Use of coherent X-ray beams in biophysics

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Max-Planck-Institut fuer Kolloid- und Grenzflaechenforschung,
Golm, October 2010

Outline

- Imaging with X-rays
- Coherence based imaging
- Energy bio-materials
- Collagen and biomineralisation
- Grating methods
- Future applications

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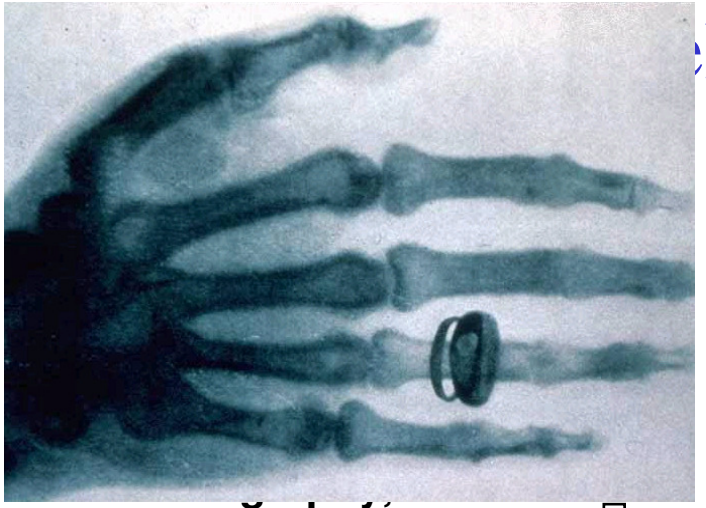
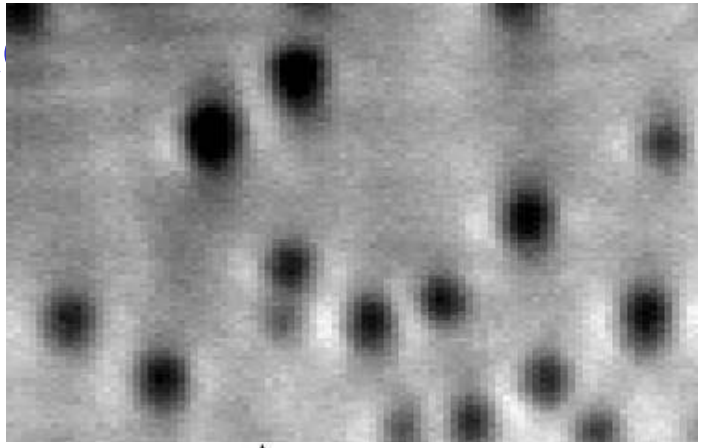
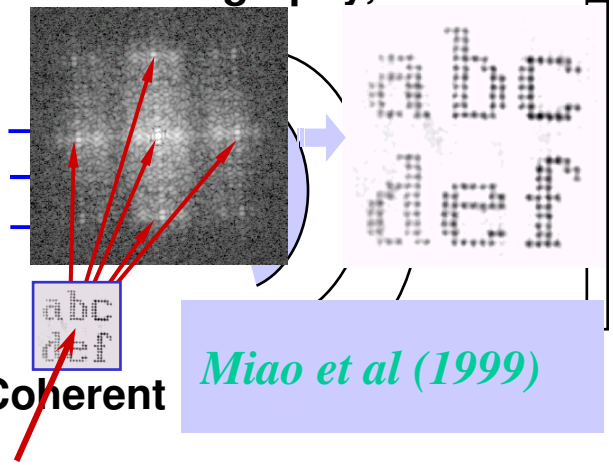
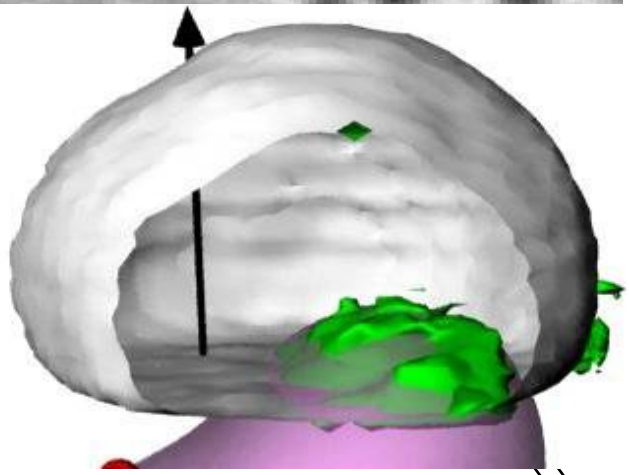
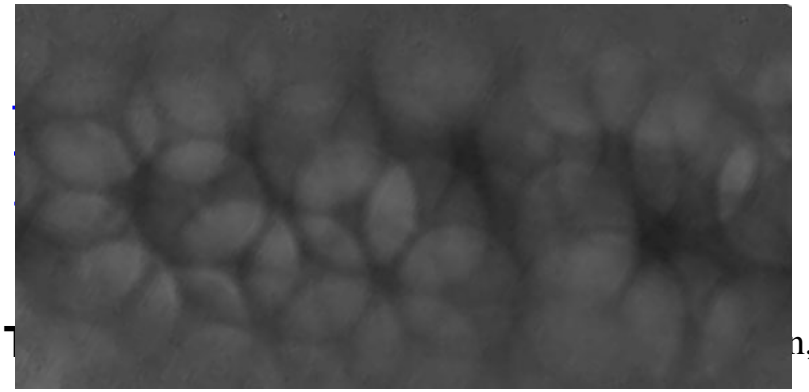


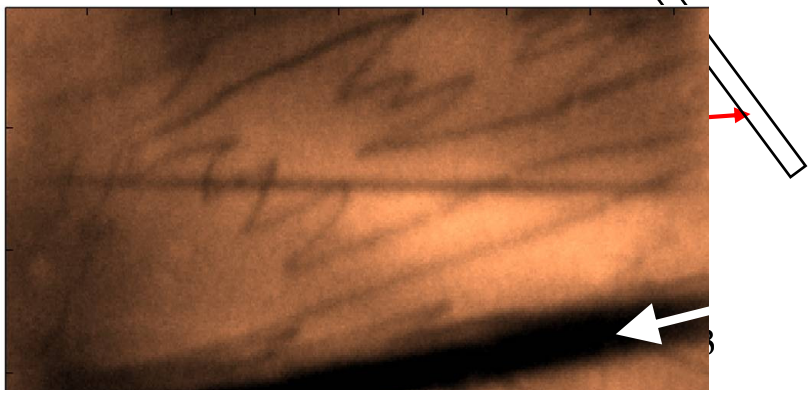




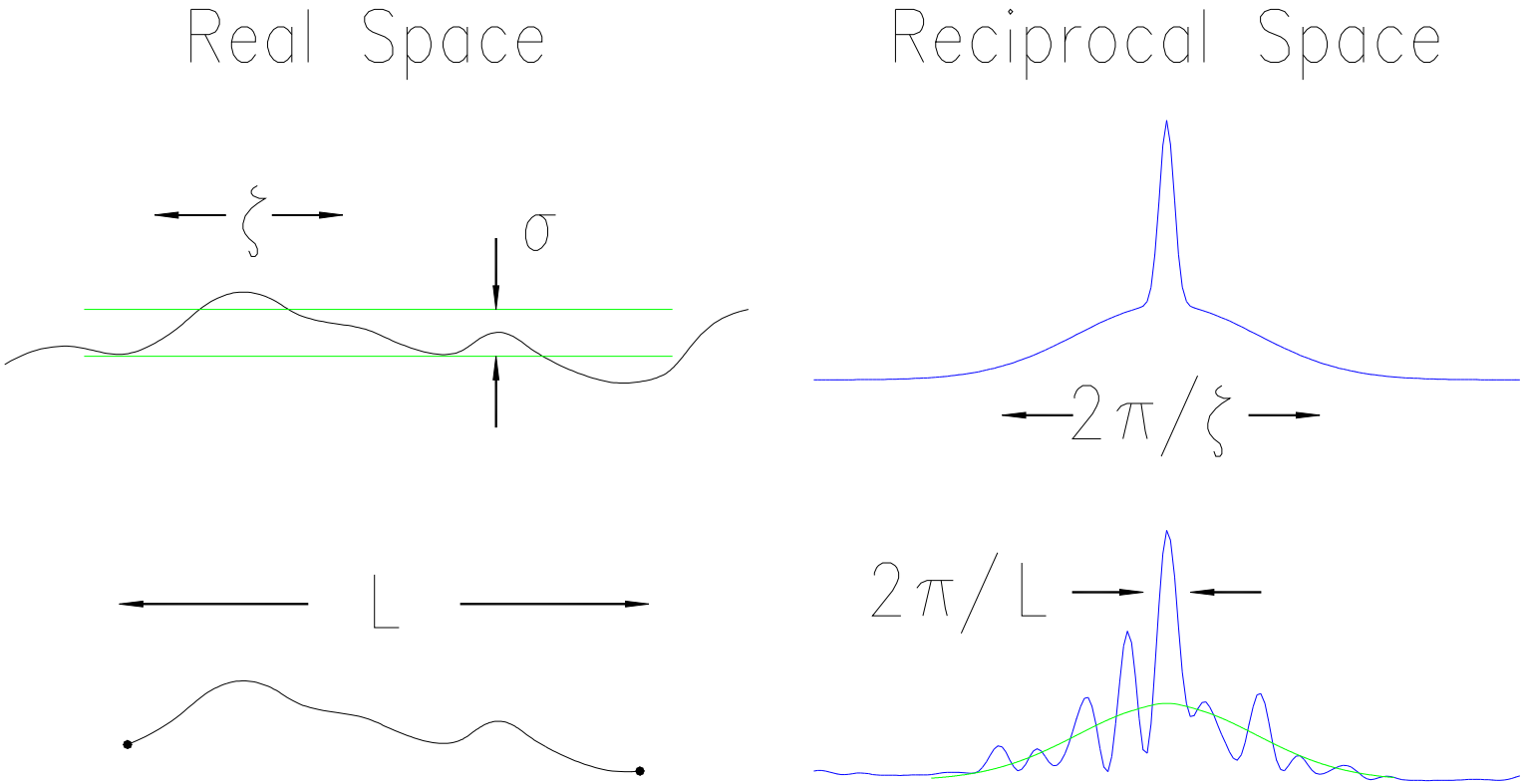
Miao et al (1999)



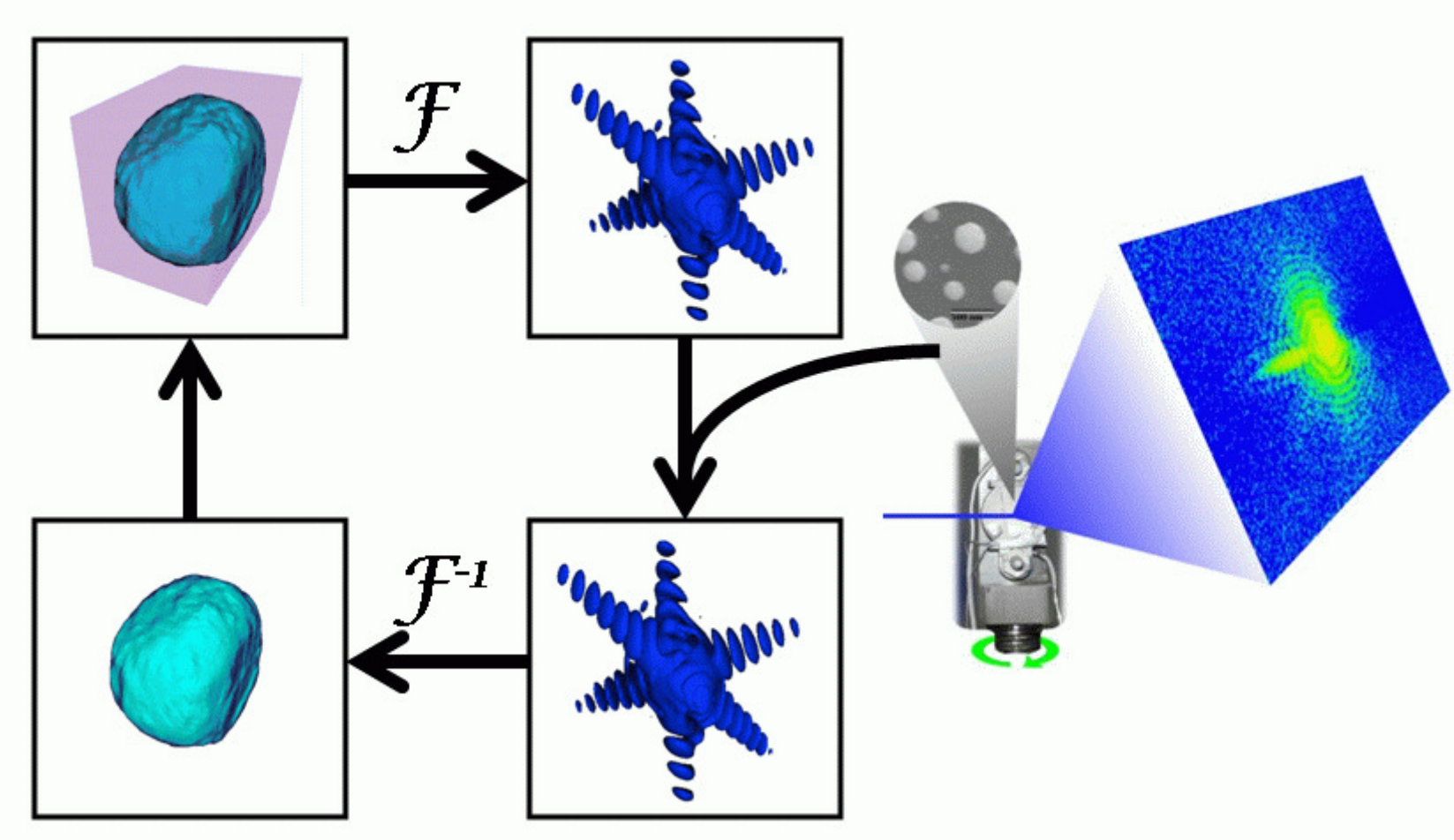




Diffuse Scattering acquires fine structure with a Coherent Beam



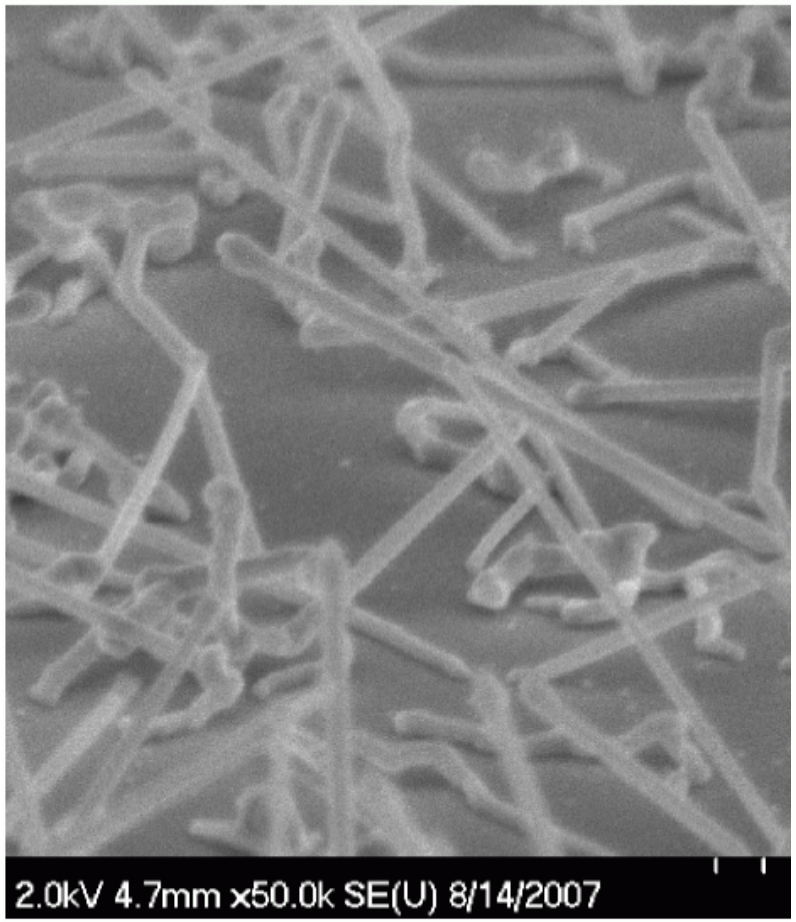
Generic "Error Reduction" method



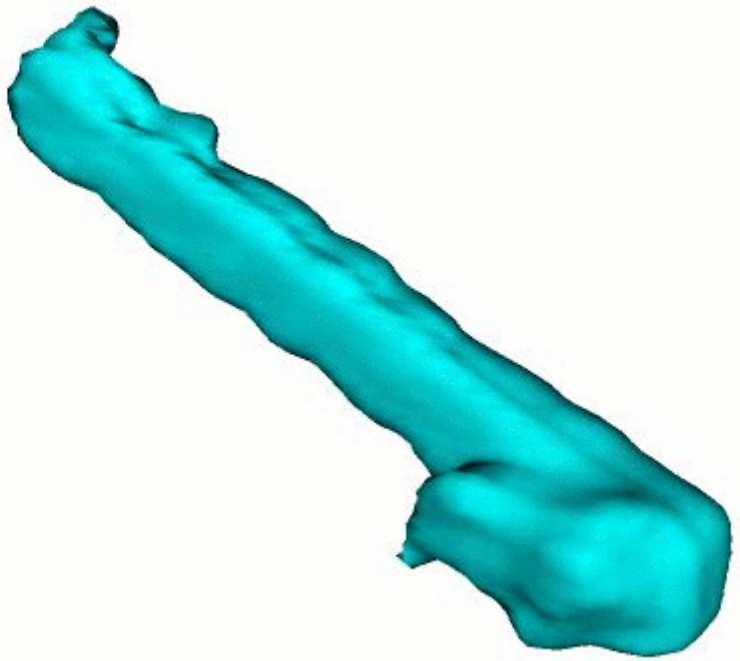
J. R. Fienup Appl. Opt. 21 2758 (1982)
R. W. Gerchberg and W. O. Saxton Optik 35 237 (1972)

Reconstruction of InP nanowire

CVD on Si, Suneel Kodambaka, UCLA

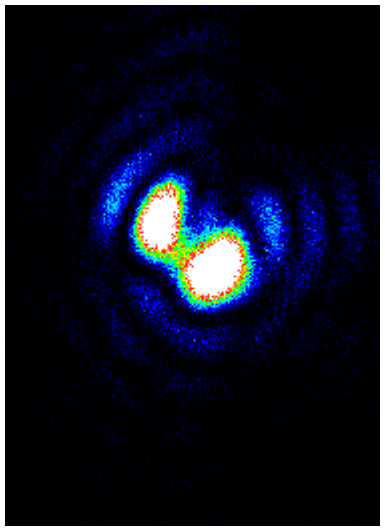


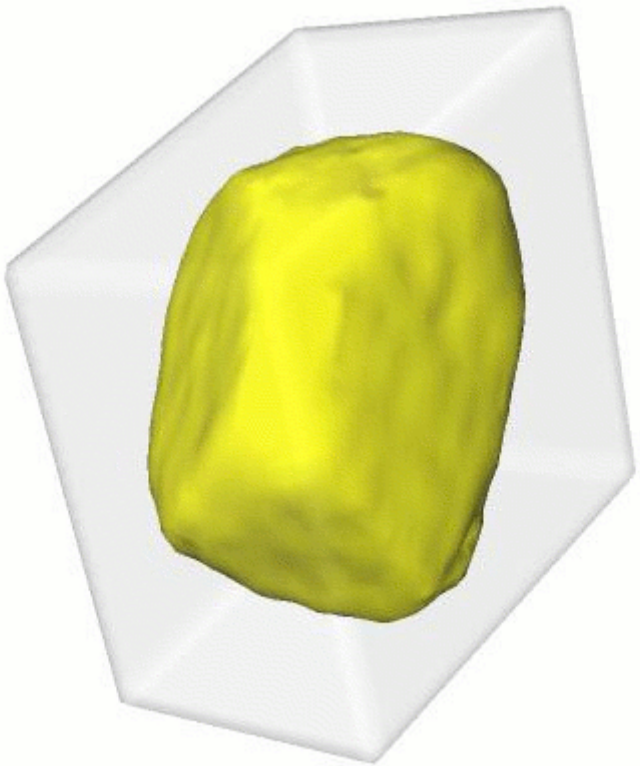
InP nanowires grown on Si (111)



Gold nanocrystal reconstruction

showing support used for 20 HIO followed by 10 ER





Cellulose Granules in Corn (Maize)

Jyotsana Lal, Ross Harder, Lee Makowski, ANL

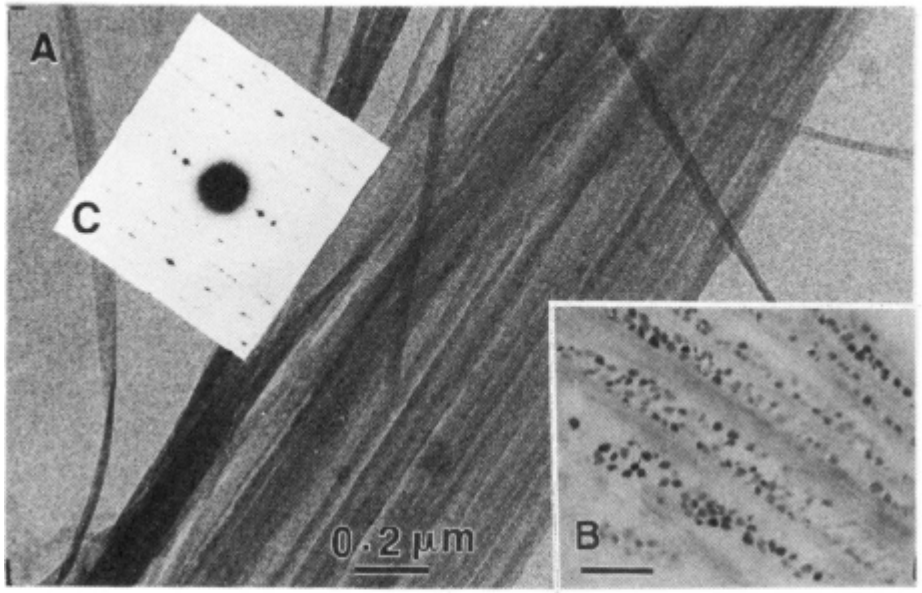
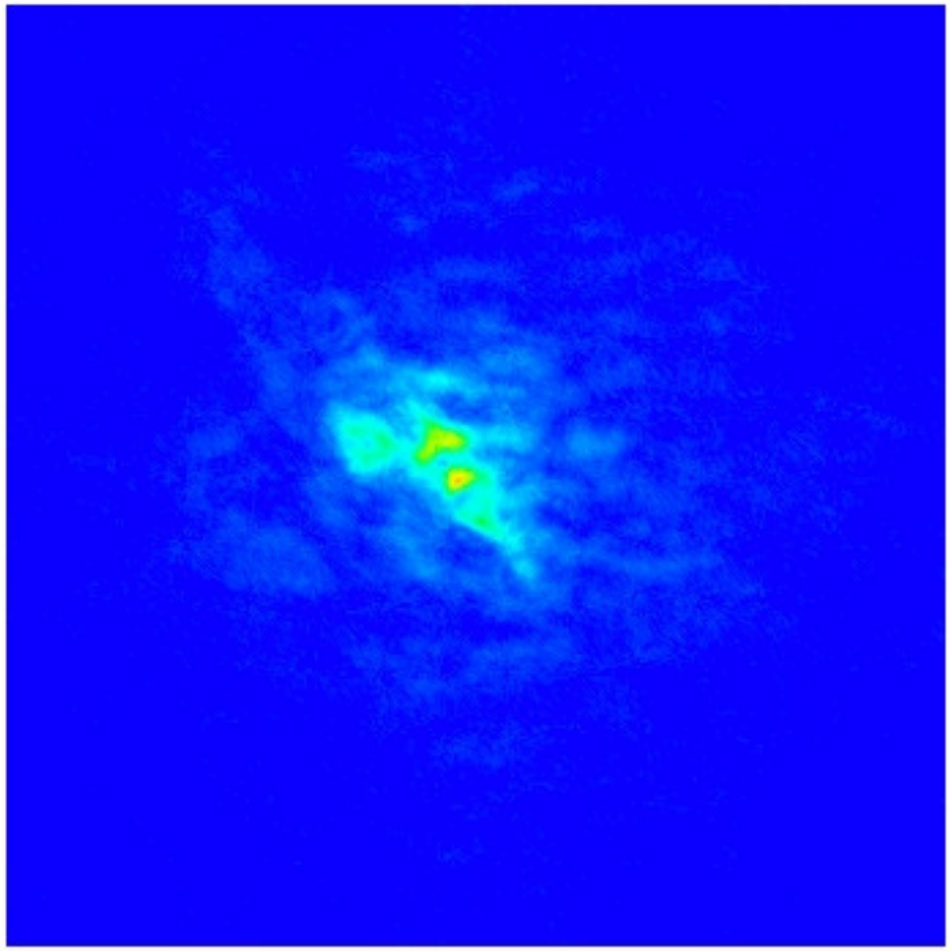
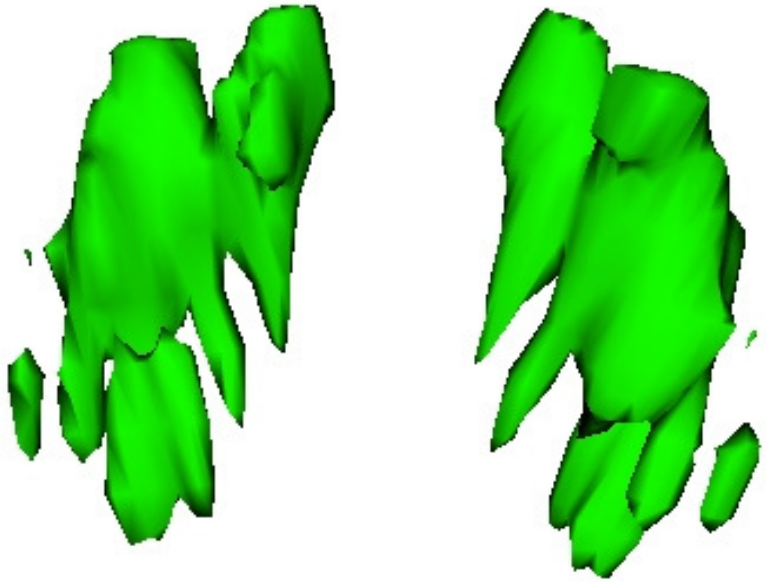
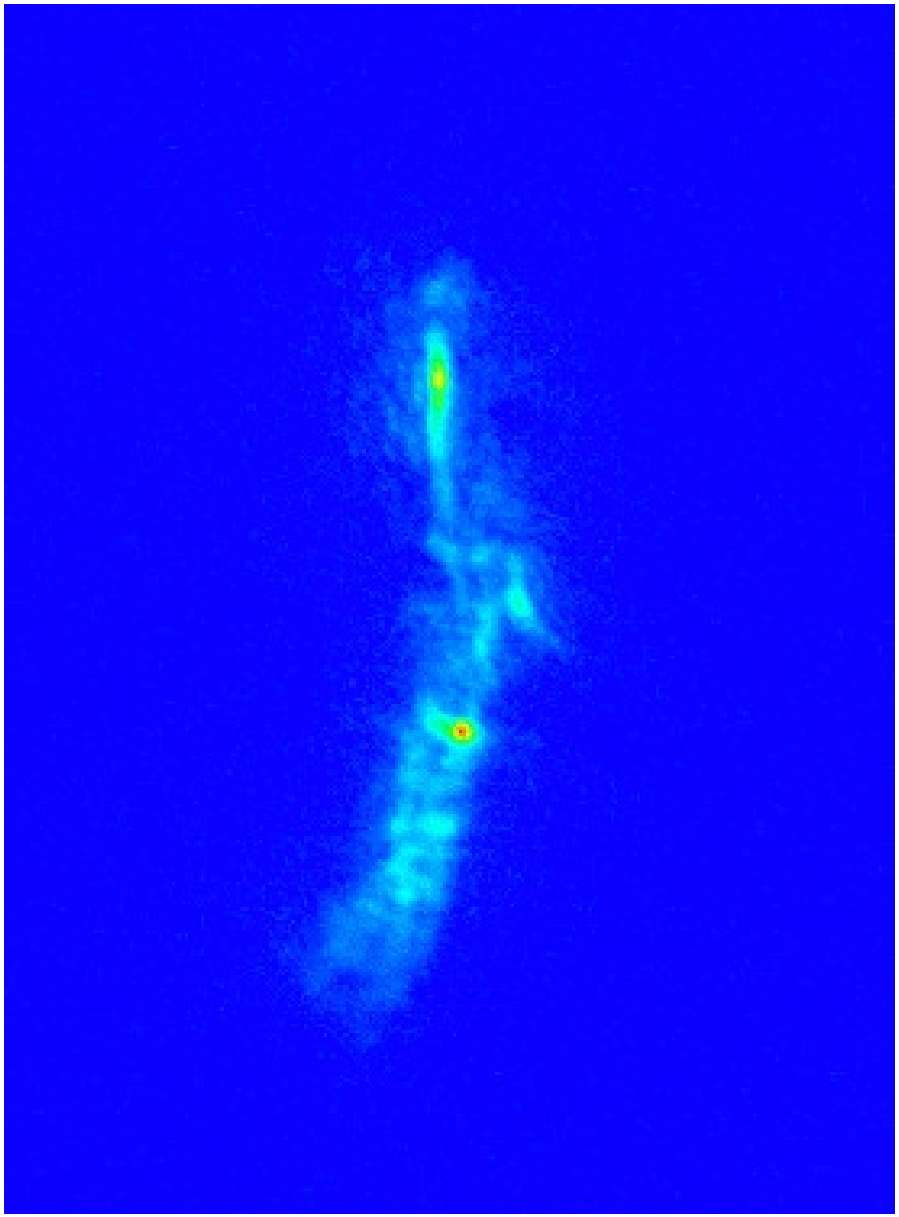


Figure 1. Ultrastructural features of *Microdictyon* cellulose microfibrils: (A) a thin layer of microfibrils unstained and unshadowed observed under low-dose imaging conditions; (B) bright-field electron micrograph of the cross section of a cell wall fragment of *Microdictyon* (the almost square section of the microfibrils is well denoted in this diffraction contrast image); (C) electron diffraction diagram of an area such as that located in the lower part of Figure 1A and recorded on an area having 200 nm in diameter.

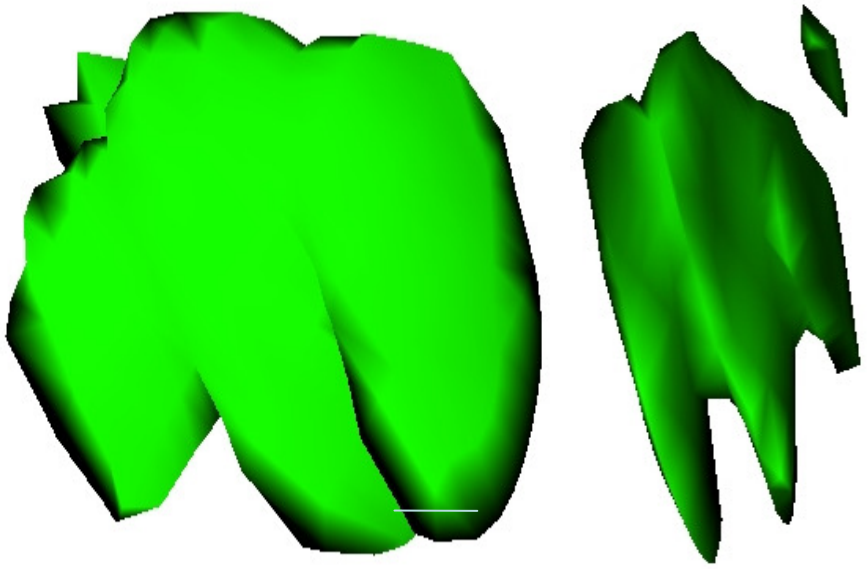
Crystals formed through coalescence of fibrils



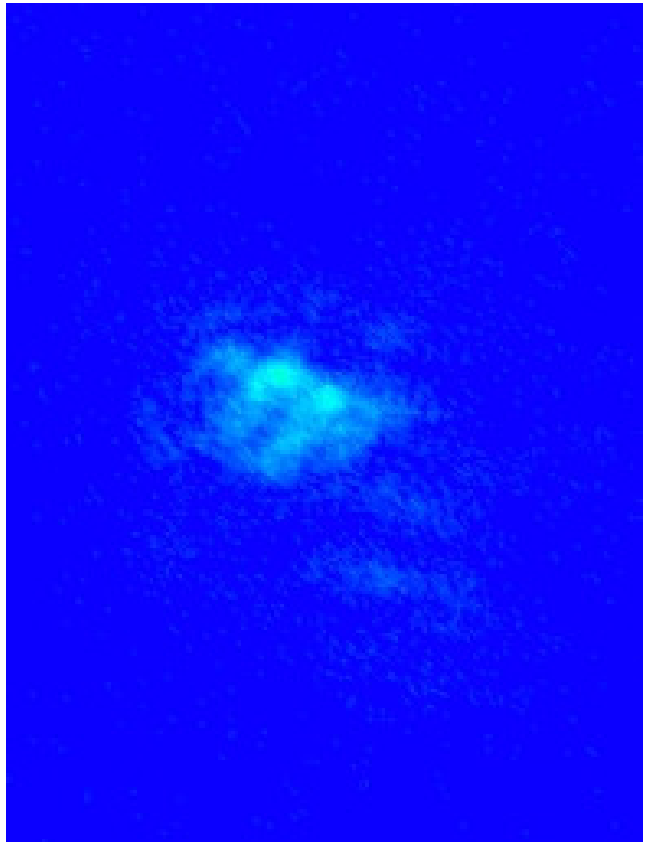


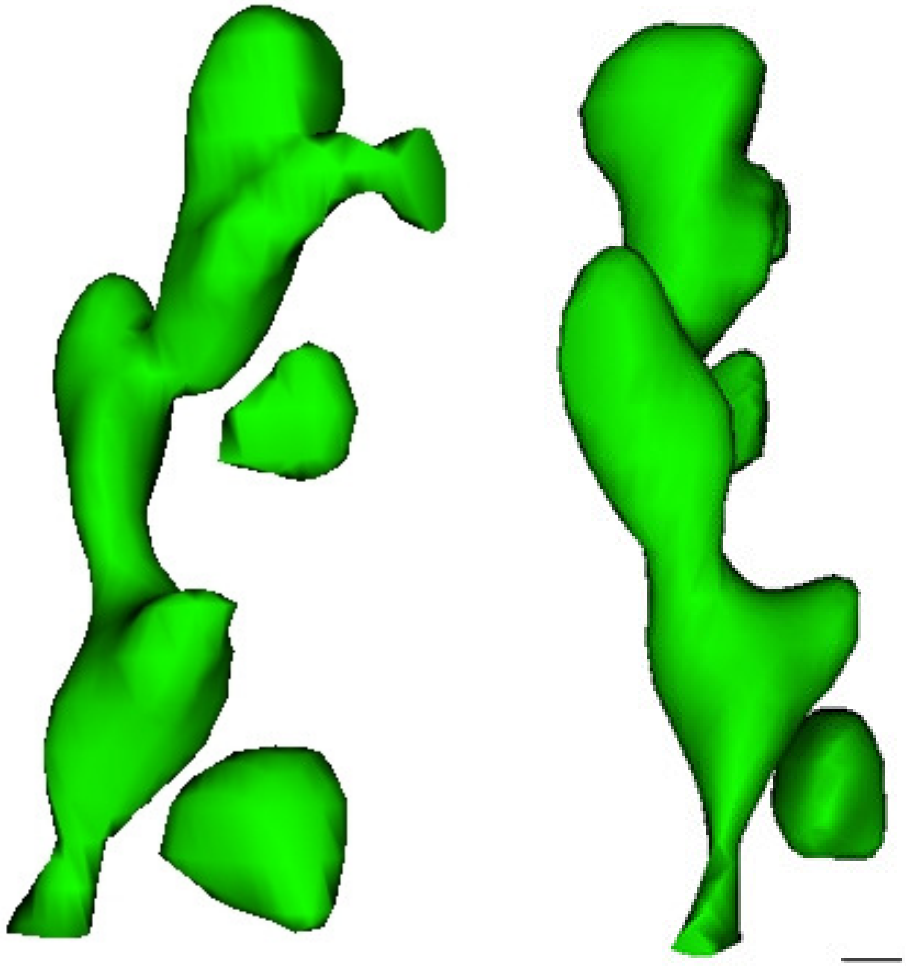


Crystals formed through packing of flat plates



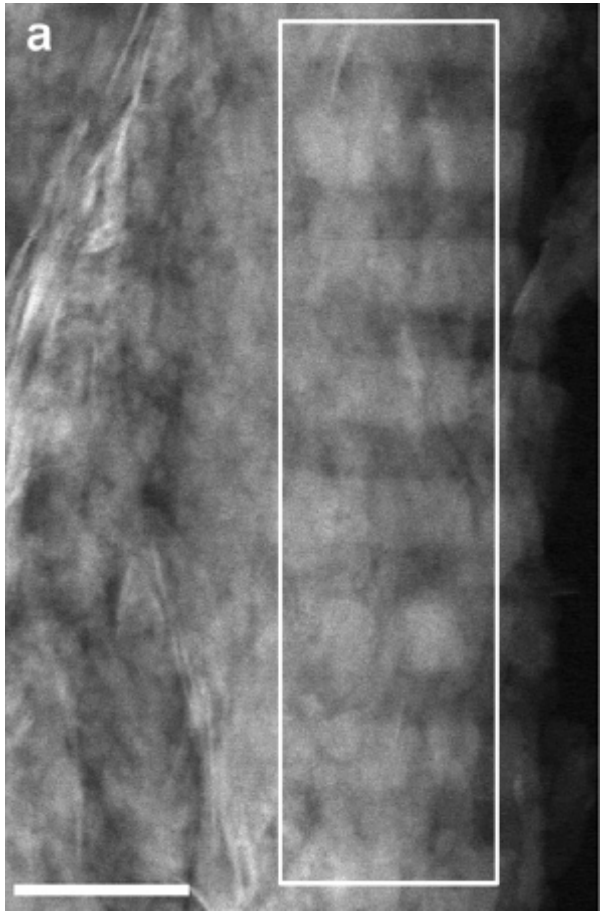
Helical arrangements of compact domains





Mike Horton's inspiration

STEM biomineralisation, AFM

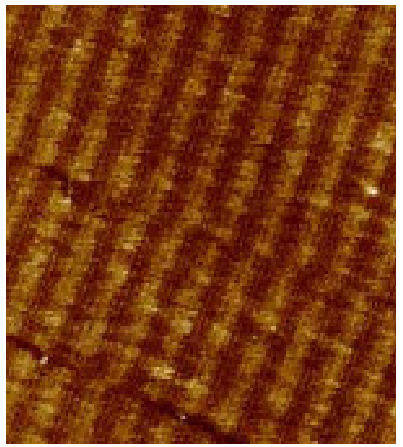


Collagen Primary Structure

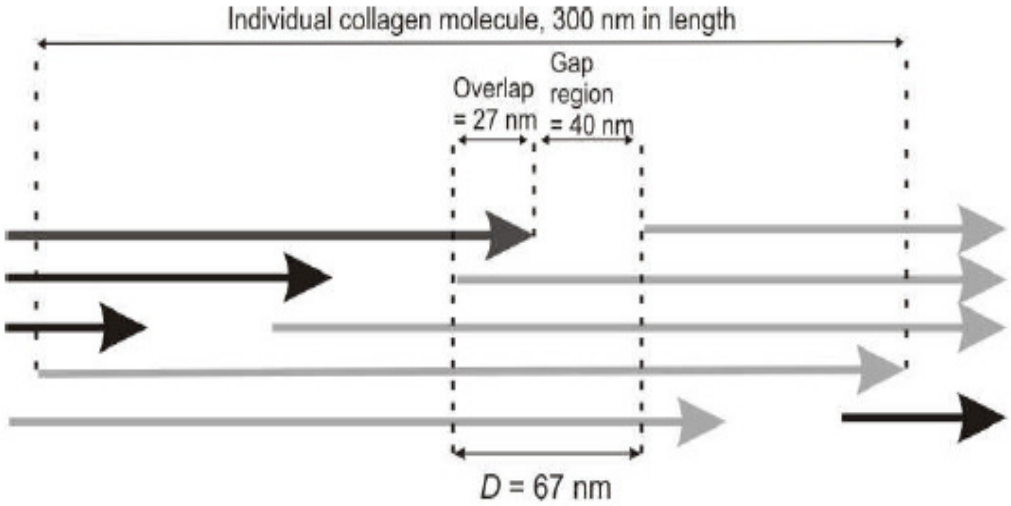
Felisa Berenguer, LCN

- Collagen is the most common protein in animal tissue (bones, teeth, tendon, cartilage, connective tissue)
- Potential applications in medicine (artificial bone, skin diseases)
- Collagen packing to built-up fibres is not completely understood

  Different proposed models by Orgel 2007, Wess 2006, Bozec 2007 …



SEM [Cisneros, 2006]

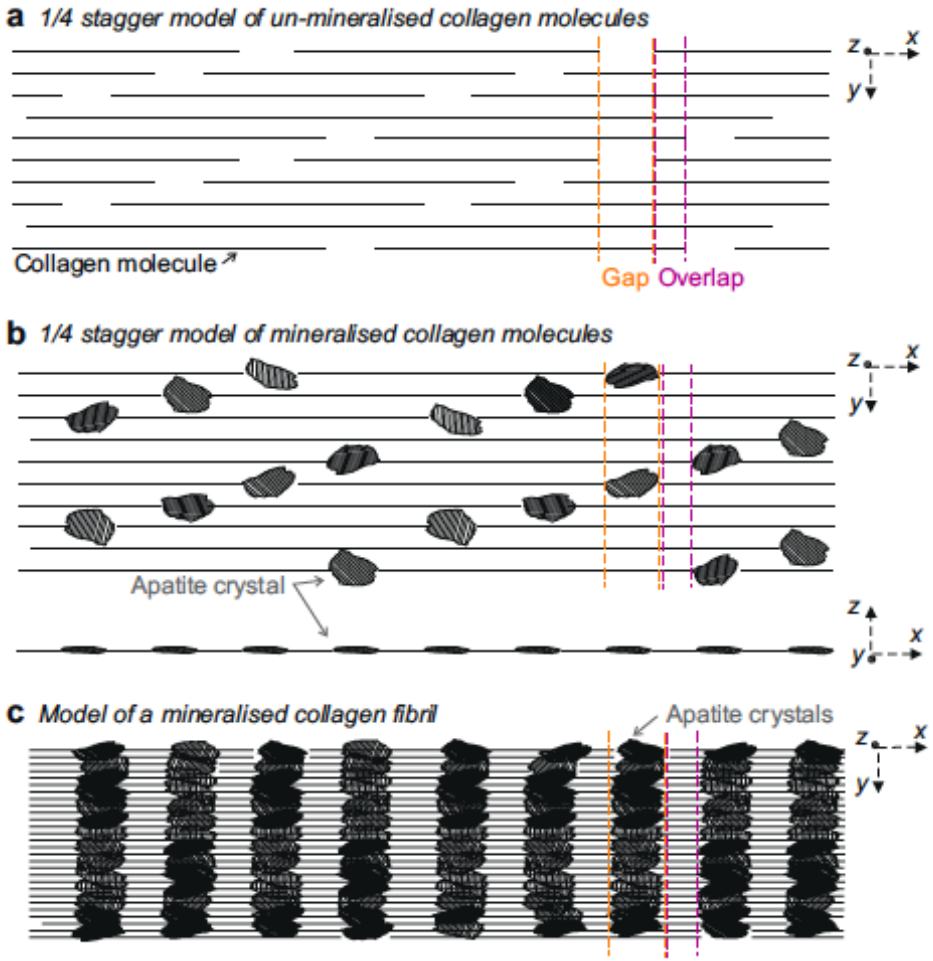


[Hodge and Petruska, 1976]

Biomineralisation Model

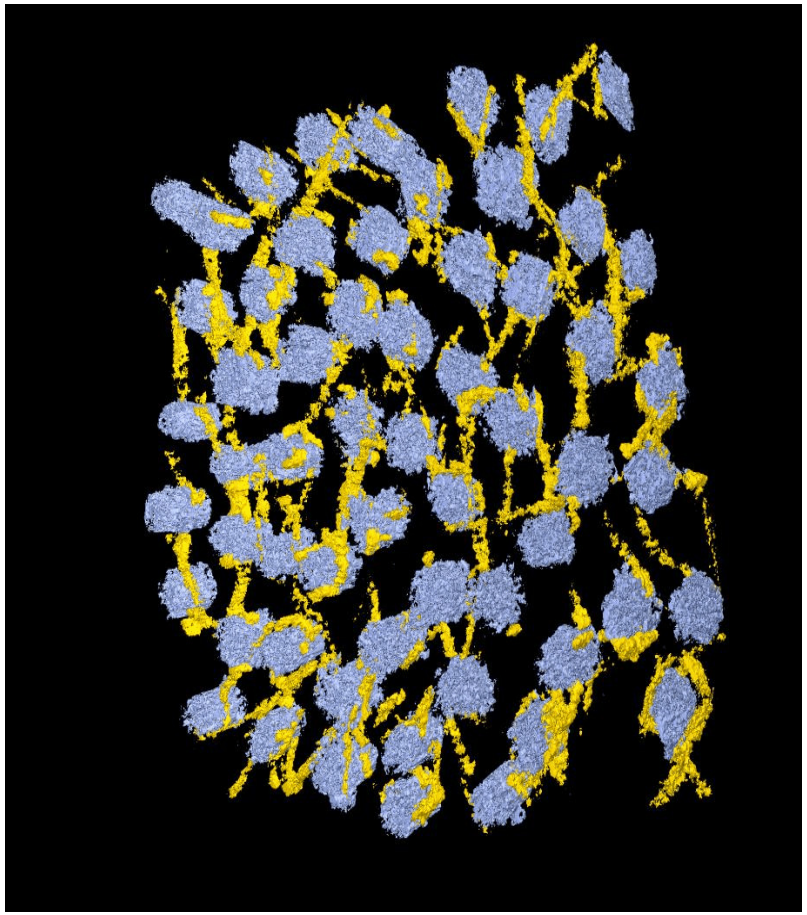
Jantou-Morris, V; Horton, MA; McComb, DW

Biomaterials 31 5275 (2010)

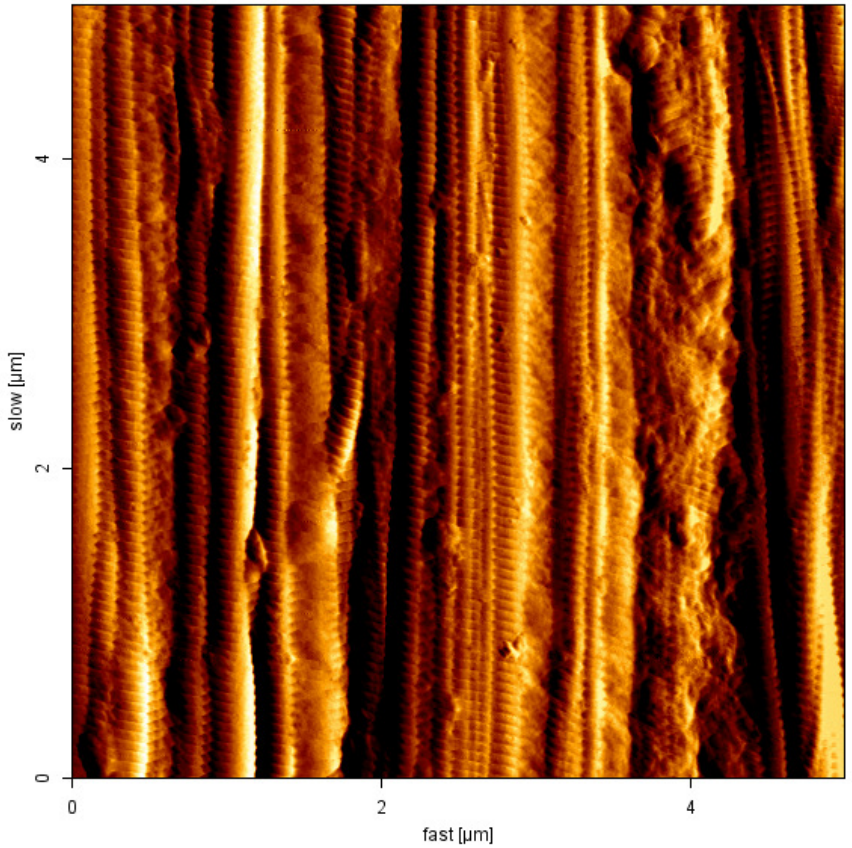


BONE ·3D tomographic reconstruction, X-ray (J. Ritchie)

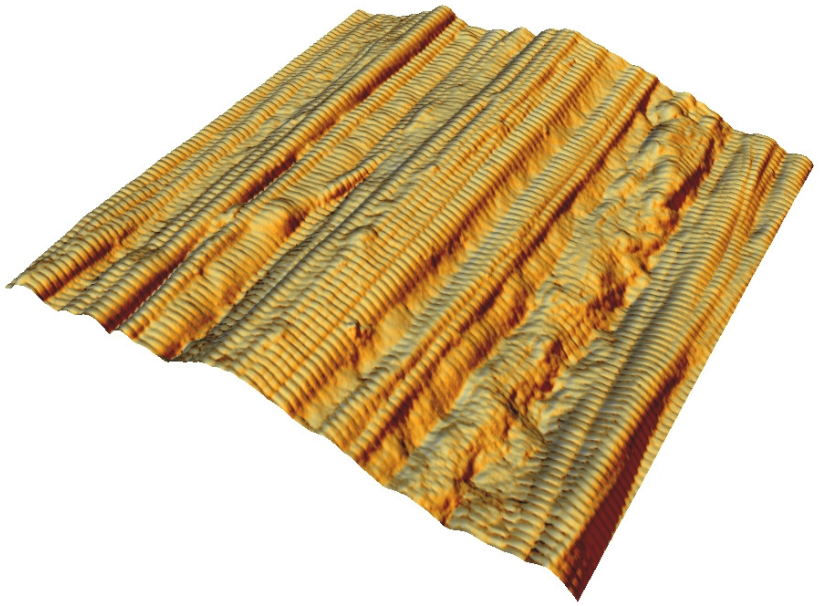
CORNEA ·3D tomographic reconstruction from EM (K. Meek)



AFM imaging of rat-tail collagen



Dehydrated rat tail tendon tissue



Strong D-banding with 67 nm periodicity:

→Diffraction pattern with strong meridional maxima at multiples of 1/67 nm^{-1}

I. K. Robinson, MPI Golm 2010

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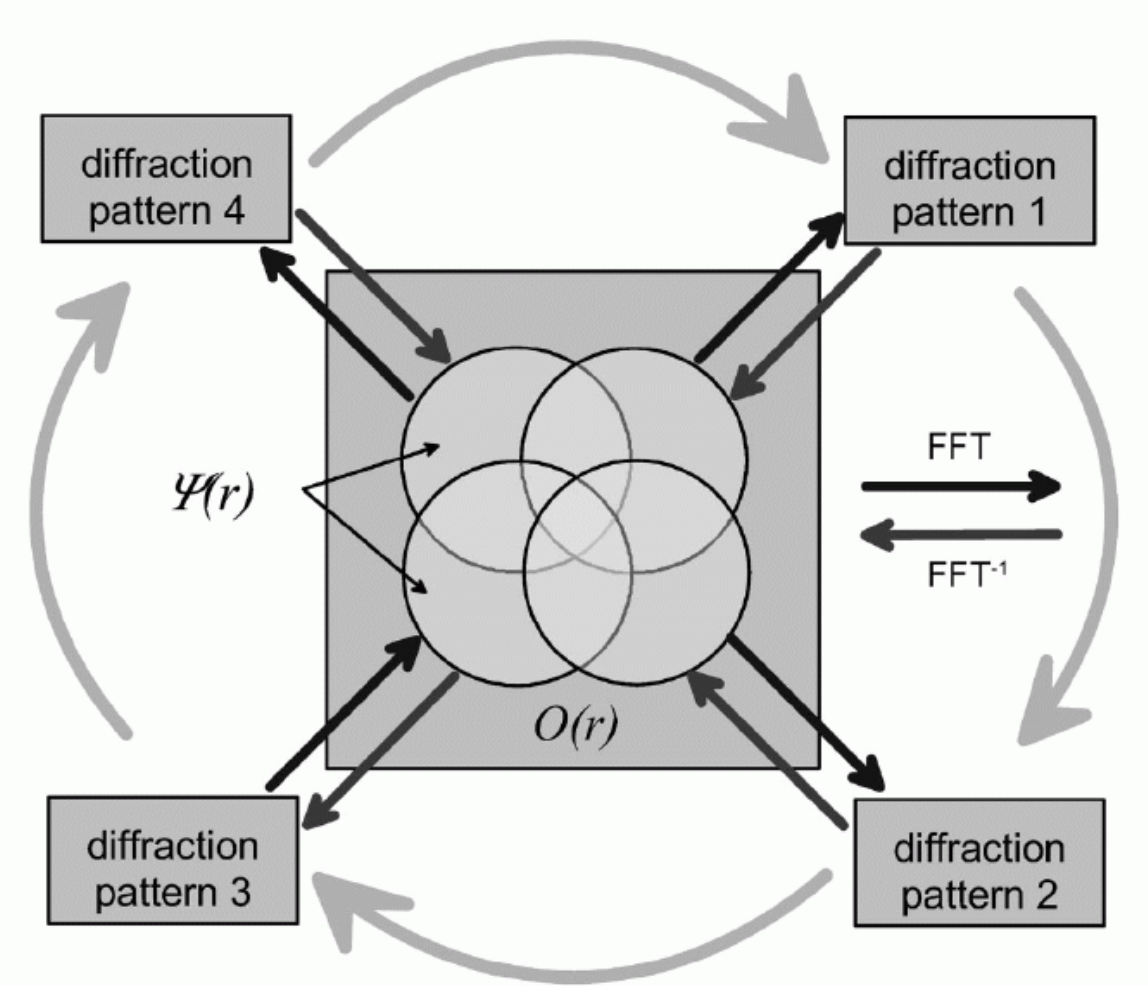
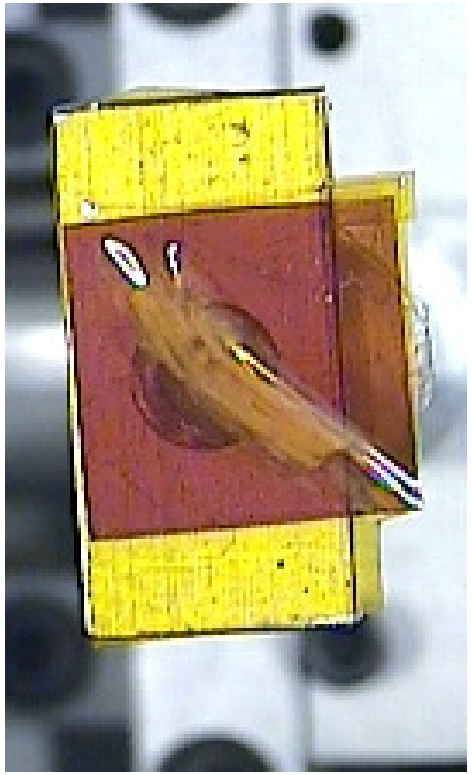
X-ray Ptychography

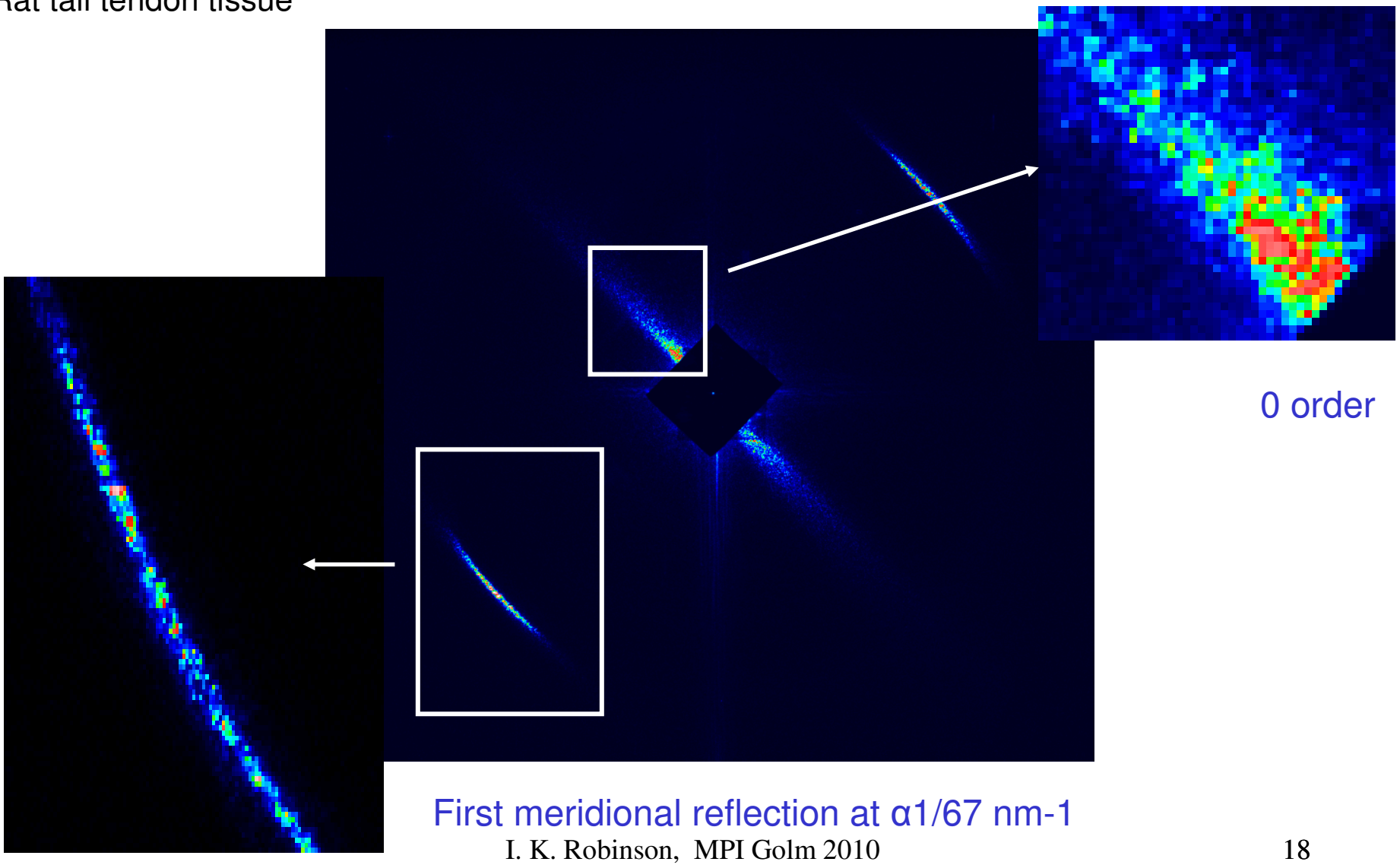




J. M. Rodenburg et al, Phys. Rev. Lett. 98 034801 (2007)

First experimental results on collagen

Rat tail tendon tissue

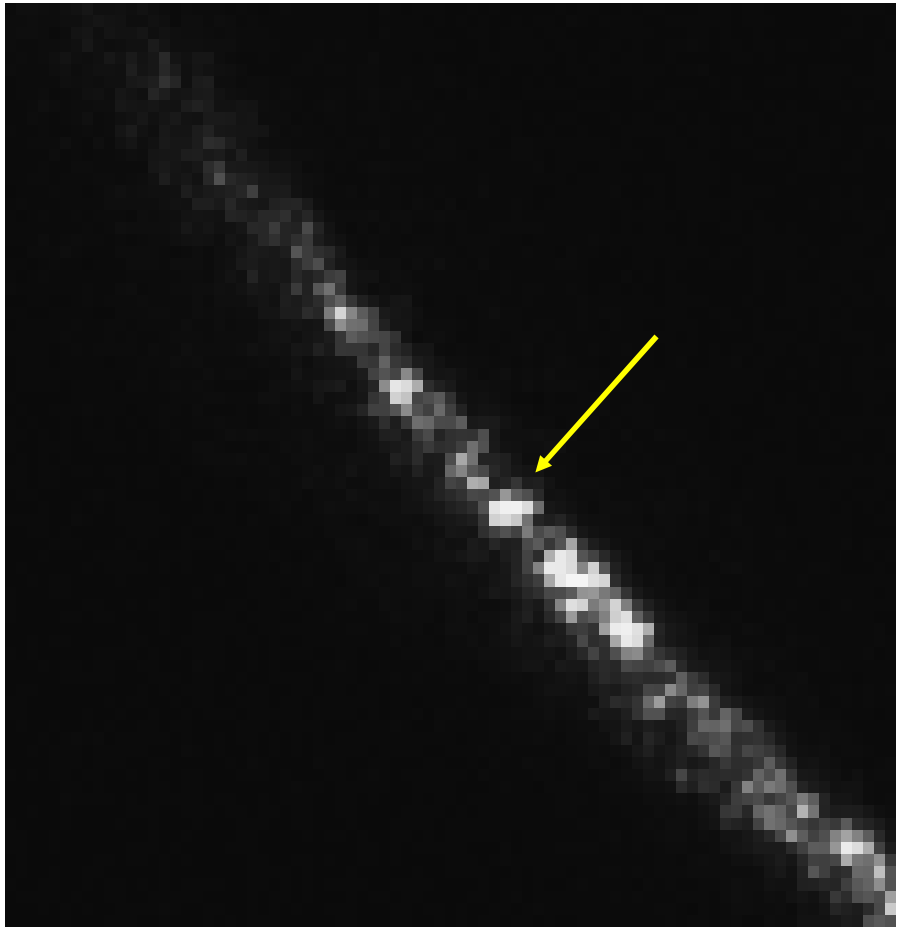


0 order

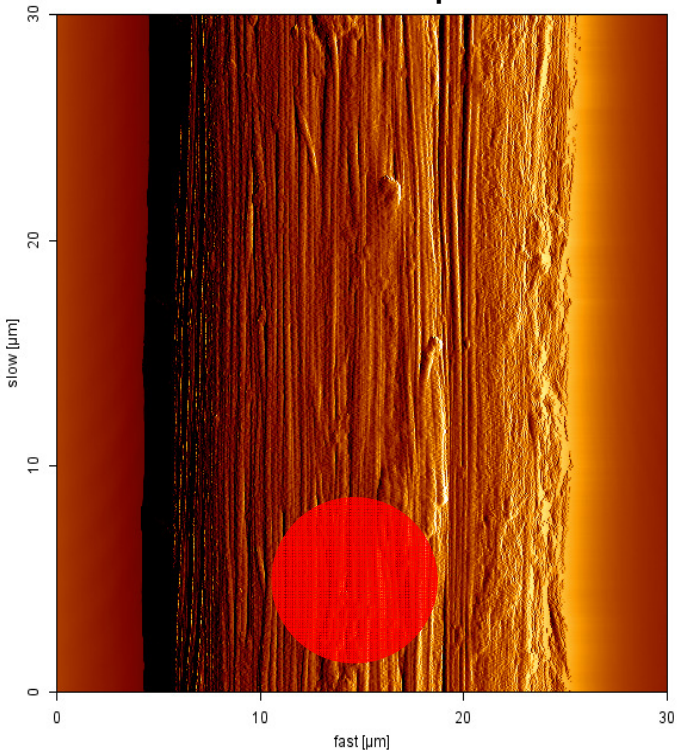
First meridional reflection at α1/67 nm-1

X-ray Ptychography

First meridional reflection



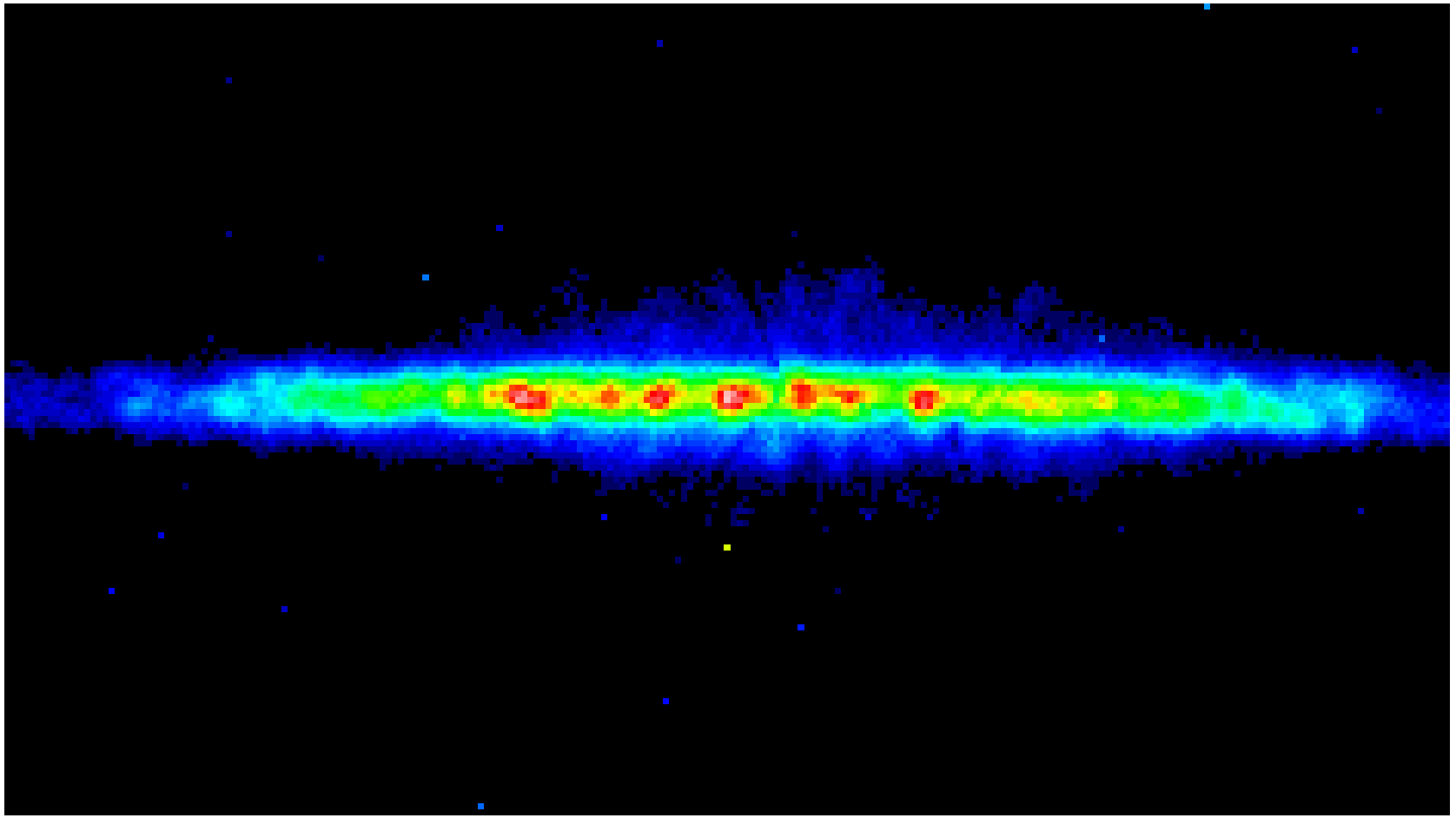
10 μm beam



Dark field imaging:
collagen distribution in different tissues

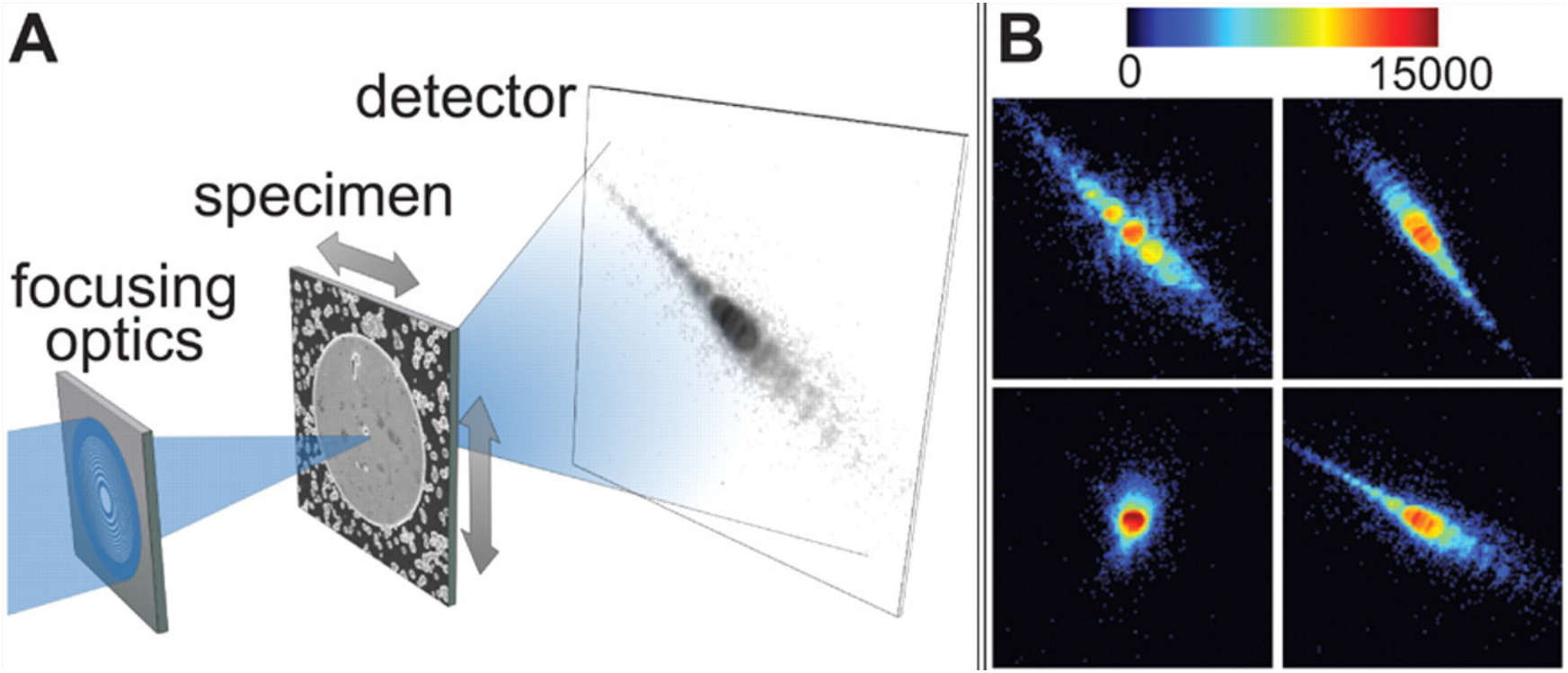
Improved collagen sample prep

Diamond I-22, Nov 2008



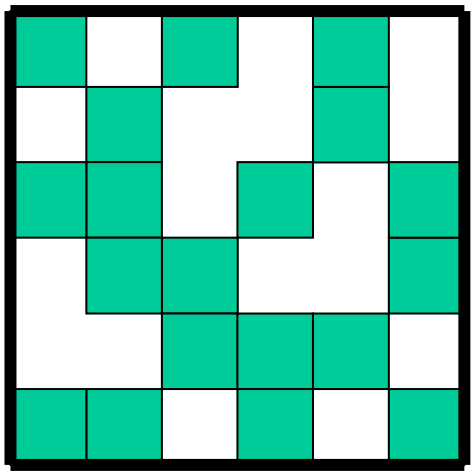
X-ray Ptychography

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

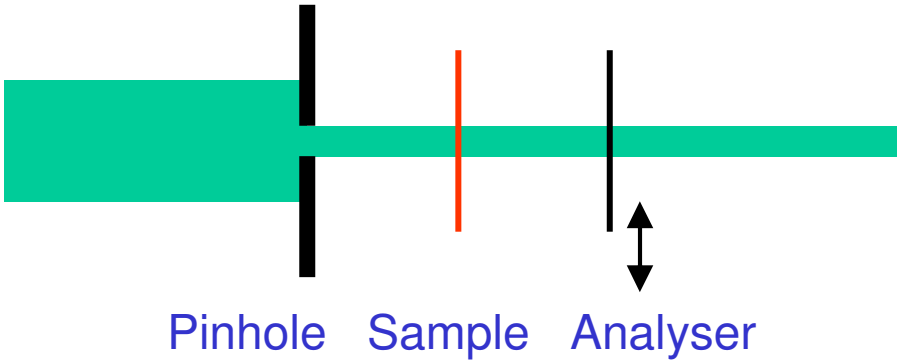


‘Random’ phase plate analyser

Joan Vila (PSI), Fucai Zhang (Sheffield)

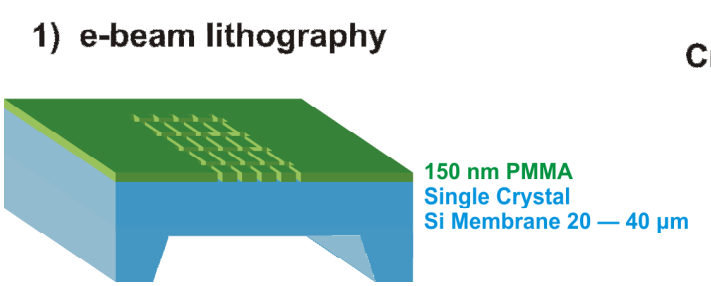


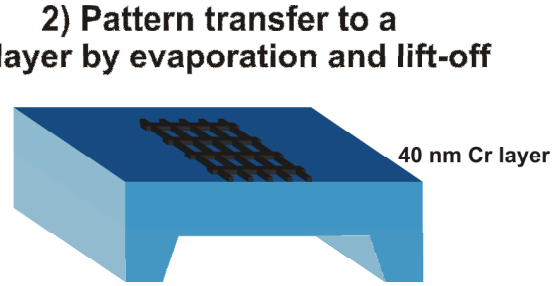
1μm

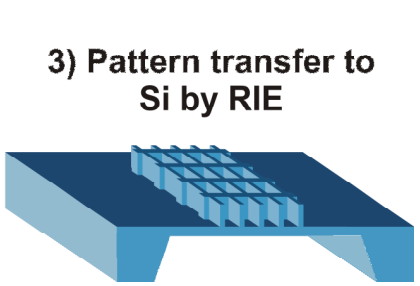


Phase plate fabrication

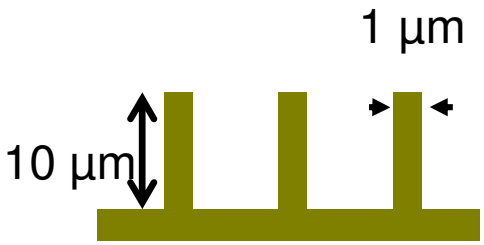
Joan Vila-Comamala, PSI



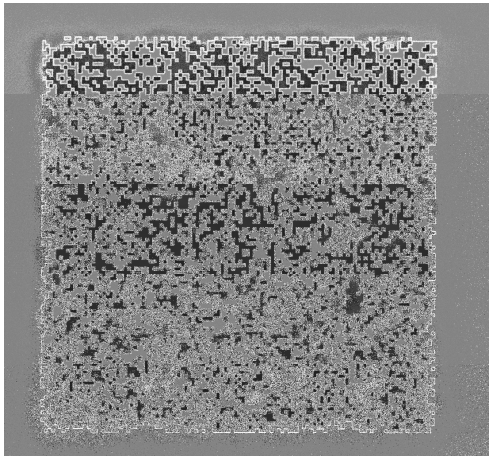


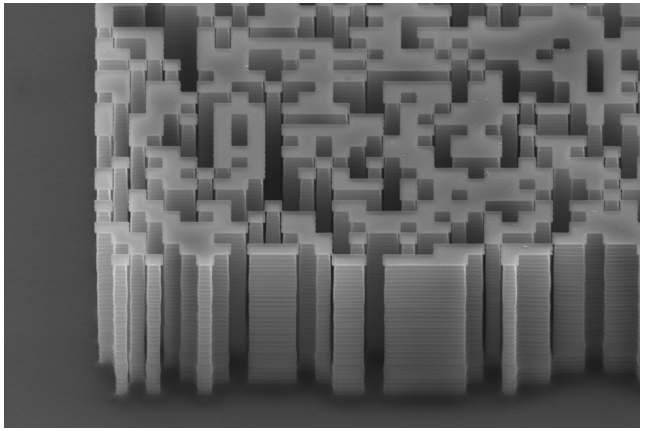


At 8.0 keV (λ=0.155 nm) → $\delta = 7.67 \cdot 10^{-6}$ **h=10.10 µm**
At 10.0 keV (λ=0.124 nm) → $\delta = 4.88 \cdot 10^{-6}$ **h=12.70 µm**



Cross section

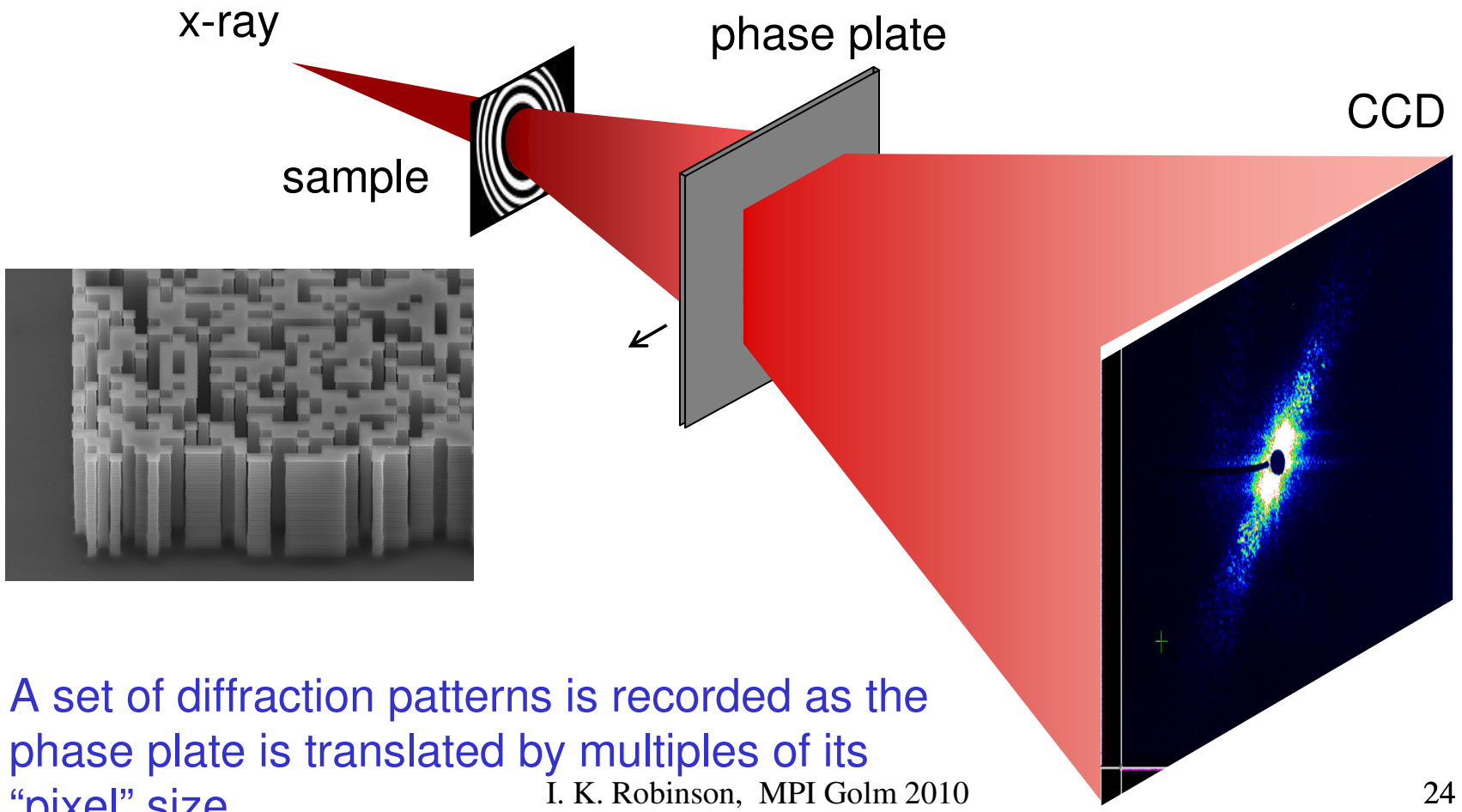




I. K. Robinson, MPI Golm 2010

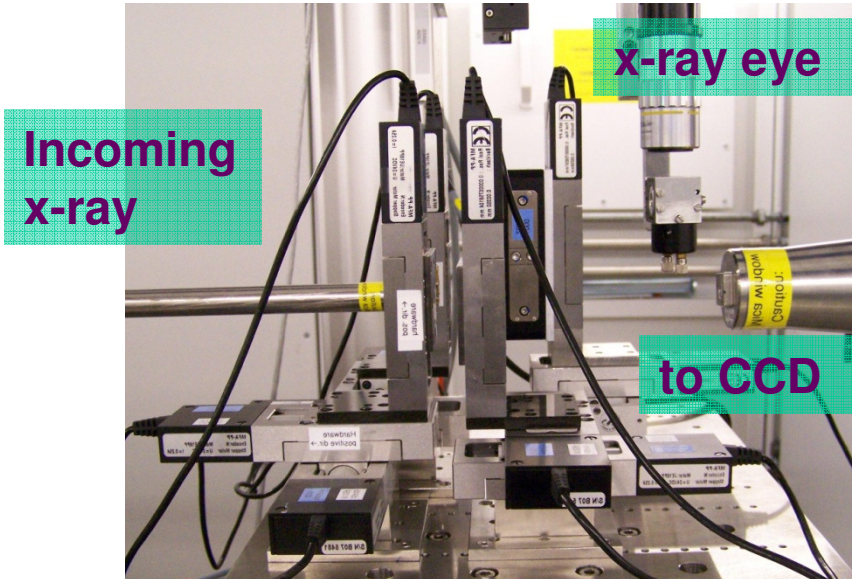
Imaging by wavefront modification

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

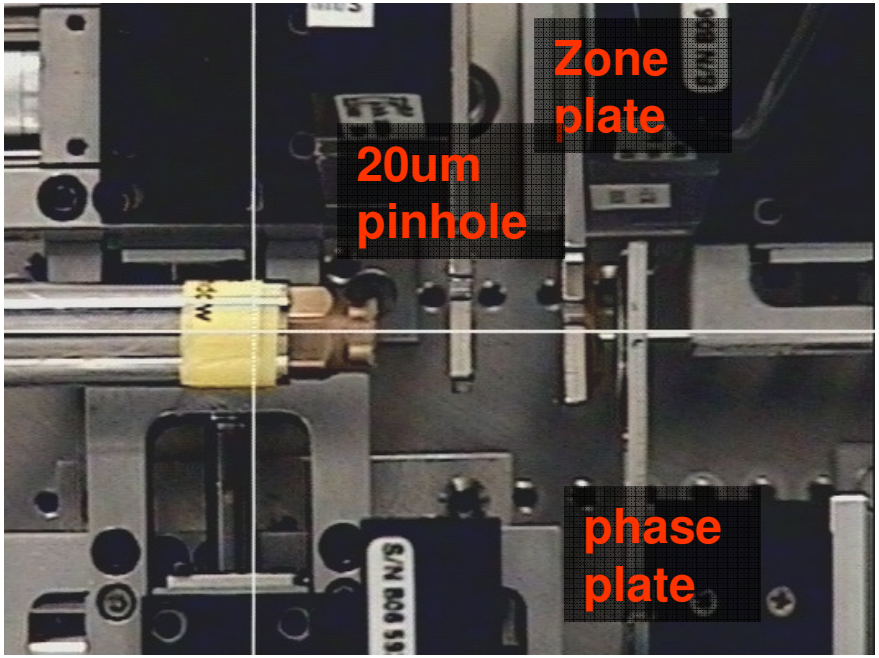


A set of diffraction patterns is recorded as the phase plate is translated by multiples of its "pixel" size

Experimental setup cSAXS (SLS)



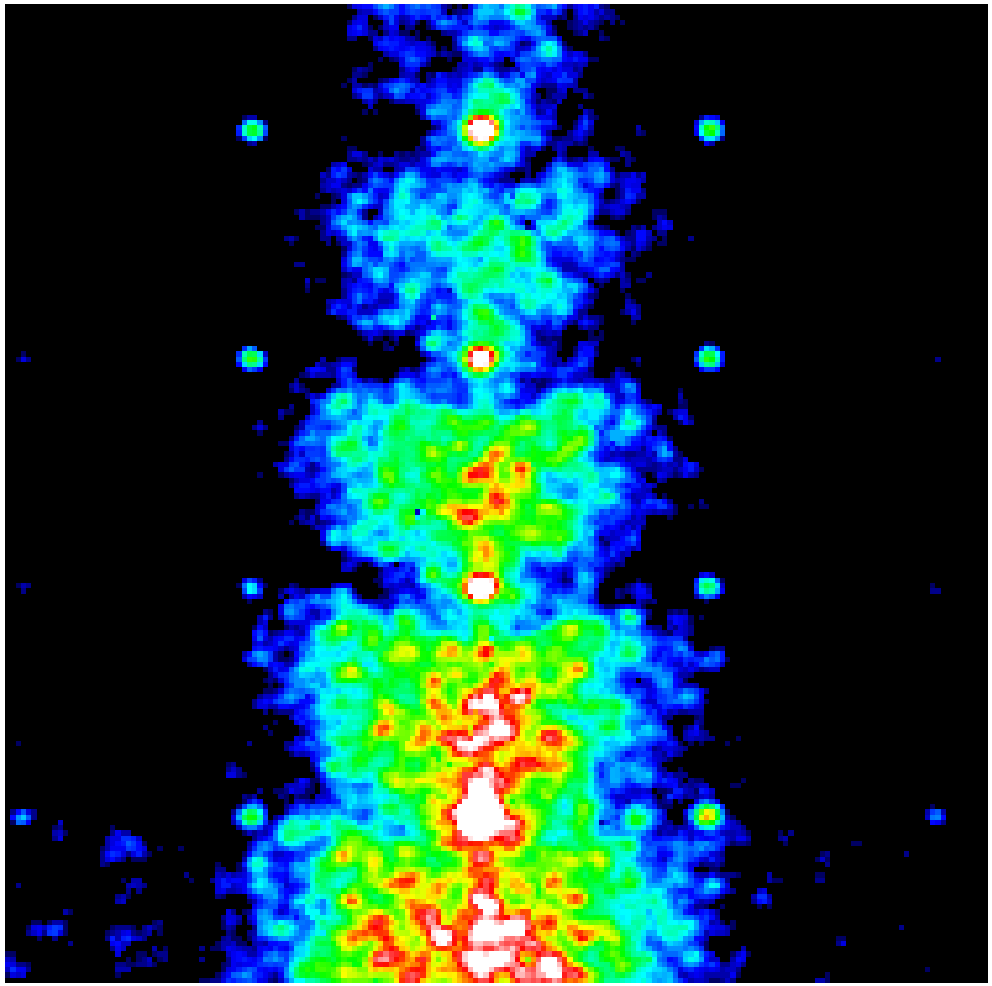
Side view

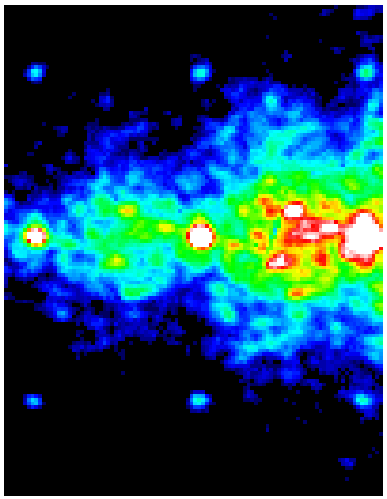


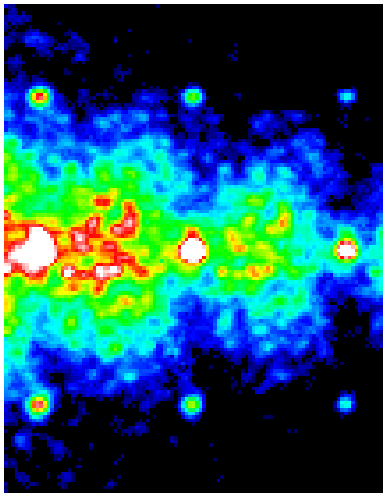
Top view (zoomed in)

Phase plate scan near forward direction

1μm step per frame

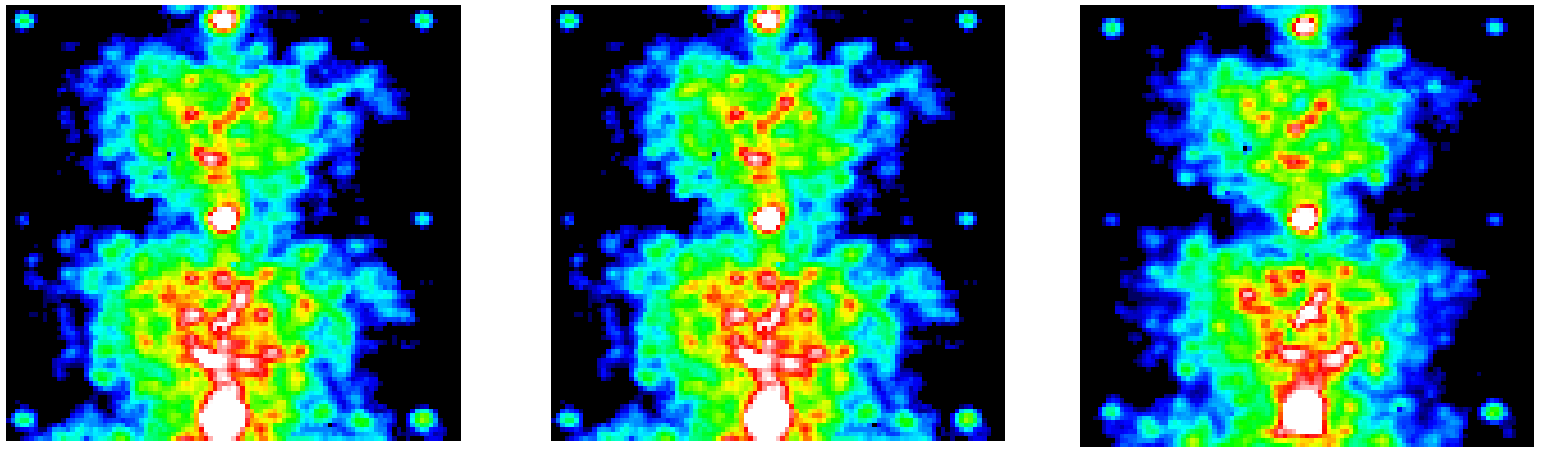




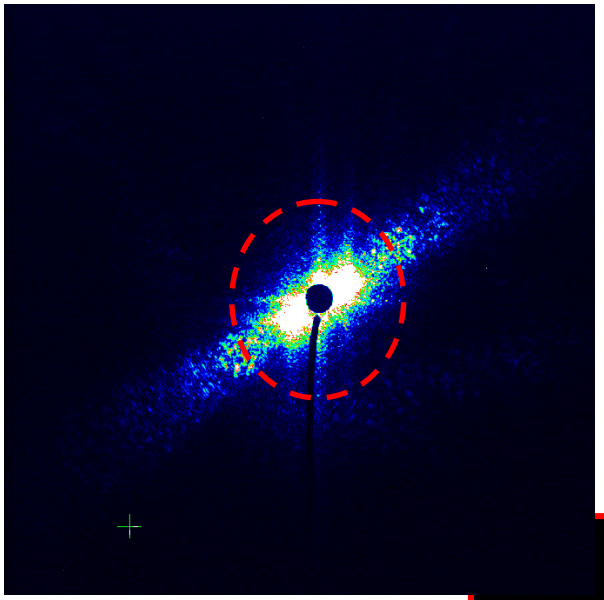


Collagen, buffer and empty cell

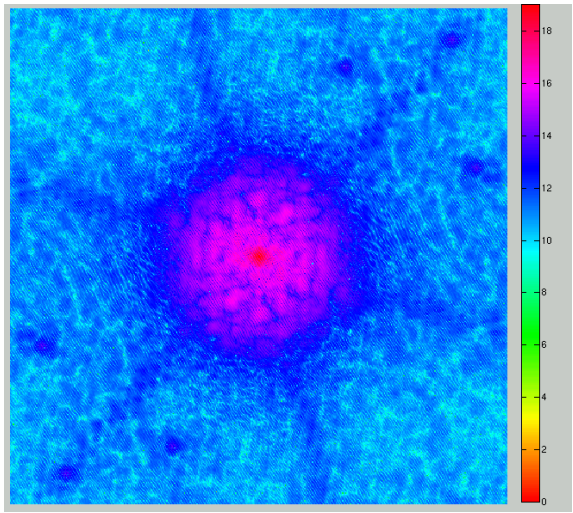
phplateFZP-236, -246 and -249



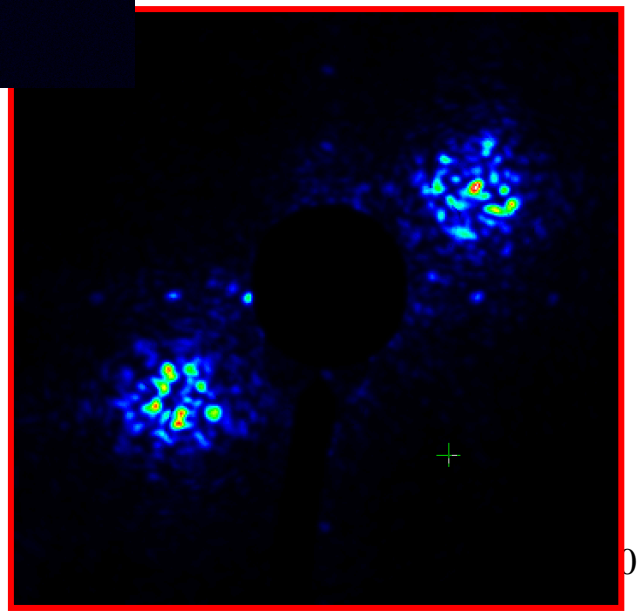
Results: Zone Plate as object



FT

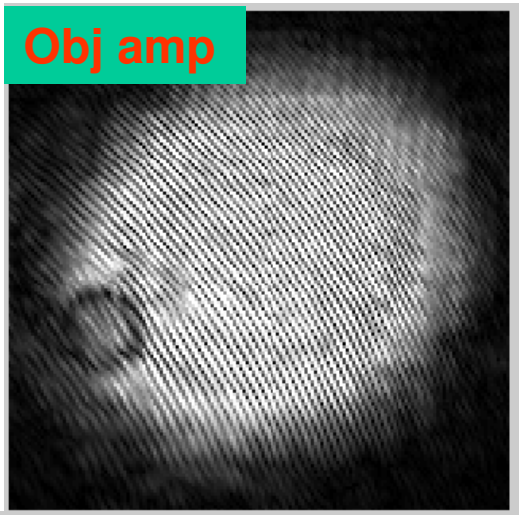


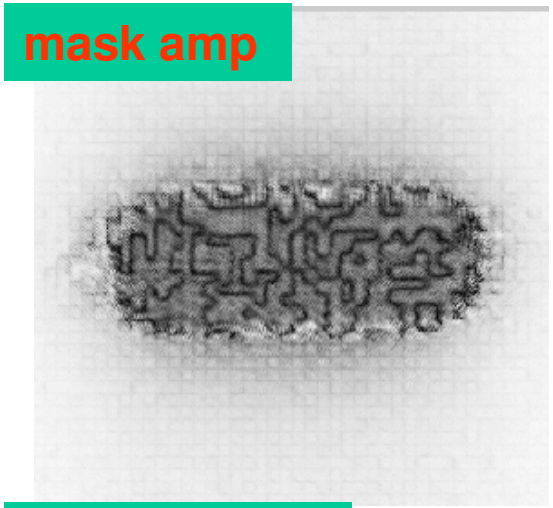
Auto correlation function

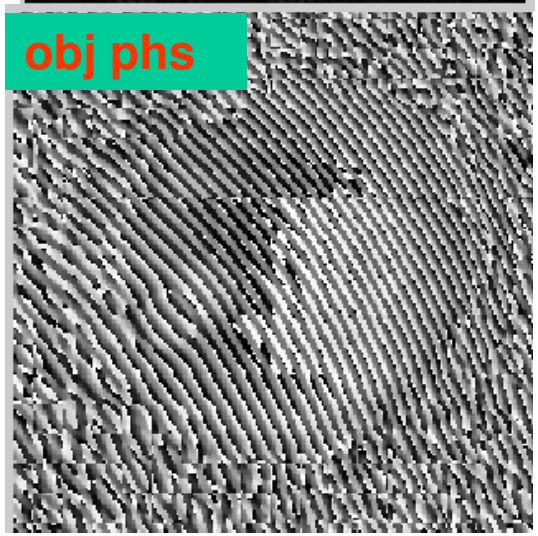


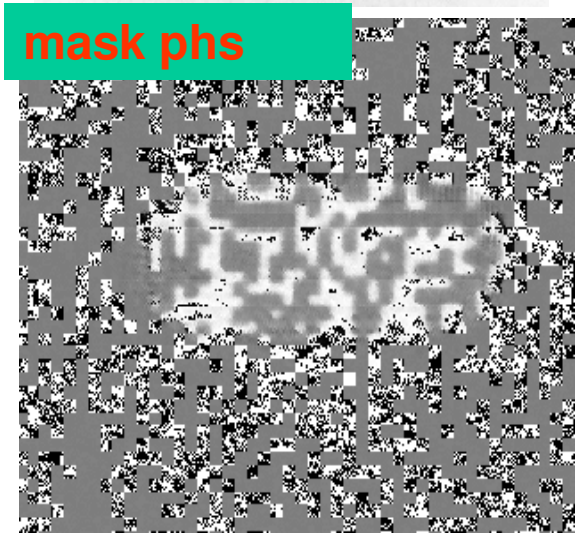
Reconstruction of Phase plate scan

1μm step per frame (512x512)





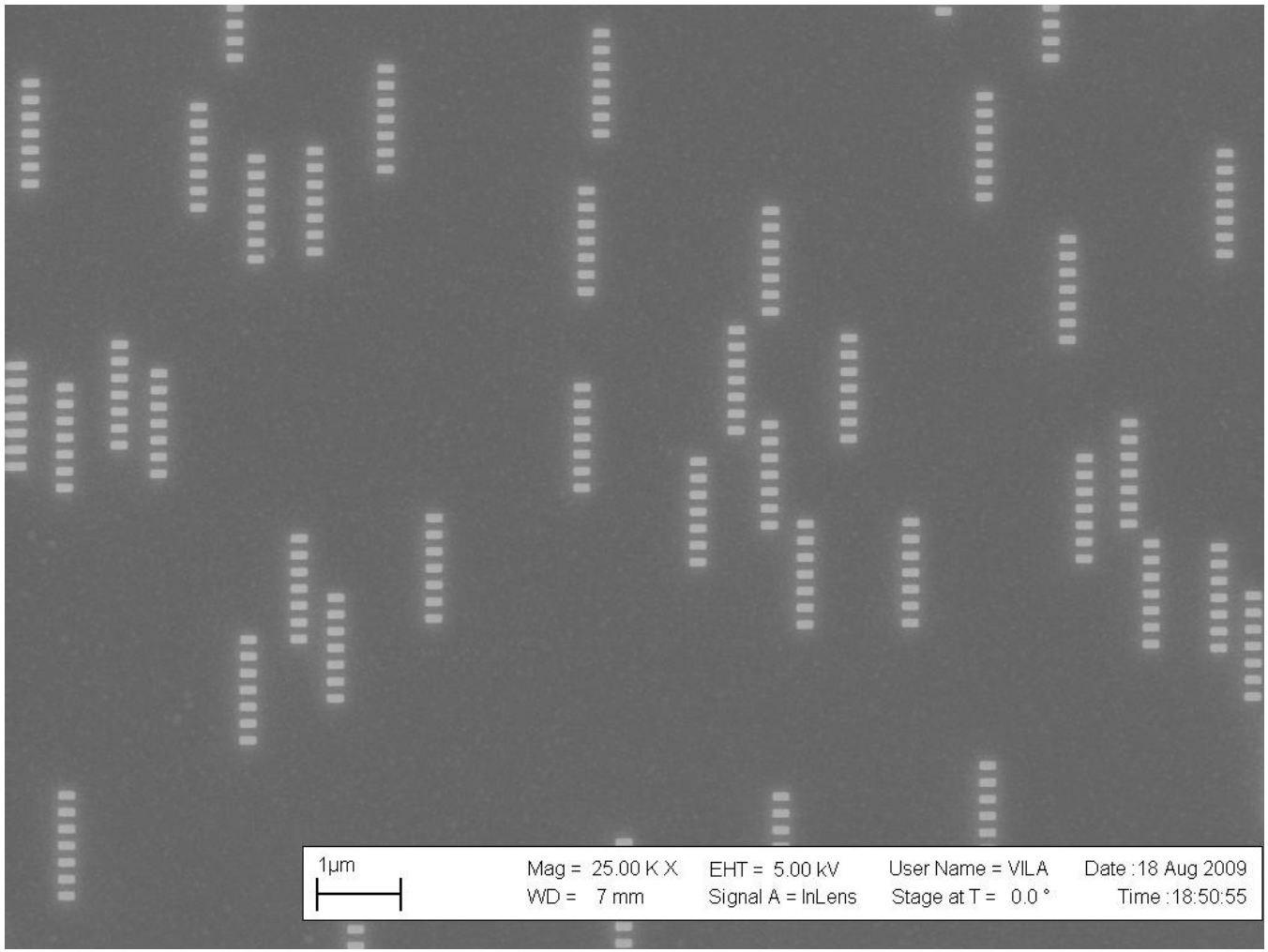




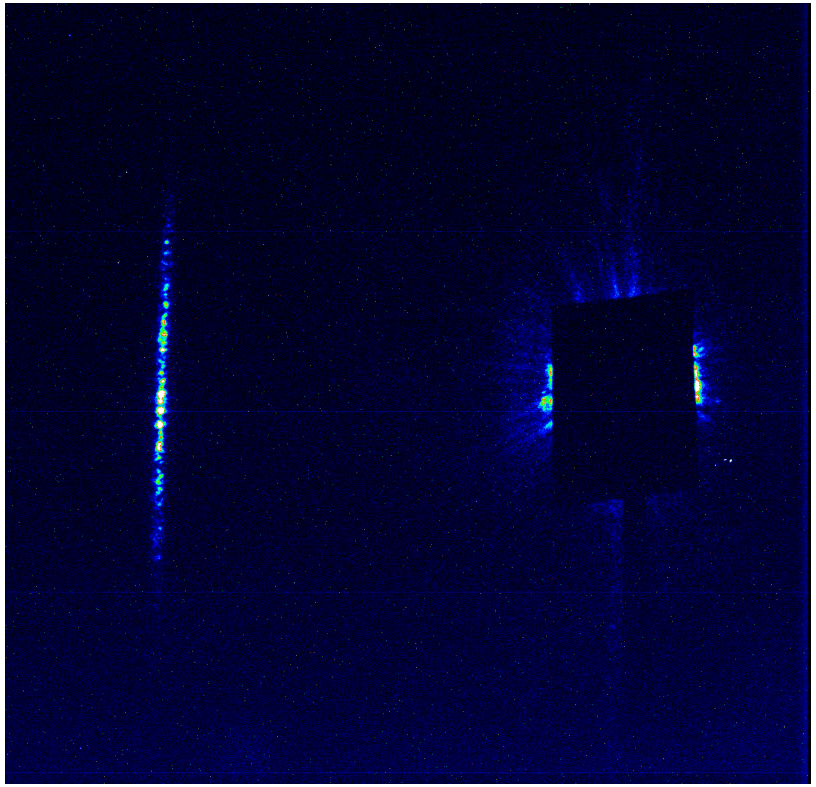
Reconstruction by F. Zhang (paper in preparation)

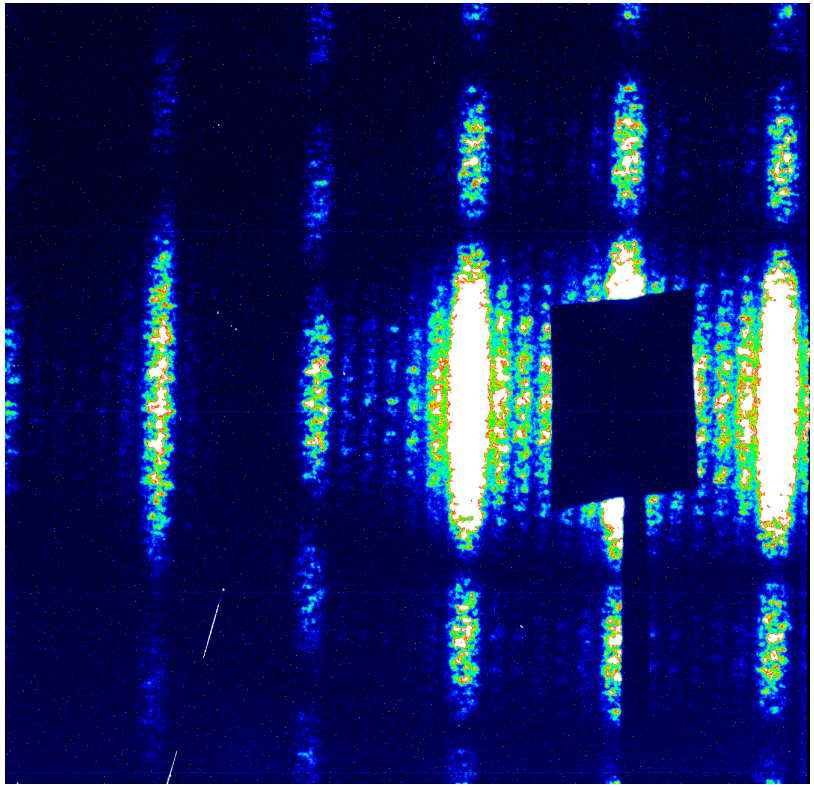
New phase plate design

R. Bean and J. Vila-Comamala, PSI

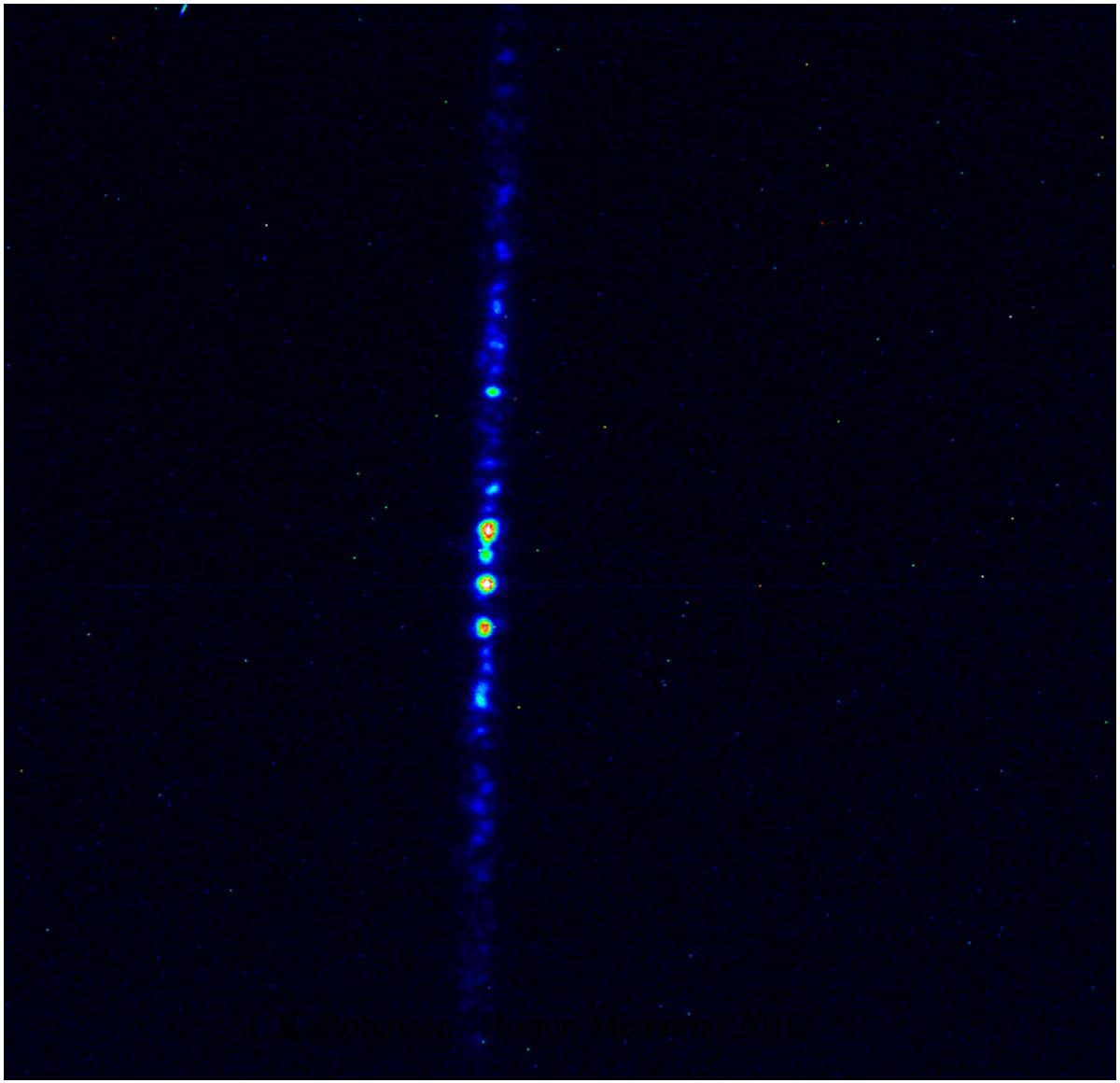


Collagen in liquid cell +/- phase plate



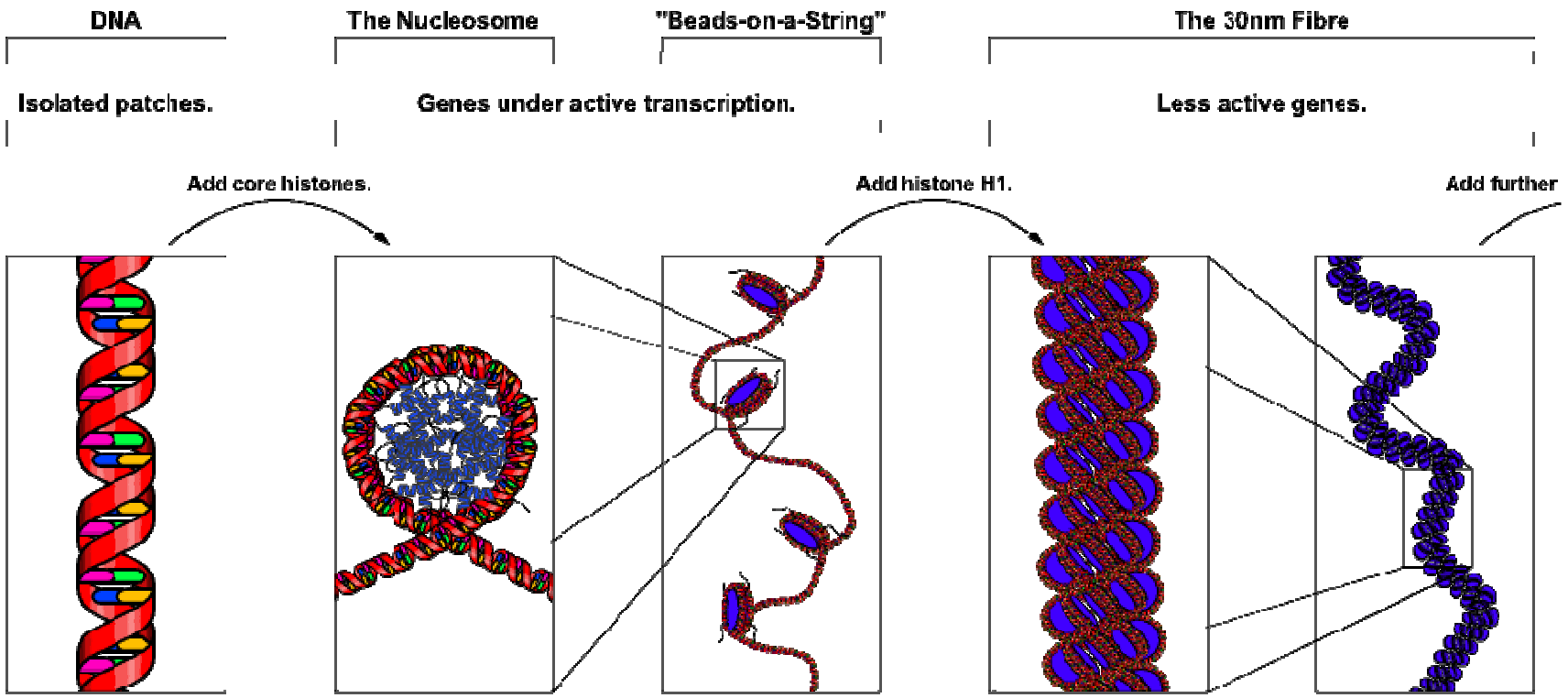


Sample+phase plate interference



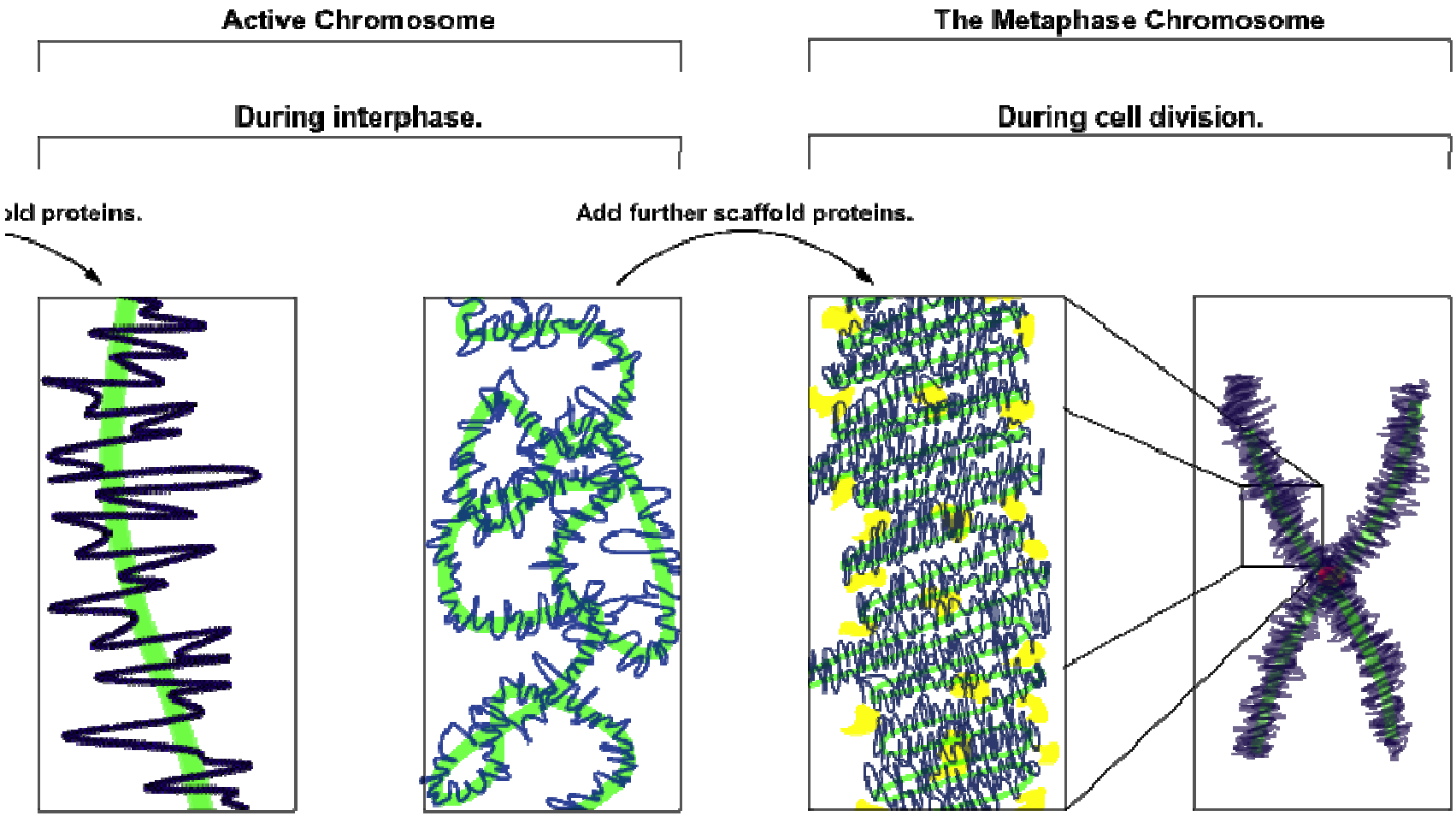
Chromosome structure I

a la wikipedia



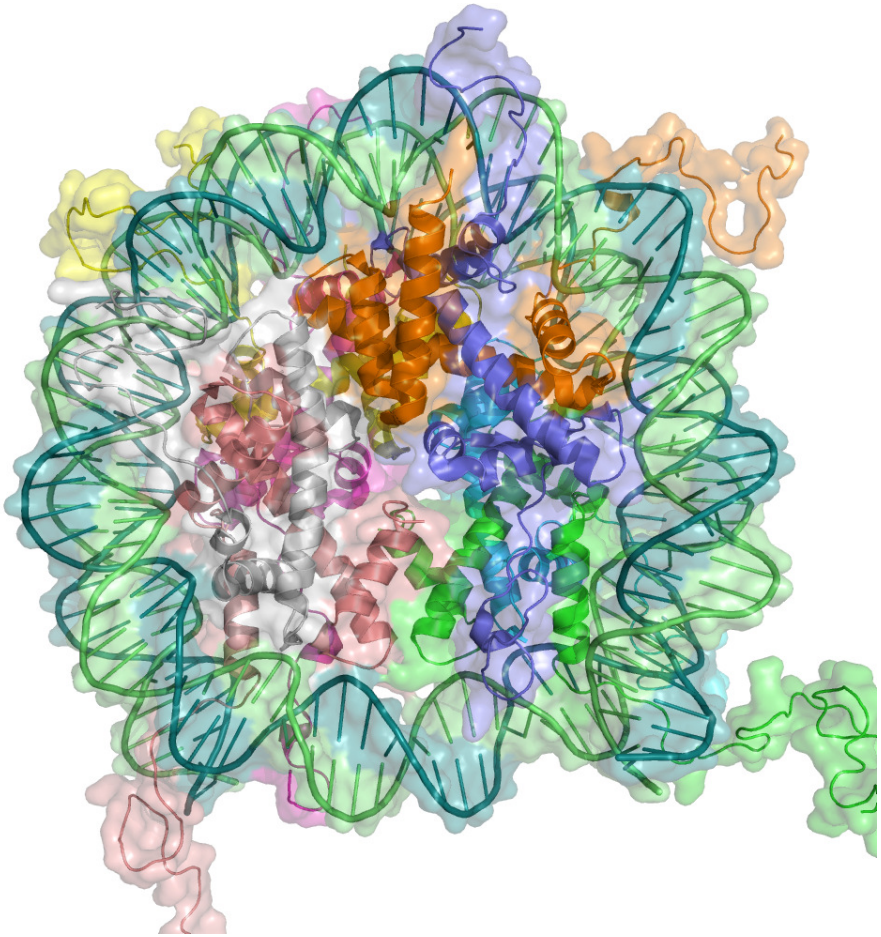
Chromosome structure II

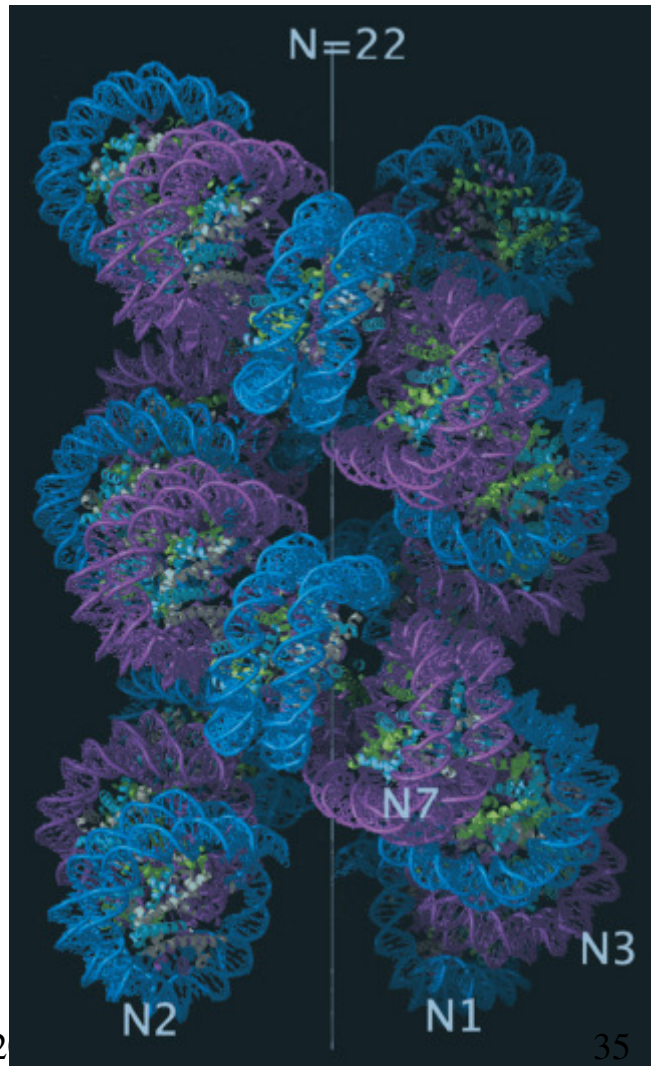
a la wikipedia



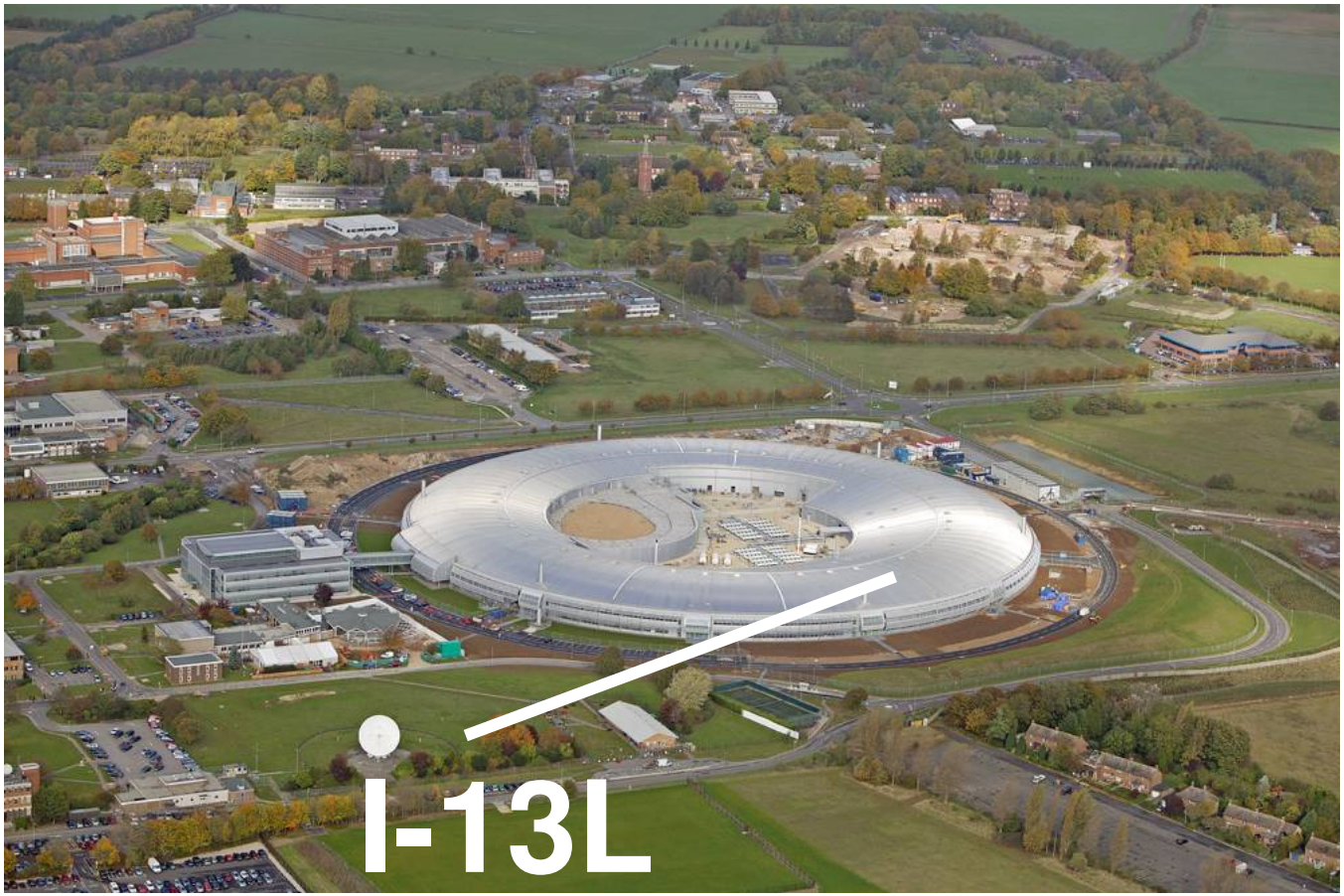
Chromosome structure III

D. Rhodes et al PNAS 103 6506 (2006)

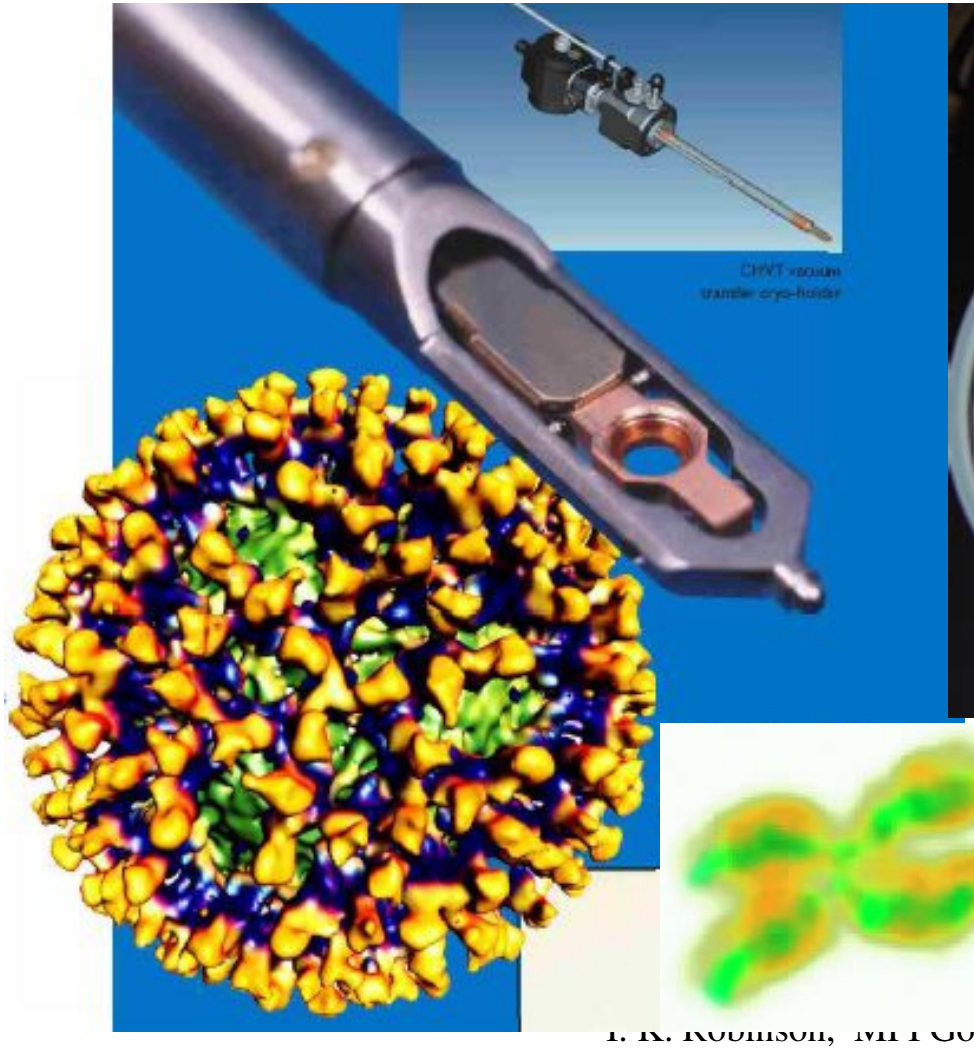


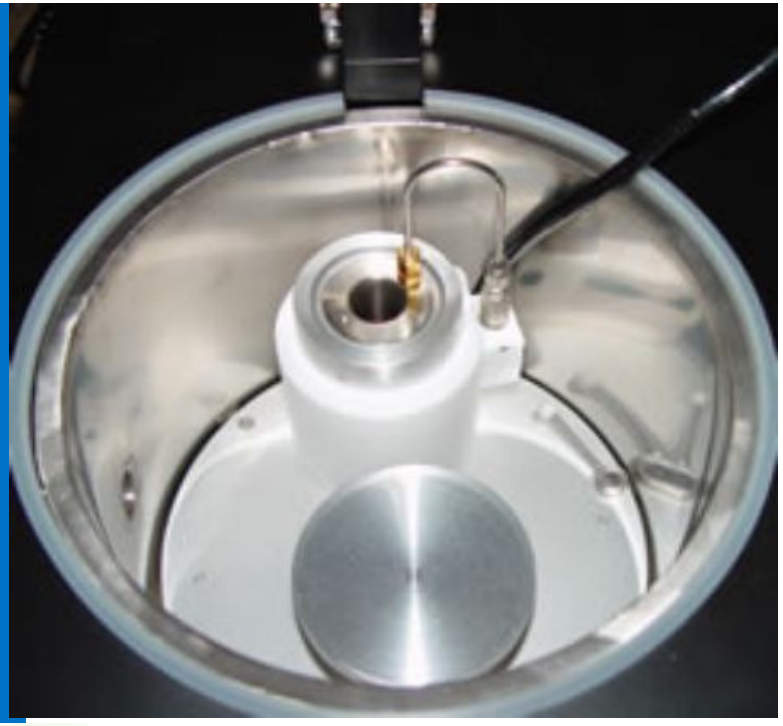


Diamond Light Source (RAL)



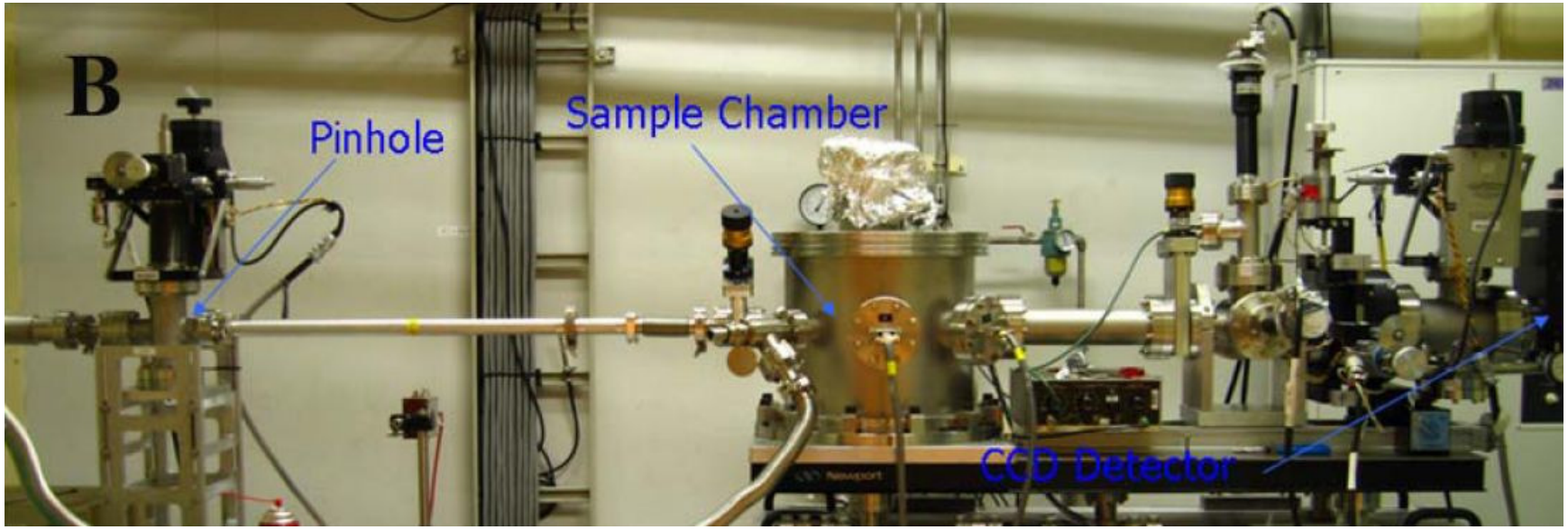
Cryotransfer system (Gatan)
Plunge cryo immersion (EMS)





Spring8 beamline BL29XUL

Nishino_BL29XUL.jpg



X ray energy 5 keV through a 20μm pinhole $1x10^{10}$ ph/sec.

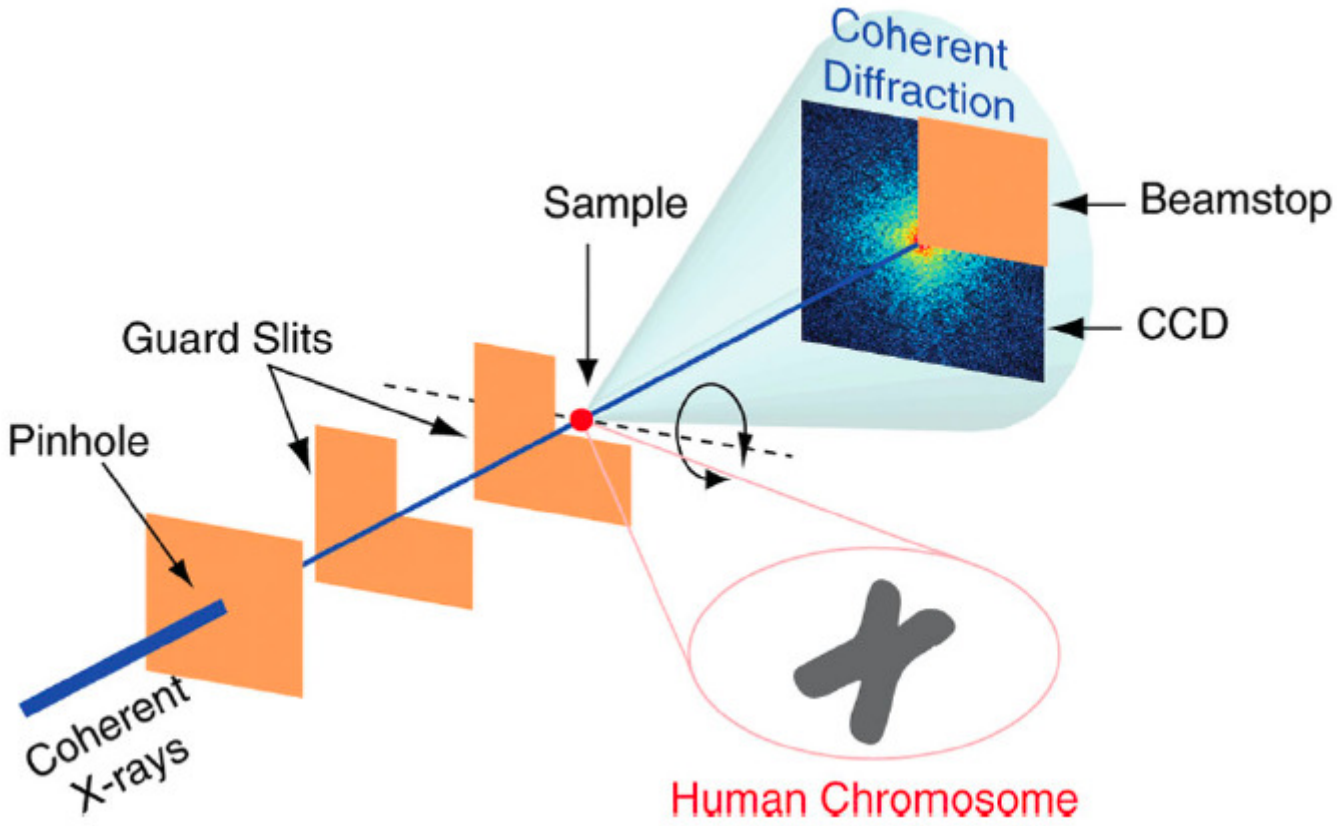
CCD pixel size 20μm, 1340x1300 pixels at 1.3m

Exposure time 2700 s

Radiation dose $4x10^{8}$ Gy ($2x10^{10}$ Gy for full 3D)

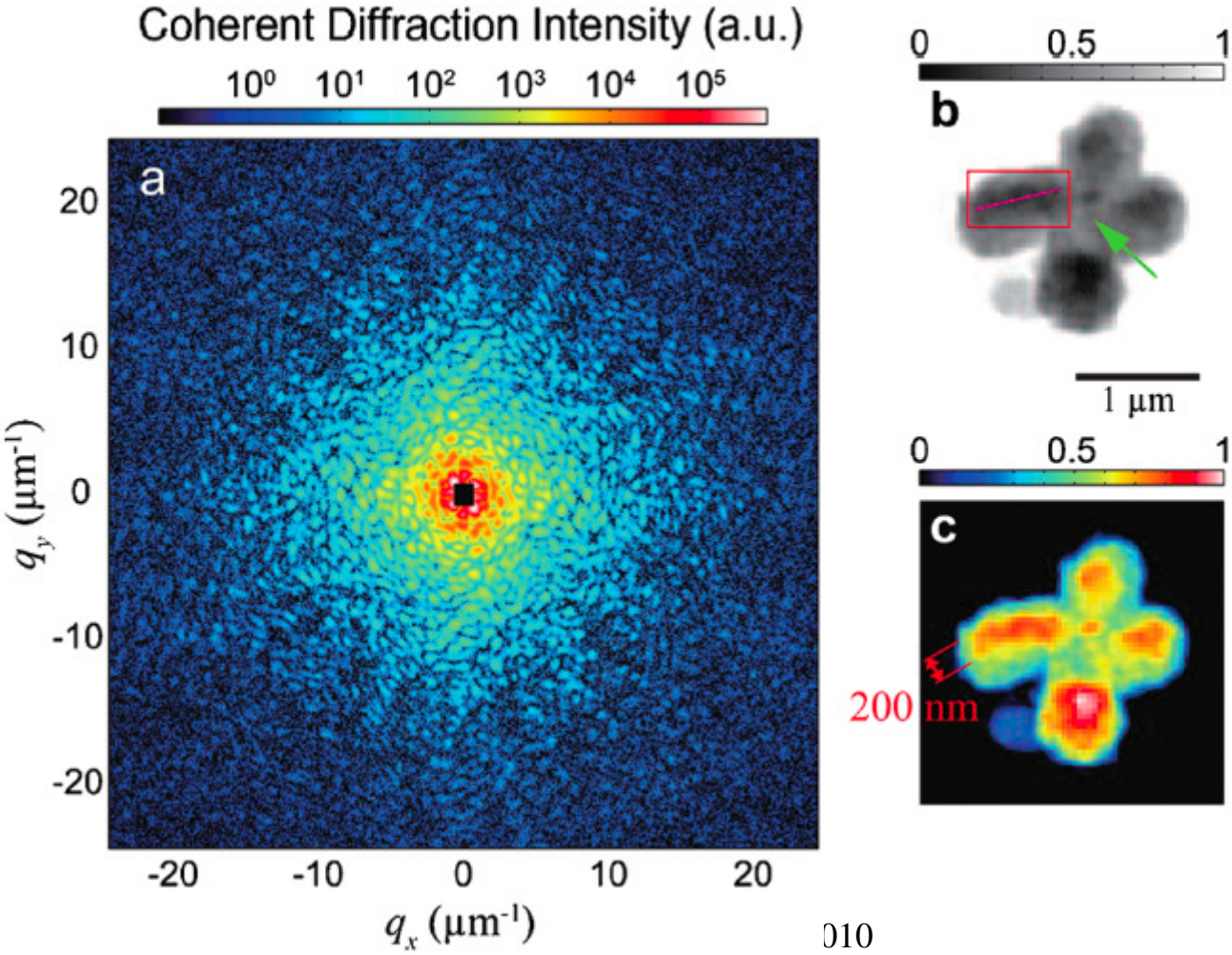
Schematic in-line CDI setup

Y. Nishino et al PRL 102, 018101 (2009)



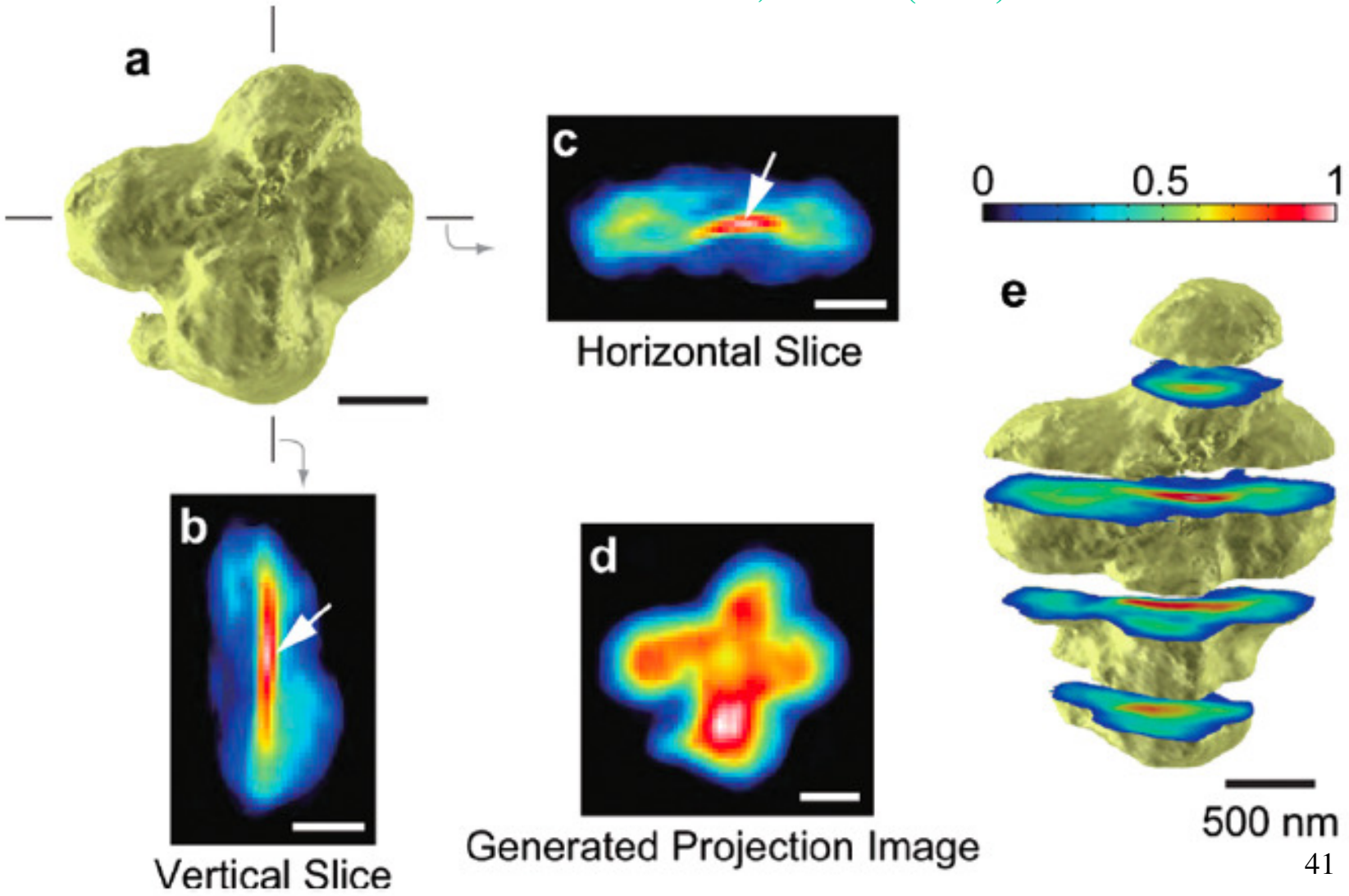
Chromosome diffraction pattern

Y. Nishino et al PRL 102, 018101 (2009)

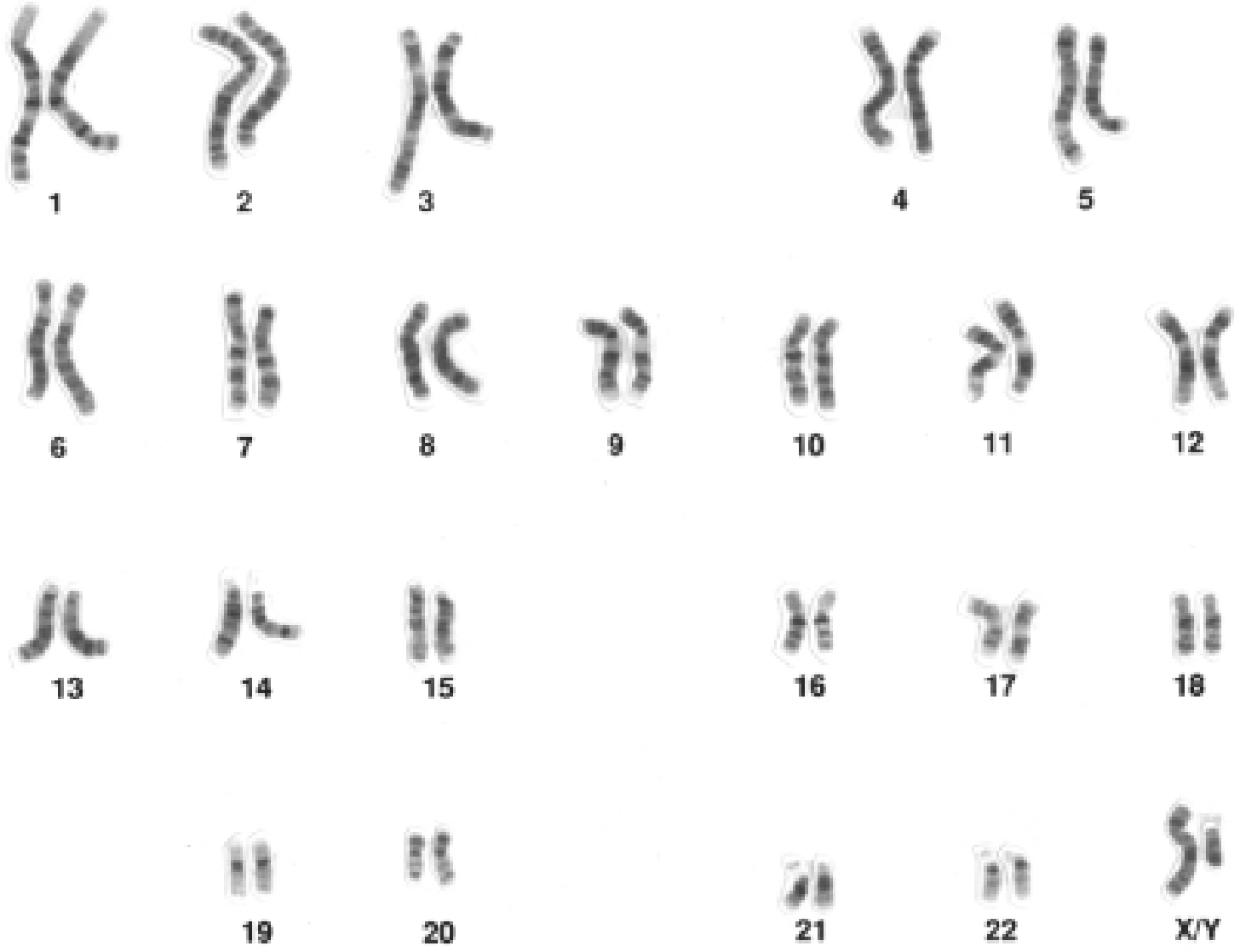


Chromosome 3D CDI result

Y. Nishino et al PRL 102, 018101 (2009)



The Human Karyotype



Conclusions

- X-ray 3D imaging on the nanoscale
- Phasing by computation instead of lens
- Biological tissue accessible by ptychography
- New phase-plate methods
- Future application to chromosome structure