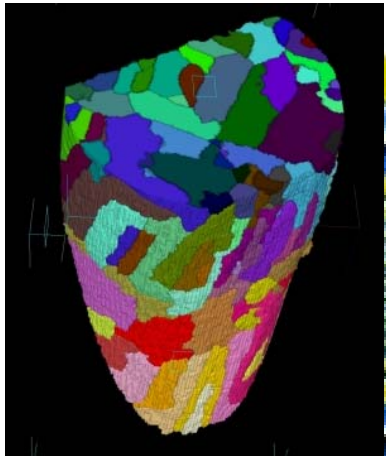
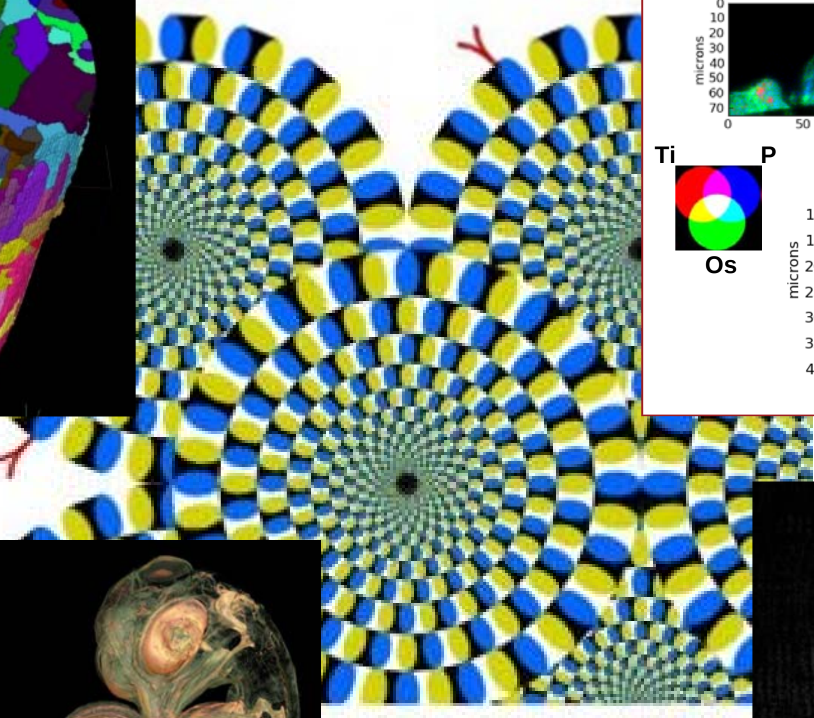
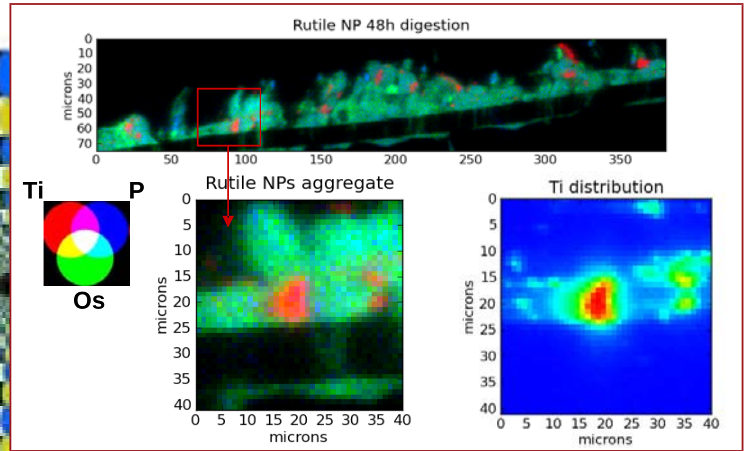
Quantitative Imaging: X-Rays and Neutrons







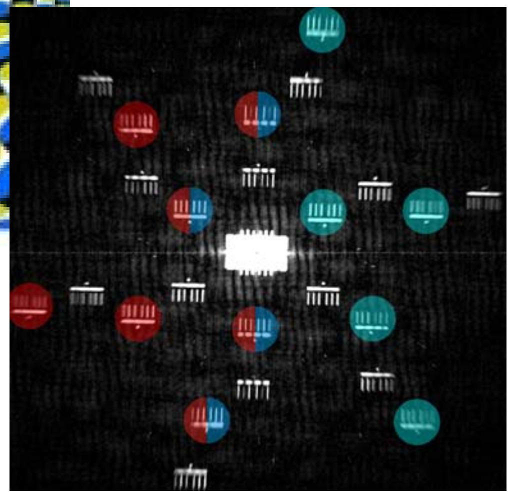
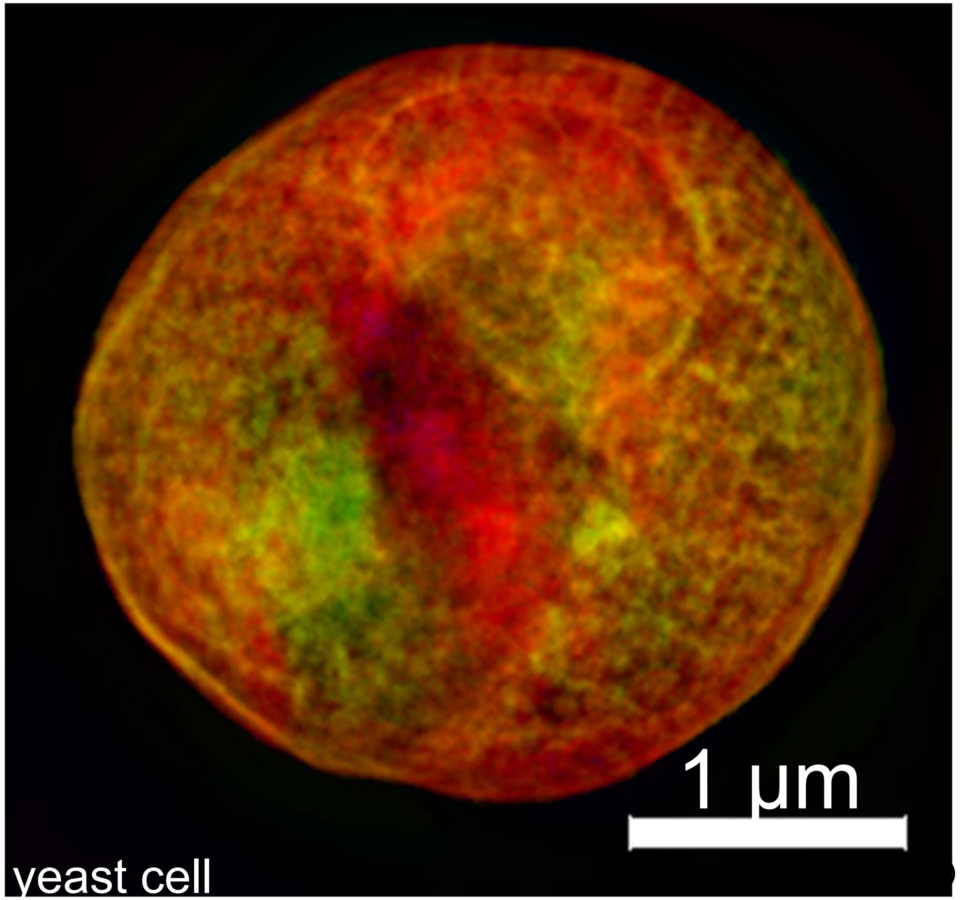


Image Credits: A. Kitaoka, P. Tafforeau, N. Kardjilov, M. Cotte, S. Eisebitt

Quantitative Imaging: X-Rays and Neutrons

? !

Shapiro *et al.*, *Proc. Nat. Acad. Sci.* **102**, 15343 (2005).

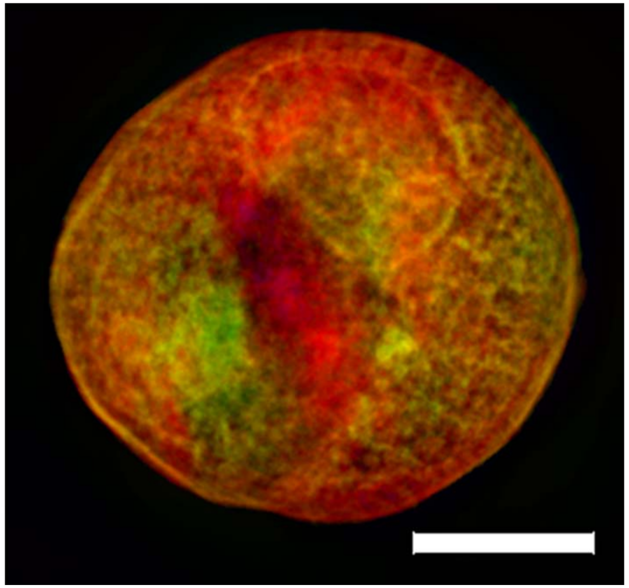


© C. Jacobsen

Thinking in space

Visualising differences in properties

Visualising the Invisible



with:

- visible light
- sound
- electrons
- X-rays
- neutrons

and by different interactions with matter

Contrast

Resolution

- Neutron interaction with matter
  - attenuation contrast
  - diffraction contrast
  - phase/dark-field contrast
  - magnetic contrast

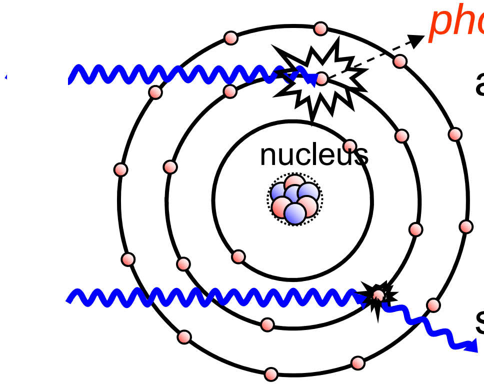
- Beam optimisation
- Detector development

Attenuation Contrast

X-rays and Neutrons

Attenuation coefficients

X-rays

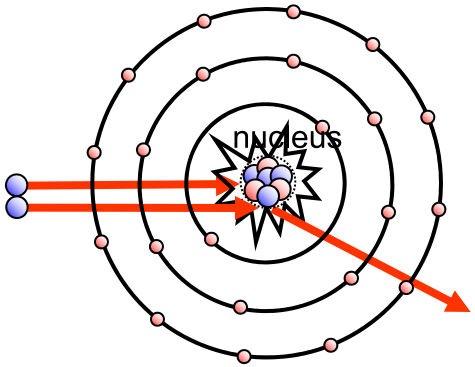


Attenuation coefficients with X-ray [cm?^{1}]

1a	2a	3b	4b	5b	6b	7b	8			1b	2b	3a	4a	5a	6a	7a	0
H 0.02																	He 0.02
Li 0.06	Be 0.22											B 0.28	C 0.27	N 0.11	O 0.16	F 0.14	Ne 0.17
Na 0.13	Mg 0.24											Al 0.38	Si 0.33	P 0.25	S 0.30	Cl 0.23	Ar 0.20
K 0.14	Ca 0.26	Sc 0.48	Ti 0.73	V 1.04	Cr 1.29	Mn 1.32	Fe 1.57	Co 1.78	Ni 1.96	Cu 1.97	Zn 1.64	Ga 1.42	Ge 1.33	As 1.50	Se 1.23	Br 0.90	Kr 0.73
Rb 0.47	Sr 0.86	Y 1.61	Zr 2.47	Nb 3.43	Mo 4.29	Tc 5.06	Ru 5.71	Rh 6.08	Pd 6.13	Ag 5.67	Cd 4.84	In 4.31	Sn 3.98	Sb 4.28	Te 4.06	I 3.45	Xe 2.53
Cs 1.42	Ba 2.73	La 5.04	Hf 19.70	Ta 25.47	W 30.49	Re 34.47	Os 37.92	Ir 39.01	Pt 38.61	Au 35.94	Hg 25.88	Tl 23.23	Pb 22.81	Bi 20.28	Po 20.22	At	Rn 9.77
Fr	Ra 11.80	Ac 24.47	Rf	Ha													

Lanthanides	Ce 5.79	Pr 6.23	Nd 6.46	Pm 7.33	Sm 7.68	Eu 5.66	Gd 8.69	Tb 9.46	Dy 10.17	Ho 10.91	Er 11.70	Tm 12.49	Yb 9.32	Lu 14.07
*Actinides	Th 28.95	Pa 39.65	U 49.08	Np	Pu	Am	Cm	Bk	Vf	Es	Fm	Md	No	Lr x-ray

neutrons

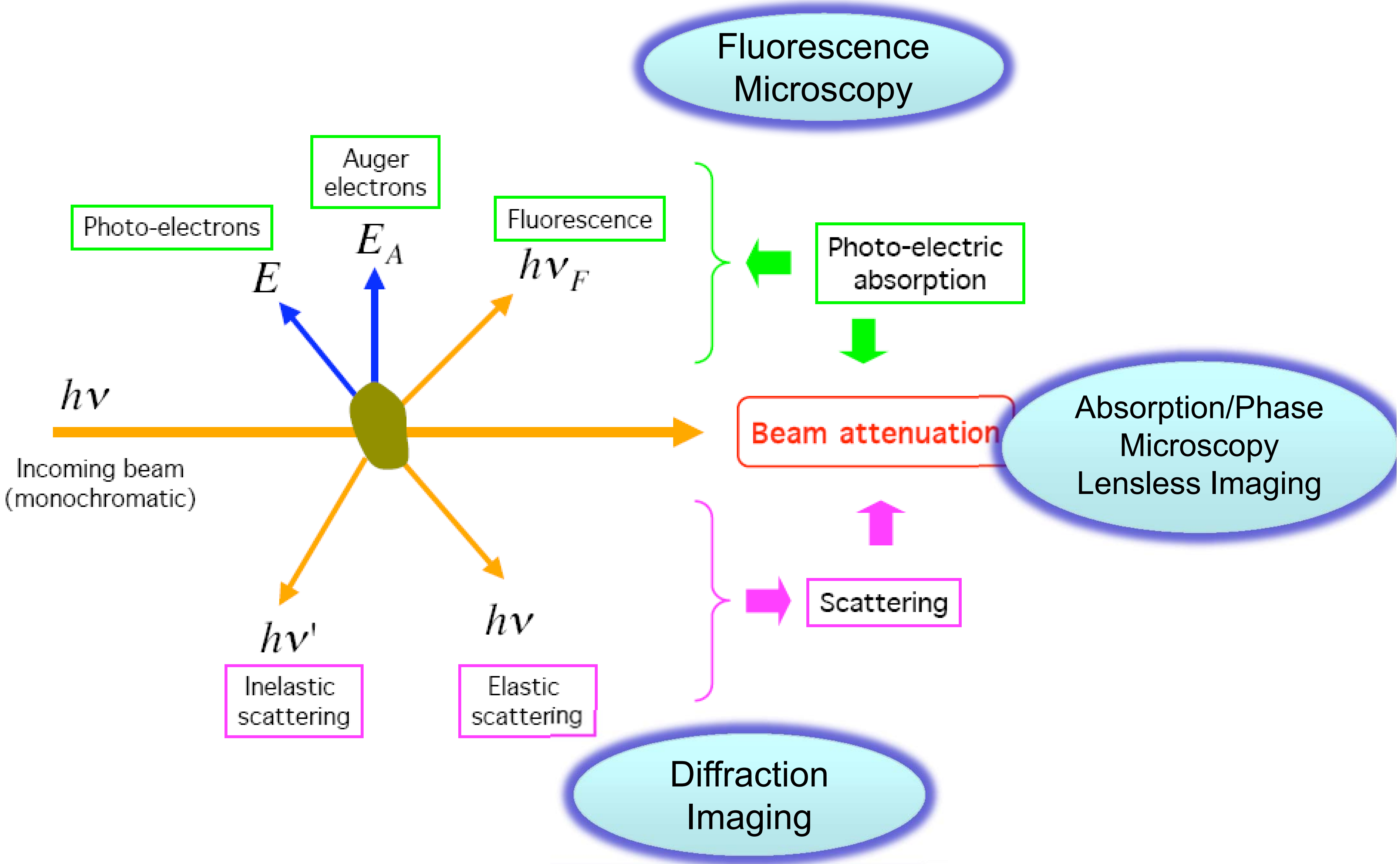


Attenuation coefficients with neutrons [cm?^{1}]

1a	2a	3b	4b	5b	6b	7b	8			1b	2b	3a	4a	5a	6a	7a	0
H 3.44																	He 0.02
Li 3.30	Be 0.79											B 101.60	C 0.56	N 0.43	O 0.17	F 0.20	Ne 0.10
Na 0.09	Mg 0.15											Al 0.10	Si 0.11	P 0.12	S 0.06	Cl 1.33	Ar 0.03
K 0.06	Ca 0.08	Sc 2.00	Ti 0.60	V 0.72	Cr 0.54	Mn 1.21	Fe 1.19	Co 3.92	Ni 2.05	Cu 1.07	Zn 0.35	Ga 0.49	Ge 0.47	As 0.67	Se 0.73	Br 0.24	Kr 0.61
Rb 0.08	Sr 0.14	Y 0.27	Zr 0.29	Nb 0.40	Mo 0.52	Tc 1.76	Ru 0.58	Rh 10.88	Pd 0.78	Ag 4.04	Cd 115.11	In 7.58	Sn 0.21	Sb 0.30	Te 0.25	I 0.23	Xe 0.43
Cs 0.29	Ba 0.07	La 0.52	Hf 4.99	Ta 1.49	W 1.47	Re 6.85	Os 2.24	Ir 30.46	Pt 1.46	Au 6.23	Hg 16.21	Tl 0.47	Pb 0.38	Bi 0.27	Po	At	Rn
Fr	Ra 0.34	Ac	Rf	Ha													

*Lanthanides	Ce 0.14	Pr 0.41	Nd 1.87	Pm 5.72	Sm 171.47	Eu 94.58	Gd 1479.04	Tb 0.93	Dy 32.42	Ho 2.25	Er 5.48	Tm 3.53	Yb 1.40	Lu 2.75
**Actinides	Th 0.59	Pa 8.46	U 0.82	Np 9.80	Pu 50.20	Am 2.86	Cm	Bk	Cf	Es	Fm	Md	No	Lr neut.

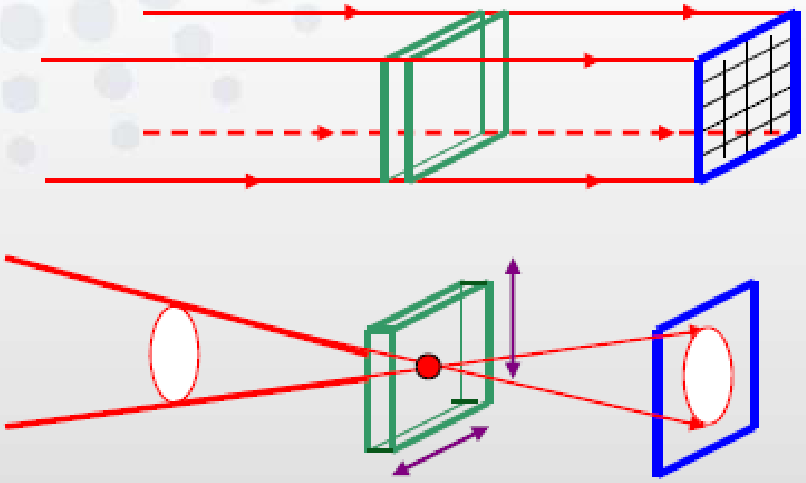
Diversity of X-ray interaction with matter



Two main techniques:

Parallel beam imaging

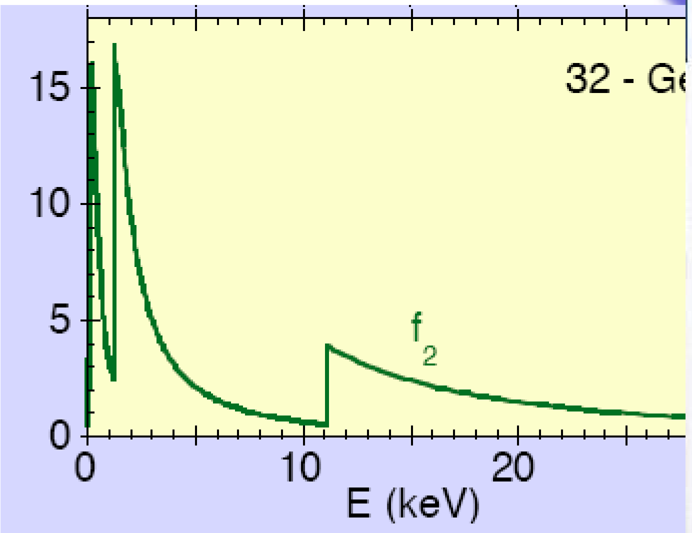
Focused beam imaging



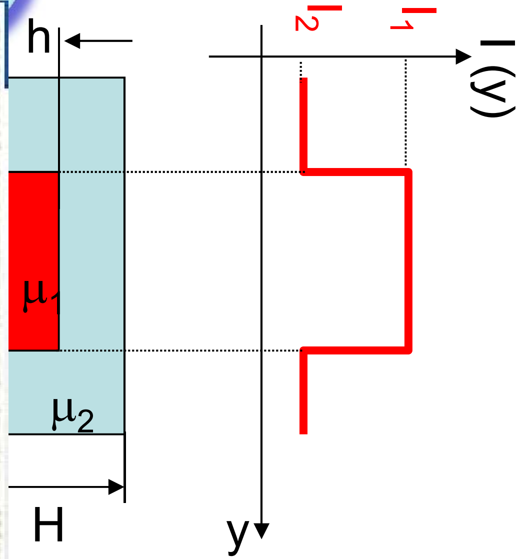
Images can map a series of local features
(including absorption, fluorescence, scattering…).

Radiography

Tomography

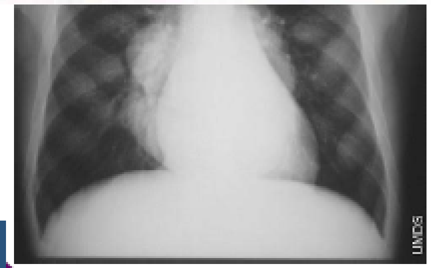


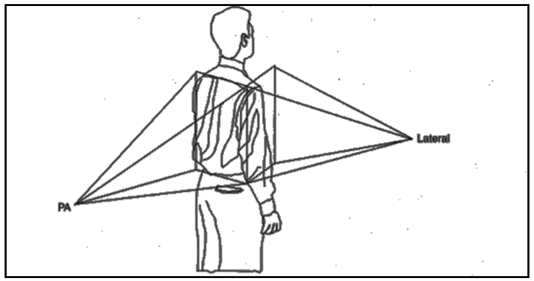
First X ray made in public. Hand of the famed anatomist, Albert von Kölliker, made during Roentgen's initial lecture before the Würzburg Physical Medical Society on January 23, 1896.



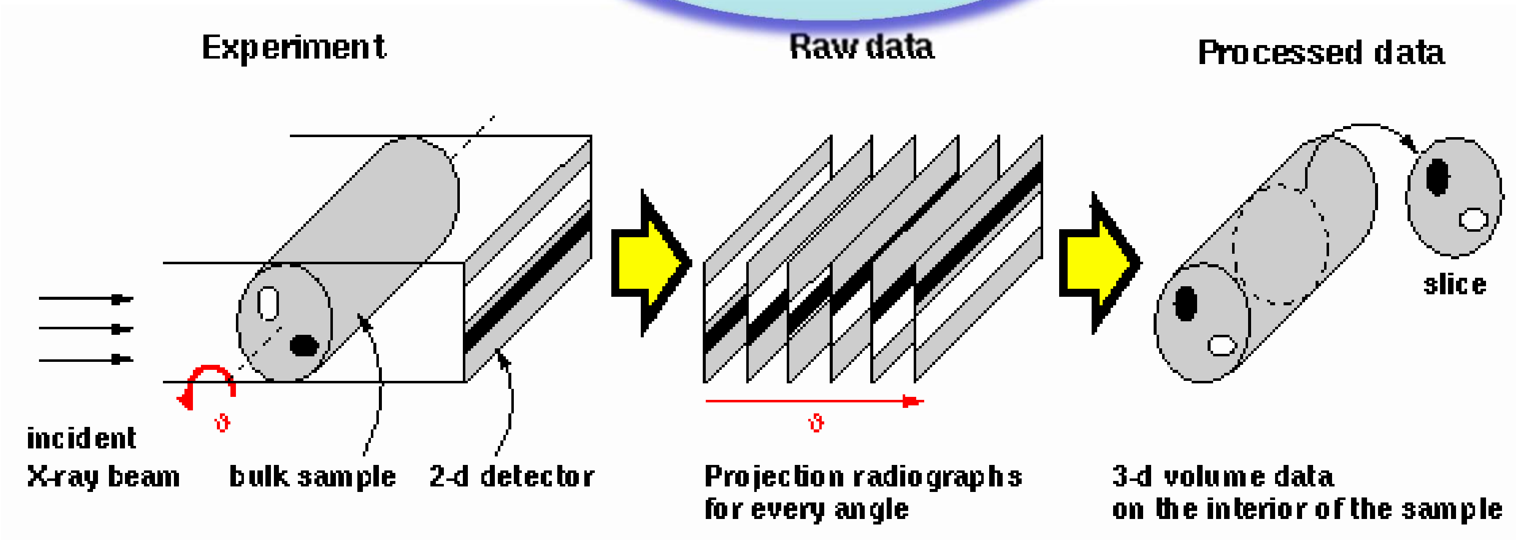
2D- … ects!

$$I(y) = I_0\, e^{-\int_0^H \mu(x,y)\,dx}$$





Radiography
Tomography



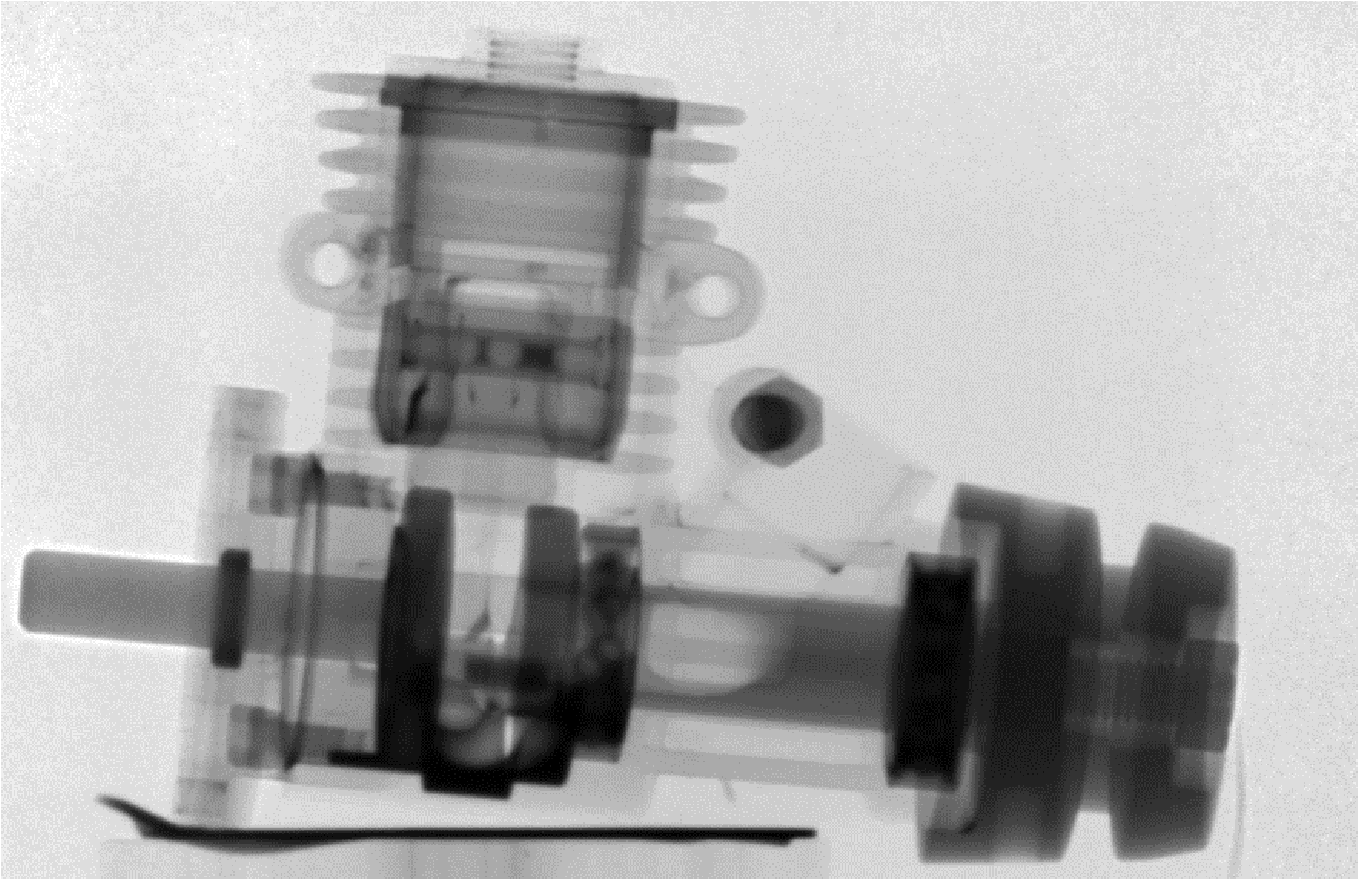
Sequence of 2D-projections images 3D-objects!

lectures of F. Marone and C. Brun

Tomography with a laboratory source: bone structure in 3D

XRADIA

Attenuation Contrast with Neutrons



1 cm

Absorption / Phase Microscopy

Absorption/Phase Microscopy

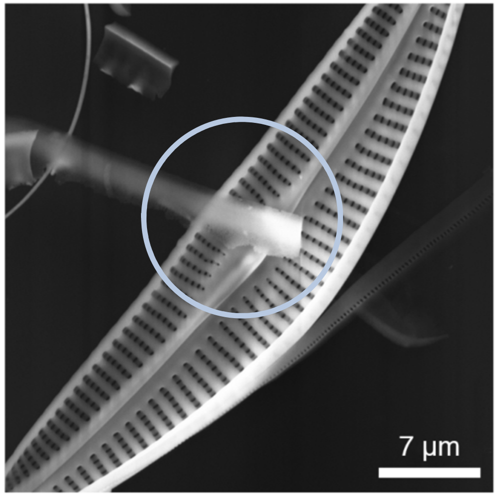
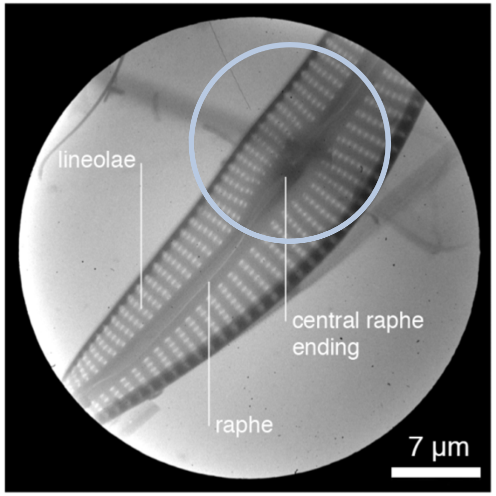
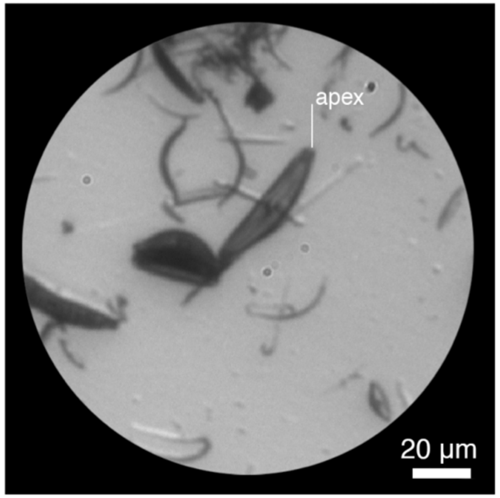
world upside down for X-rays:

refractive index $n < 1$ for matter

challenge for optics and detectors

X-ray microscopy – Why?

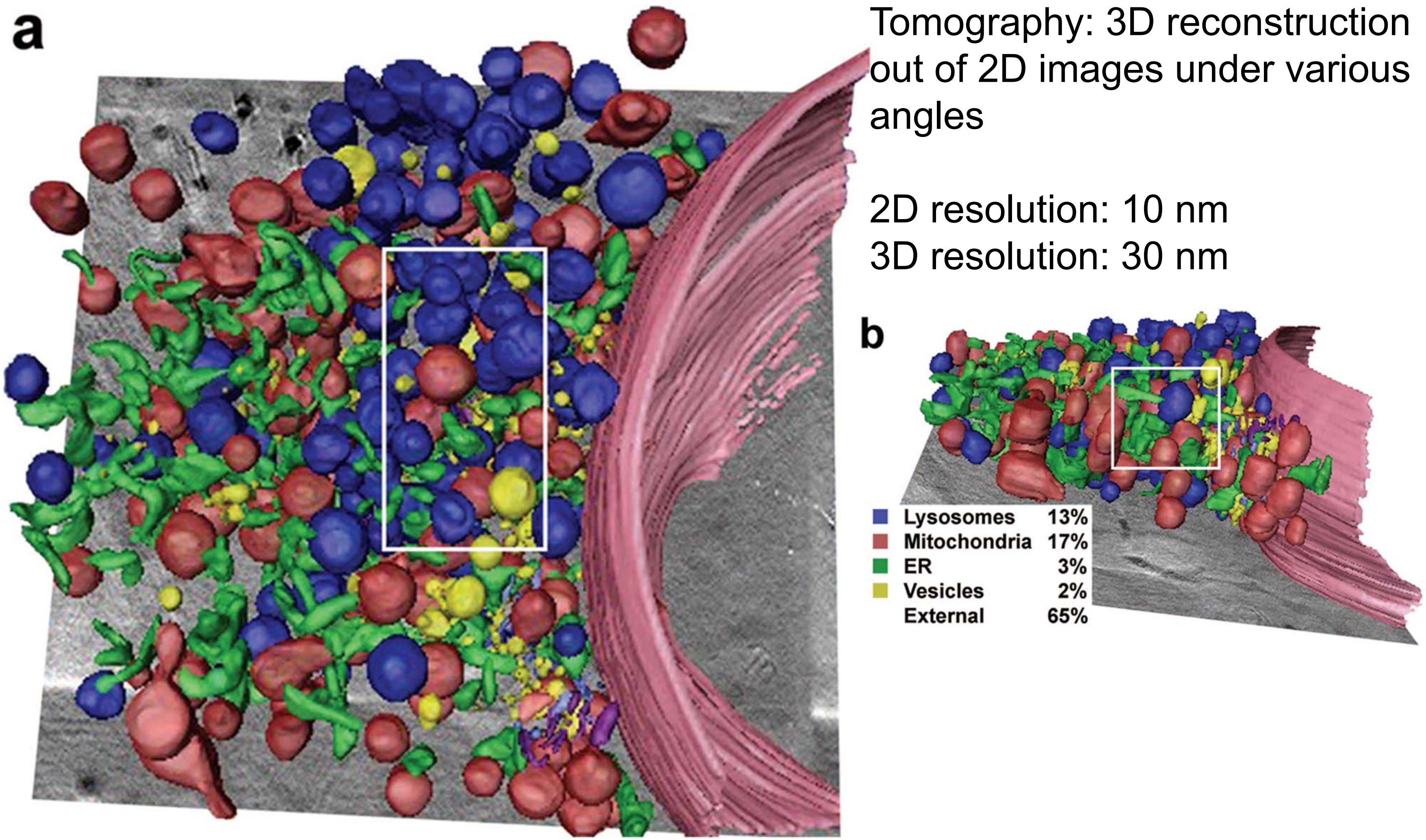
Filling the gap!

	Scanning Electron Microscopy	Transmission X-ray Microscopy	Visible Light Microscopy
			
resolution	~ 1-2 nm	< 30 nm	> 200 nm
	surface scan	inner/outer structure	inner/outer structure

3D imaging of internal structures feasible!
→ Tomography

shown specimen: diatom

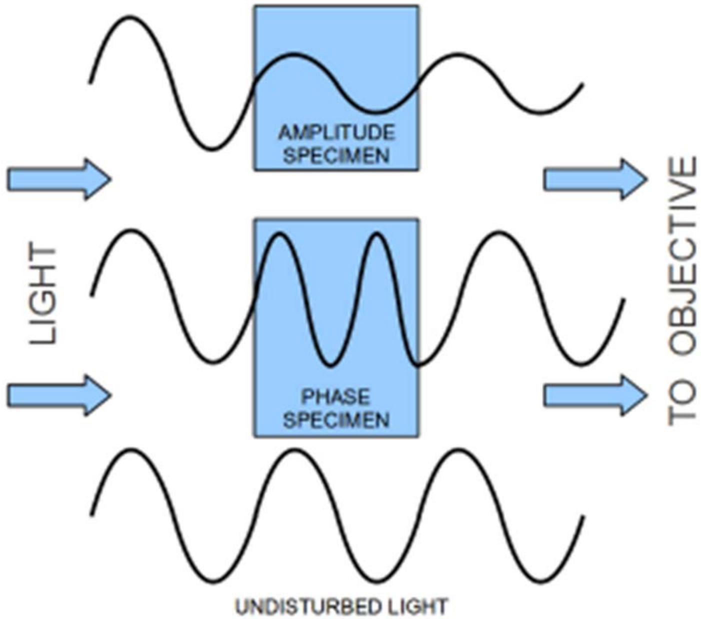
Birgit Kanngießer

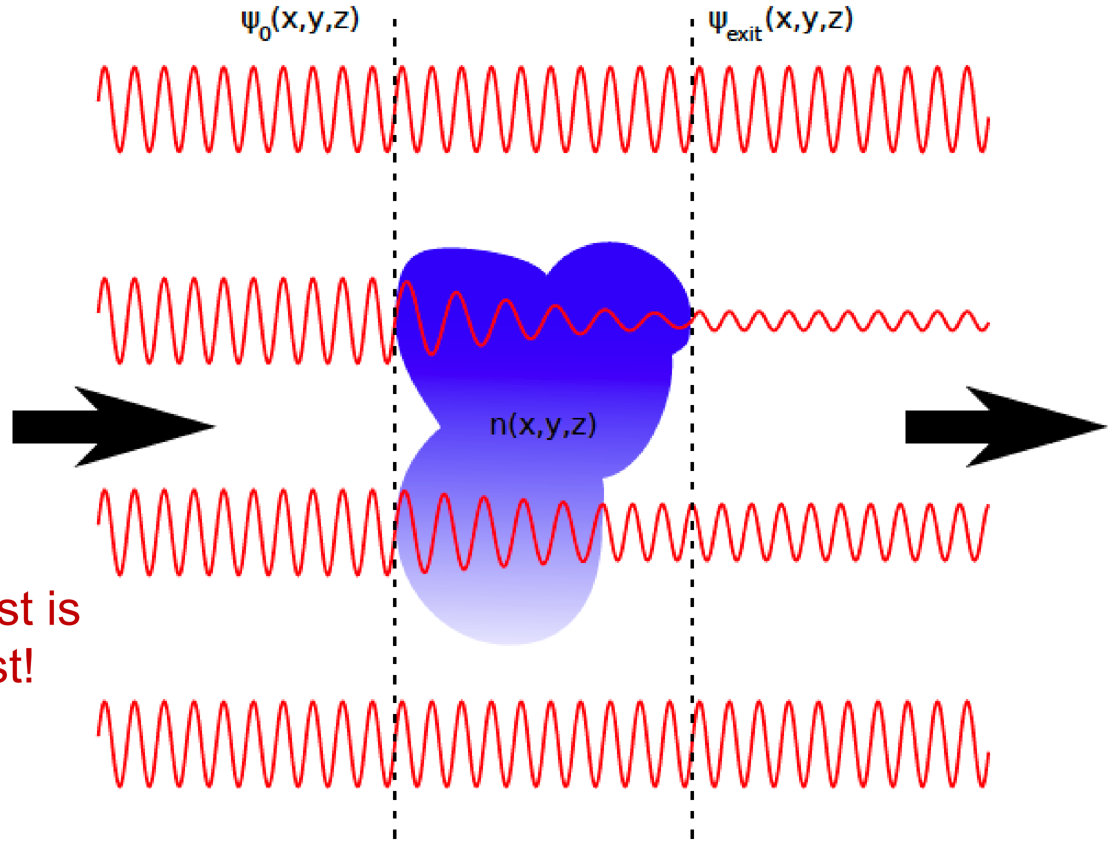


Tomography: 3D reconstruction out of 2D images under various angles

2D resolution: 10 nm
3D resolution: 30 nm

G. Schneider et al., Nature Methods **7** (2010), 985-987

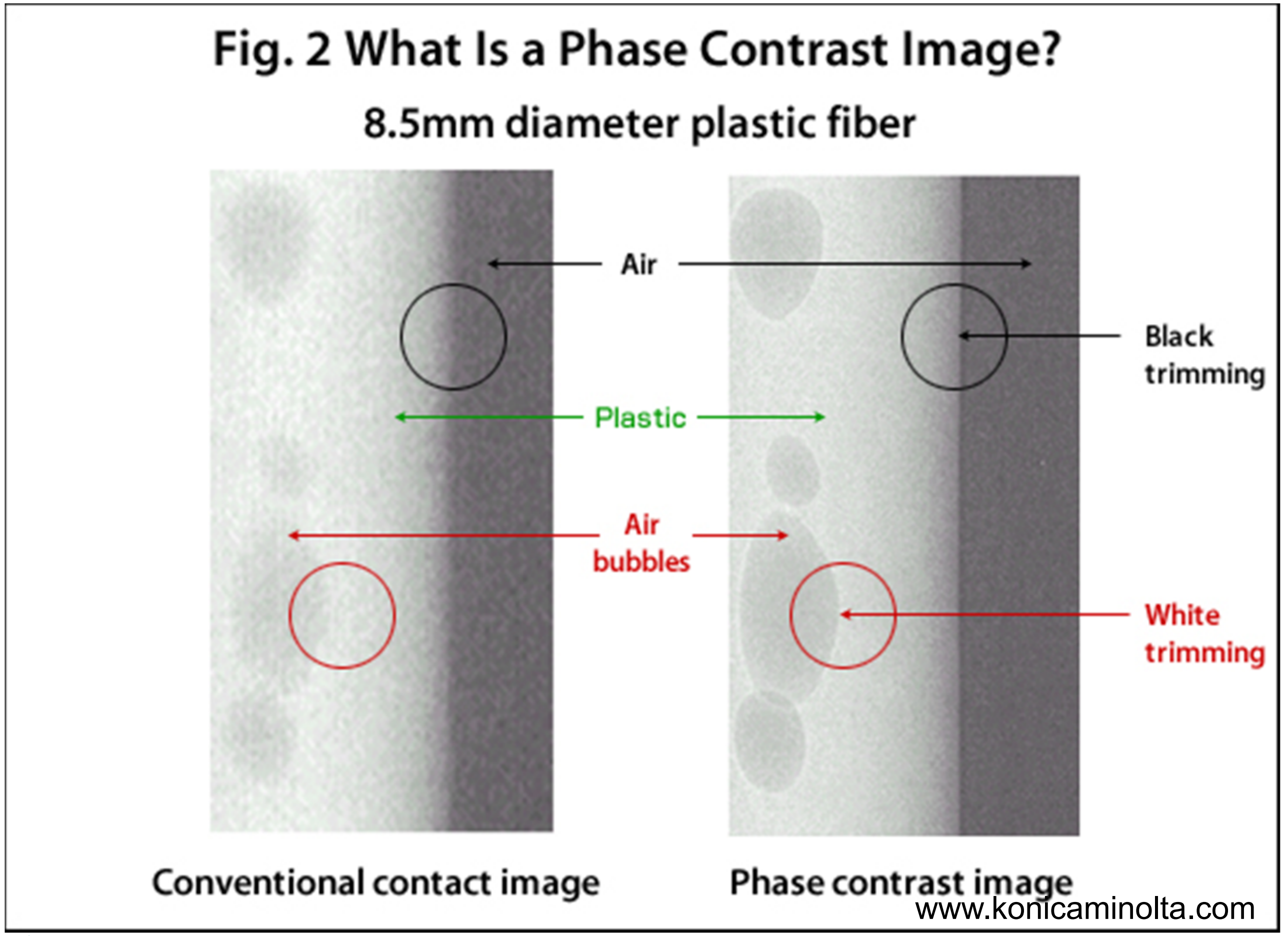




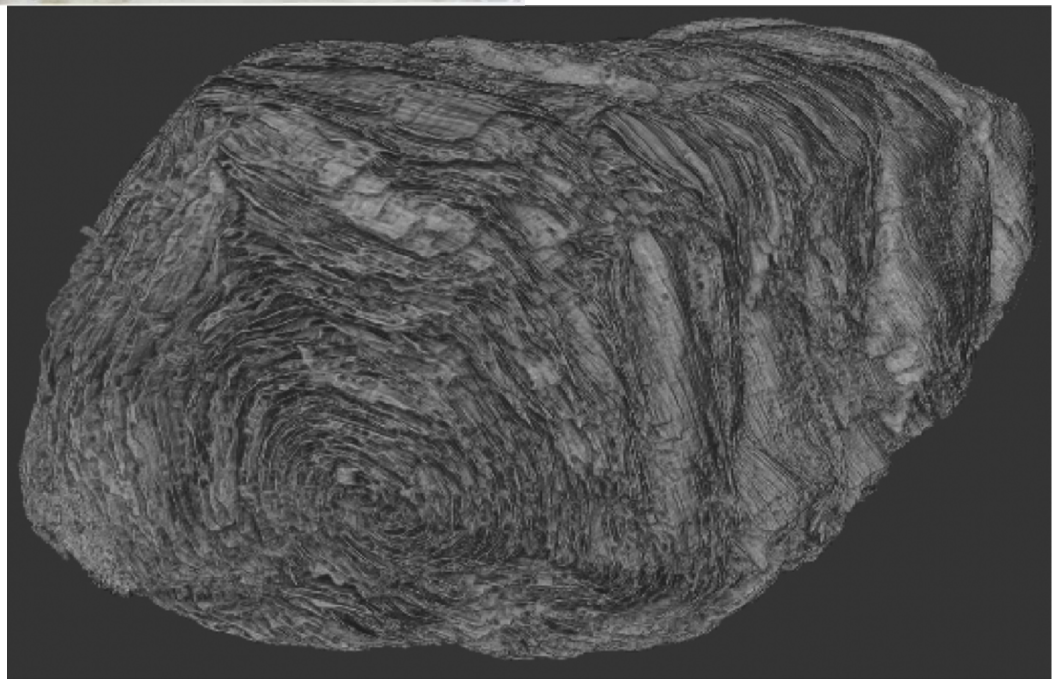
For hard X-rays phase contrast is larger than absorption contrast!

Ideal case: use absorption and phase contrast $\Rightarrow$ holography

Phase contrast Imaging



lectures of P. Cloetens and M. Osterhoff

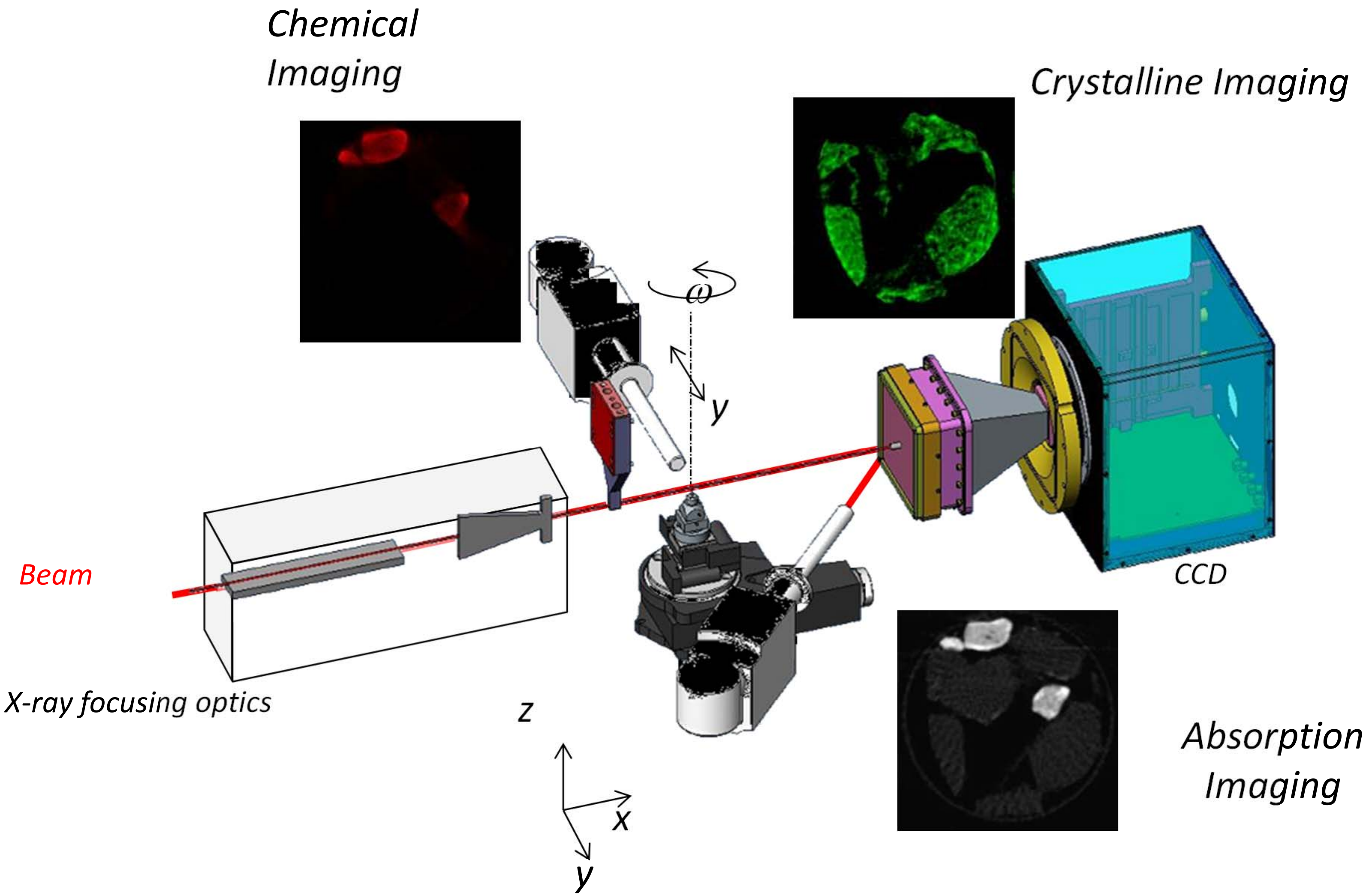


Revealing letters in rolled Herculaneum papyri by X-ray phase-contrast imaging

V. Mocello et al.
NATURE COMMUNICATIONS
6:5895, 2015

Phase contrast: spider (Excillum laboratory X-ray source)

Multi-Modal Imaging

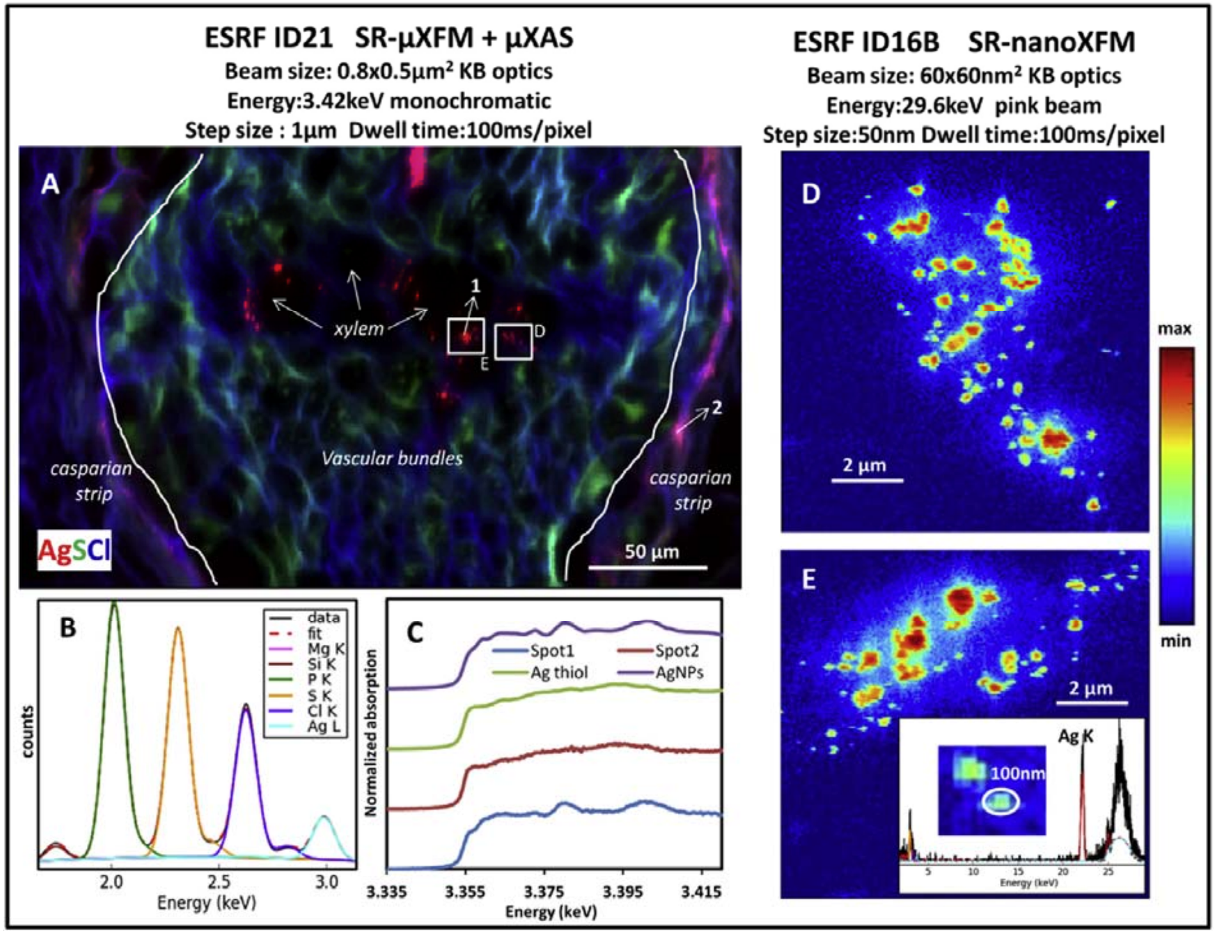


Credit: Pierre Bleuet doi:10.1038/nmat2168

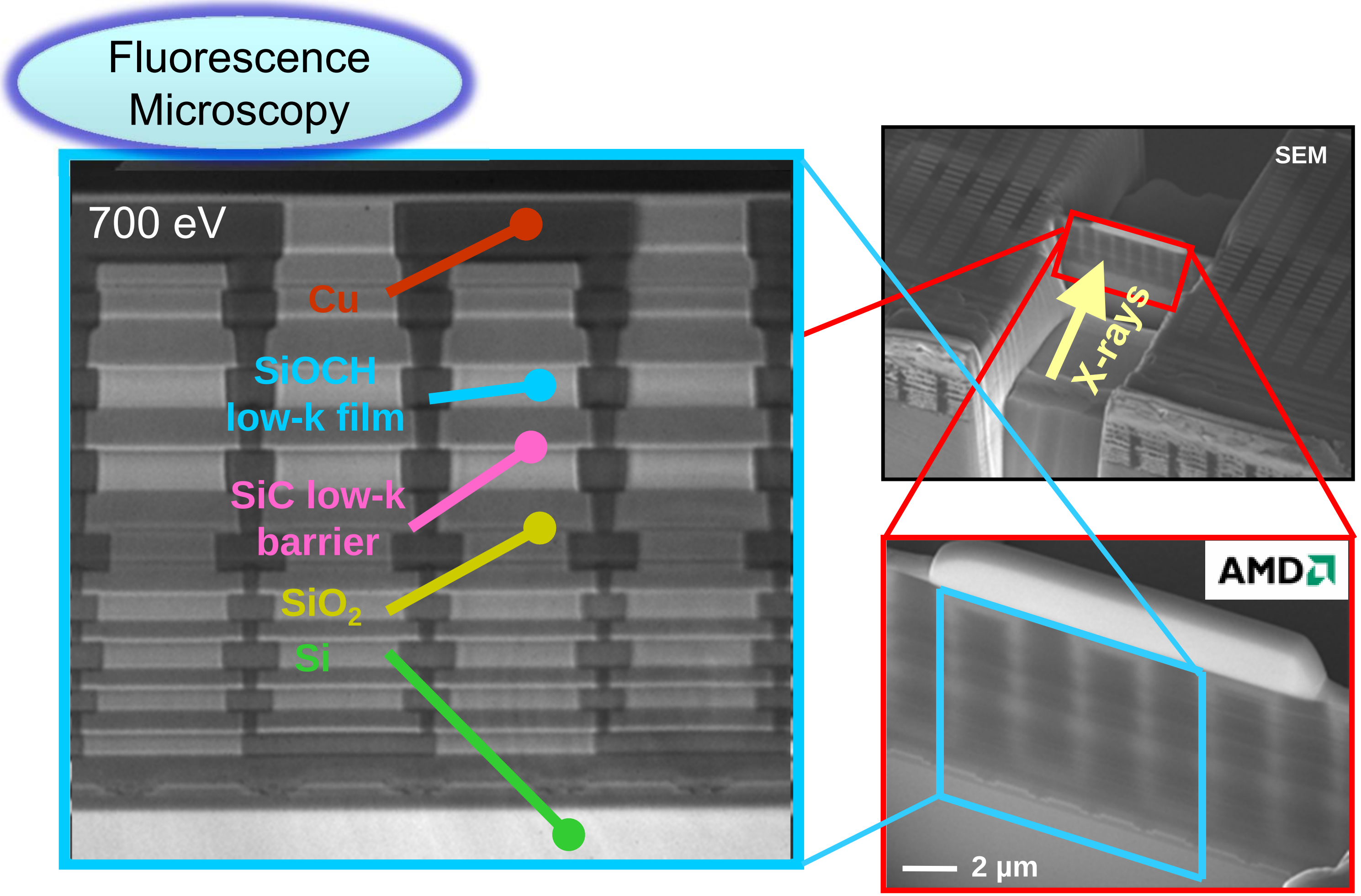
Fluorescence Microscopy

Tricolor map of the vascular bundles and casparian strip of a sunflower plant root exposed for 3 days in hydroponics to Ag NPs at 100 mg/kg

lecture of M. Cotte



H.A. 16 Castillo-Michel et al. / Plant Physiology and Biochemistry 110 (2017) 13e32



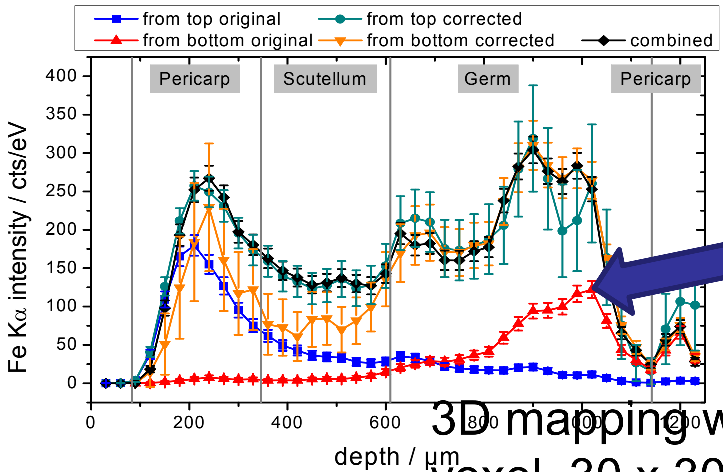
chemcial changes in the layer structure of a semiconductor

M.A. Meyer, E. Zschech (AMD), P. Guttmann (Uni Göttingen), G. Schneider (BESSY)

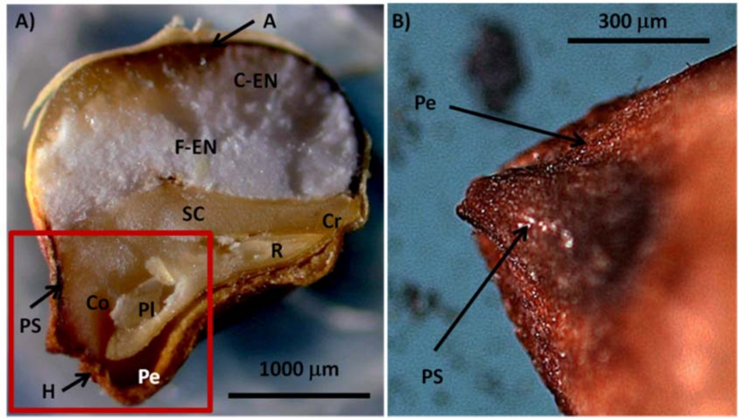
Pearl millet seeds for poultry production:

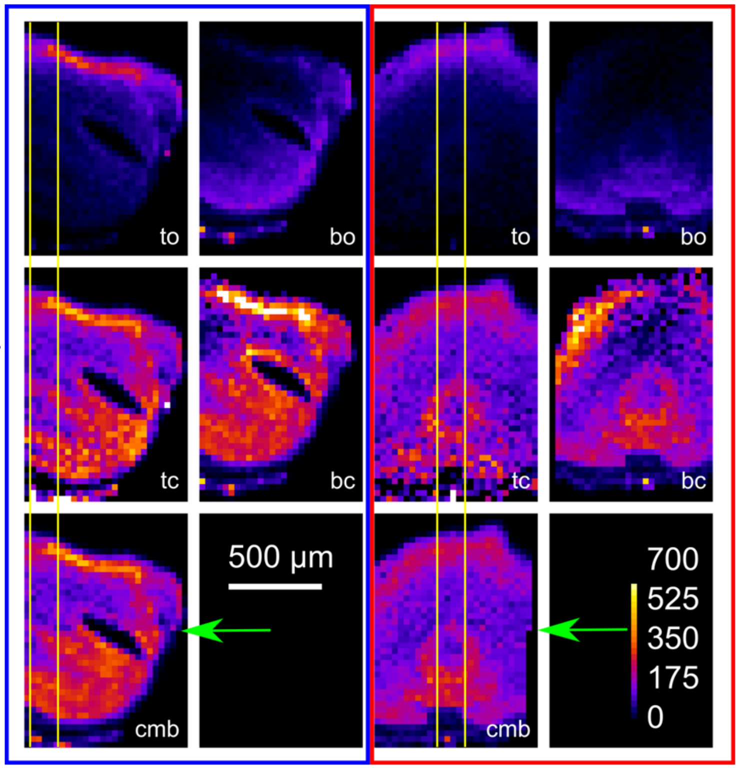
Biofortification: where are the minerals?

Comparison of seeds with low and high Fe content – absorption correction necessary



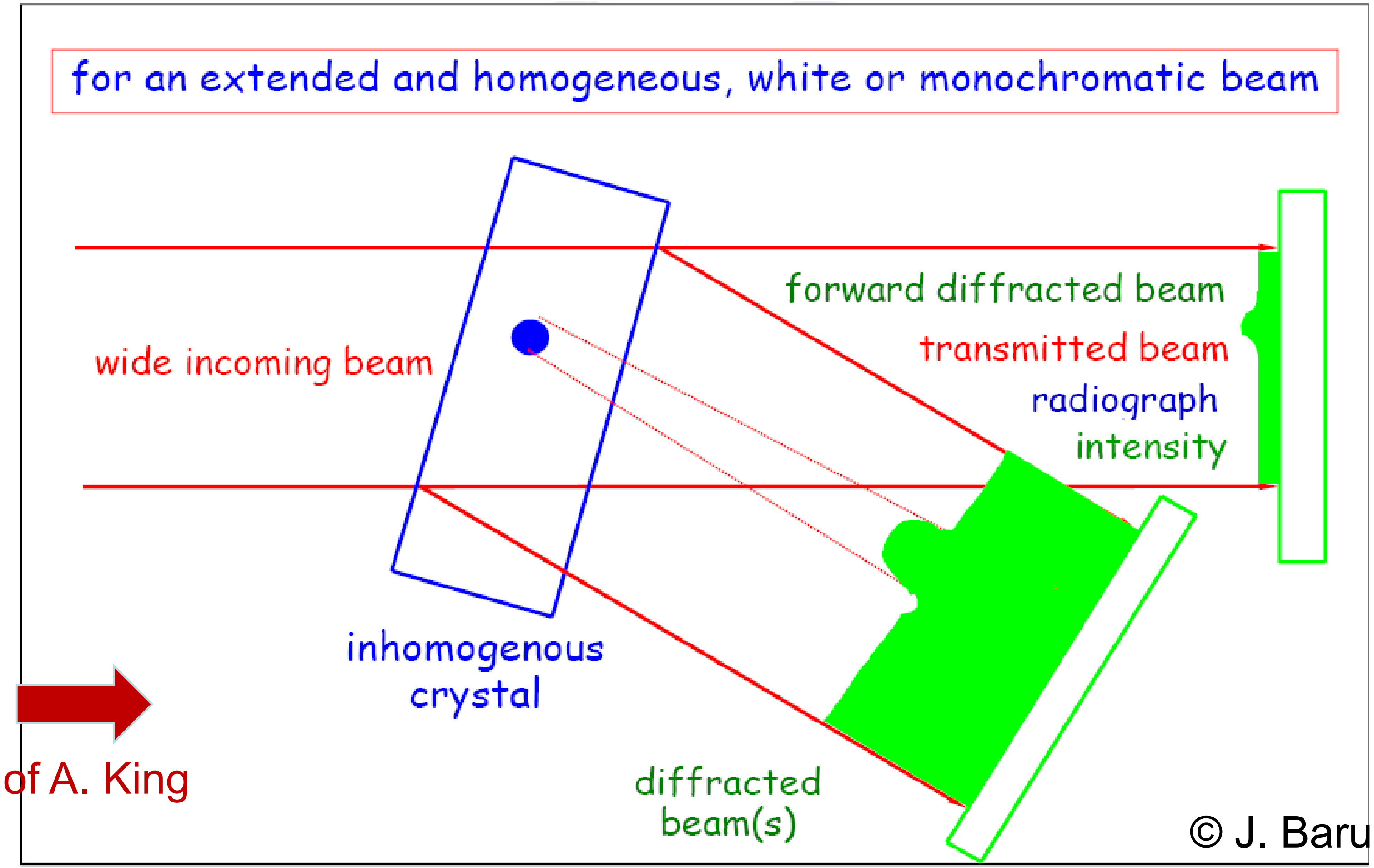
3D mapping with 15 s per voxel, 30 x 30 x 30 µm³, 2.7 10^4 voxel, => 2 weeks





coop. Prof. K. Vogel-Mikuš, University of Ljubljana, Slovenia

Diffraction Imaging



lectures of A. King

© J. Baruchel

Grain size distribution
in UO_2 sample

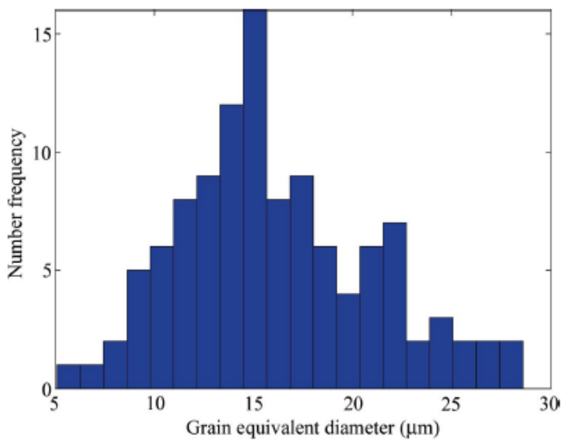


Figure 7
Histogram of the average grain diameters in the UO_2 sample shown in Fig. 6.

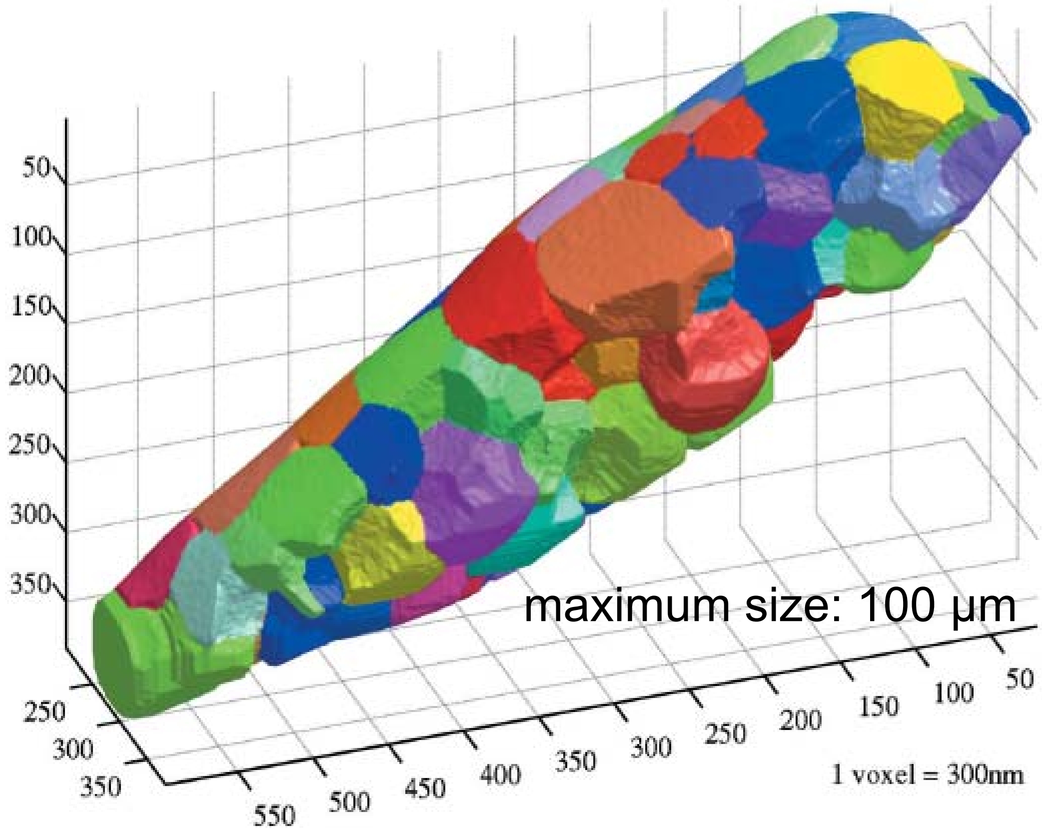
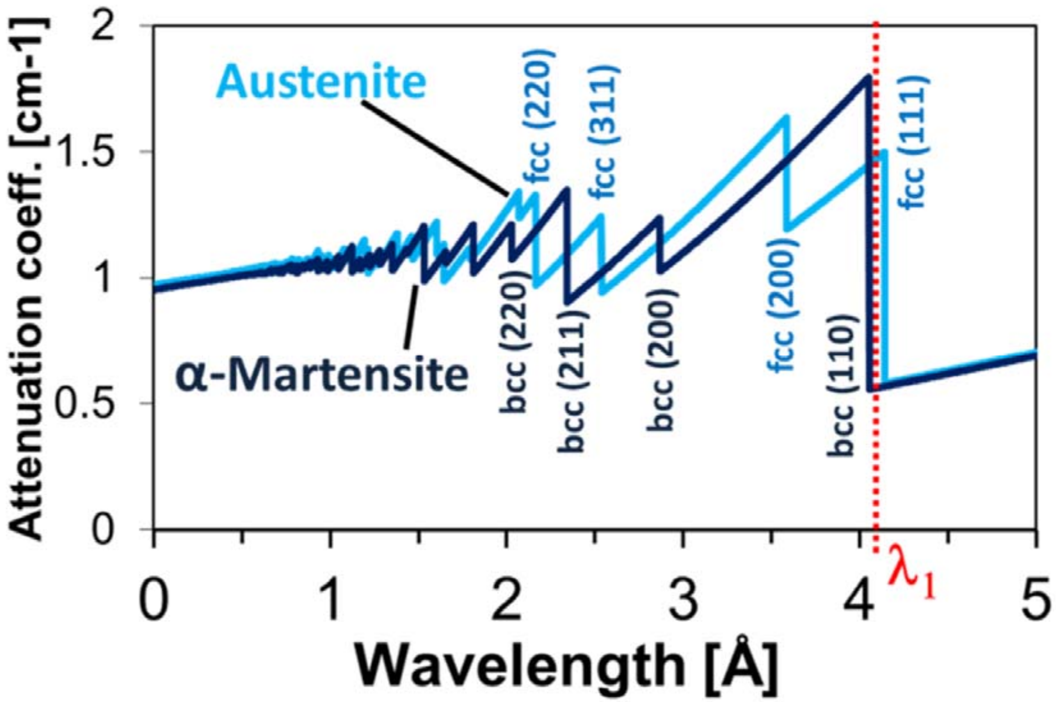


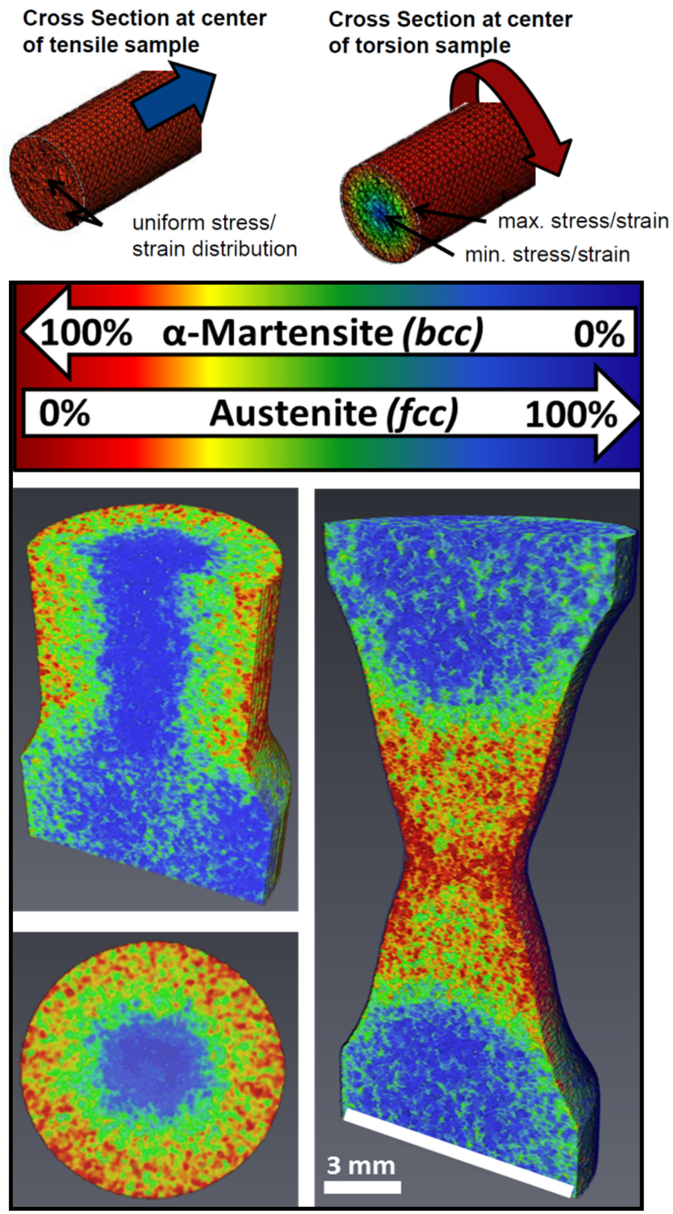
Figure 6
High-resolution DCT grain map of a UO_2 sample containing 119 grains. Some grains are not rendered for better visibility of other subsurface grain boundaries.

Péter Reischig et al., **J. Appl. Cryst. 46 (2013).**

3D Phase mapping in metals with neutrons

Energy-selective neutron tomography of TRIP-steel



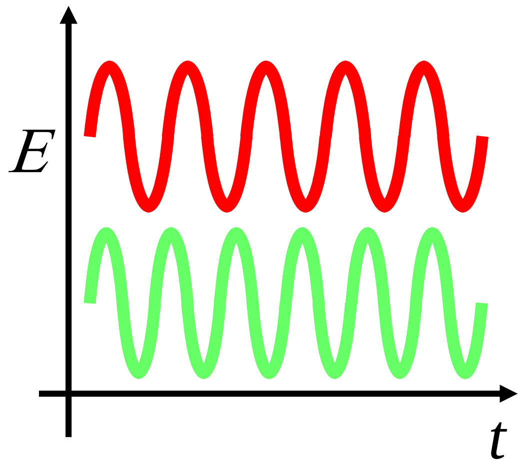


lecture of E. Lehmann

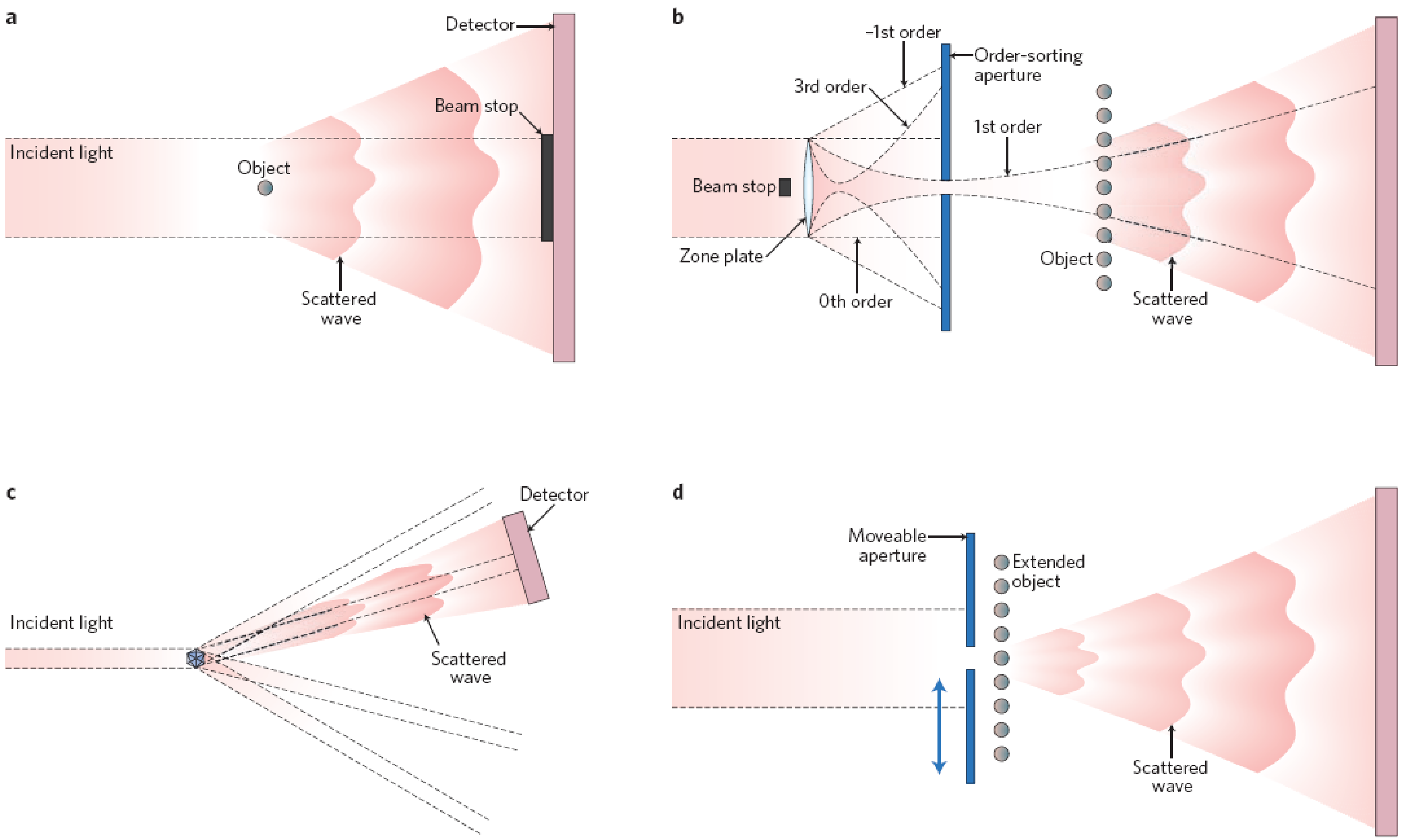
R. Woracek et al., **Advanced Materials 26** (2014)

© N. Kardjilov

The Big Jump: Coherence



Chasing phase information
with Coherent Diffraction Imaging,
Ptychography, and Holography



Experimental configurations for X-ray coherent diffractive imaging

Henry N. Chapman and Keith A. Nugent, Nature photonics, 2010

CDI and Holography

Coherent lensless X-ray imaging

Henry N. Chapman[1] and Keith A. Nugent[2*]

REVIEW ARTICLE | FOCUS NATURE PHOTONICS DOI: 10.1038/NPHOTON.2010.240

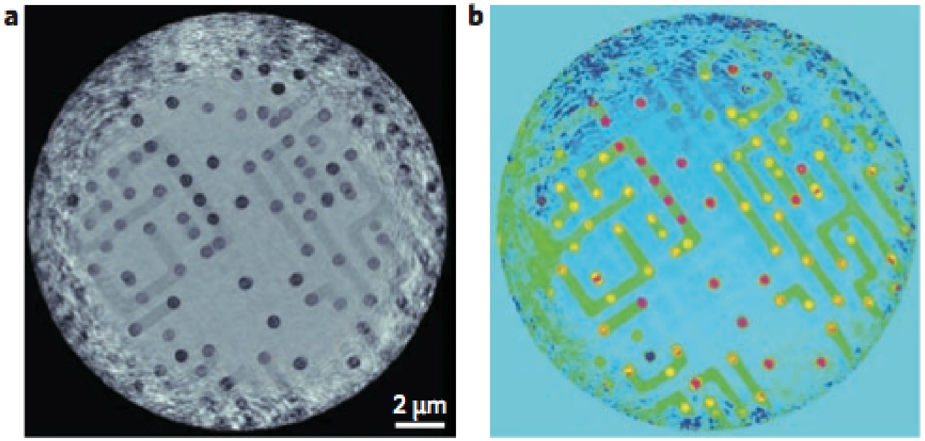


Figure 4 | Scanning diffraction microscopy is able to recover images of extended objects. a,b, Amplitude (**a**) and phase (**b**) distribution of an integrated circuit sample used as a test object. The form of the illuminating probe can also be recovered during the iterative image reconstruction scheme. The pixel size is 36 nm and the sample is 200 µm thick. The X-ray energy used was 7.11 keV. Images courtesy of Pierre Thibault from the Technical University of Munich, Germany.

lecture of M. Guizar-Sicairos

CDI

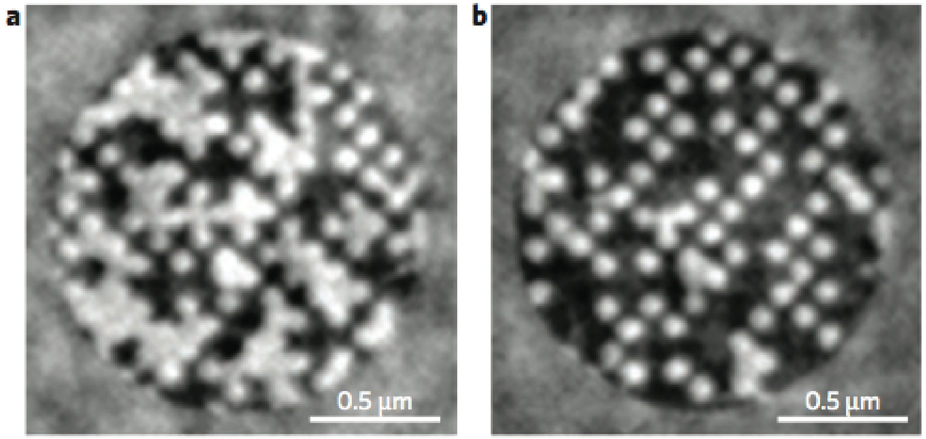
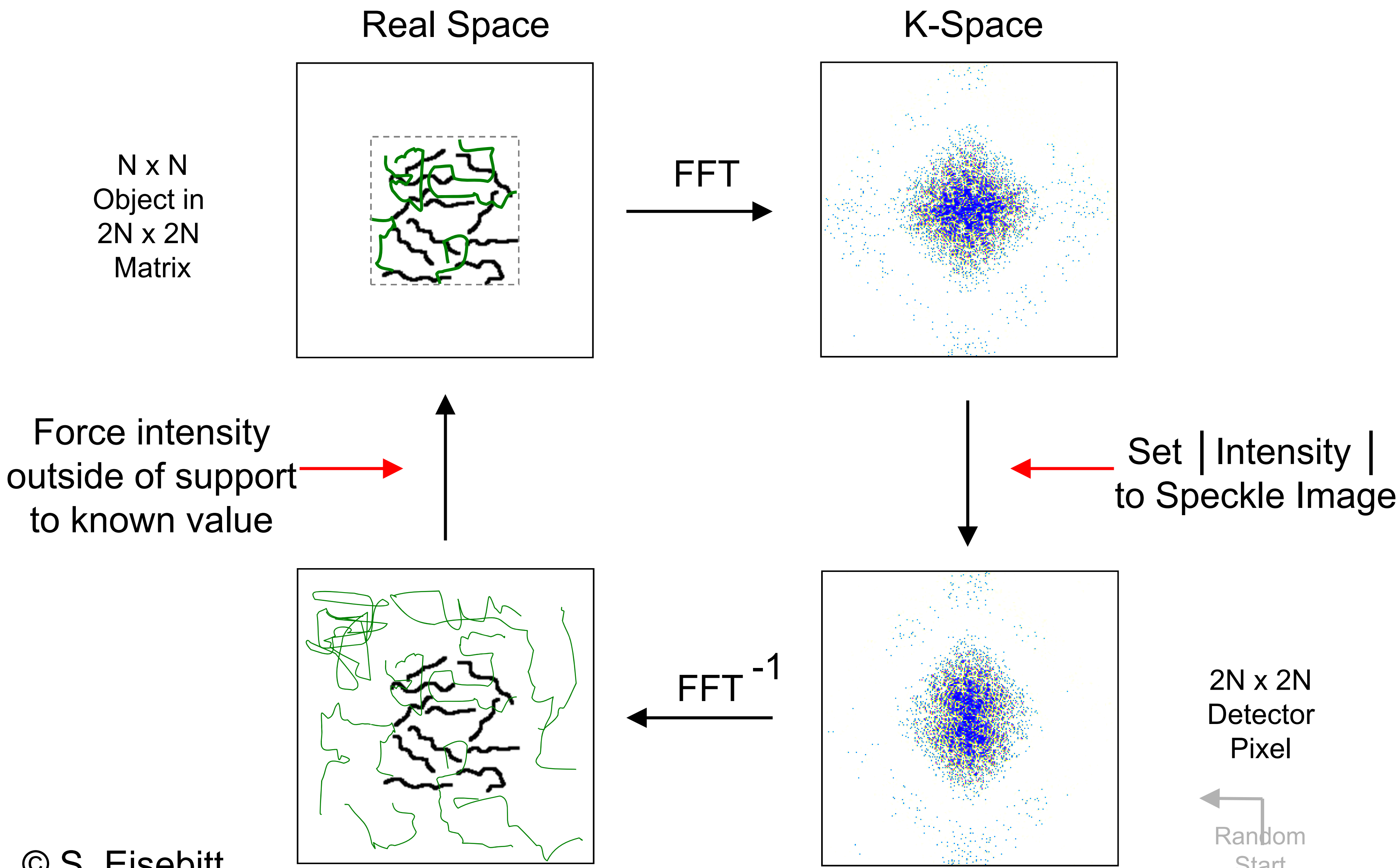


Figure 5 | Holographic reconstructions of a sample containing bit-patterned magnetic media. a,b, The bits consist of a substrate with 80 nm × 80 nm elevated squares in a 120 nm pitch array, coated with a magnetic multilayer film [Co(5.5 Å)/Pd(9 Å)]$_{24}$ plus seed and cap layers. The black/white contrast is based on X-ray circular dichroism and corresponds to the local magnetization in the magnetic film pointing up/down. Two magnetic states at different points within a magnetization cycle are shown. Images courtesy of Stefan Eisebitt from the Technical University of Berlin, Germany.

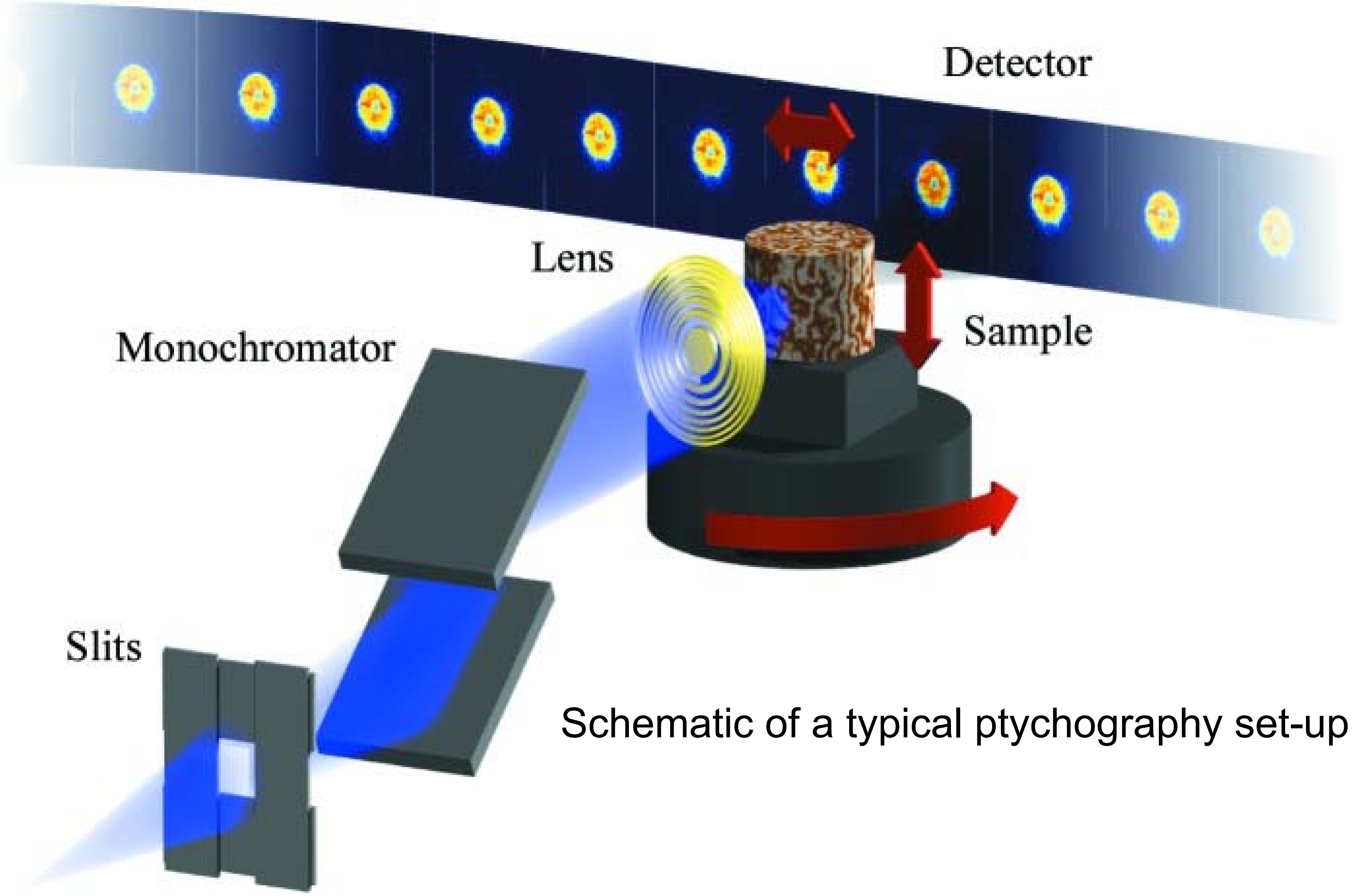
Holography

Iterative Phase Reconstruction



© S. Eisebitt

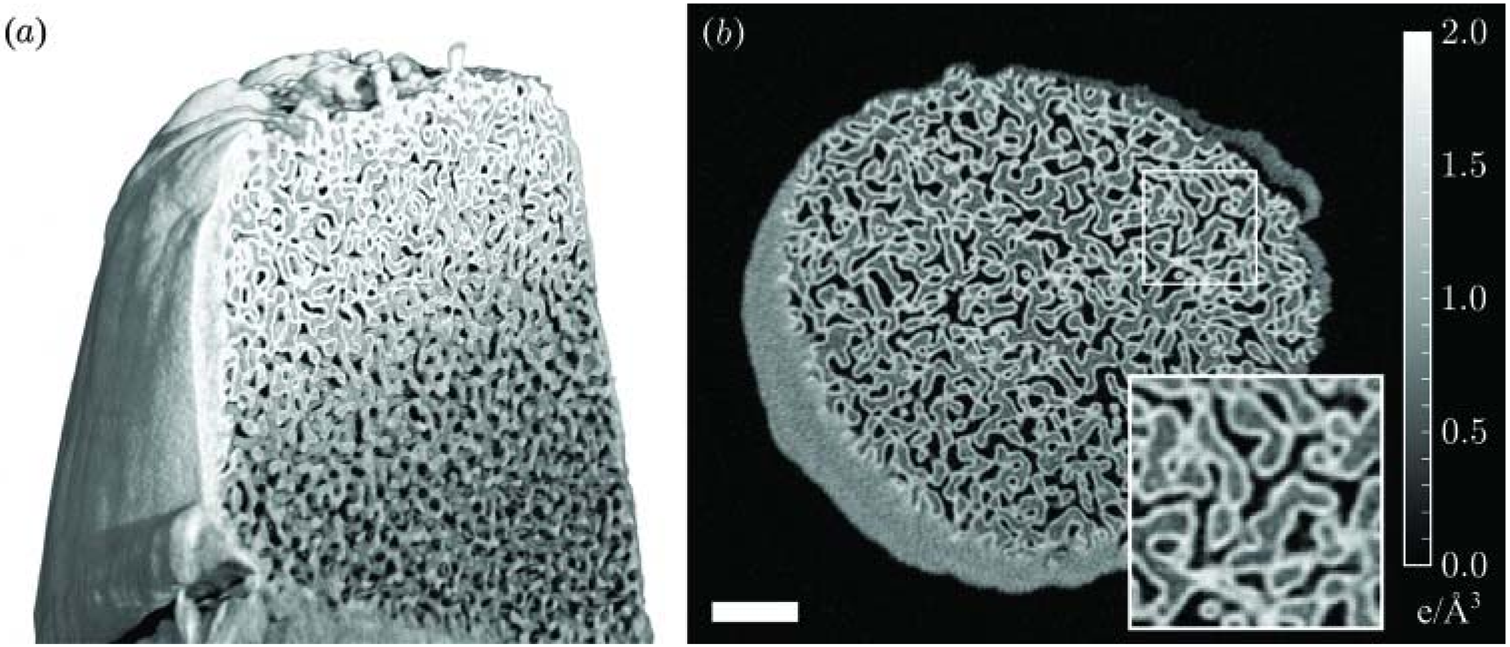
Oversampling factor >2 is required



Schematic of a typical ptychography set-up.

Thibault et al., J Synchrotron Rad. 21 (2014), 1011–1018.

Ptychography

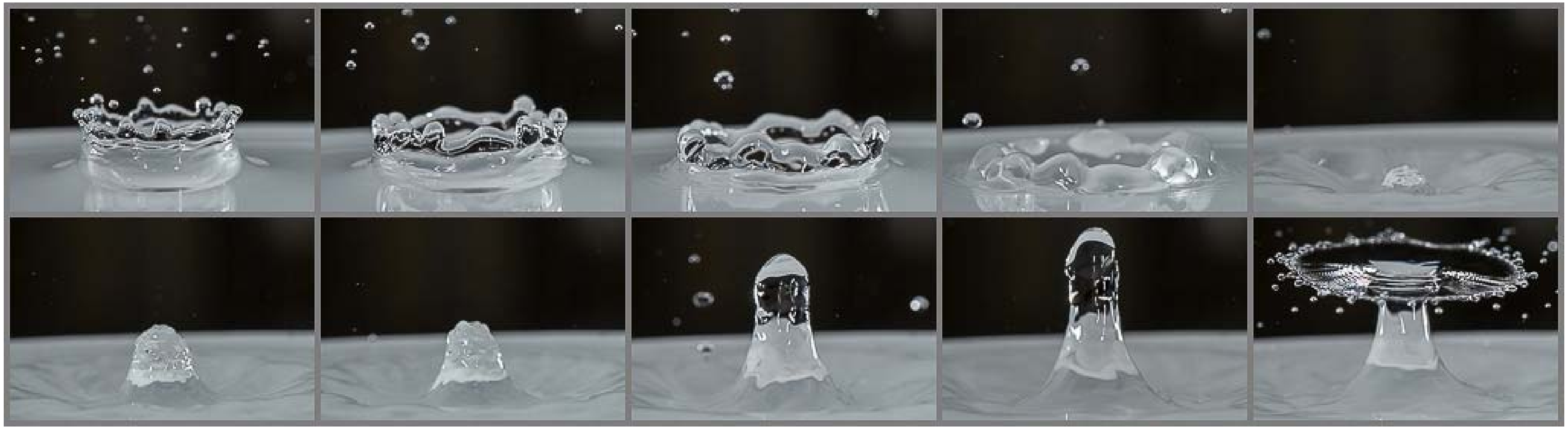


1 μm

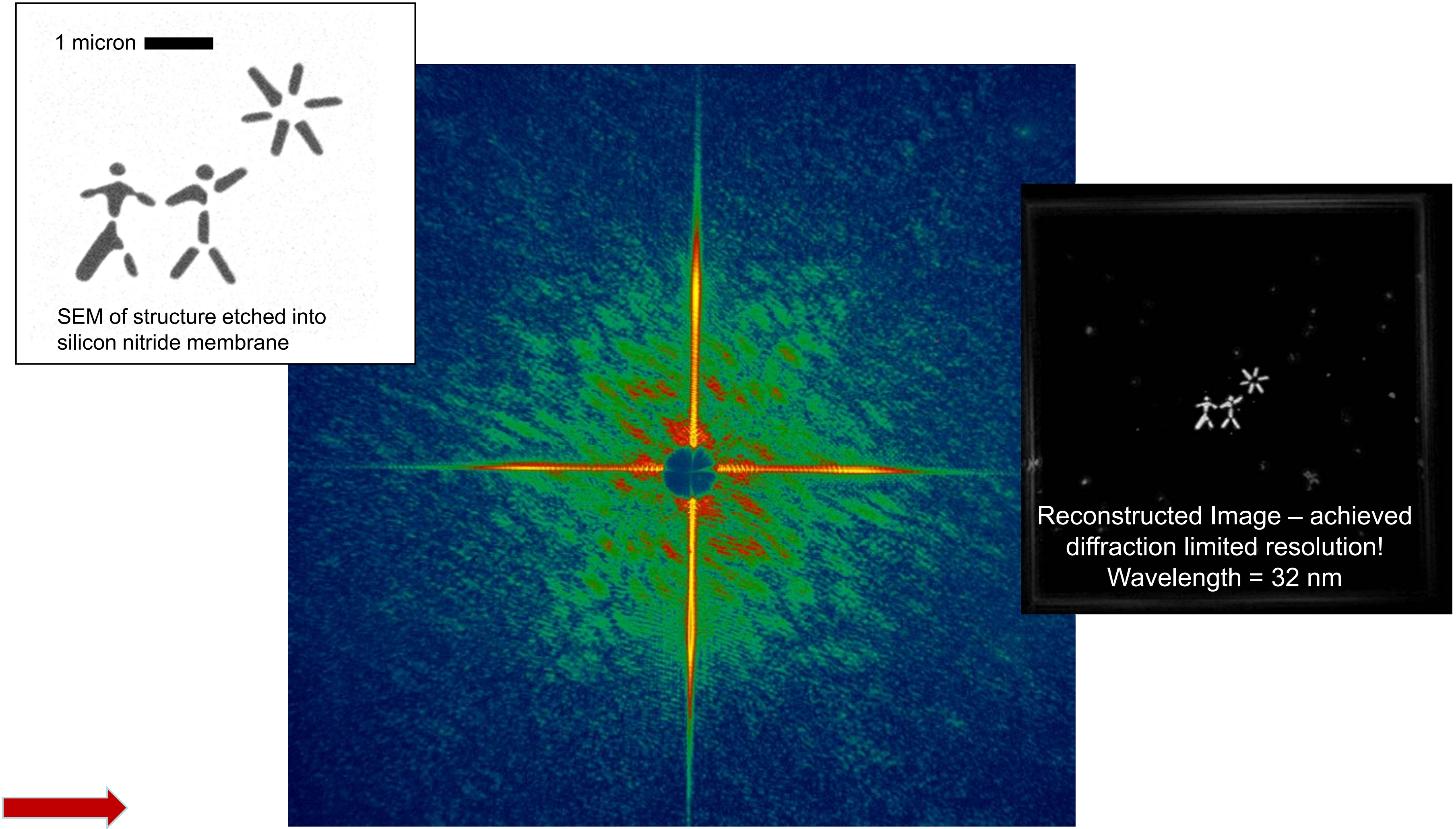
X-ray ptychographic tomography of a nanoporous glass sample. (a) Rendering of three-dimensional reconstruction with 22 nm resolution shows a gradient of the thickness of the Ta2O5 conformal coating in the axial direction. (b) Axial section with a clear differentiation between air, glass and the conformal coating. The scale bar is 1 μm. The inset in (b) corresponds to the 1.5 μm × 1.5 μm region indicated with a white rectangle.

Thibault et al., J Synchrotron Rad. 21 (2014), 1011–1018.

Getting Dynamic



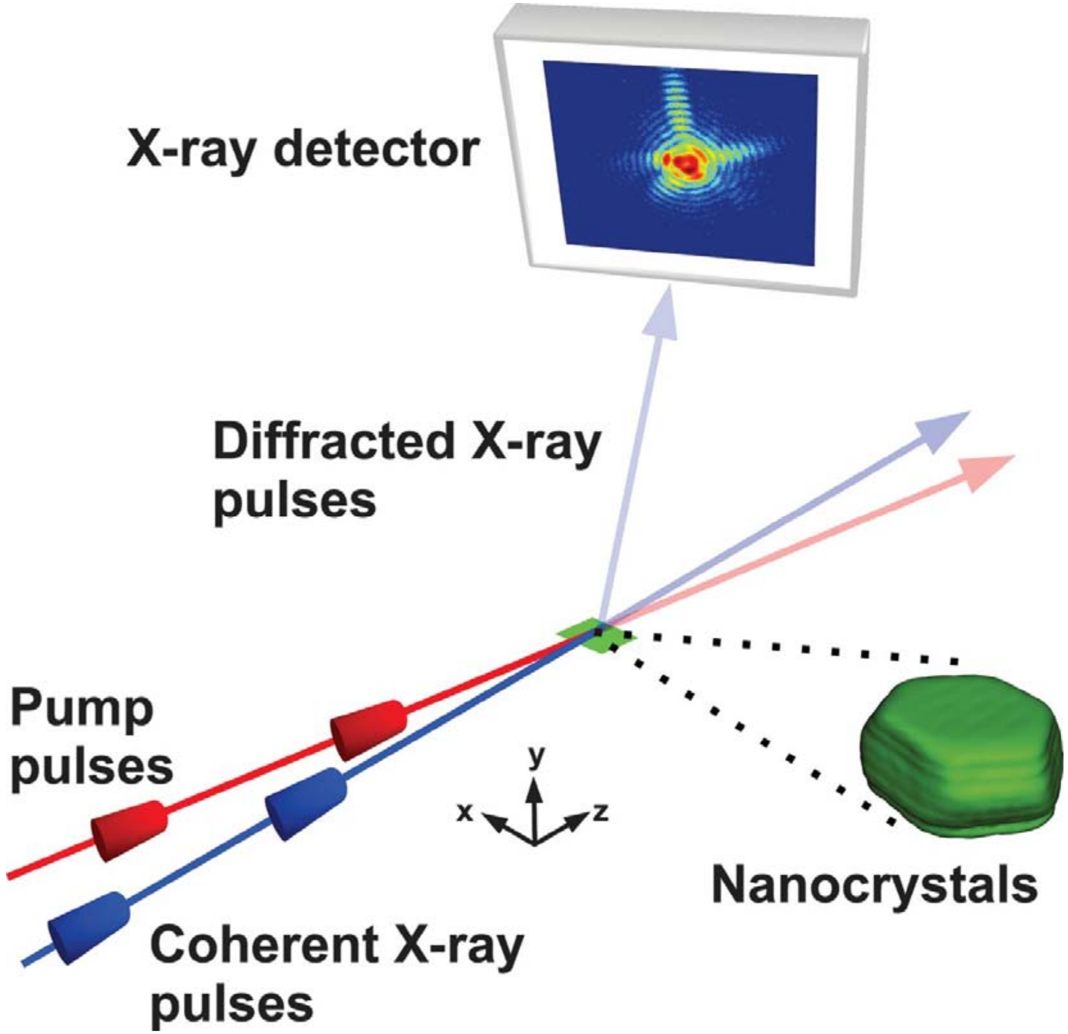
Single shot CDI with FEL



→ lecture of S. Eisebitt and R. Mokso

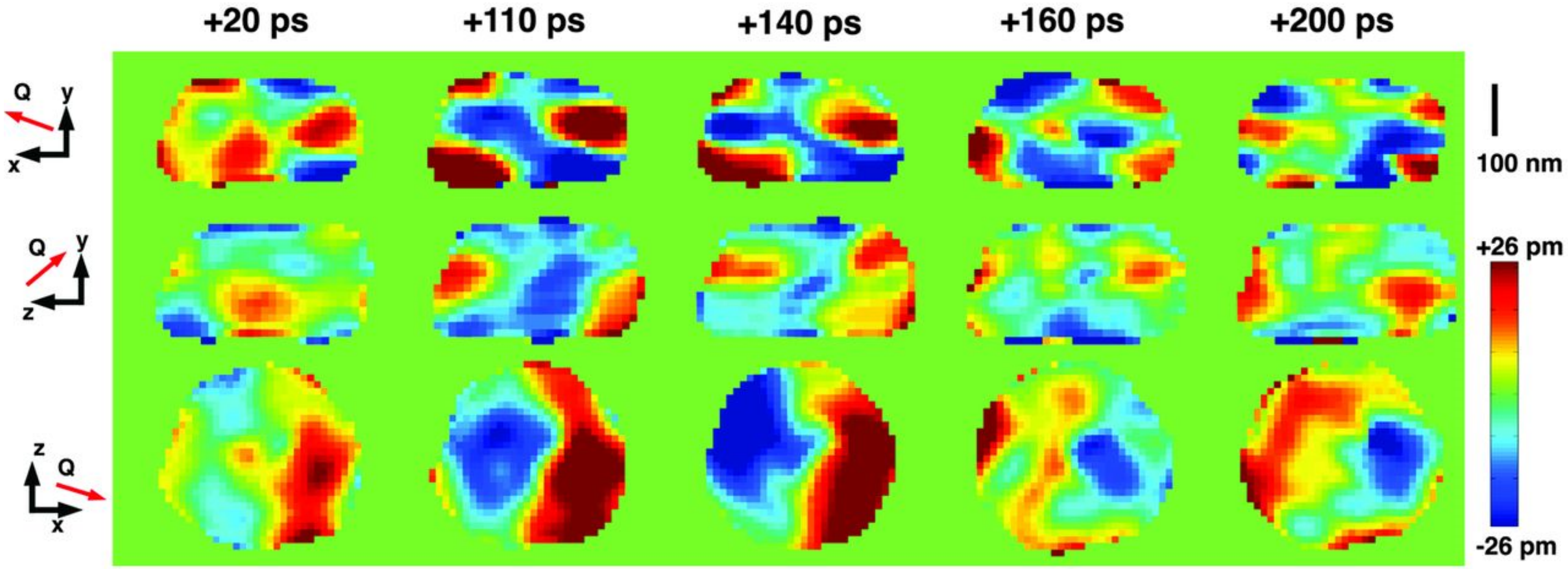
H. Chapman et al. Nature Physics **2**, 840 (2006)

Ultrafast time-resolved Bragg coherent diffraction imaging.Optical pulses (red) perturb the sample (green), generating phonons.



J. N. Clark et al. Science 2013;341:56-59

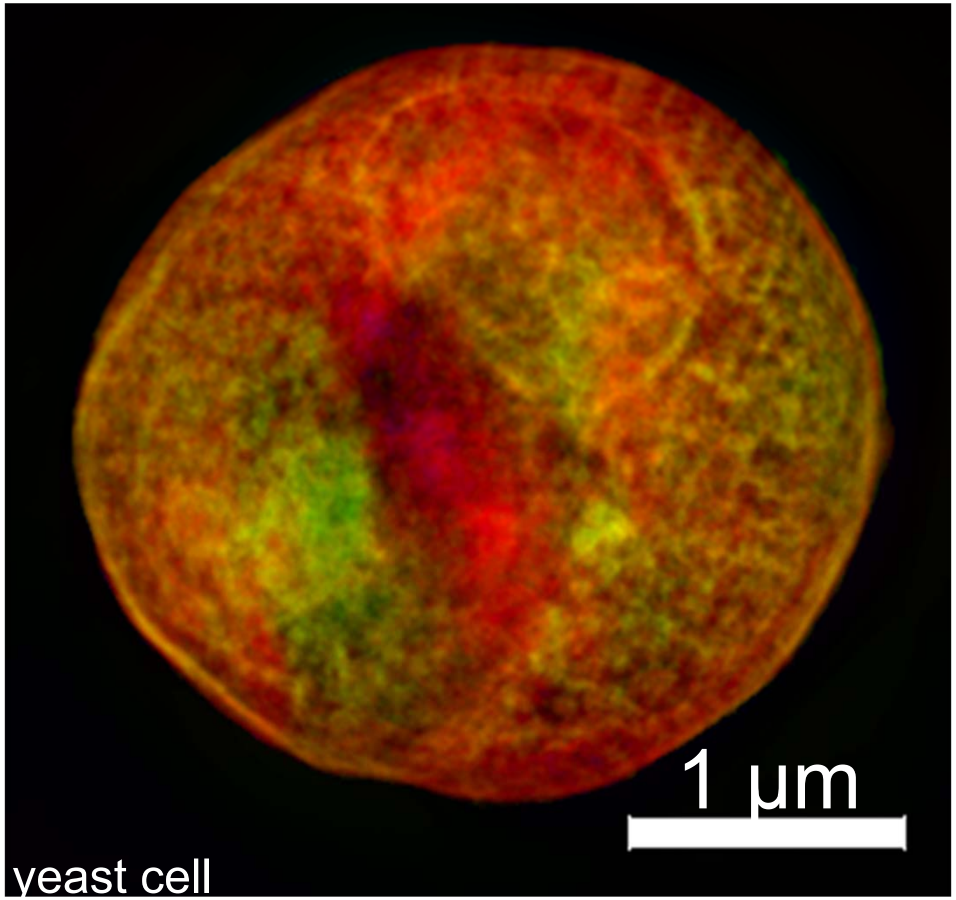
Imaging of acoustic phonons in a nanocrystal.Orthogonal cut planes through the center of nanocrystal I showing the projected displacement as a function of delay time.



J. N. Clark et al. Science 2013;341:56-59

Quantitative Imaging: X-Rays and Neutrons

? !



© C. Jacobsen

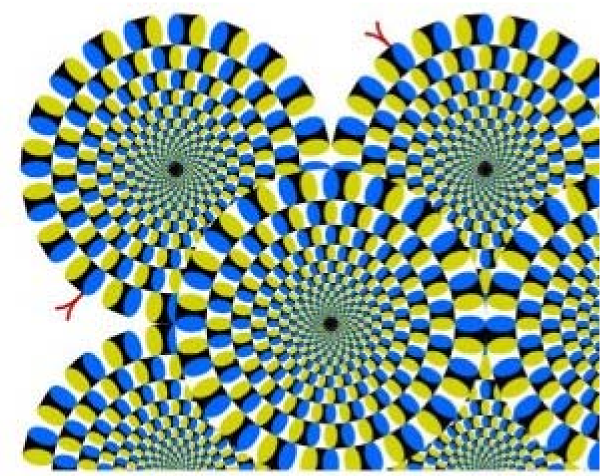
Shapiro *et al.*, *Proc. Nat. Acad. Sci.* **102**, 15343 (2005).

Thinking in space and in time

Filming differences in properties

"Image, Imaging, Imagination"

"seeing is believing":
Does the new way of data representation in form of images change the way of the scientific approach?
Is the dependence of images produced on the used methods and data evaluation still present in the scientific process?
Do artifacts play a role in interpretations?



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→ Discussion tomorrow afternoon