Microscopy innovations for Diamond Phase III

Ian Robinson
Diamond Fellow
Surface & Interface Village

"Away day"
Abingdon
July 2006

diamond

Expert Contributions from

- Franz Pfeiffer (SLS)
- Qun Shen (APS)
- Yong Chu (APS)
- Christoph Rau (APS)
- Paul Fenter (ANL)

diamond

Menu of X-ray Microscopies

- Hard / ~~Soft~~ X-rays
- ~~Scanning~~ / Full-field
- Phase / Amplitude contrast
- Coherent / Incoherent illumination
- Magnified / Actual size
- Diffraction (dark field) / Transmission

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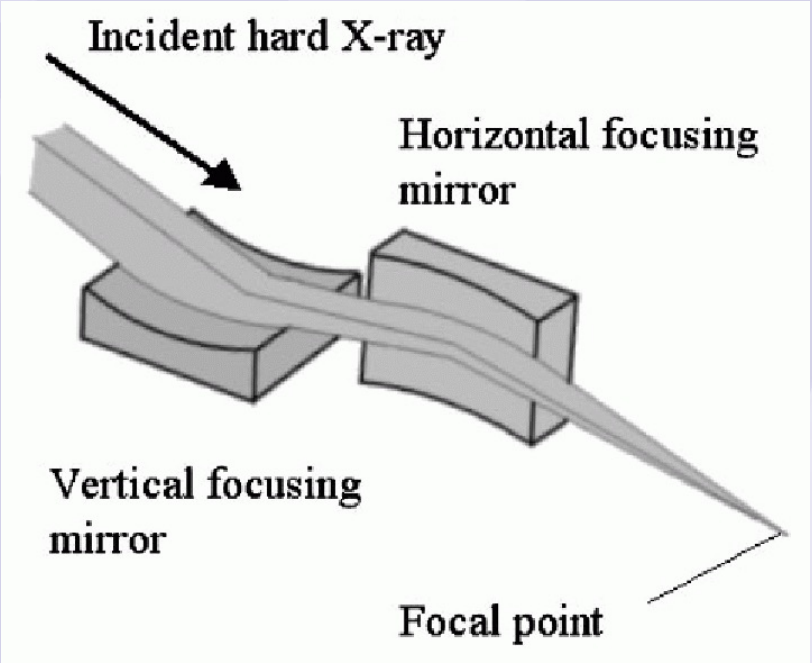
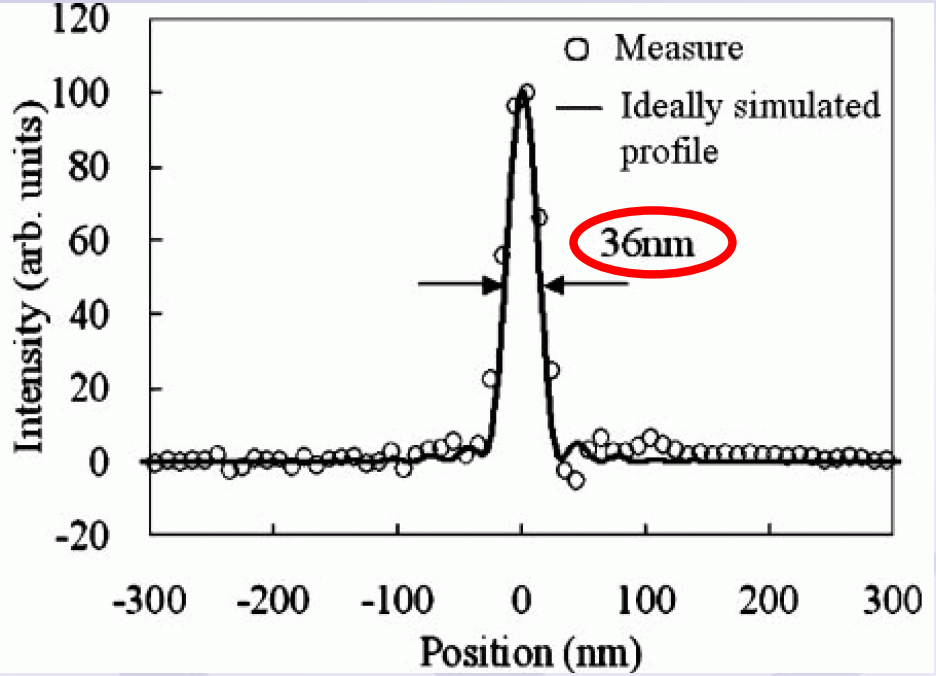
Nanoprobe Advances





- H. Mimura et al, JJAP 44 L539 (2005) U. Osaka
- 2 nm peak to valley, 0.1 nm RMS, Pt mirrors
- 1-km-long beamline (BL29XUL) Spring-8 15keV
- Elastic Emission Machining (EEM)

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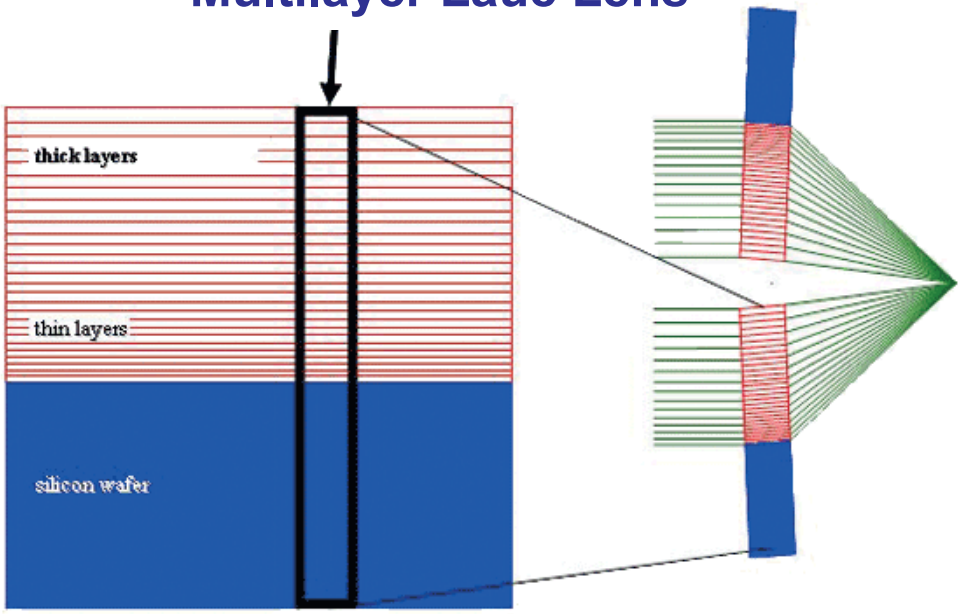
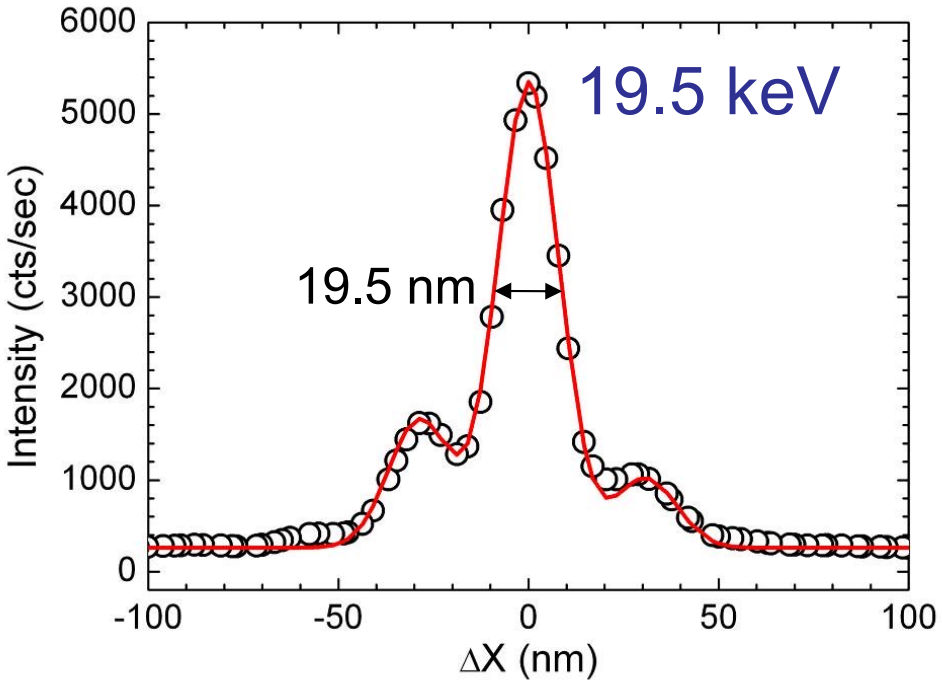
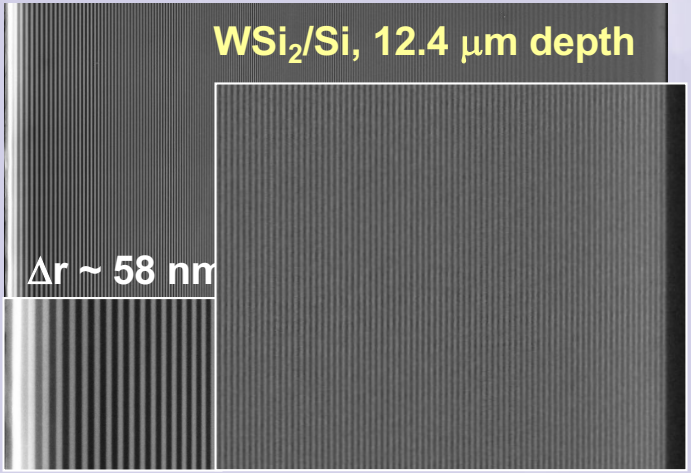
Advanced Focusing Optics: Pathway for 5 nm Focusing of Hard X-rays (Q. Shen)

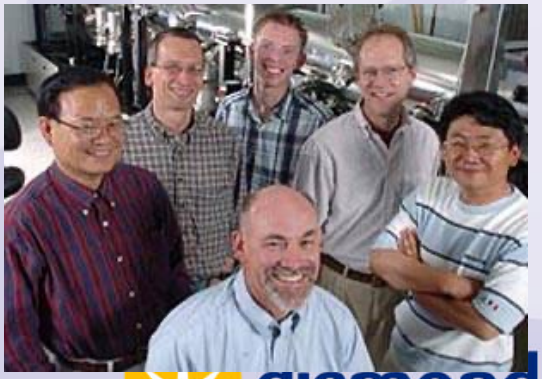
Multilayer Laue Lens







H.C. Kang, J. Maser, G.B. Stephenson, C. Liu, R. Conley, A.T. Macrander, S. Vogt *Phys. Rev. Lett.* *96, 127401 (2006)*



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Menu of X-ray Microscopies

- Hard / ~~Soft~~ X-rays
- ~~Scanning~~ / Full-field
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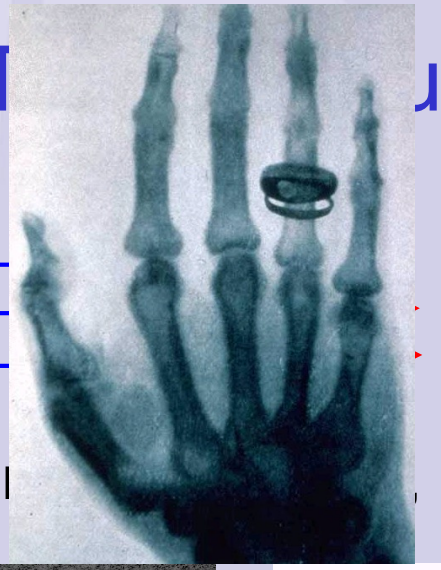
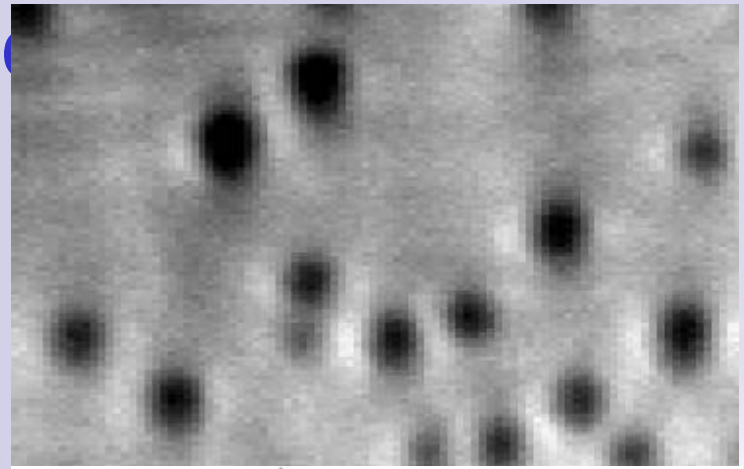
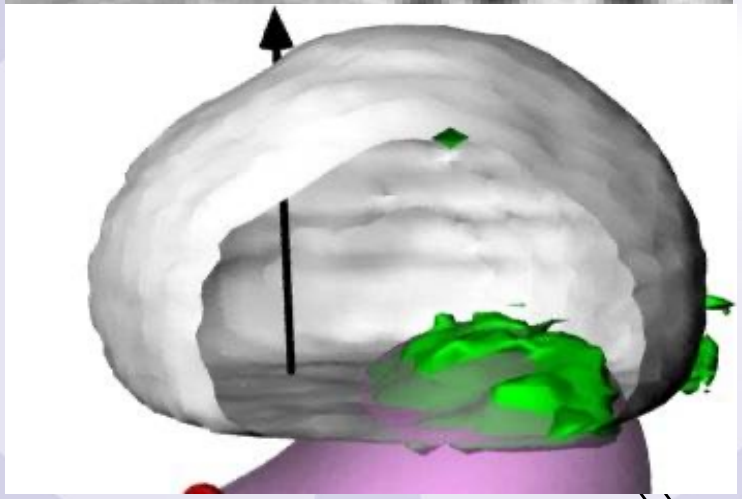
T ull-Field Mi

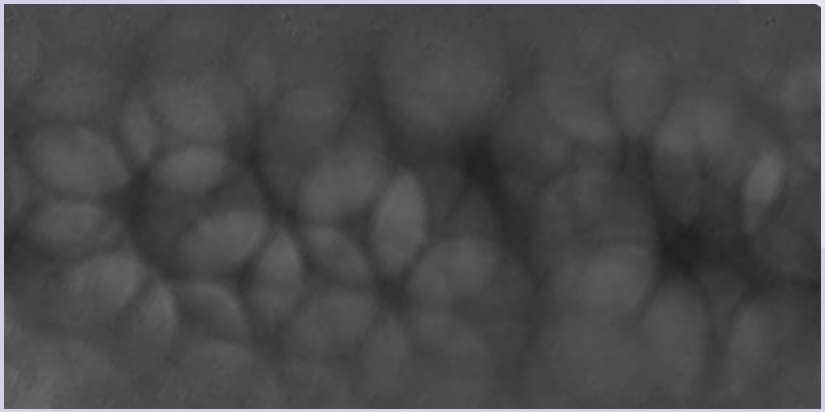


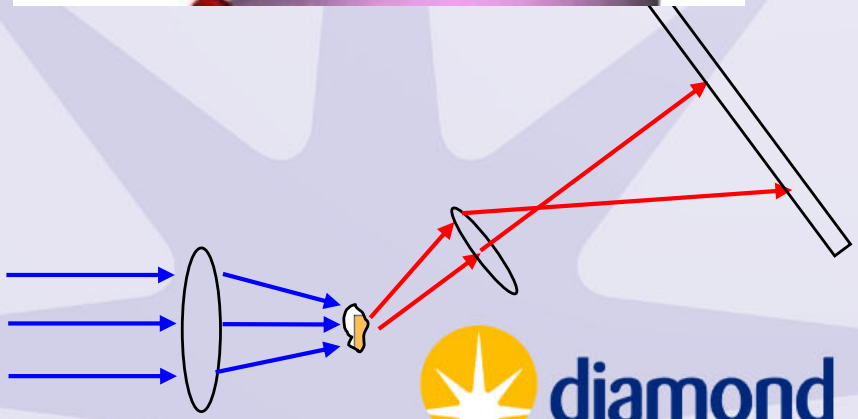




Coherent

Miao et al (1999)





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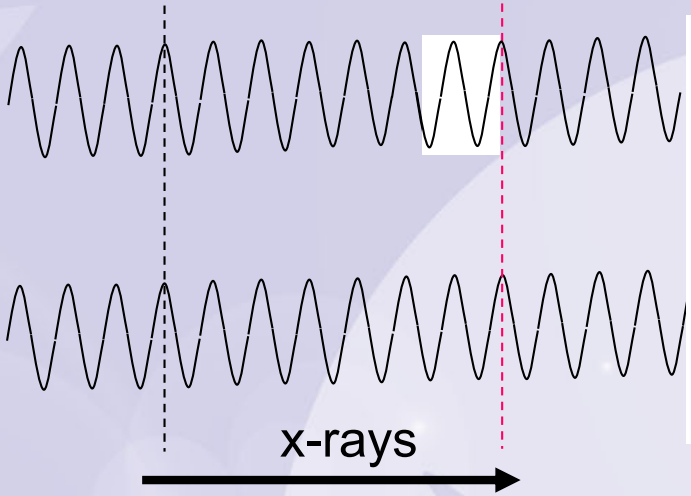
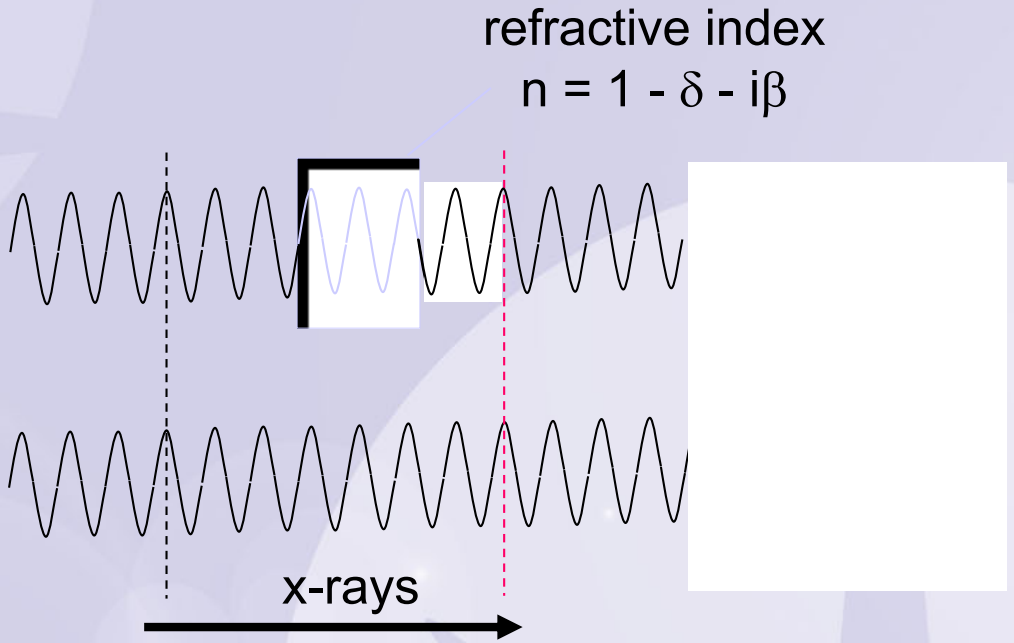
Full-Field Diffraction Microscopy

Phase sensitive x-ray imaging

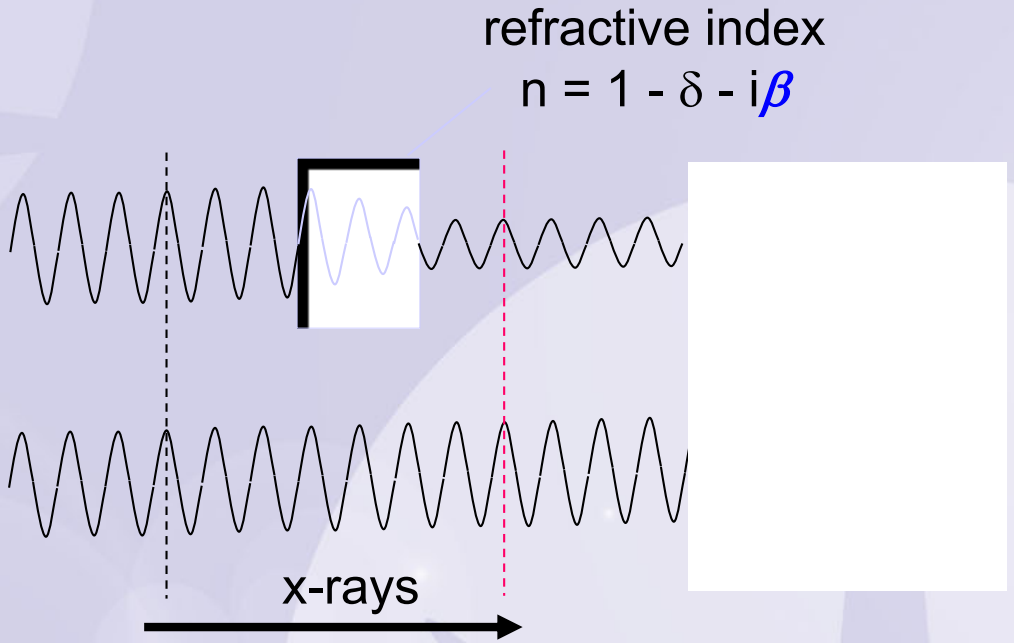


Coherent Beams

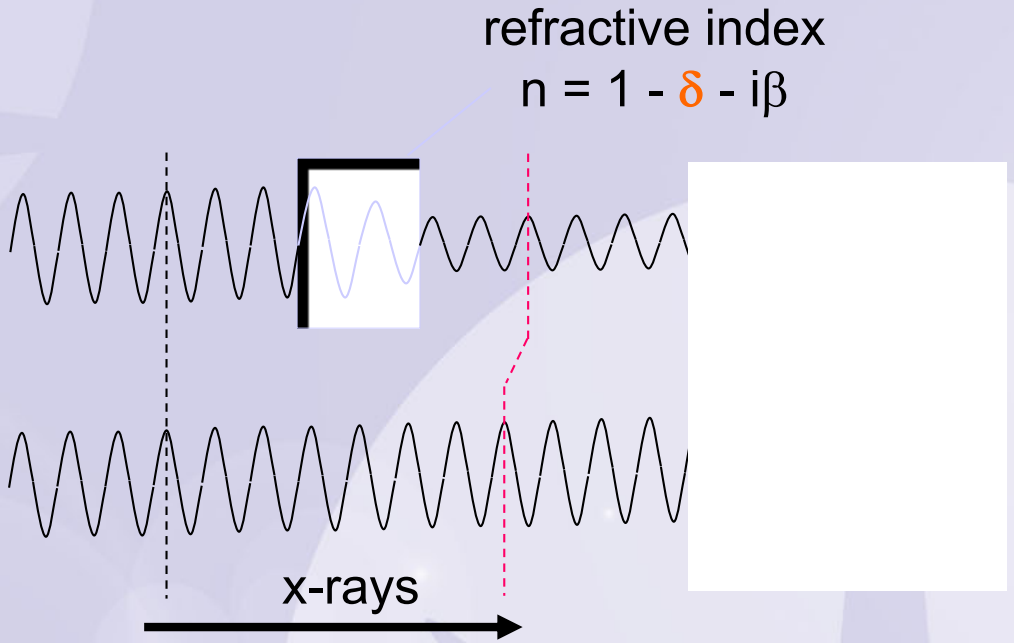
Phase sensitive x-ray imaging



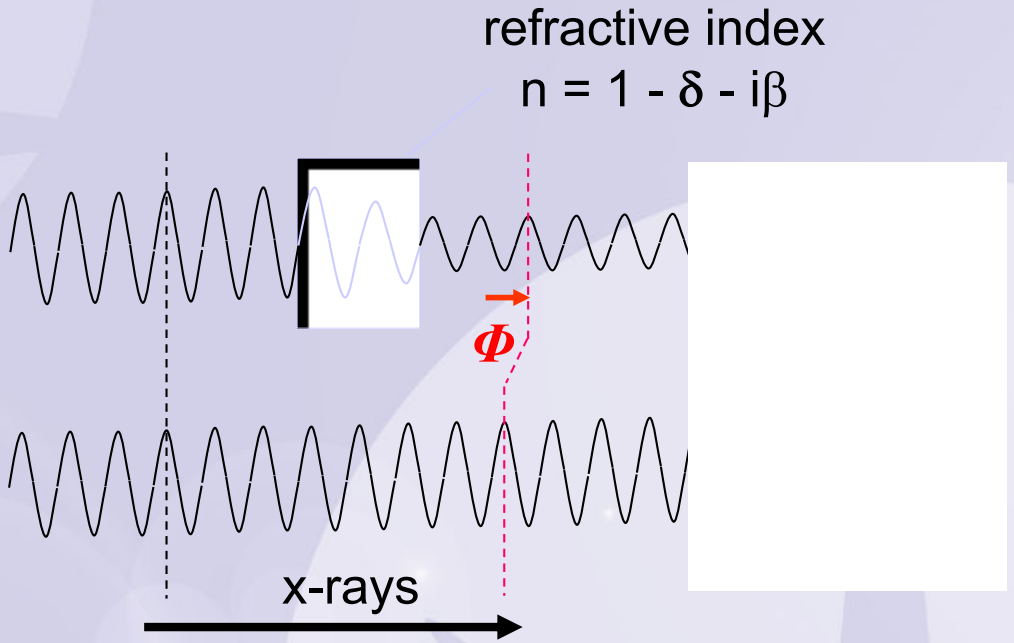
Phase sensitive x-ray imaging



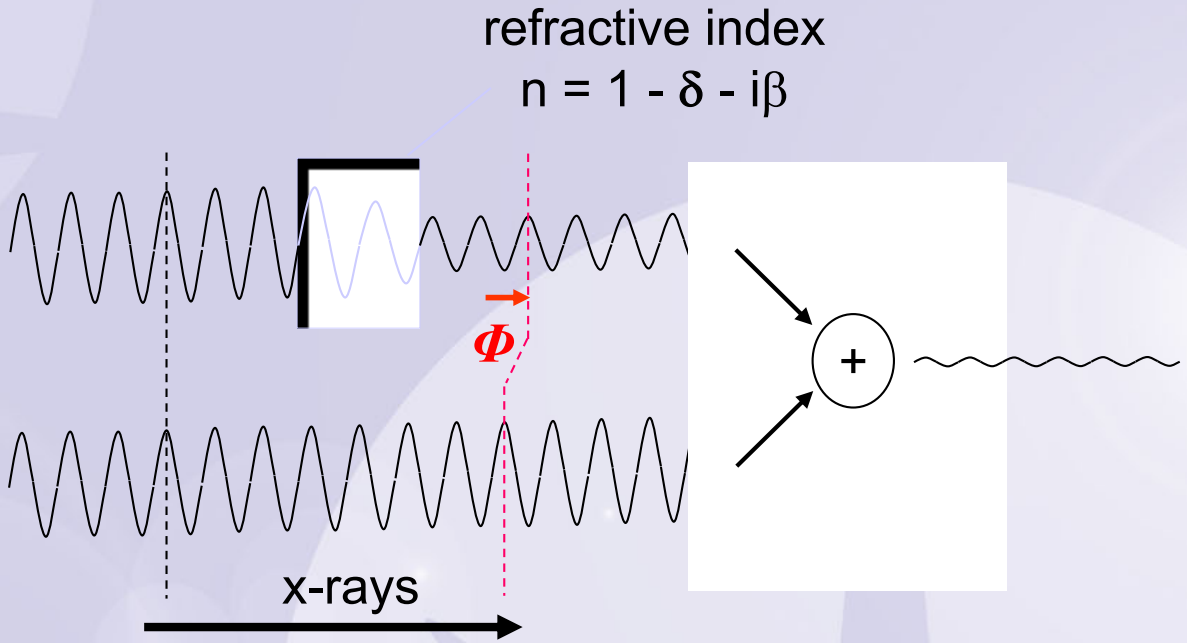
Phase sensitive x-ray imaging



Phase sensitive x-ray imaging



Phase sensitive x-ray imaging

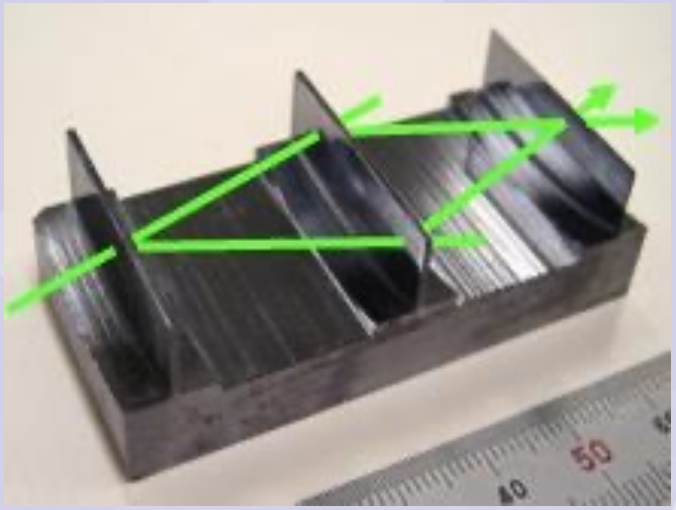


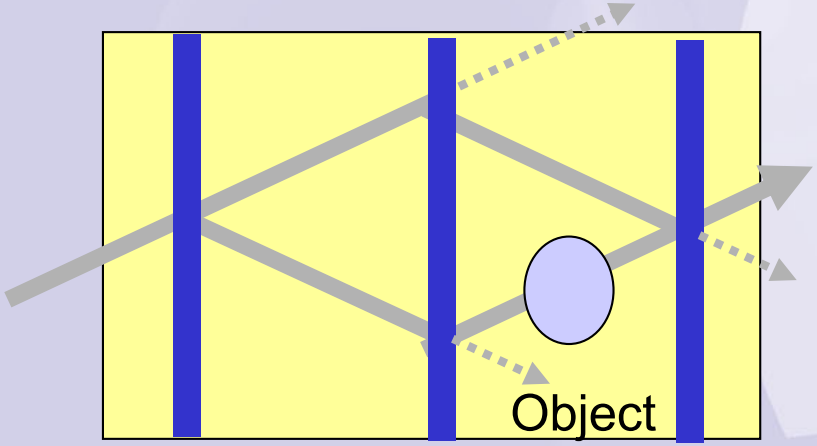
To obtain phase sensitive images, measure:

Φ ***with a crystal interferometer (Bonse & Hart 1965)***

Crystal Interferometers

Bonse & Hart (1965)





Momose et al. (2005)

PS/PMMA polymer blend
Phase tomography

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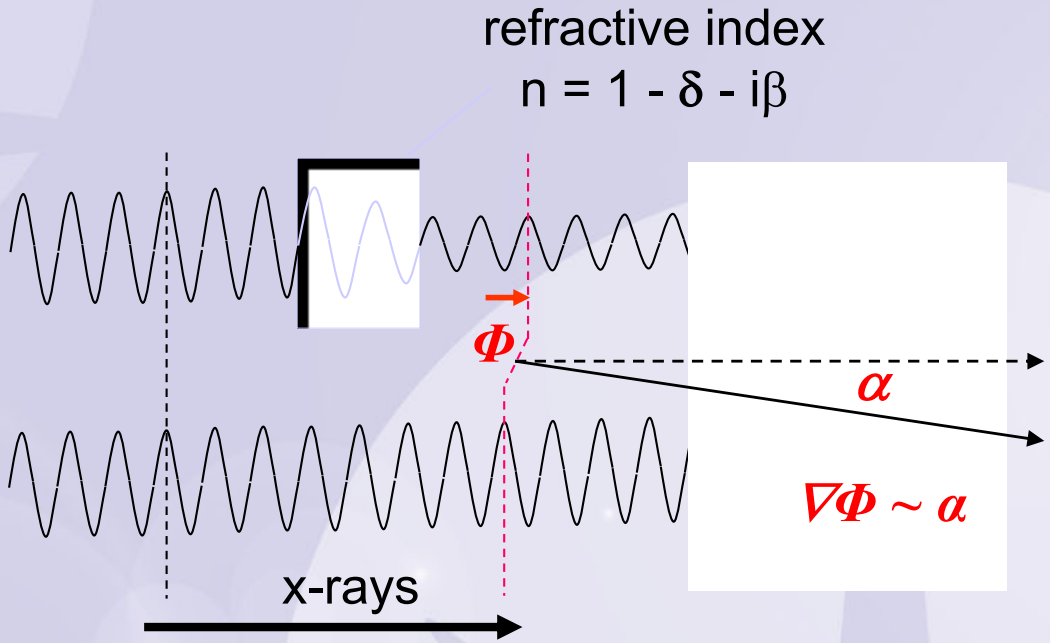
Phase sensitive x-ray imaging



To obtain phase sensitive images, measure:

Φ ***with a crystal interferometer (Bonse & Hart 1965)***

∇Φ ***with diffraction enhanced imaging (Chapman 1997)***

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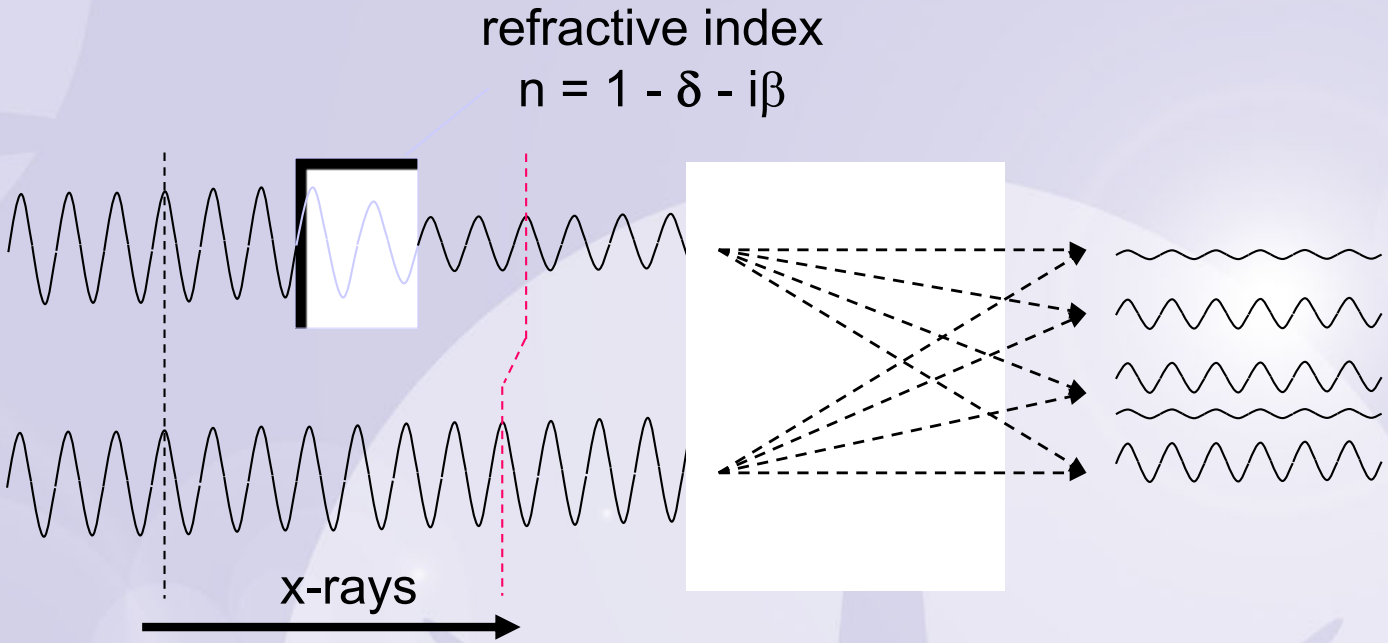
Phase sensitive x-ray imaging



To obtain phase sensitive images, measure:

Φ	***with a crystal interferometer (Bonse & Hart 1965)***
∇Φ	***with diffraction enhanced imaging (Chapman 1997)***
ΔΦ	***with in-line holography (Cloetens 1999)***

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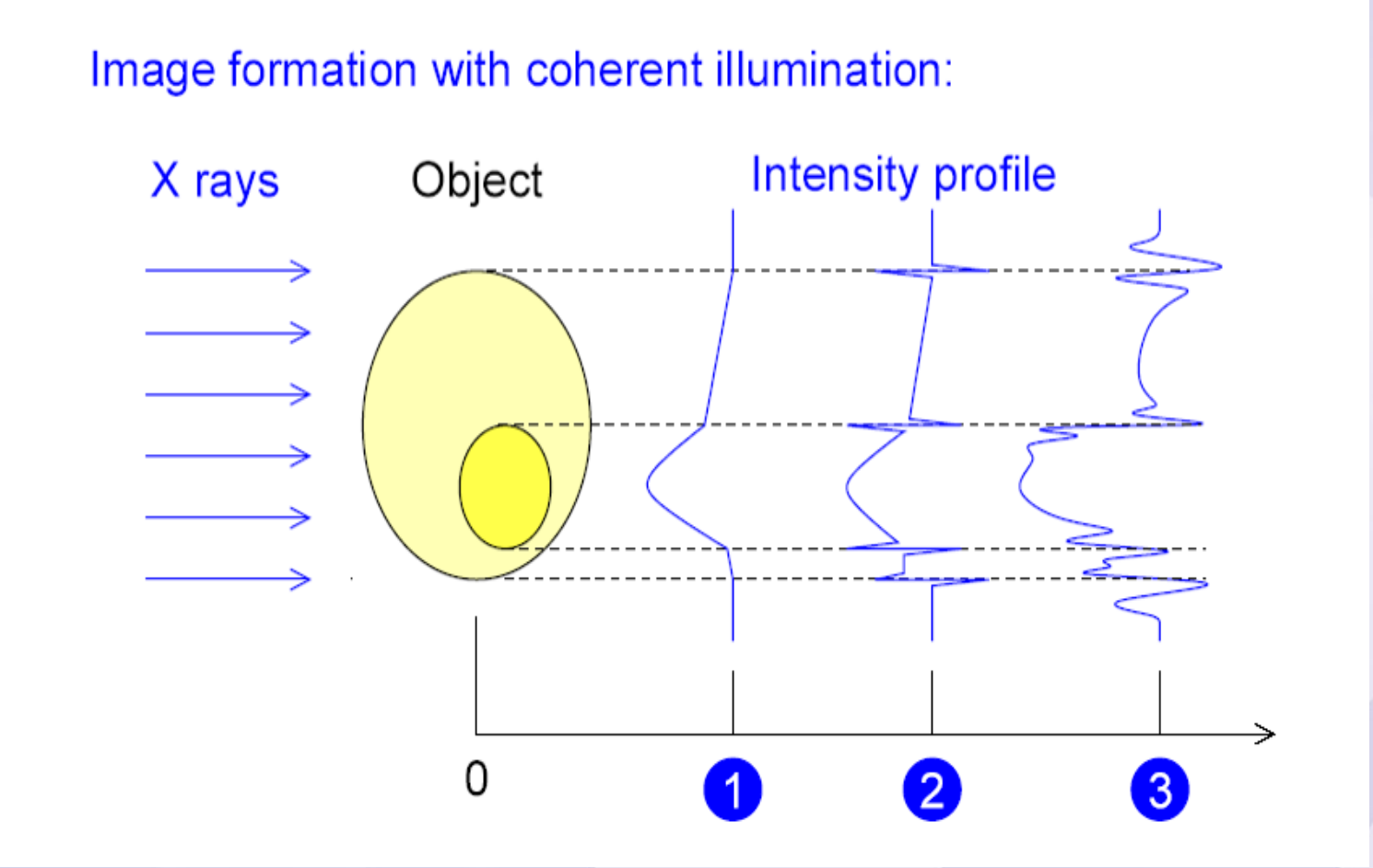
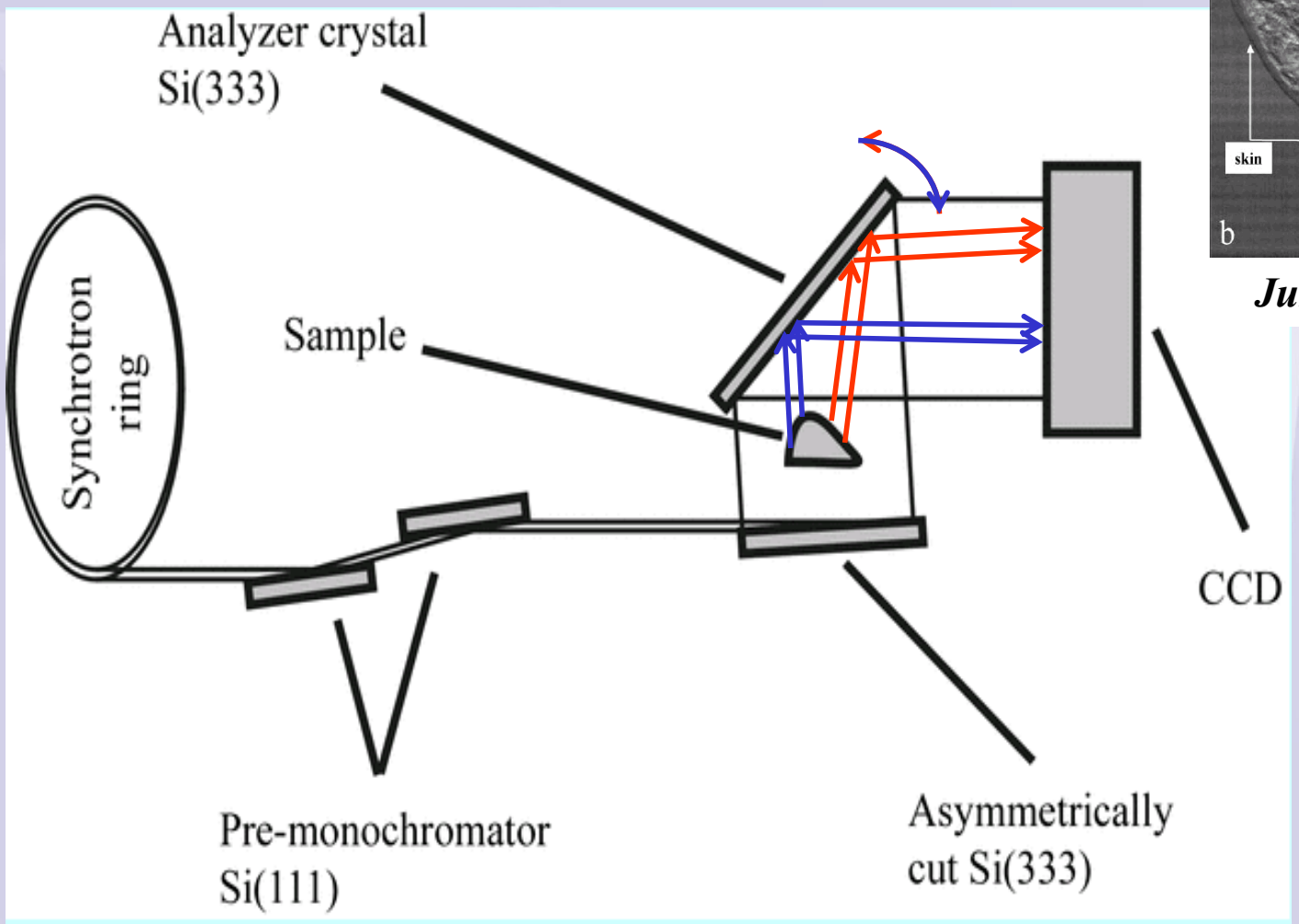
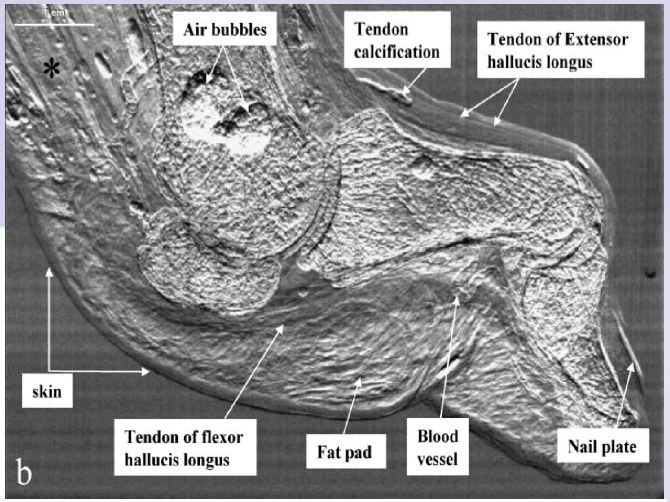
Free Space Propagation



Diffraction Enhanced Imaging (DEI)

Chapman et al. (1997)





Jun Li et al., J. Anat 202, 463 (2003)

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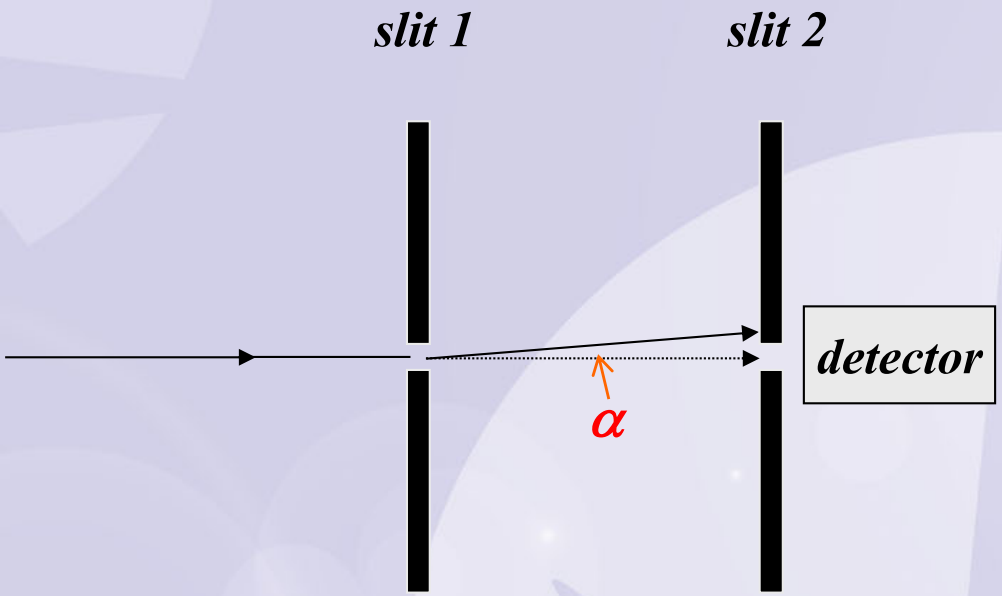
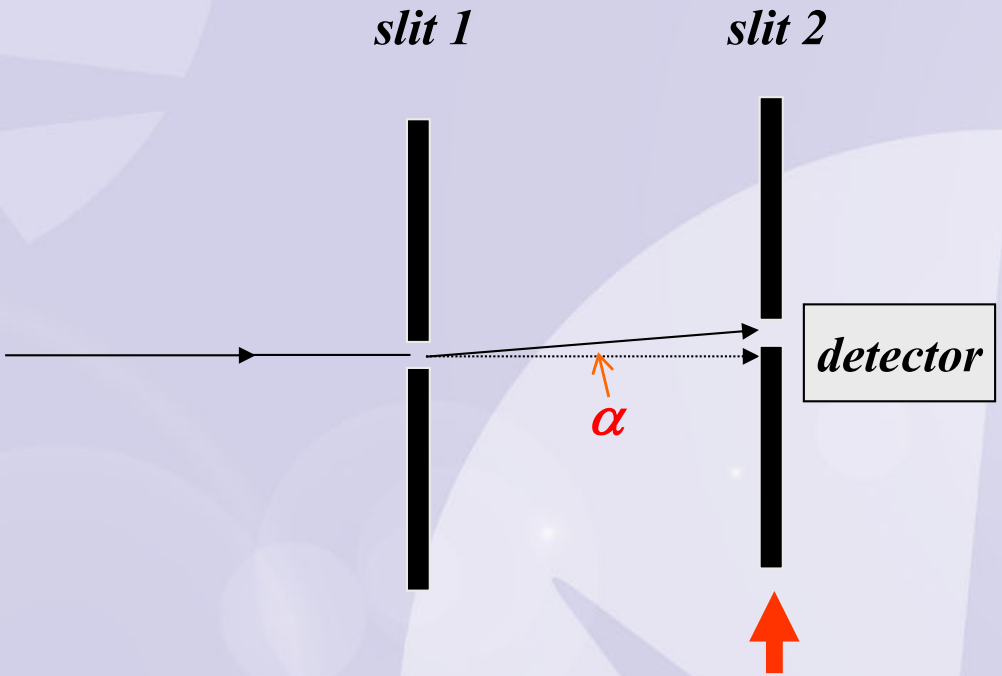
Grating Interferometer



Idea: polychromatic detection of angles

Grating Interferometer



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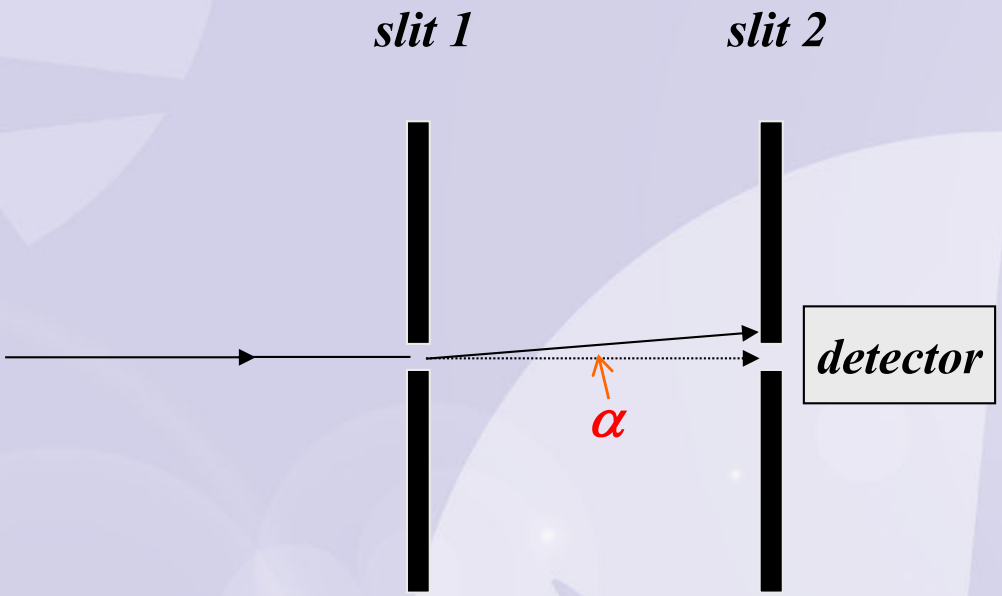
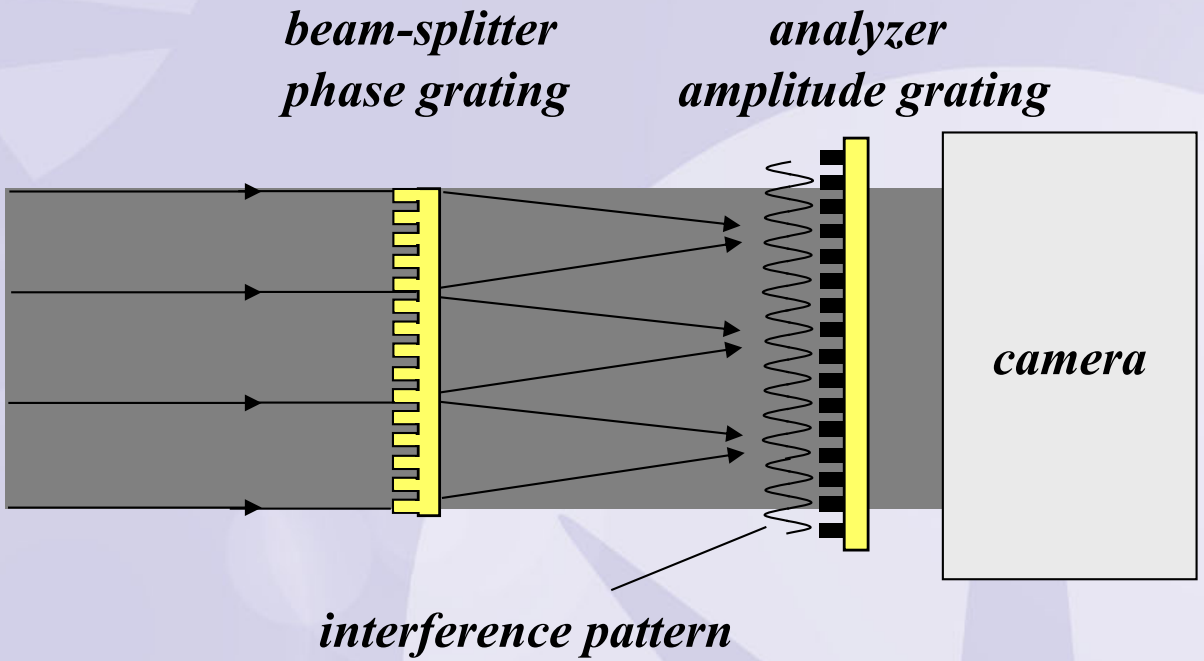


Idea: polychromatic detection of angles

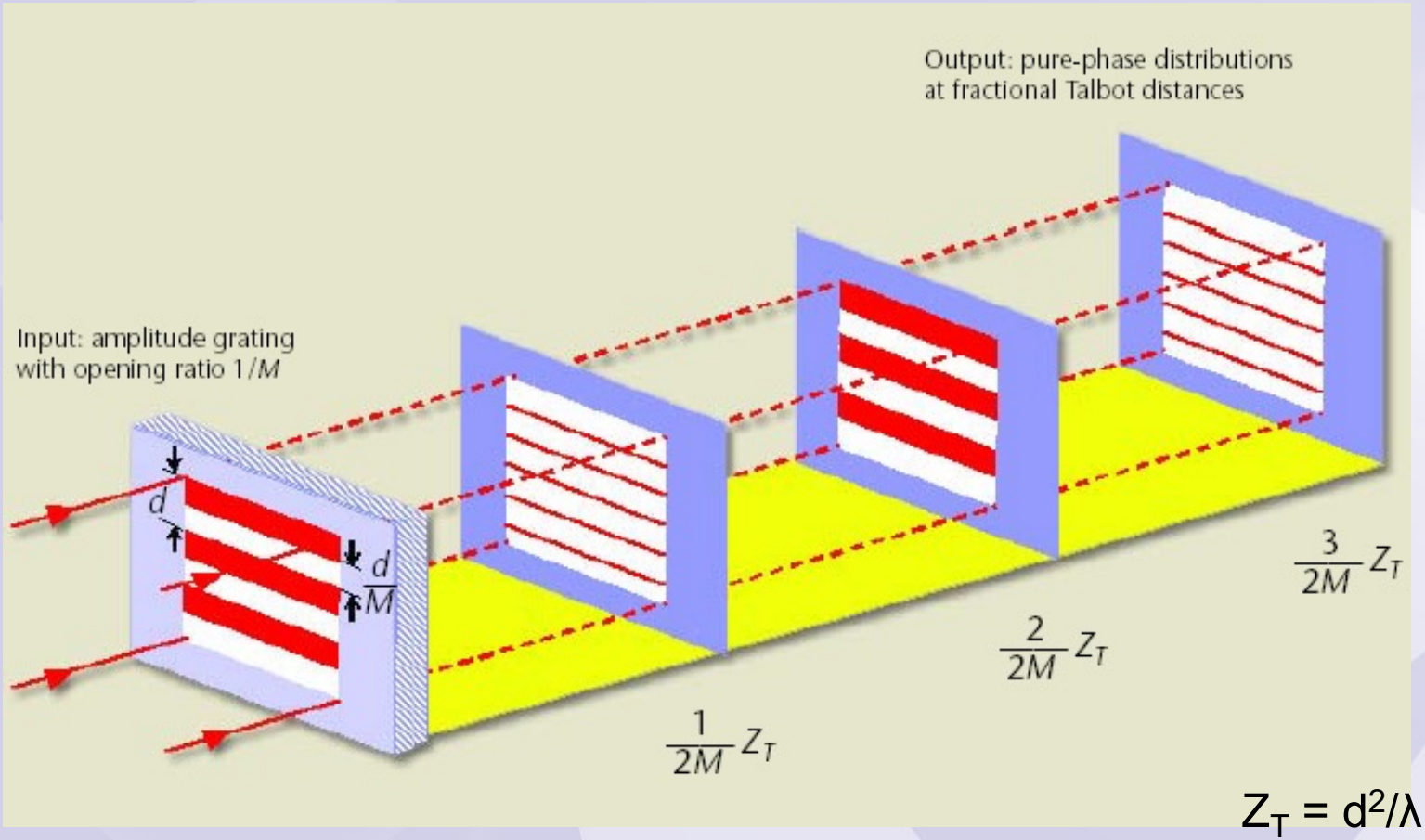
Grating Interferometer



- *phase grating as beam splitter*
- *absorption grating as transmission mask*
- *x-ray wavelength $\lambda \sim 0.1$ nm, grating periods ~ 2-4 µm*

Patent pending, # 05 002 121.9 (2005)

Talbot Self-Imaging Effect



$Z_T = d^2/\lambda$

C. Zhou et al, Optics and Photonics News, Nov 2004

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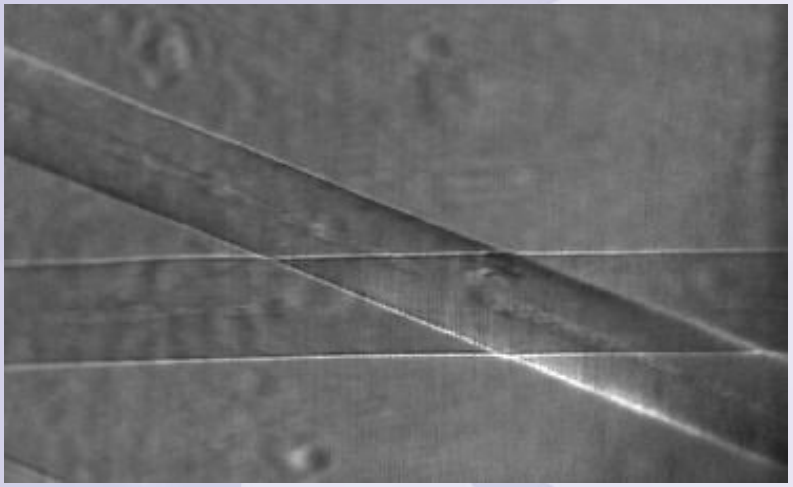
Scan of grating position



- **Energy = 10.05keV FOV 670x410 μm^2 Exposure 500ms**
- **Camera Kodak Apogee KX2e , 14bit, 9 μm pixel 20X Objective lens,**
- **YAG scintillation screen with 6μm thick Eu-doped active layer**
- **Images 4x4 binned , effective pixel size 1.8 μm, resolution >4 μm**

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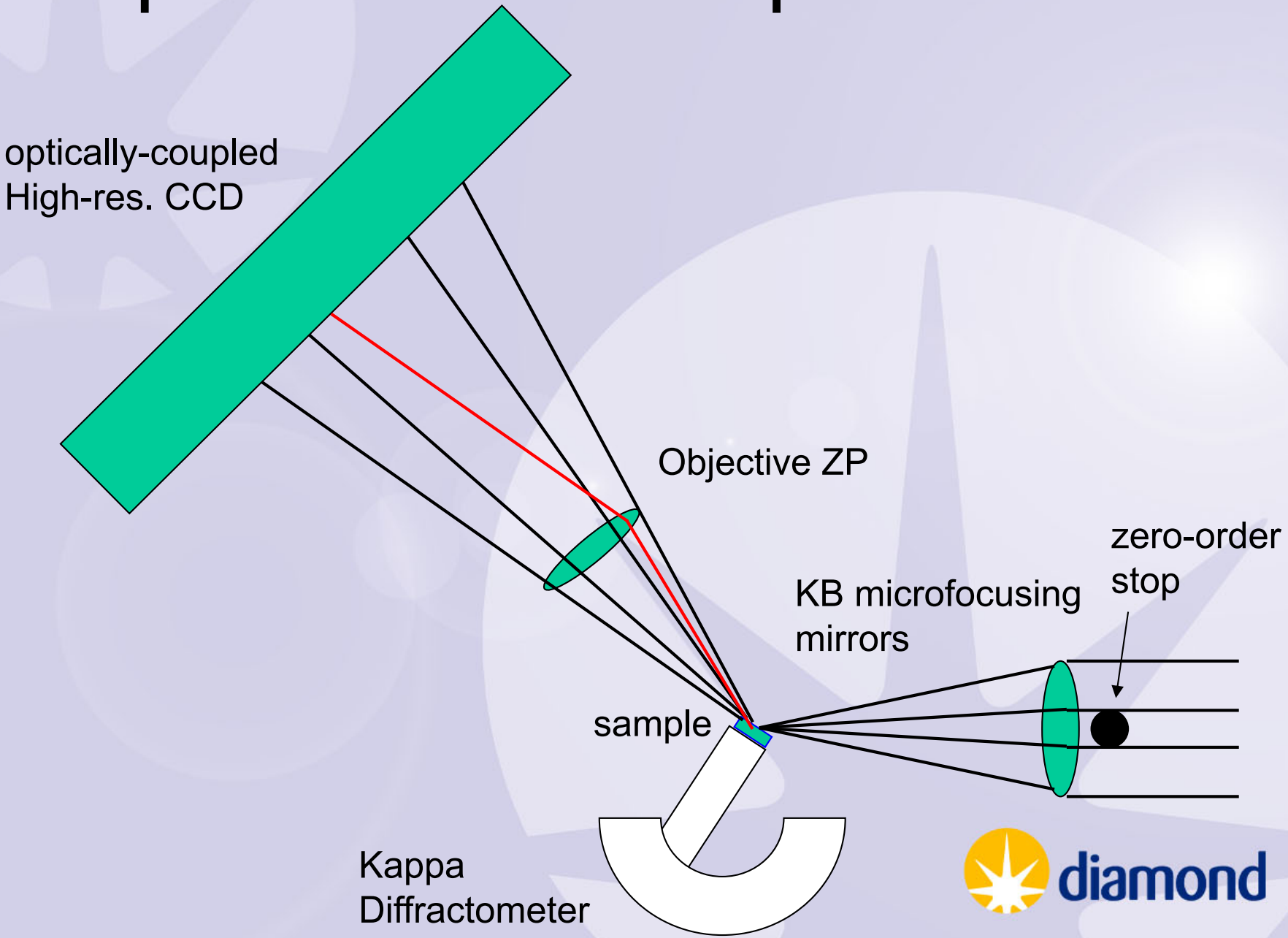
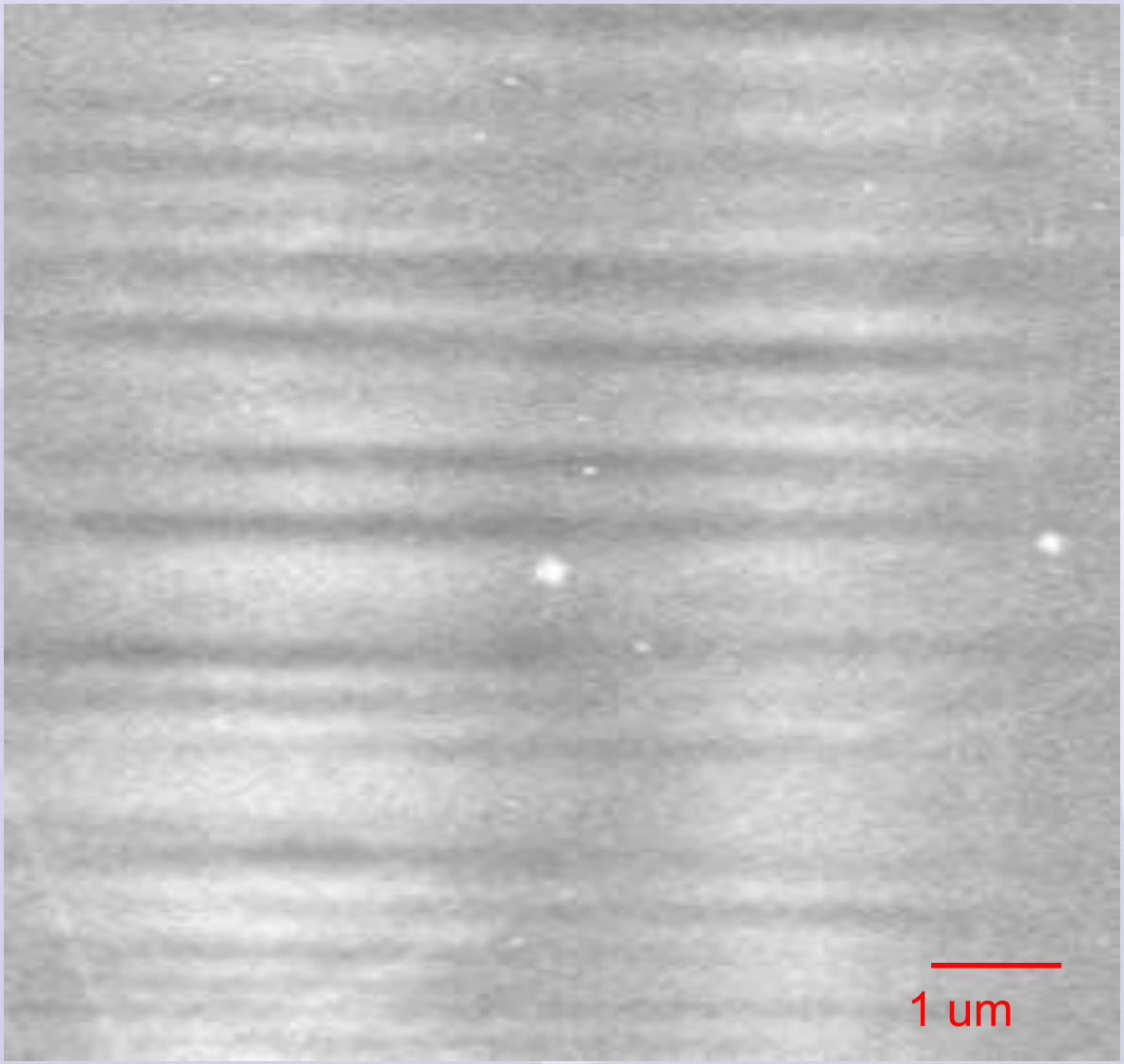
Experimental Setup at 32-ID



Magnified Real-Space Image of the Surface of RuO_2 (Y. Chu, APS)



Measured at Q=(0.2, 0.2, 0)

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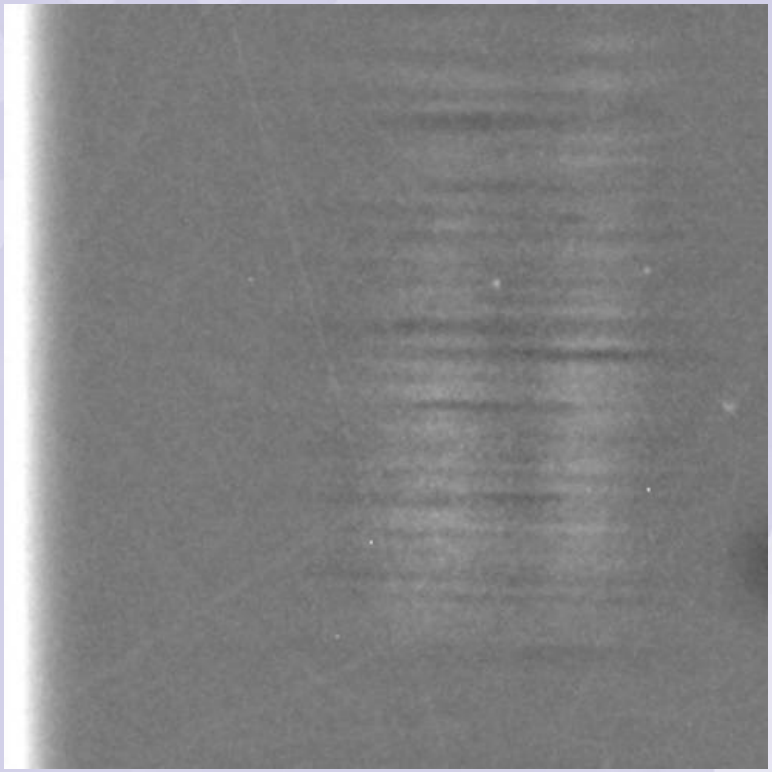
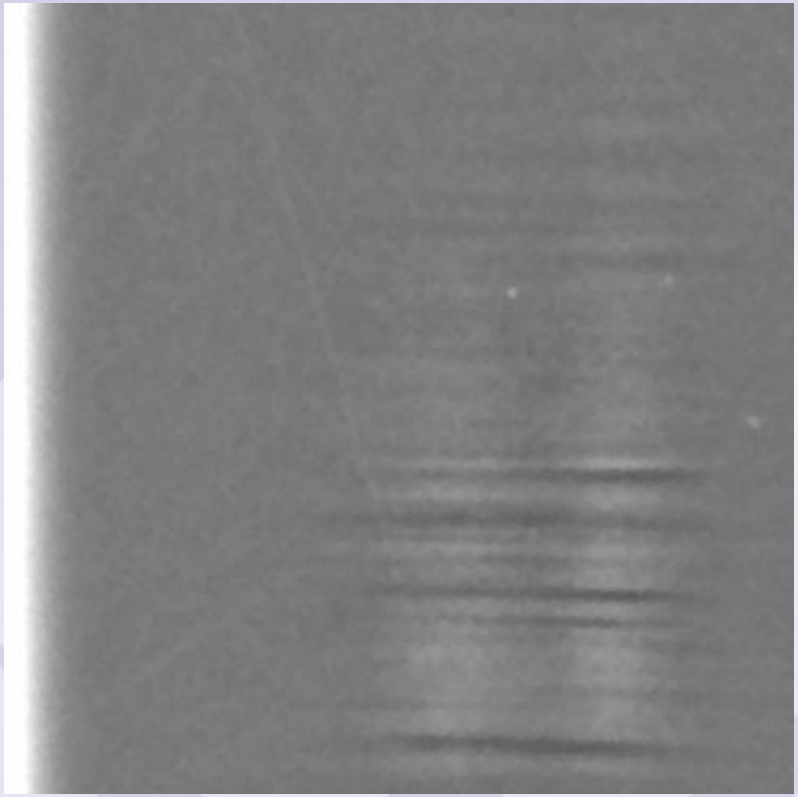


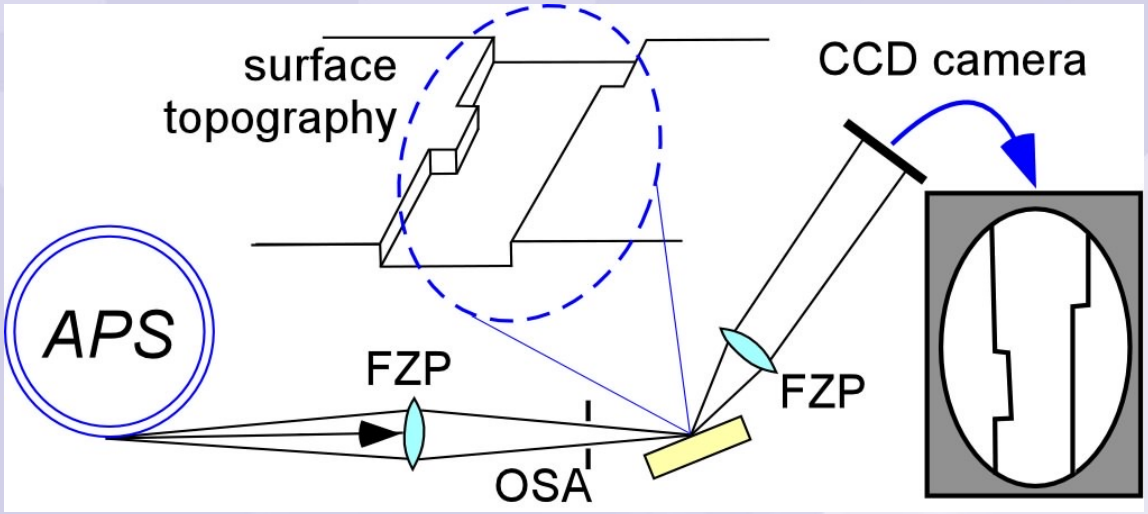
detY=0



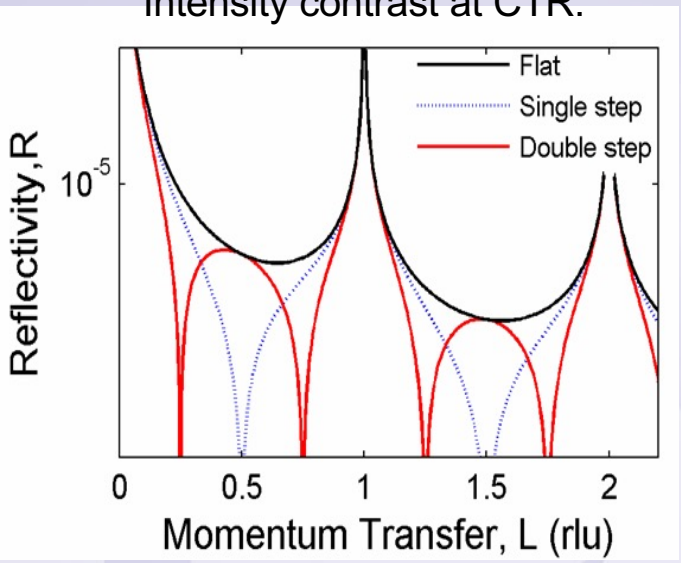
detY=400um

Phase-Contrast X-ray Diffraction Microscopy

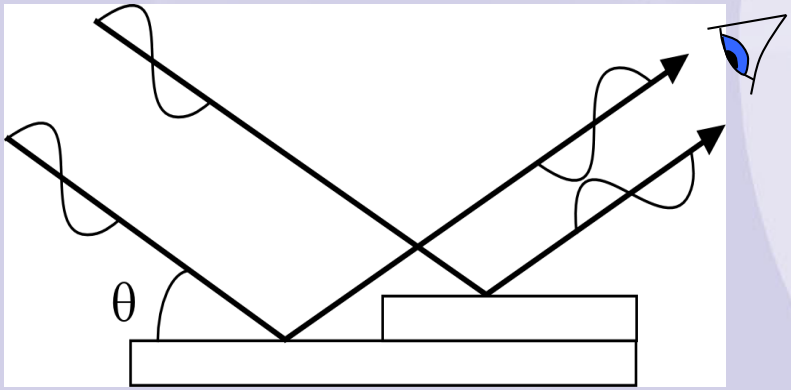
*P. Fenter, C. Park, Z. Zhang, and S. Wang, in review (2006)



Intensity contrast at CTR:



Phase contrast mechanism:



X-ray Reflection Interface Microscopy

Characteristics:

→ Strong contrast at defects (~100%), but weak reflected beam intensity ($R < 10^{-5}$)

→ Sub-nm vertical sensitivity, but modest lateral resolution (~100 nm, set by FZP)

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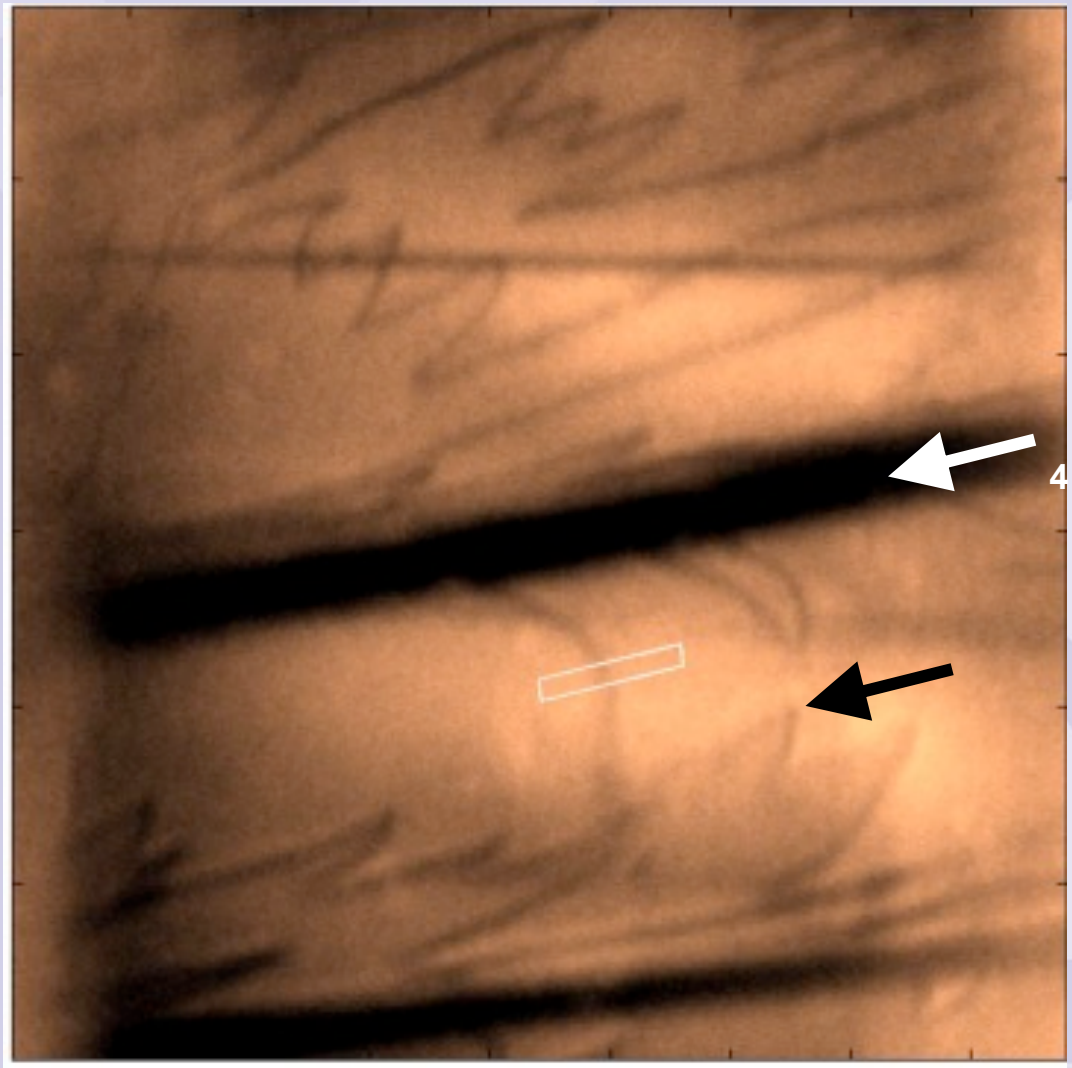
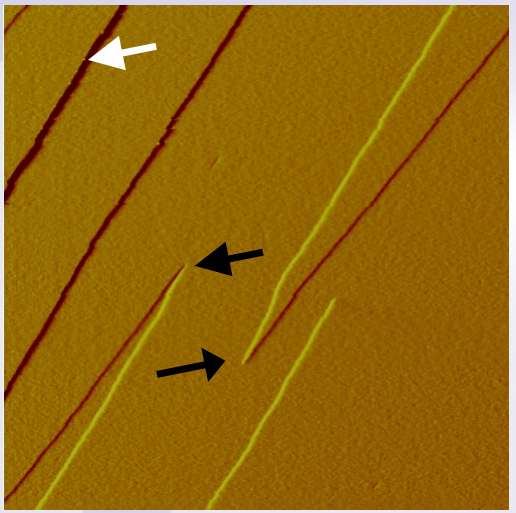
Observation of Surface Step Distributions

P. Fenter, C. Park, Z. Zhang, and S. Wang, in review (2006)
APS 12-ID-D, December, 2005
Step distributions on Orthoclase, $KAlSi_3O_8$ (001)





Teng et al., GCA **65,** 3459 (2001)

Imaging Conditions:

- θ = 1.4°
- E = 10 keV
- L = 0.25 rlu (Q = 0.24 Å^{-1})
- Sample held in air

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Microscopy at Diamond

- I-18 microfocus, scanning probe
- I-06 PEEM, with side branch
- I-12 JEEP, high energy radiography
- B-22 Infrared Microspectroscopy
- I-13 coherence, CXD

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Microscopy at Soleil

- SMIS infrared, 1-10um
- DISCO, 200-900nm, X-PEEM
- LUCIA, 0.8-8keV microfocus
- proposed hard X-ray microprobe
- proposed soft X-ray TXM and STXM

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Opportunities for Phase III

- Lens-coupled imaging of diffraction
  - combine with lensless imaging by CXD
- Phase contrast full-field tomography
  - modest coherence requirements
  - magnification by propagation
  - low-beta source (or virtual source)

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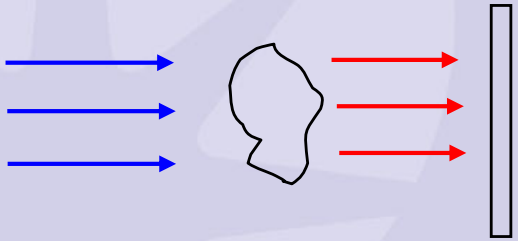
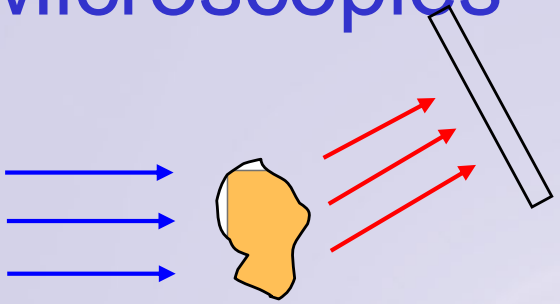
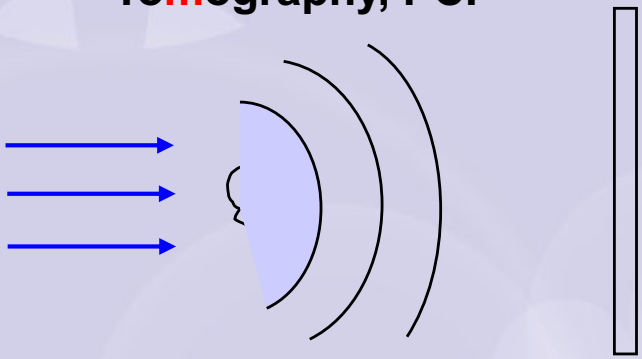
Summary: Hard X-ray Microscopies



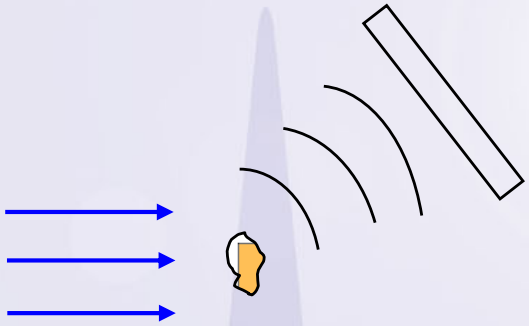
Projection Imaging,
Tomography, PCI



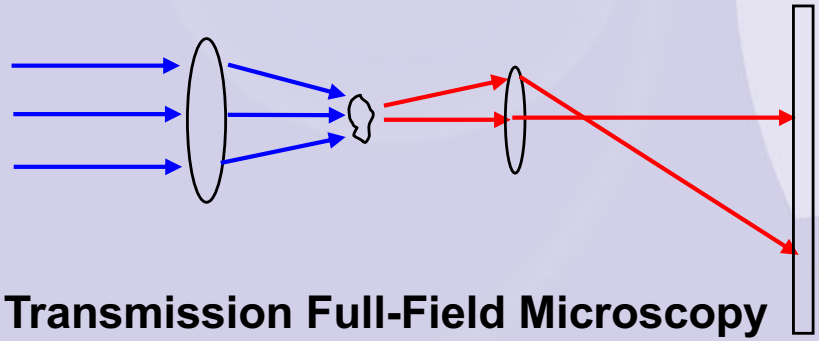
X-ray Topography



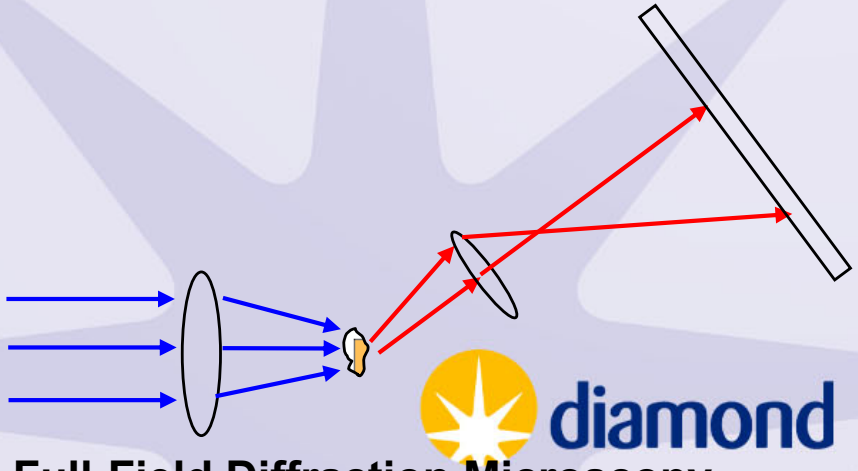
Coherent Diffraction imaging



Coherent X-ray Diffraction



Transmission Full-Field Microscopy



Full-Field Diffraction Microscopy

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