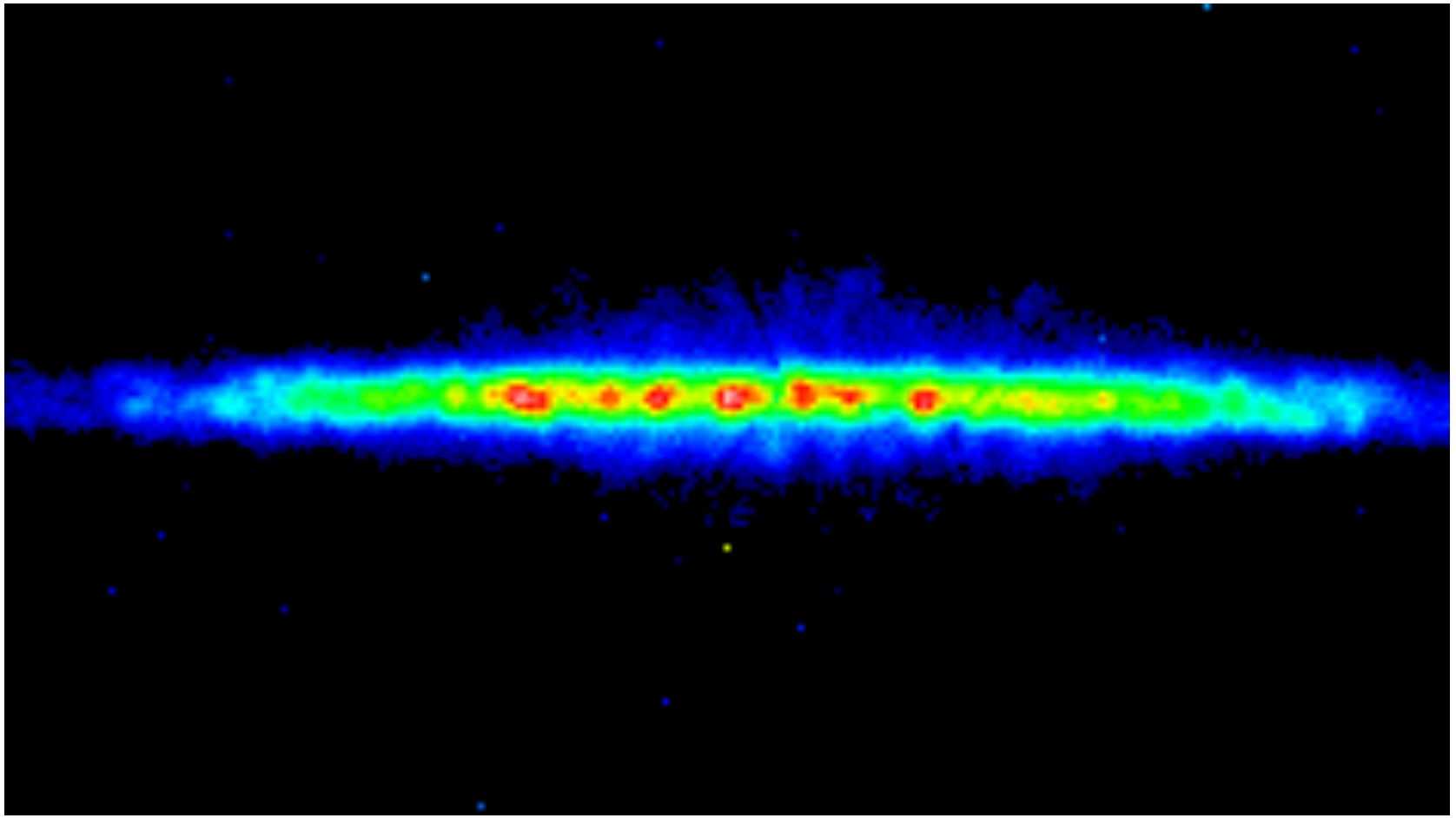
10 μm beam



Dark field imaging:
collagen distribution in different tissues

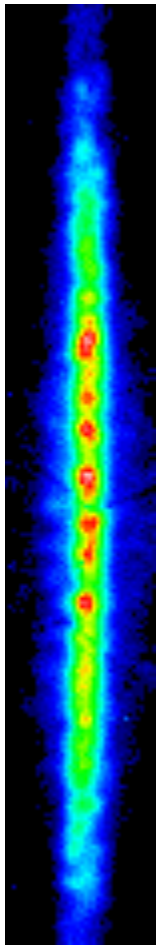
Improved collagen sample prep

Diamond I-22, Nov 2008



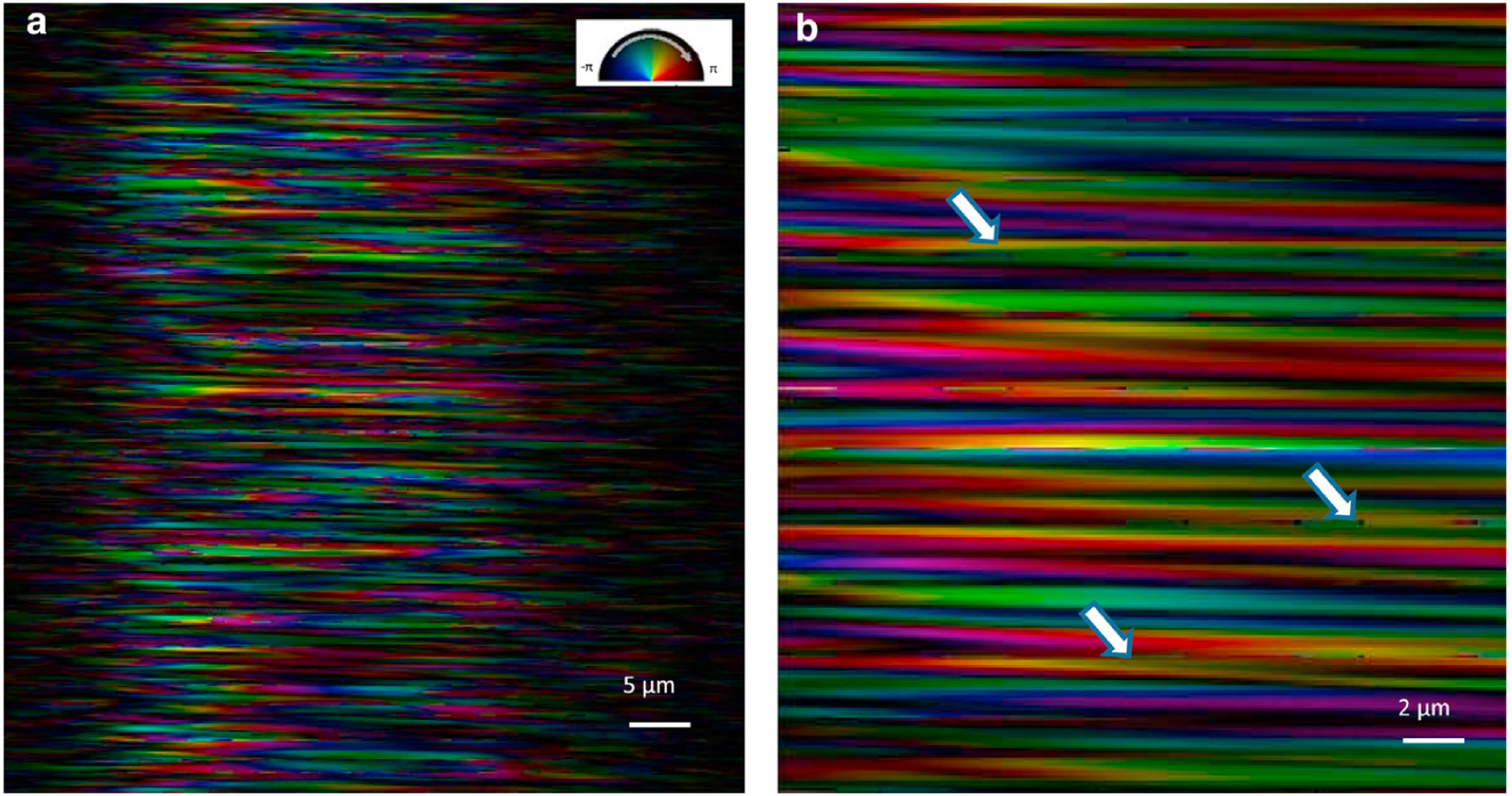
Collagen imaged at 67nm Bragg peak

1μm fibrils cut by 20μm beam



Collagen imaged with Bragg peak

Felisa Berenguer et al, Biophys. J. **106** 459 (2014)



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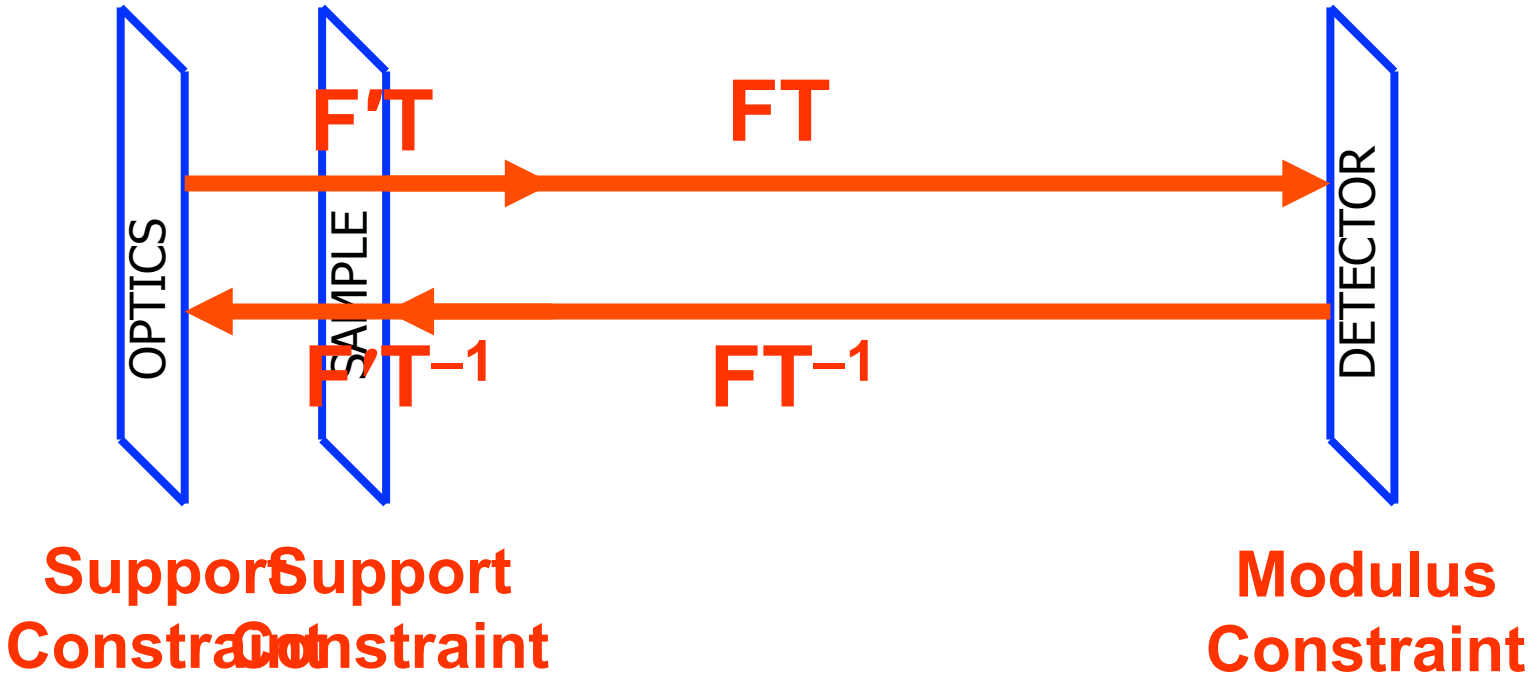
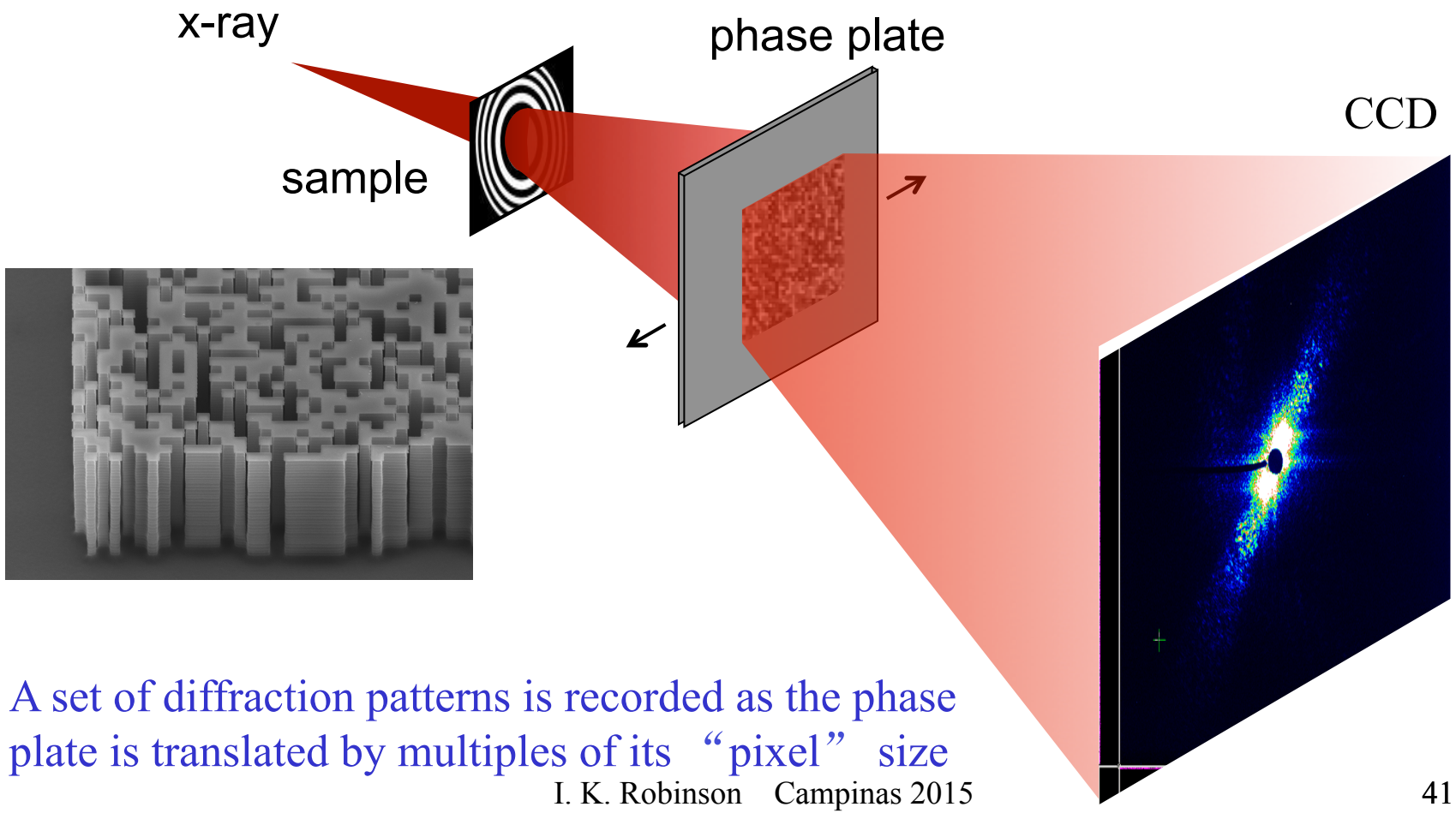
Coherent Diffractive Imaging
General 3-plane Method



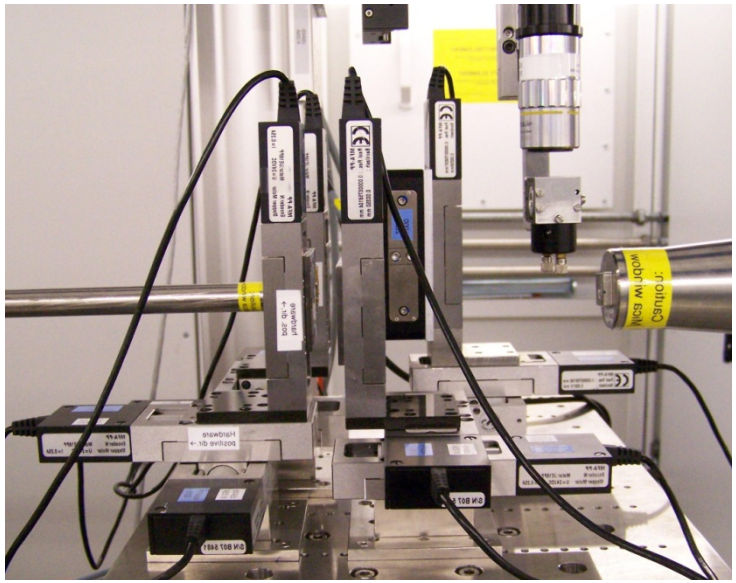
Imaging by wavefront modification

F. Zhang *et al.,* Phys Rev A 75 (2007)
I. Johnson *et al.,* Phys Rev Lett 100 (2008)

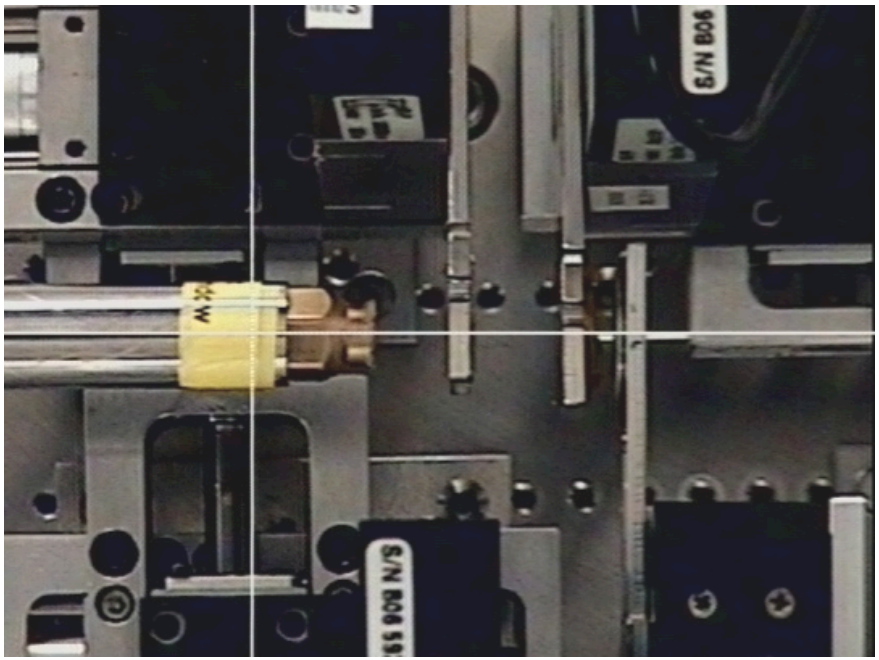


A set of diffraction patterns is recorded as the phase plate is translated by multiples of its "pixel" size

Experimental setup cSAXS (SLS)

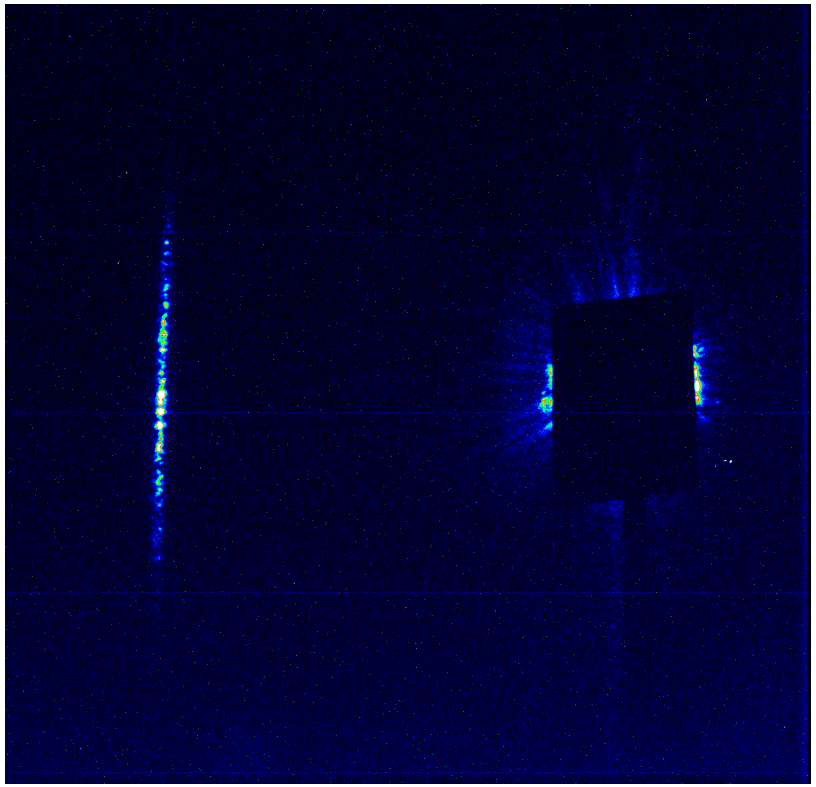


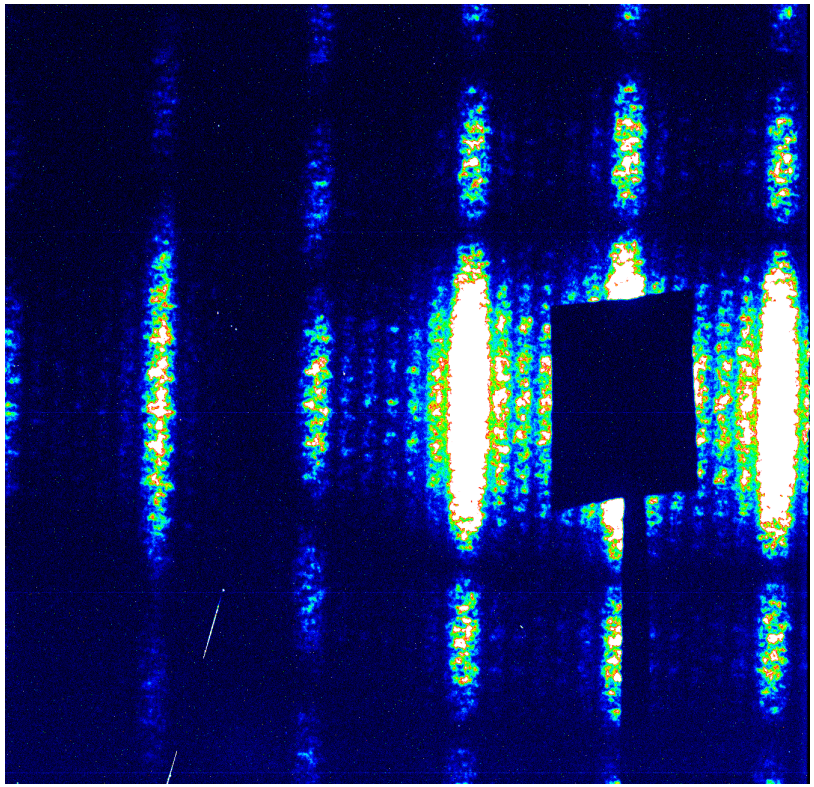
Side view



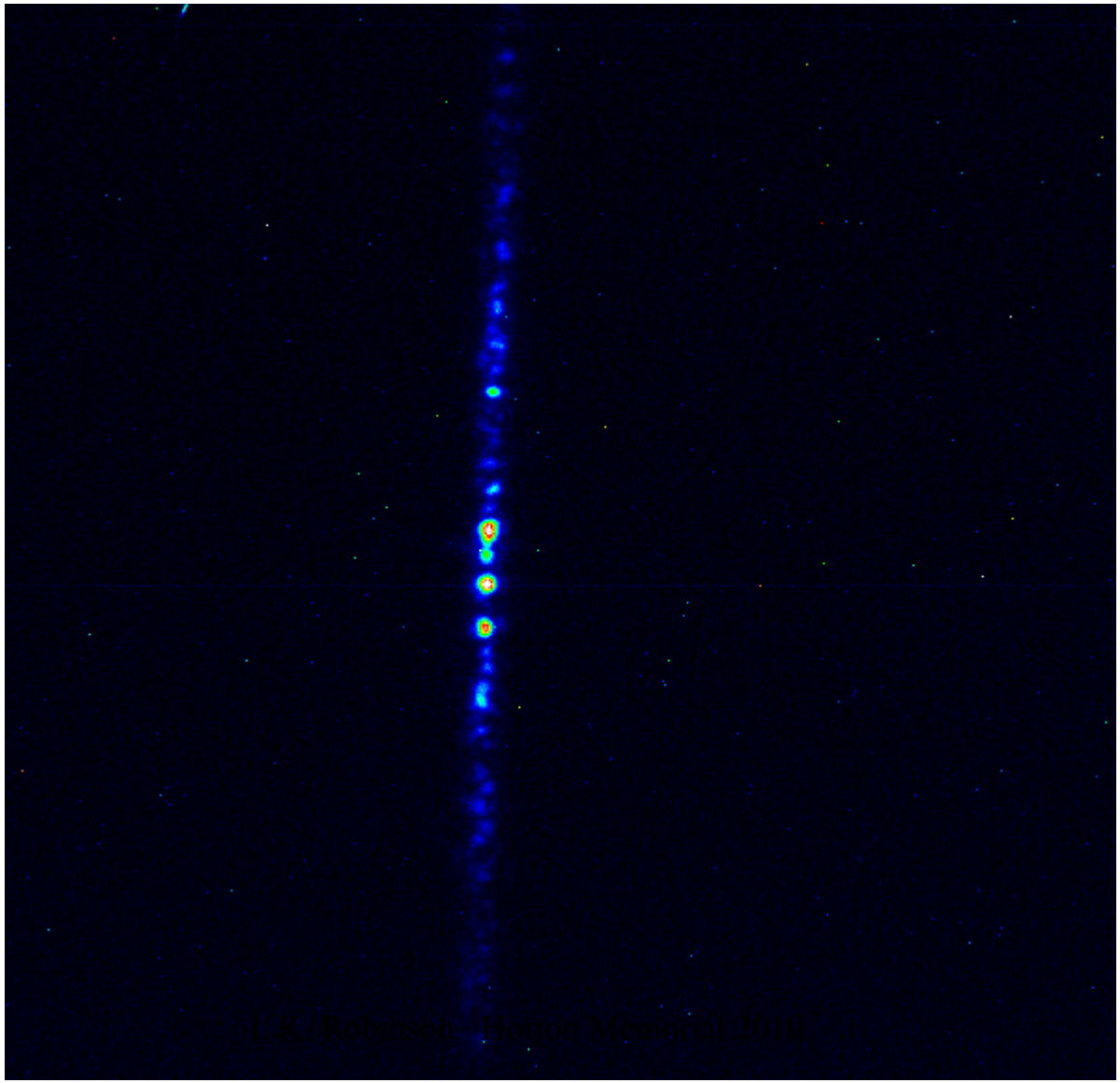
Top view (zoomed in)

Collagen in liquid cell +/- phase plate



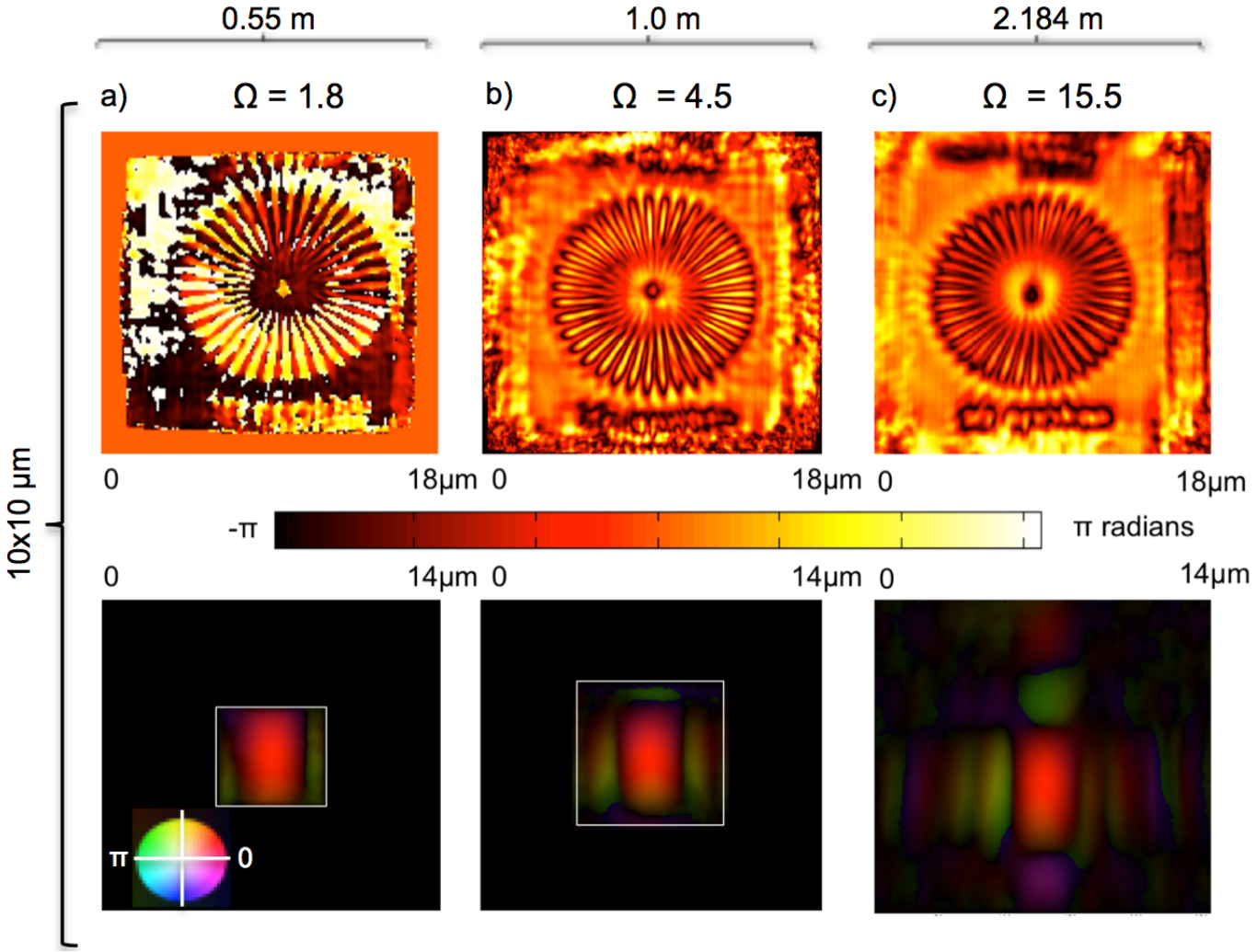


Sample+phase plate interference



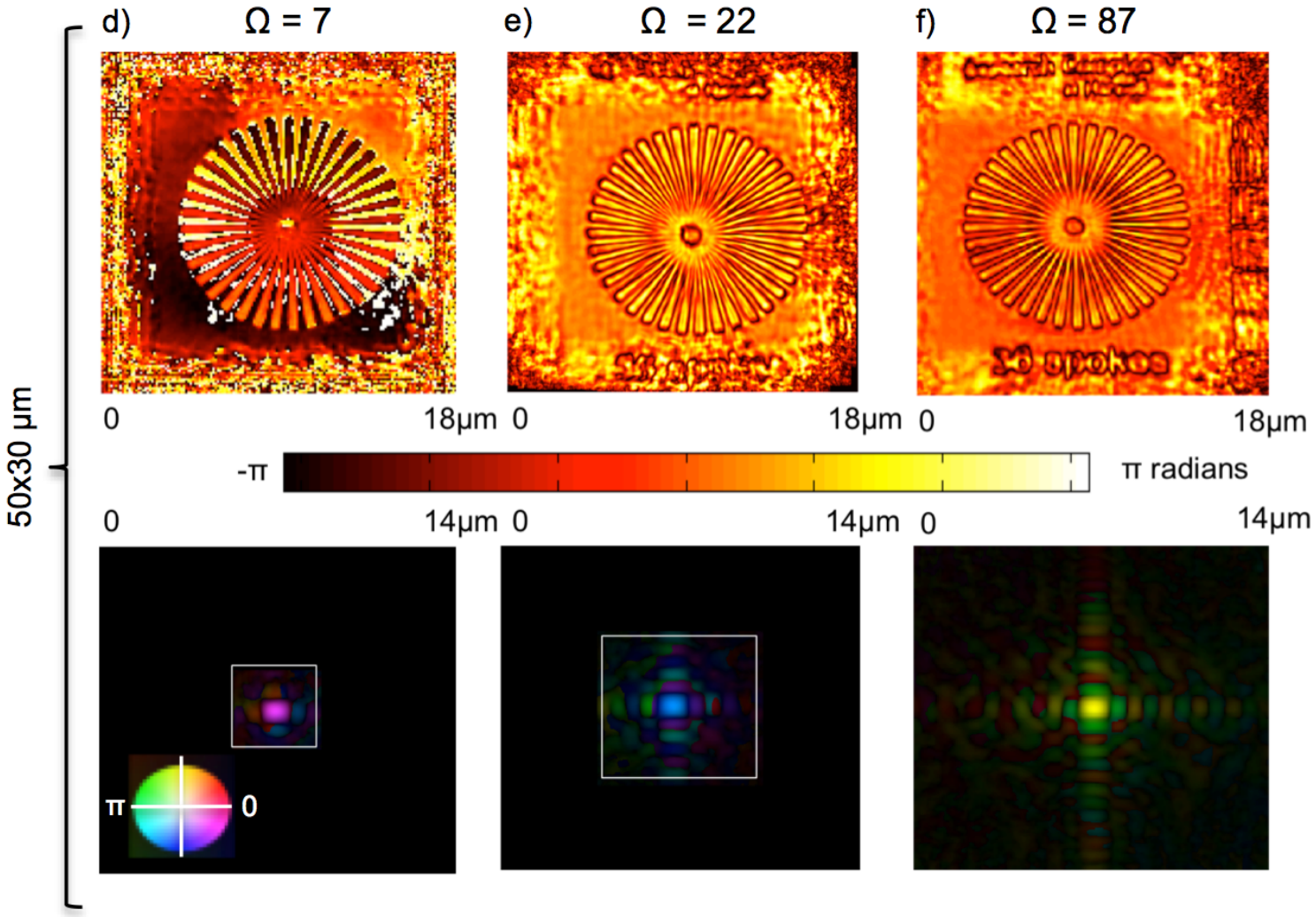
Diversity in Ptychography

Nicolas Burdet et al, Optics Express 22 10294 (2014)



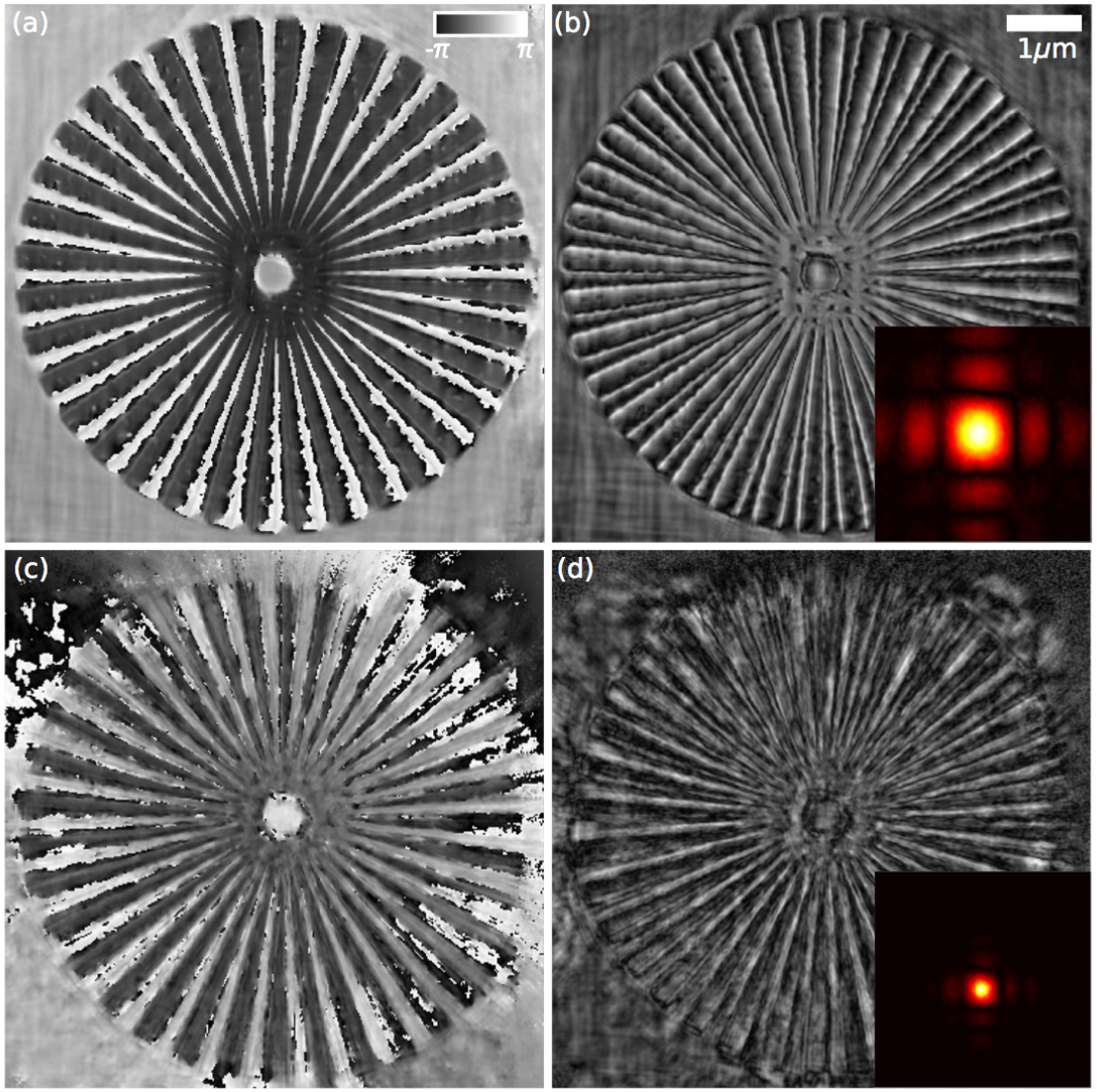
Diversity in Ptychography

Nicolas Burdet et al, Optics Express 22 10294 (2014)



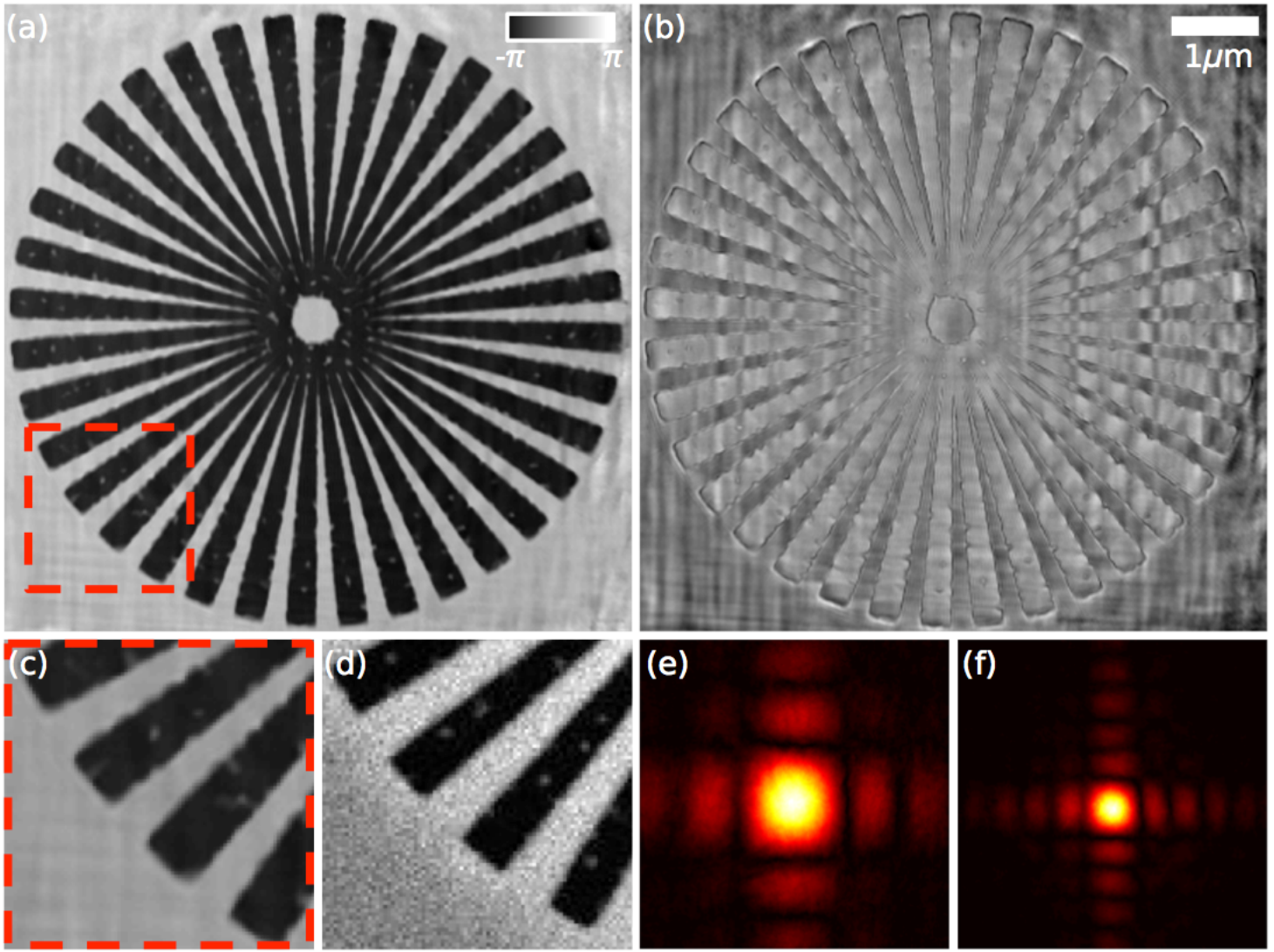
Probe-diverse Ptychography

I. Peterson, et al submitted to Optics Express



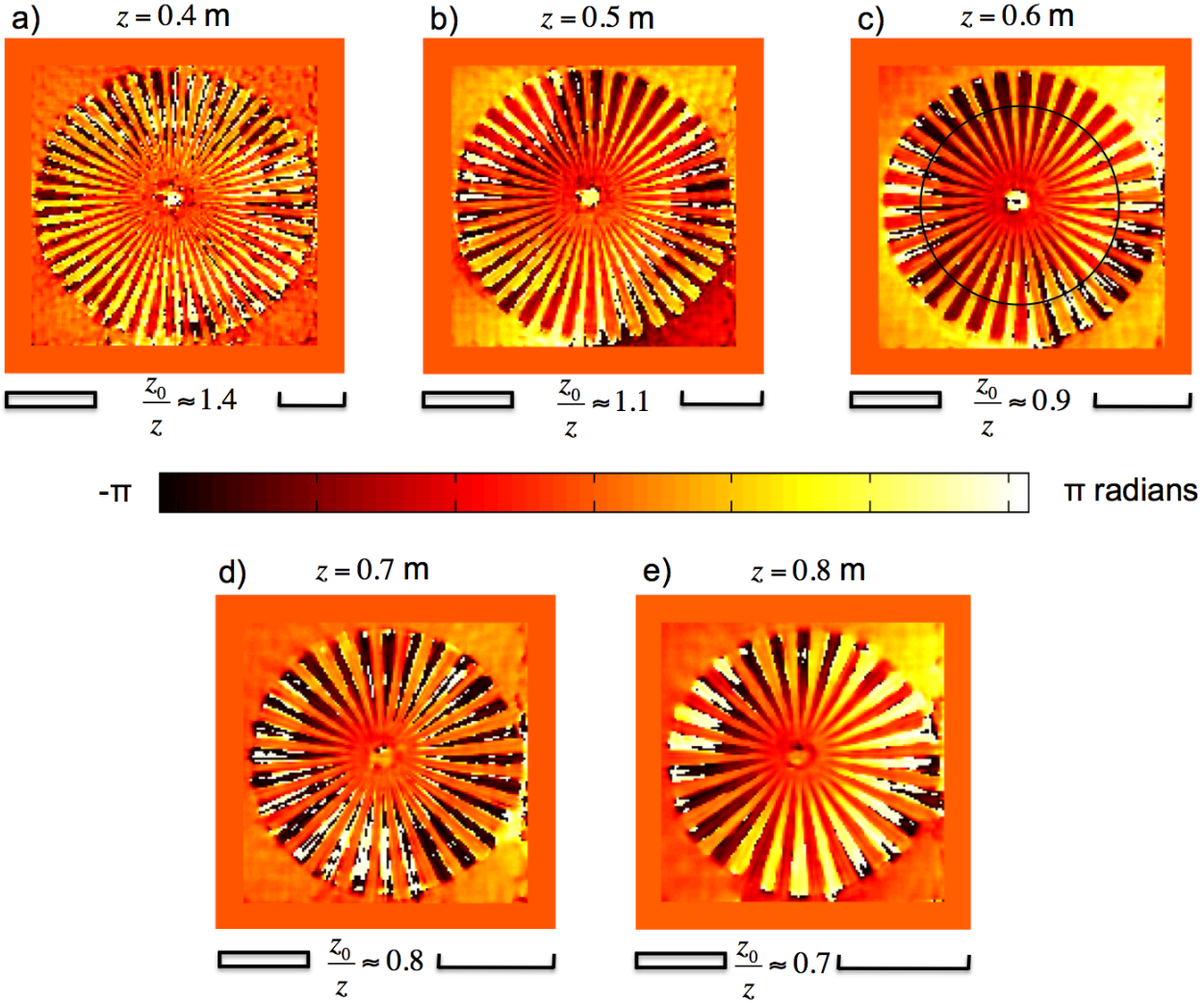
Probe-diverse Ptychography

Isaac Peterson, et al submitted to Optics Express



Ptychography Artefacts?

Nicolas Burdet et al, Optics Express 22 10294 (2014)



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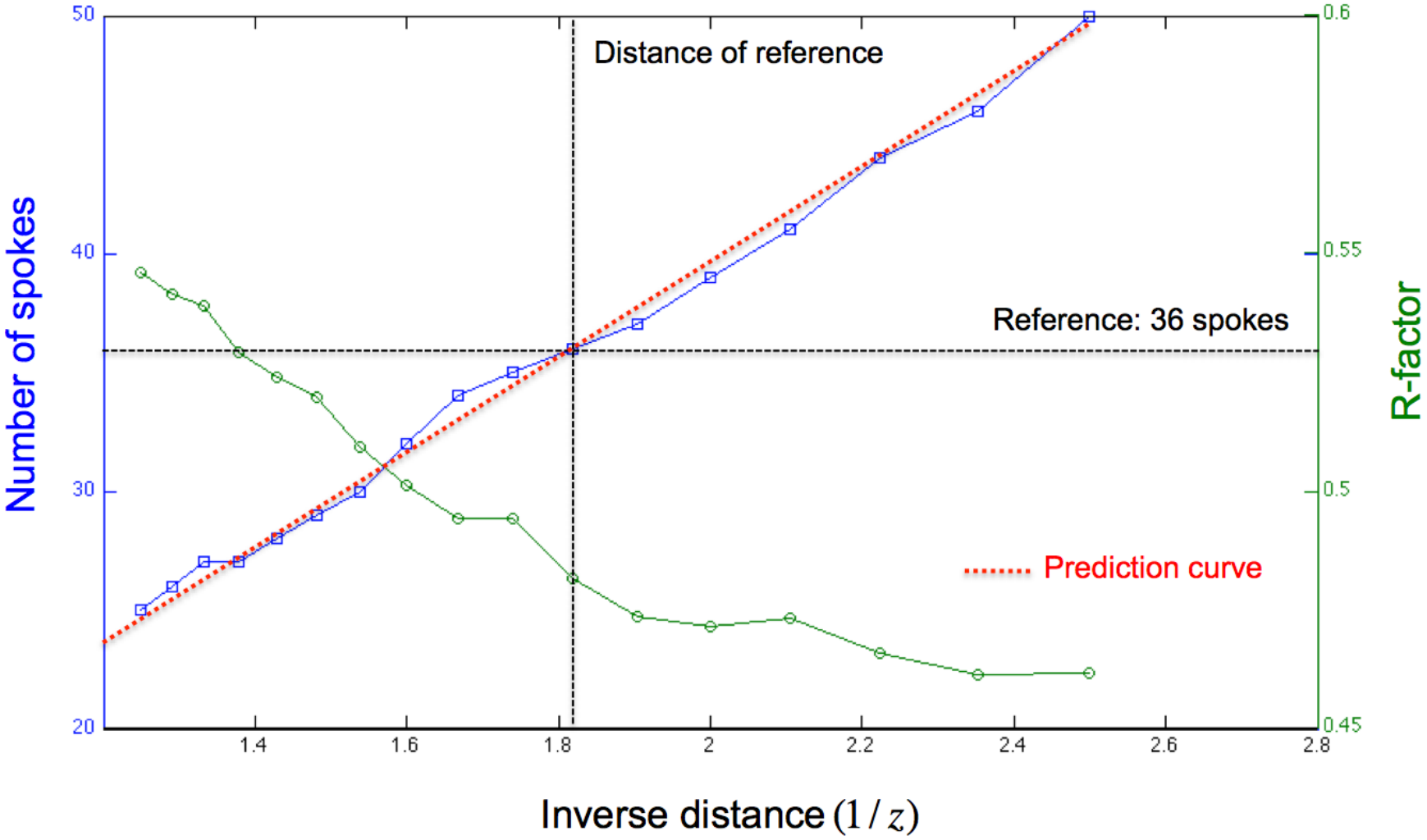

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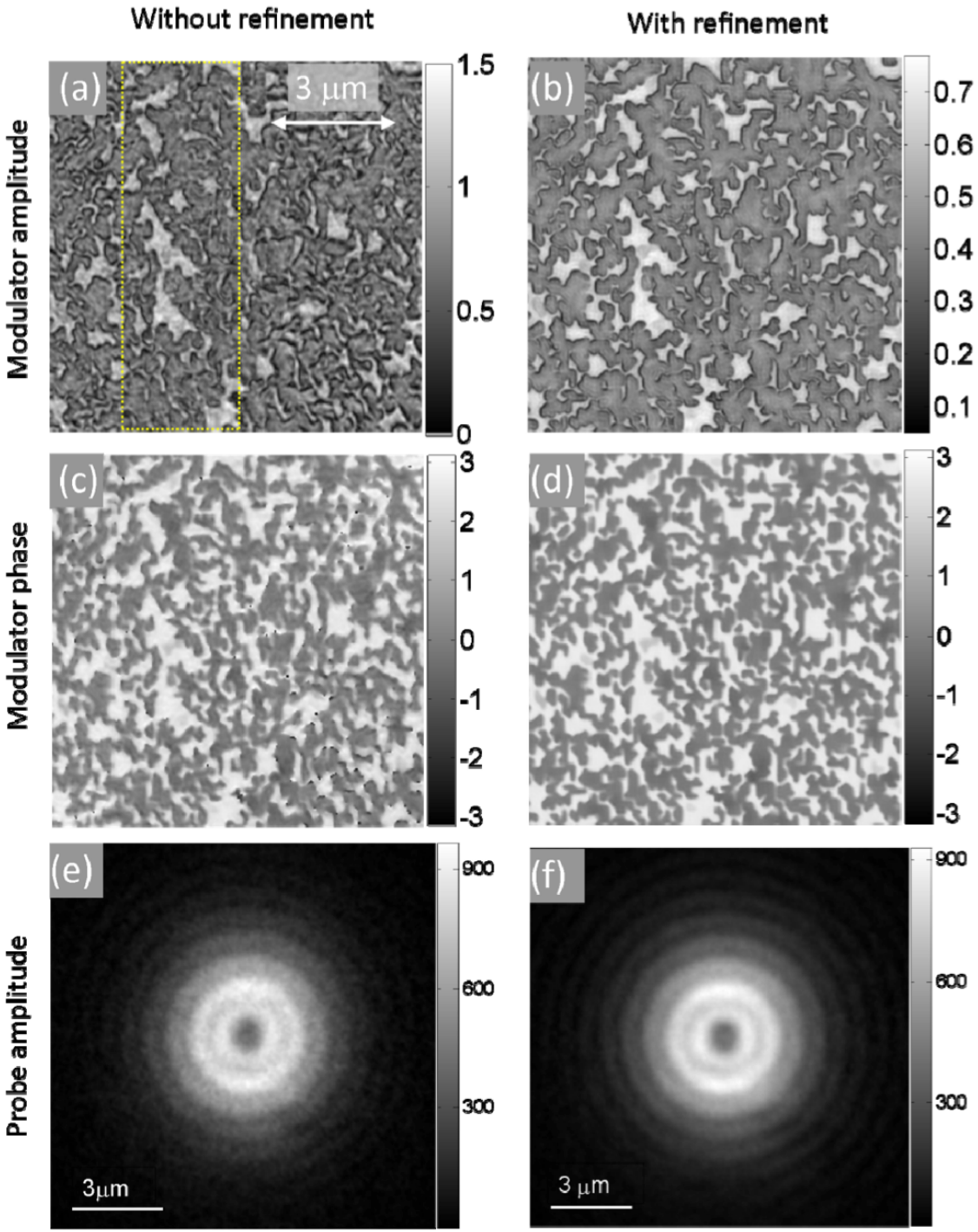
V. Probe Diversity
VI. Position correction

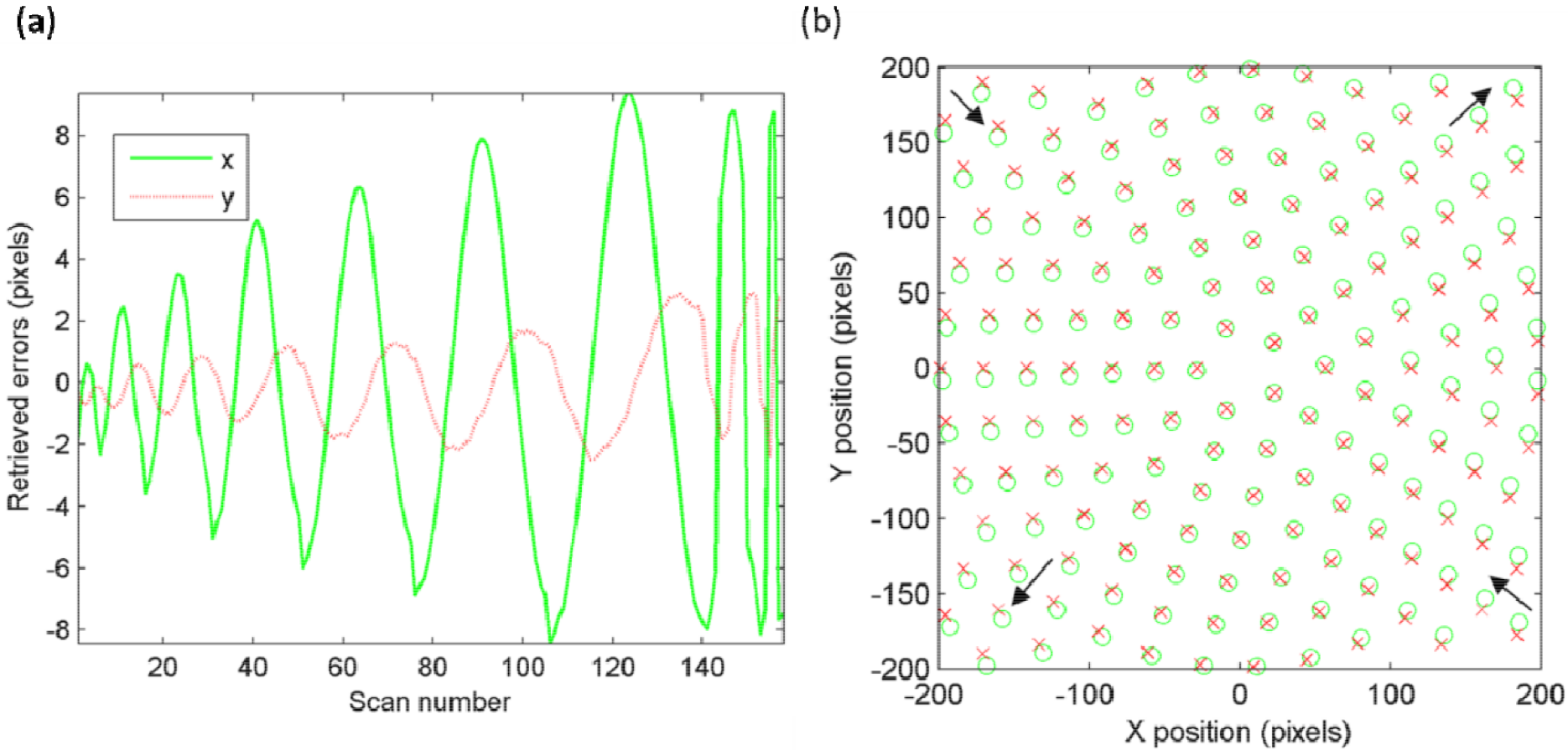


Probe Position Correction

Fucai Zhang et al Optics Express 21 13592 (2013)

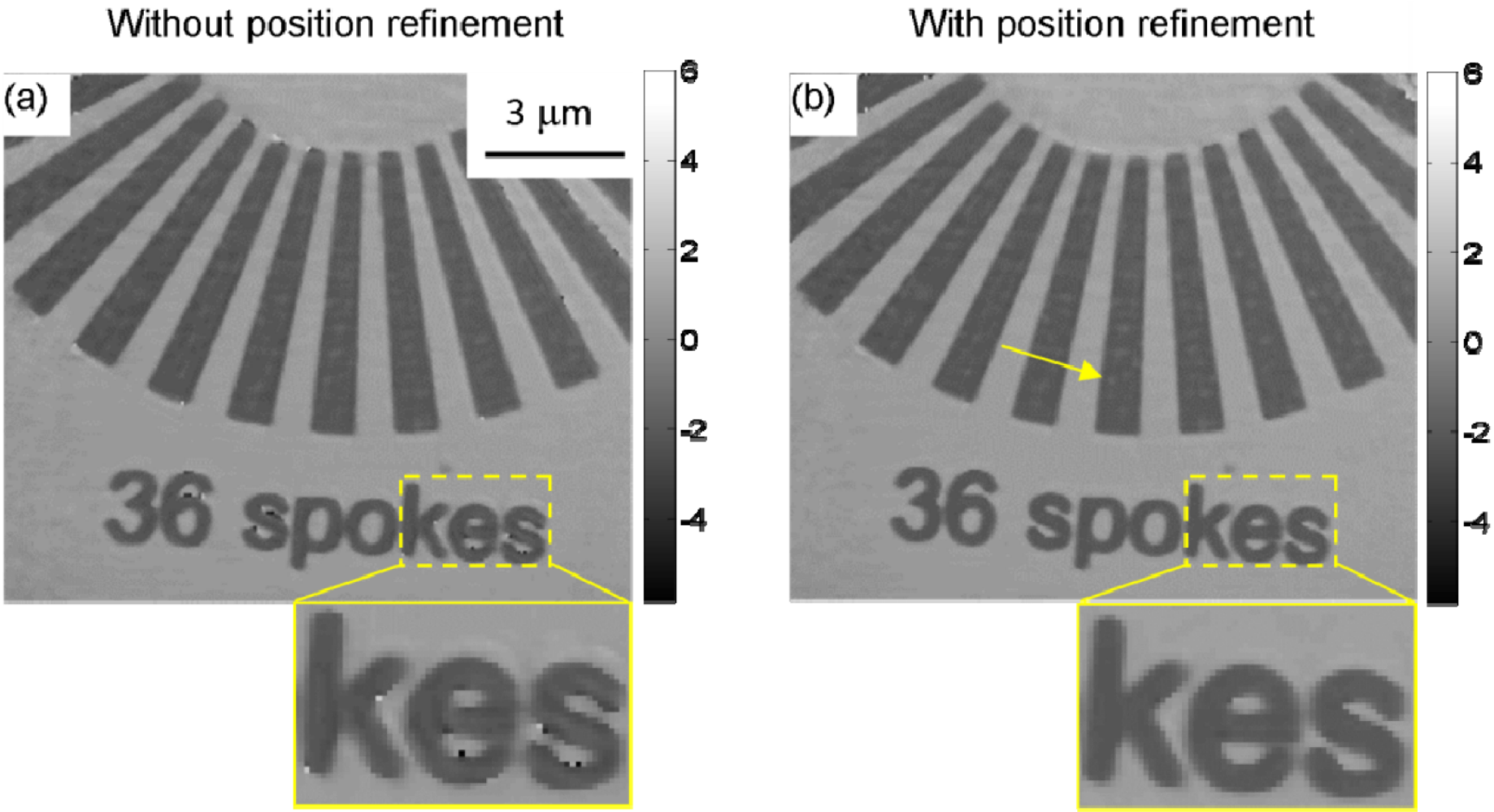
Probe Position Correction

Fucai Zhang et al Optics Express 21 13592 (2013)



Probe Position Correction

Fucai Zhang et al Optics Express 21 13592 (2013)



Lecture 2 Topics

I. Ptychography Setup
II. Propagation Uniqueness
III. Bragg Ptychography
IV. Collagen Imaging
V. Probe Diversity
VI. Position correction