Status of the PHase Analyzer System (PHASY)

Ralf Hendrik Menk
for the PHASY collaboration
Sincrotrone Trieste, Italy

PHASY R.H.Menk A.Pillon, Elettra, Italy, A.Bravin, S.Fiedler, S.Bayat, ESRF, France, C. Hall, B. R. Dobson, K Cheung Cheung, R. Lewis, Daresbury Lab, UK, M. Lohmann, J. Metge, Hasylab, DESY, Germany, F.Arfelli, L.Rigon, University Trieste, Italy, O. Herzog, G. Ioannidis, B. Gottfried, University Bremen, Germany, H.-J. Besch, G.Heitner, K. Kuper, A. Khromova , H. Plothow-Besch, A.H. Walenta, L. Yu, University Siegen, Germany, W. Knüpfer, D. Mattern, J. Freudenberger, P. Schardt, Siemens Vacuum Technology Division, Erlangen, Germany

The European Commission
Community Research
Improving Human Research Potential
& the Socio-economic Knowledge Base

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What is PHASY all about?

- What is PHASY
- Who is PHASY
- DEI basics
- How does it look
- Orasis software
- Compact source
- Dose consideration
- Higher reflections
- Why this increase
- What is feasible
- Index finger joints
- Cartilage and bones
- In vitro images
- in vivo images
- beyond m. imaging
- Limitations
- Acknowledgements

- 5 years project supported by EU:
  - March 2000- February 2005
- Aim:
  - thorough study and the full exploitation of the "Diffraction Enhanced Imaging" technique
- Milestones:
  - 4 DEI systems developed and installed at the synchrotrons
  - Evaluation of the physical properties and requirements (source, crystals, imaging detectors)
  - Feasibility and medical applications studies
  - design study of a final synchrotron - and a x-ray tube based system

Who is PHASY?

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- Synchrotron light sources
  - Elettra (Trieste, Italy)
  - ESRF (Grenoble, France)
  - DESY (Hamburg, Germany)
  - SRS (Daresbury, UK)
- Universities
  - Trieste (Italy)
  - Bremen (Germany)
  - Siegen (Germany)
- Industrial Partnership
  - Siemens AG (Erlangen, Germany)

DEI basics

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Phase shift in the object => Photons are refracted at μrad angles

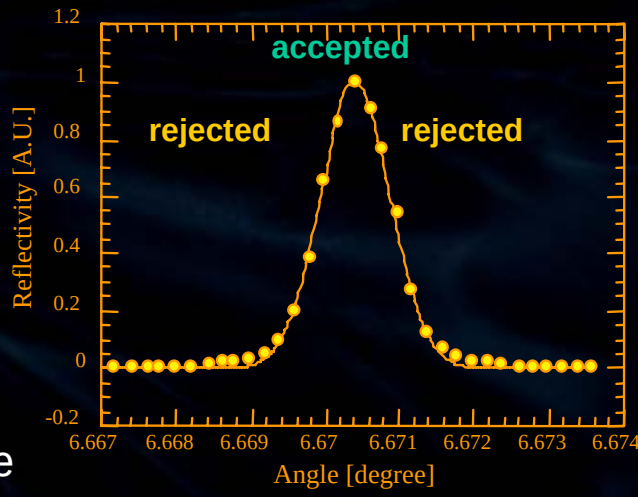
The analyzer crystal acts as an angular filter, the filtering function being the rocking curve (FWHM: 1-20 μrad)

Photons deviated outside the rocking curve width are not diffracted by the analyzer towards the detector

» Extinction contrast

Photons deviated within the rocking curve width are diffracted by the analyzer towards the detector, the probability being given by the rocking curve

» Refraction contrast



Extinction and refraction contrast depend on the position of the analyzer on the rocking curve

How does the system looks like?

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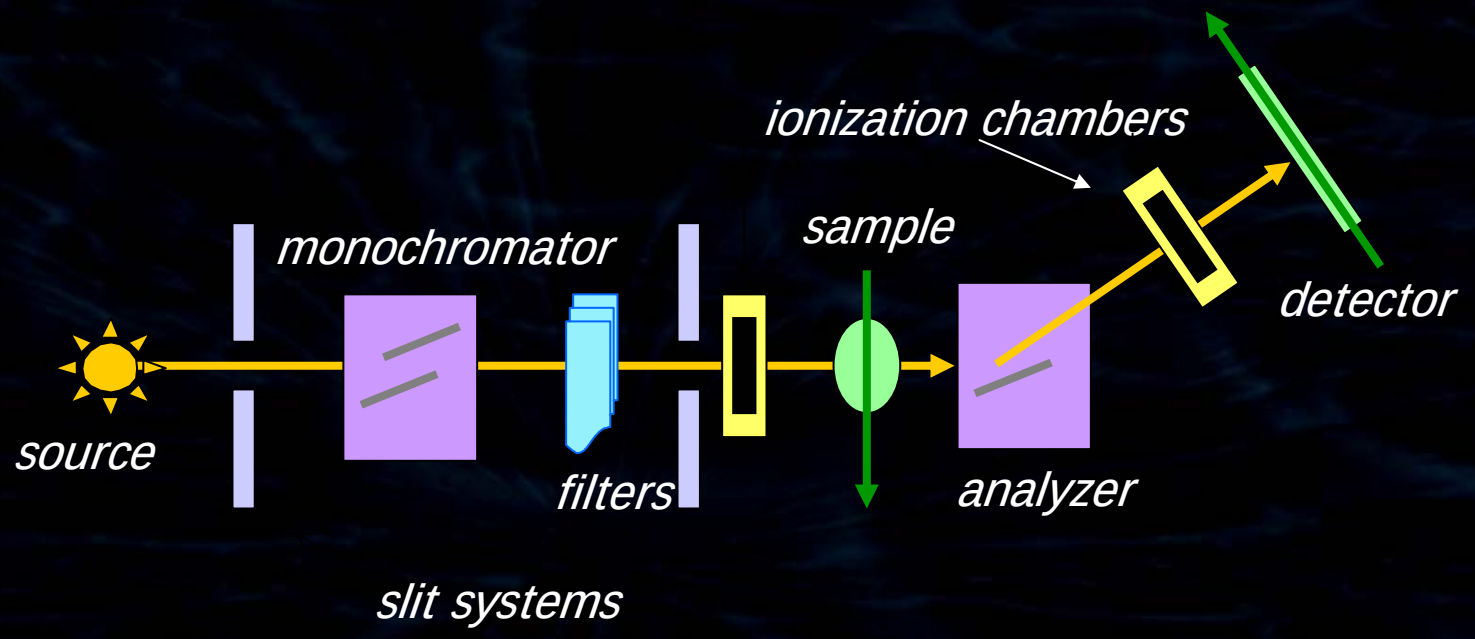

- A second (analyzer) crystal between sample and detector
- recording of two images and separation into apparent absorption image and refraction image

D.Chapman et al, *Diffraction Enhanced x-ray imaging*, Phys.Med.Biol. 42, (1997), 2015 - 2025

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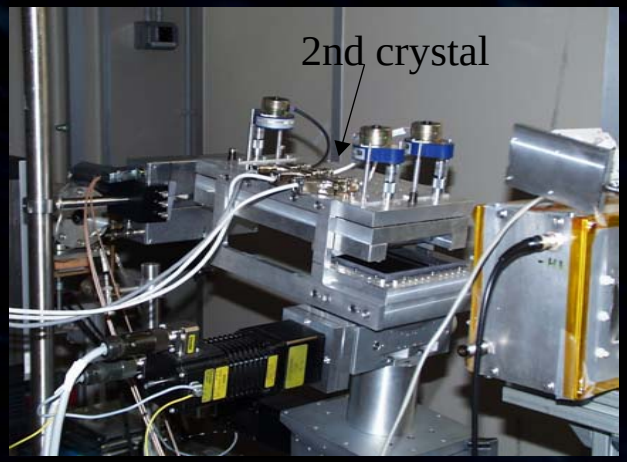
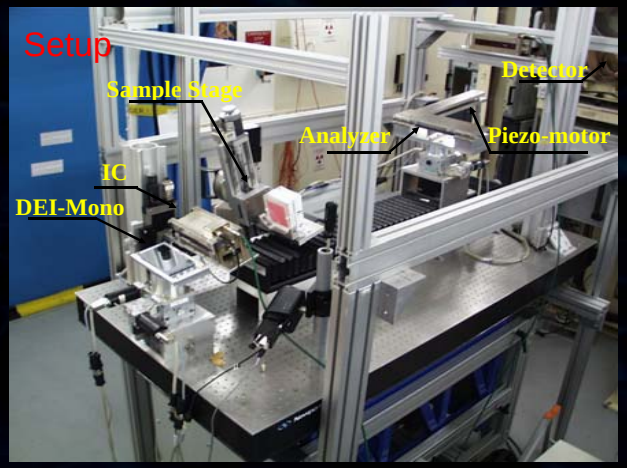
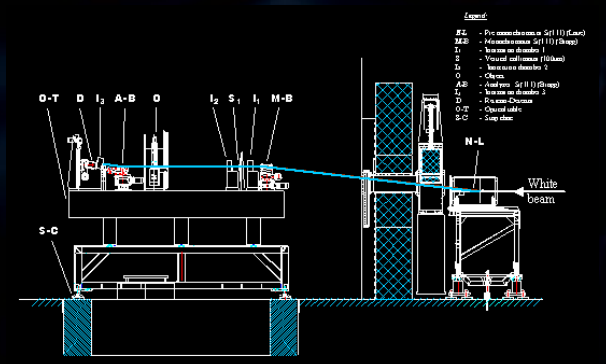
Elettra



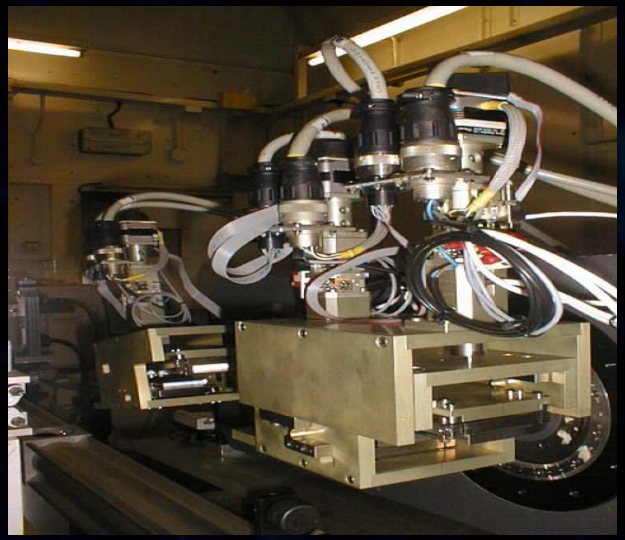
ESRF (in-vivo)



HASYLAB



SRS



System comparison

Synchrotron Source	Energy range [keV]	Analyzer (Bragg mode)	Beam size mm^2	Angular resolution μrad	Beam divergence σ(h,v) mrad	Detector
Elettra BM	8-35	Single Si (111) Double Si (111) (333)	0.6*150	< 0.5	7*0.2	2*2k CCD 14 μm pixel Fuji image plate 50 μm pixel
ESRF Wiggler	20-70	Single Si (333)	1*100	< 0.1	0.7*0.07	2*2k CCD 50 μm pixel
SRS BM	12-40	Double Si (311)	1*40	0.1	2*0.1	2*2k CCD 20 μm pixel
HASYLAB Wiggler	10-70	Double Si (333) Double Si (111)	0.5 50	0.02	0.25*0.43	2*2k CCD 5 μm pixel photodiode array 25 μm

See poster session

Orasis software

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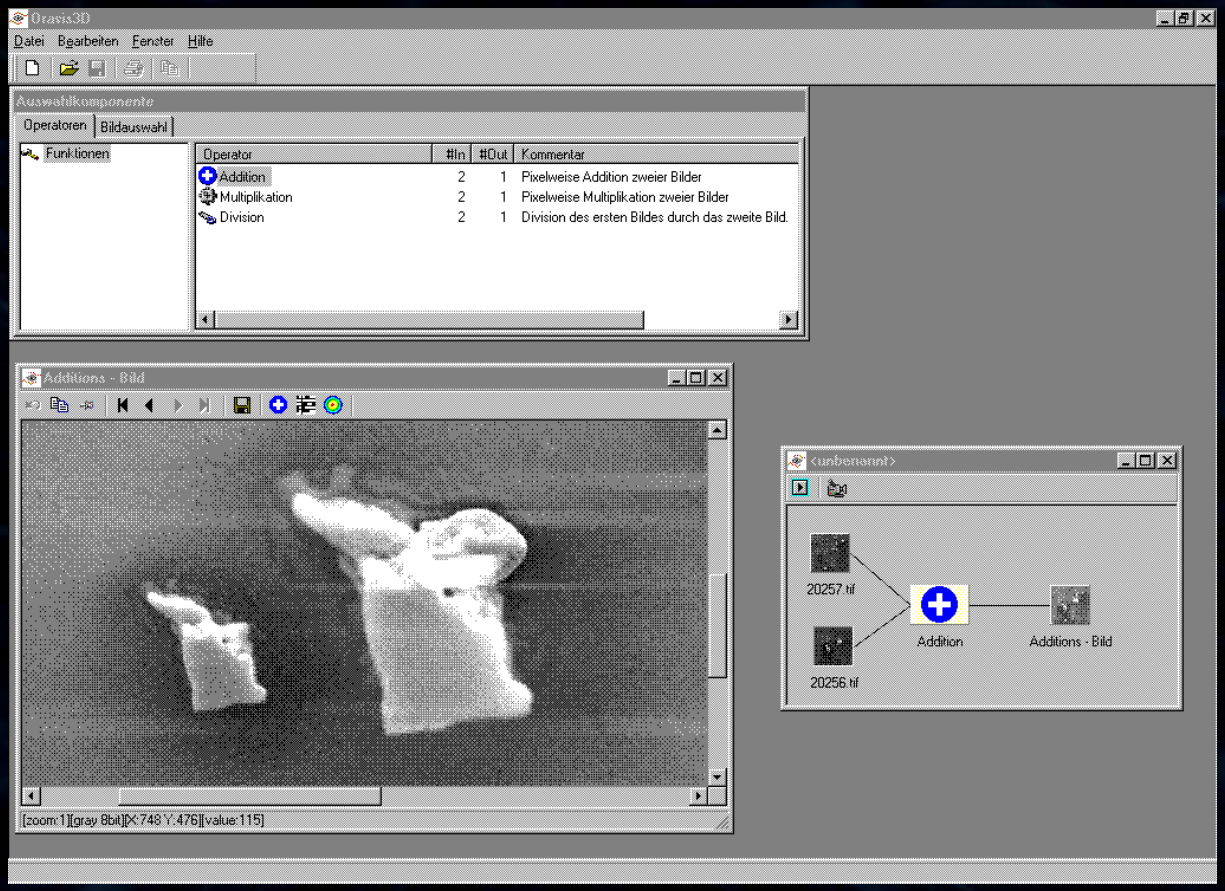

Image processing tool of the University Bremen

- Graphical programming
- Image processing library
- easy user interface for off line data crunching

Compact source

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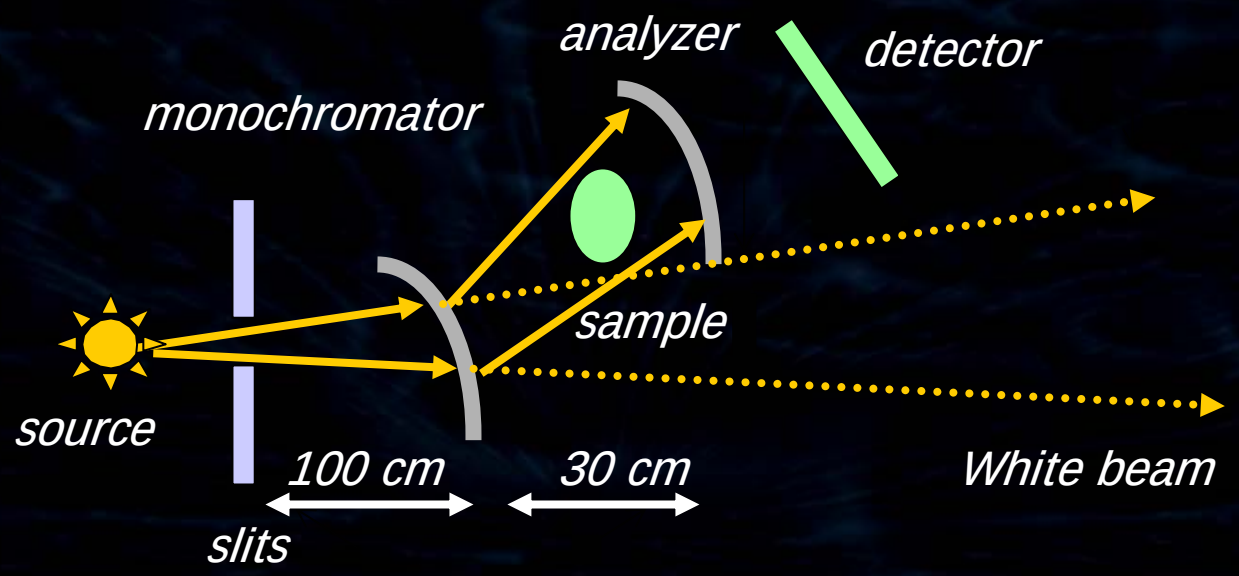
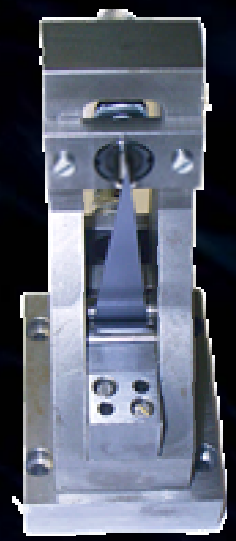
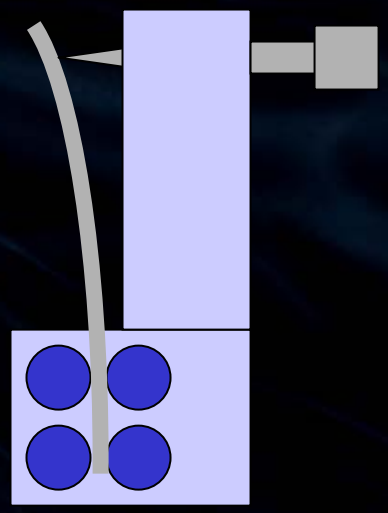


Siemens (source)
University Siegen optics





Dose and contrast considerations in absorption

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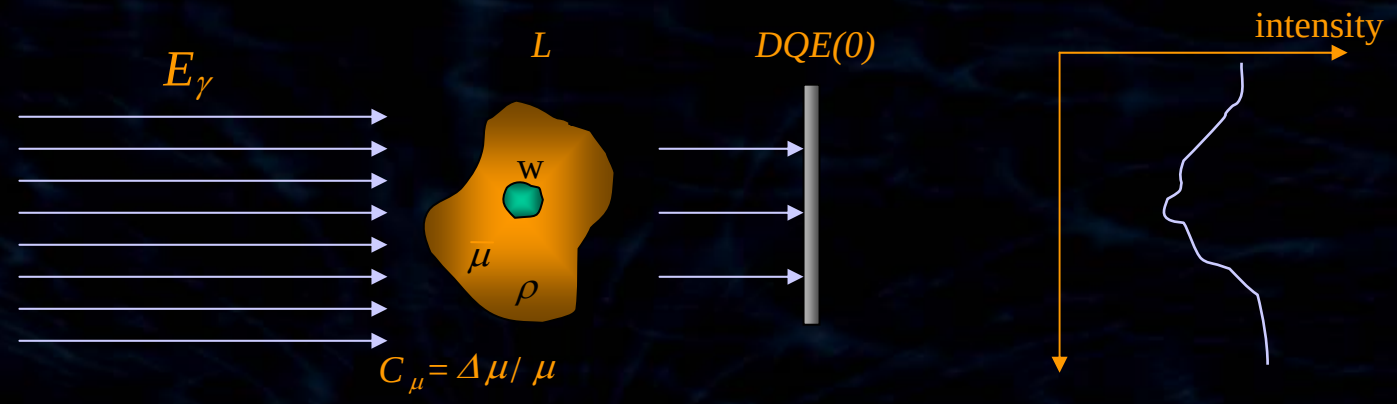
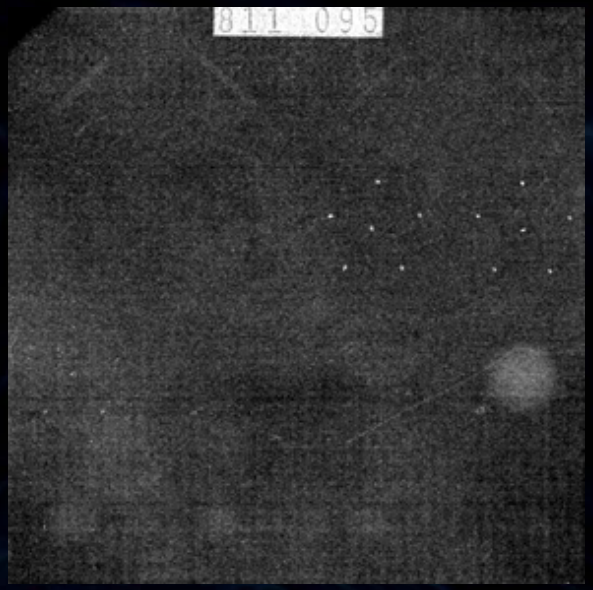


$$D_{skin} = \frac{2 \cdot e^{\bar{\mu}} \cdot L \cdot SNR_{\Delta S}^2}{DQE(0) \cdot \bar{\mu}^2 \cdot w^4 \cdot C_\mu^2} \cdot E_\gamma \cdot \left(\frac{\bar{\mu}}{\rho}\right) \approx \frac{1}{w^4 \cdot C_\mu^2}$$

ACR (American College of Radiology) Mammography Quality Assurance Object



Absorption Image
Elettra
25 keV
2.6 mGy

Dose and contrast considerations

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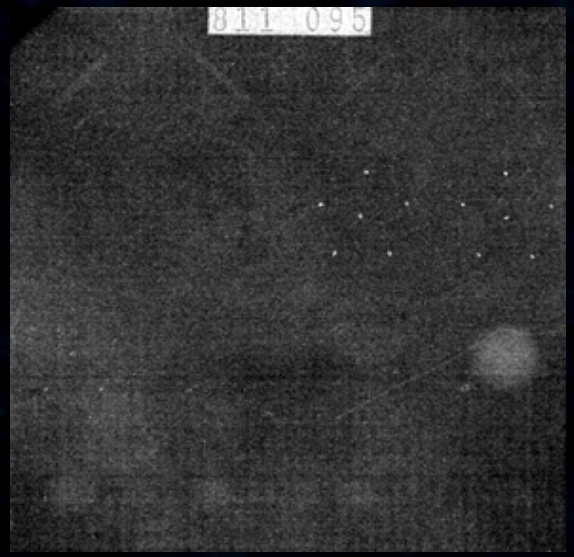
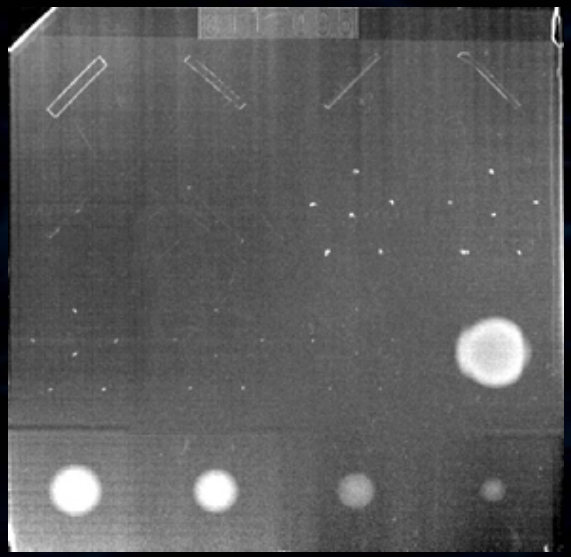
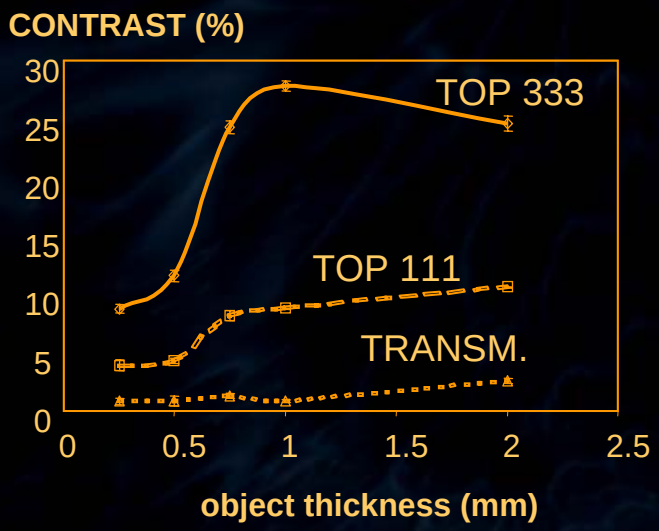


Absorption Image Elettra
25 keV 2.6 mGy



DEI - Peak [333] Elettra
25 keV 0.5 mGy



$$D_{skin} \approx \frac{1}{w^4 \cdot C_\mu^2}$$

$$C_\mu = 25 \Rightarrow$$

$$D_{skin}^{DEI} \approx \frac{1}{625 w^4} D_{skin}^{absorption}$$

Higher reflections

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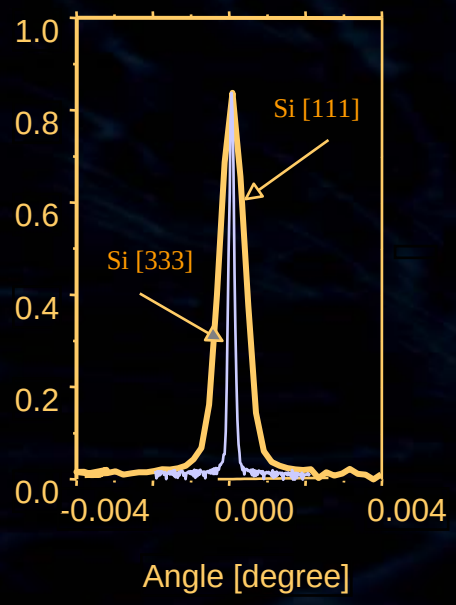
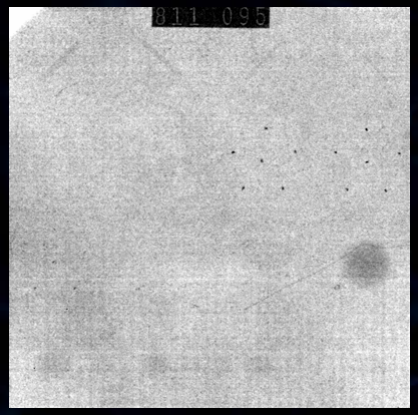
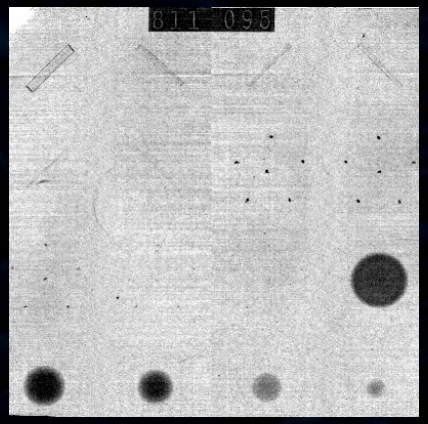
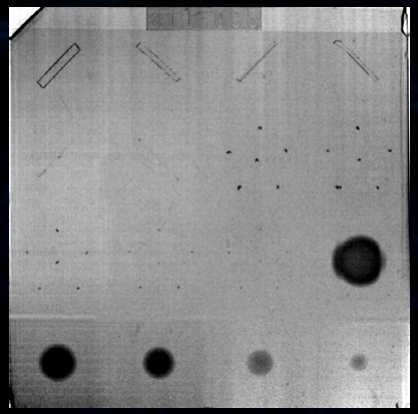




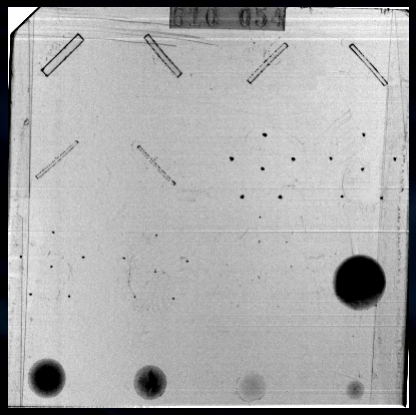
Absorption Image
Elettra 25 keV 2.6 mGy



DEI - Top [111] Elettra
25 keV 2.3 mGy



DEI - Top [333] Elettra
25 keV 0.5 mGy



DEI - Top [444] NSLS
21.1 keV 1.8 mGy

L. Rigon et al., *Diffraction Enhanced Imaging utilizing different crystal reflections at Elettra and NSLS* Proceedings of SPIE, **4682** (2002) 255-266

Why this increase?

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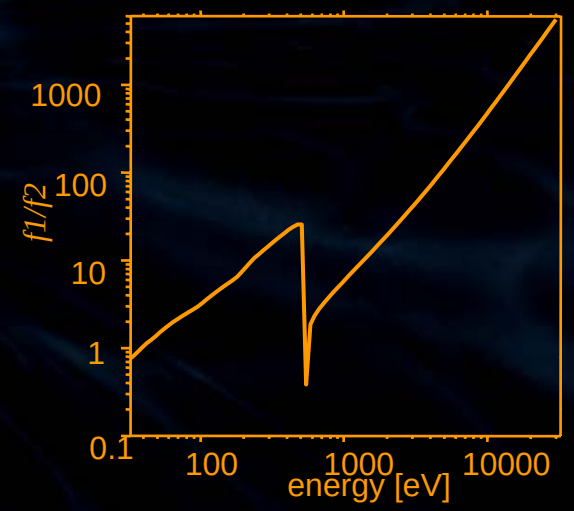
$$\varphi(x,y) = -r_e \cdot \lambda \cdot \int \rho_e(x,y,z) \cdot dz \qquad \Delta\alpha \approx \frac{\lambda}{2 \cdot \pi} \cdot \frac{\partial \varphi(x)}{\partial x}$$

$\varphi, \Delta\alpha \approx Z$ like Compton - absorption ~ Z^5

- Compton and photo effect cross sections ~ r^2_e
- $r_e \lambda >> r^2_e$
- phase shift is weakly coupled to absorption through the dispersion relations
- interference with primary wave (phase contrast)



What is feasible?

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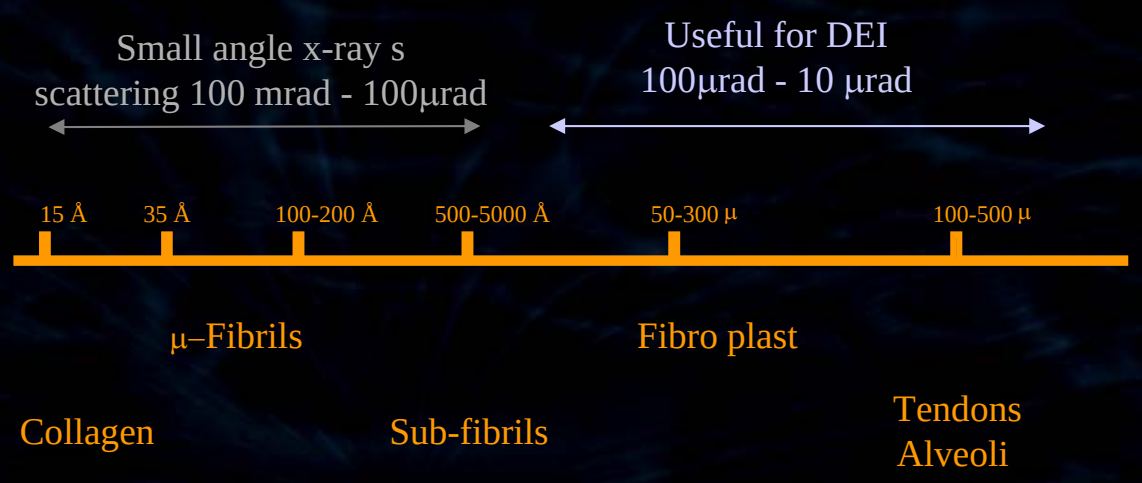

Excellent tool for diagnosing

- Breast cancer
- bone structures + tendons
- bone cartilage interfaces
- lung and internal organs
- materials
- etc

Index finger proximal interphalangeal joint

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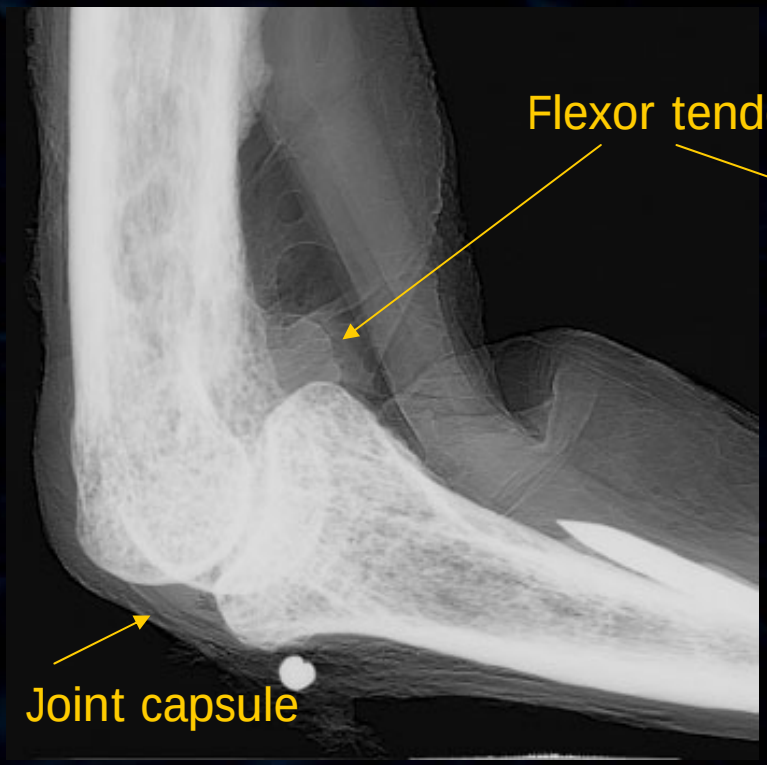

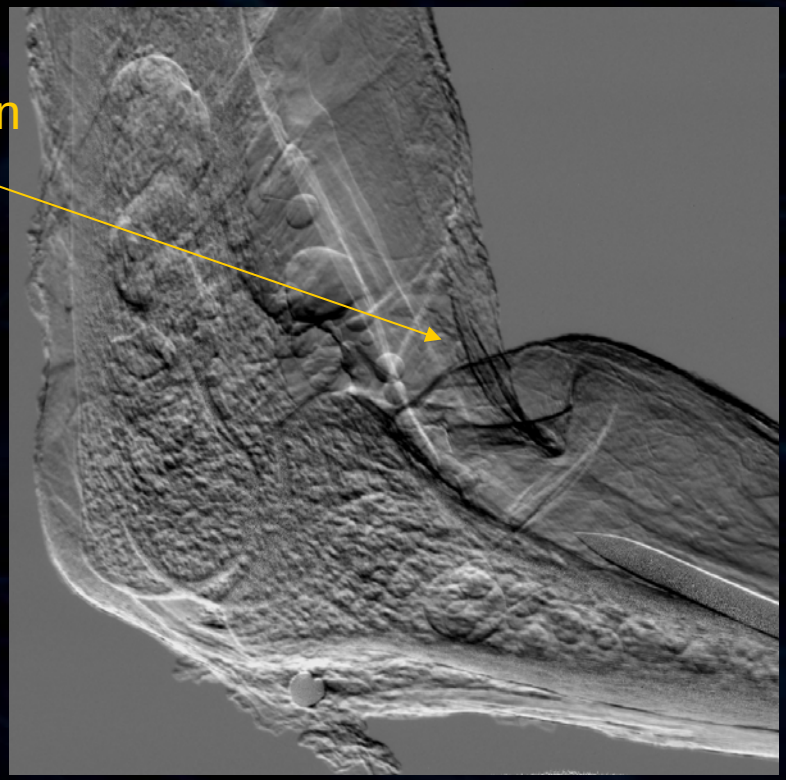

Images taken at Elettra at 20 keV
University Trieste, Daresbury Elettra

Cartilage and bone cartilage interfaces

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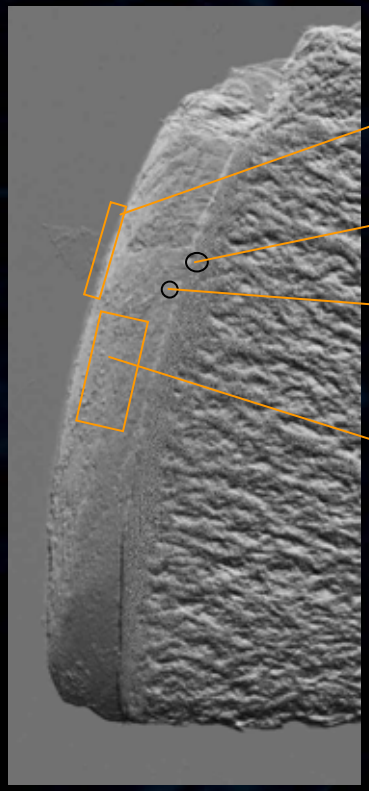

Superficial Layer (Zone of horizontal collagen fibers with flat cells)

Subchondral Bone Plate (Important for diagnosis in osteoarthritis)

Tidemark (Border between normal and mineralized cartilage)

Transitional and Deep Layer (chondrocytes, collagen fiber switches from horizontal to vertical orientation, increasing stiffness and material density)

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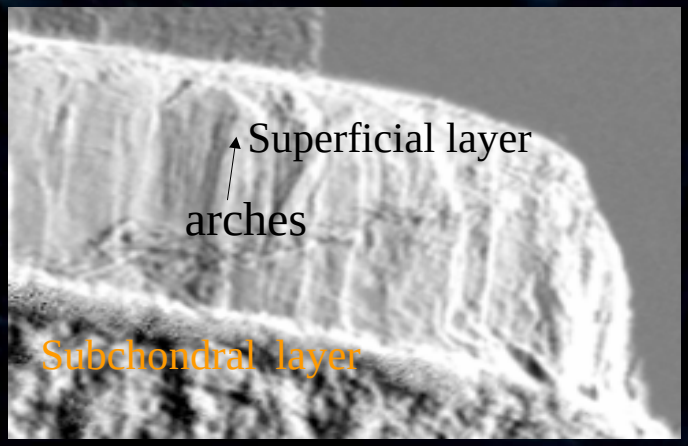
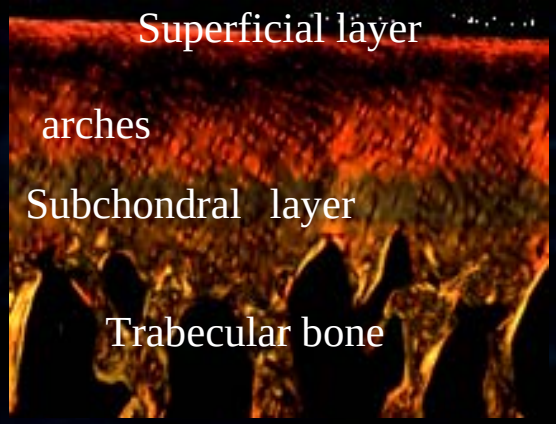
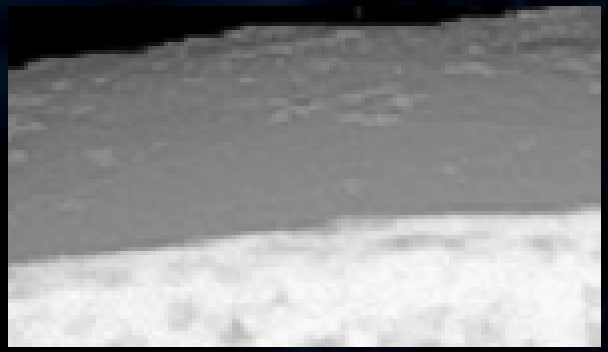
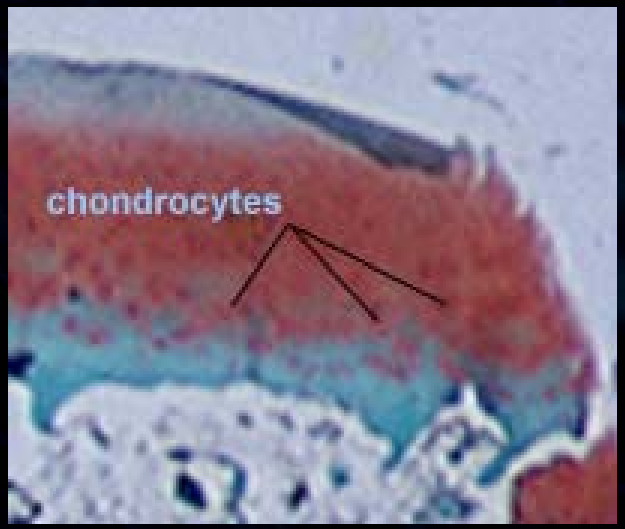


Refraction image Elettra





Apparent absorption image Elettra



Sample preparation and histological cuts Majumdar

Cartilage and enzyme treatments, Implants

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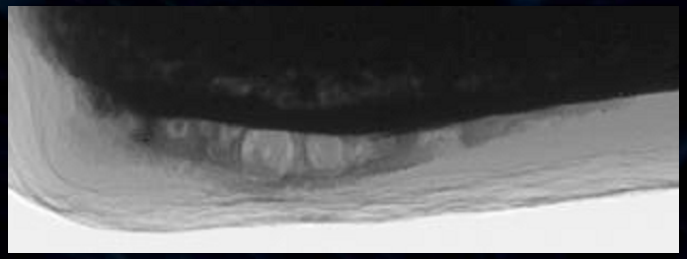
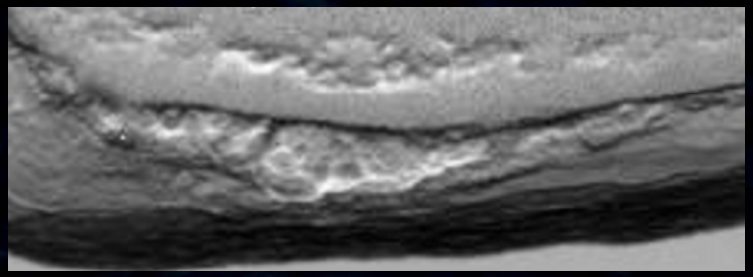
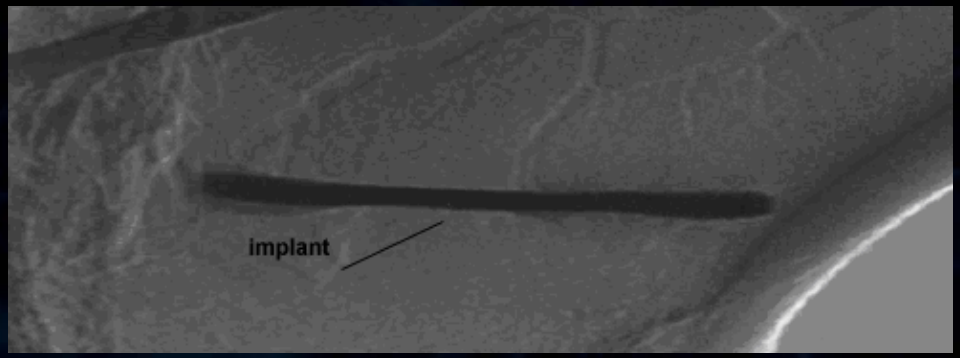
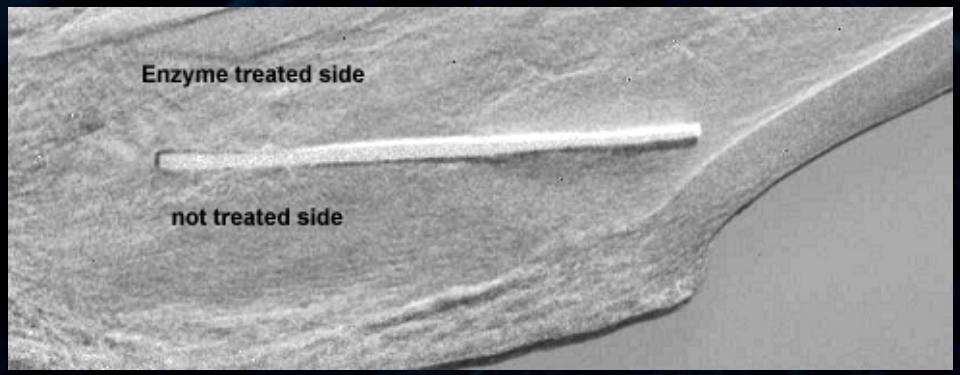






healing of titanium inplants



Sample provided by Mollenhauer & Muehlmann

In vitro mouse lung images Elettra 17 keV

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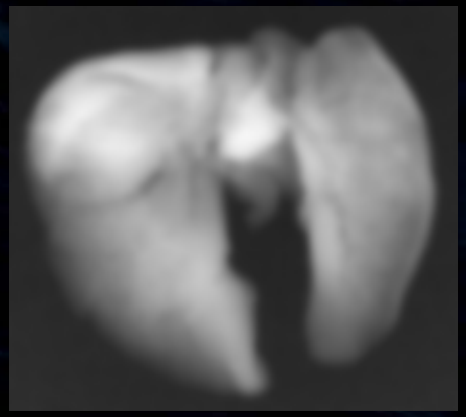
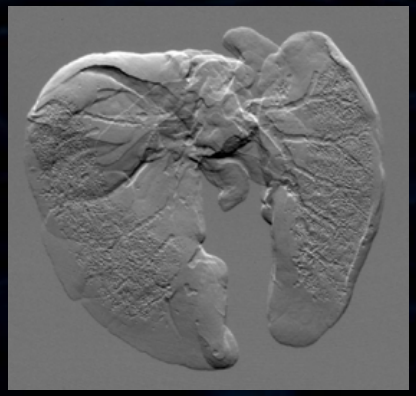
Sample fixed in formalin

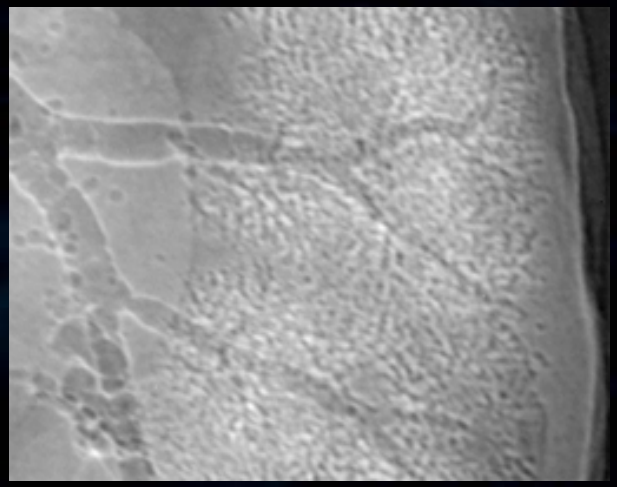


Transmission image

Apparent absorption image



Refraction image



Zoom extinction contrast

Zoom reverse contrast

R.A.Lewis et al., *X-ray refraction effects: application to the imaging of biological tissues,* Brit. J. Radiol., **76** (2003) 301–308

In vitro images

- What is PHASY
- Who is PHASY
- DEI basics
- How does it look
- Orasis software
- Compact source
- Dose consideration
- Higher reflections
- Why this increase
- What is feasible
- Index finger joints
- Cartilage and bones
- In vitro images
- in vivo images
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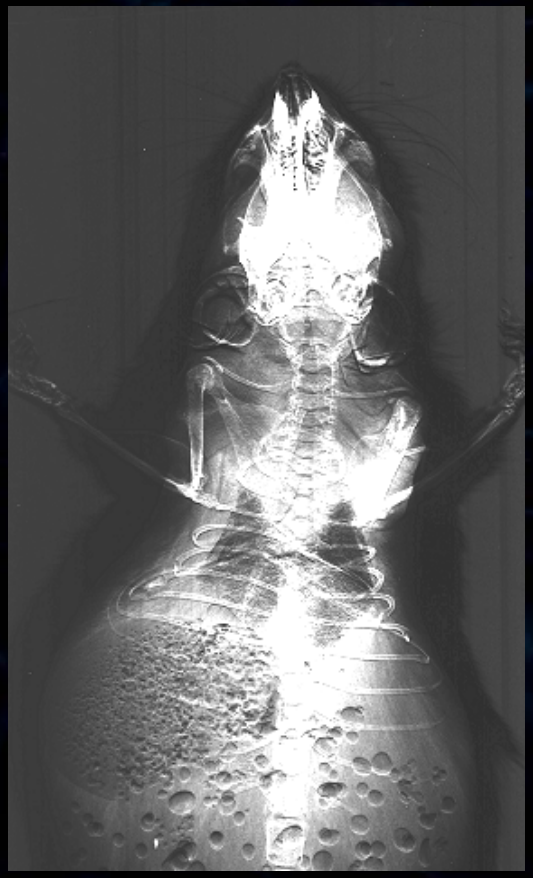
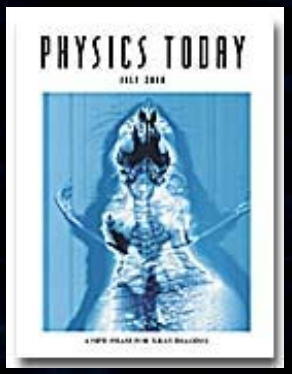
- Limitations
- Acknowledgements

DEI - Top [111] Elettra

DEI - far slope [111] Elettra





In vivo lung images ESRF

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Far slope image

Tomographic reconstruction

Limitations

- multiple scattering destroys refraction / extinction contrast
- can be partially recovered by DEI tomography

Beyond medical imaging

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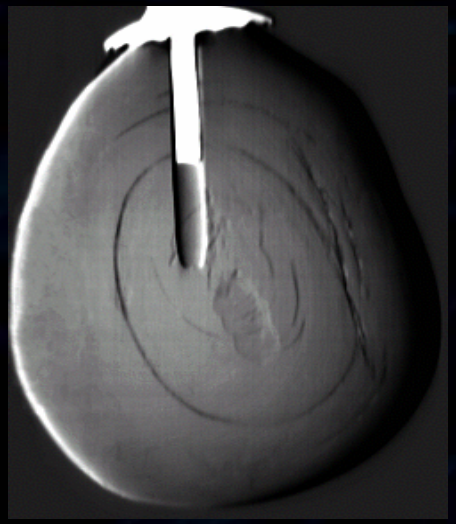
Possible applications in other fields

- material science
- food science/control
- archeology
- paleontology



Hasylab group

Beyond medical imaging

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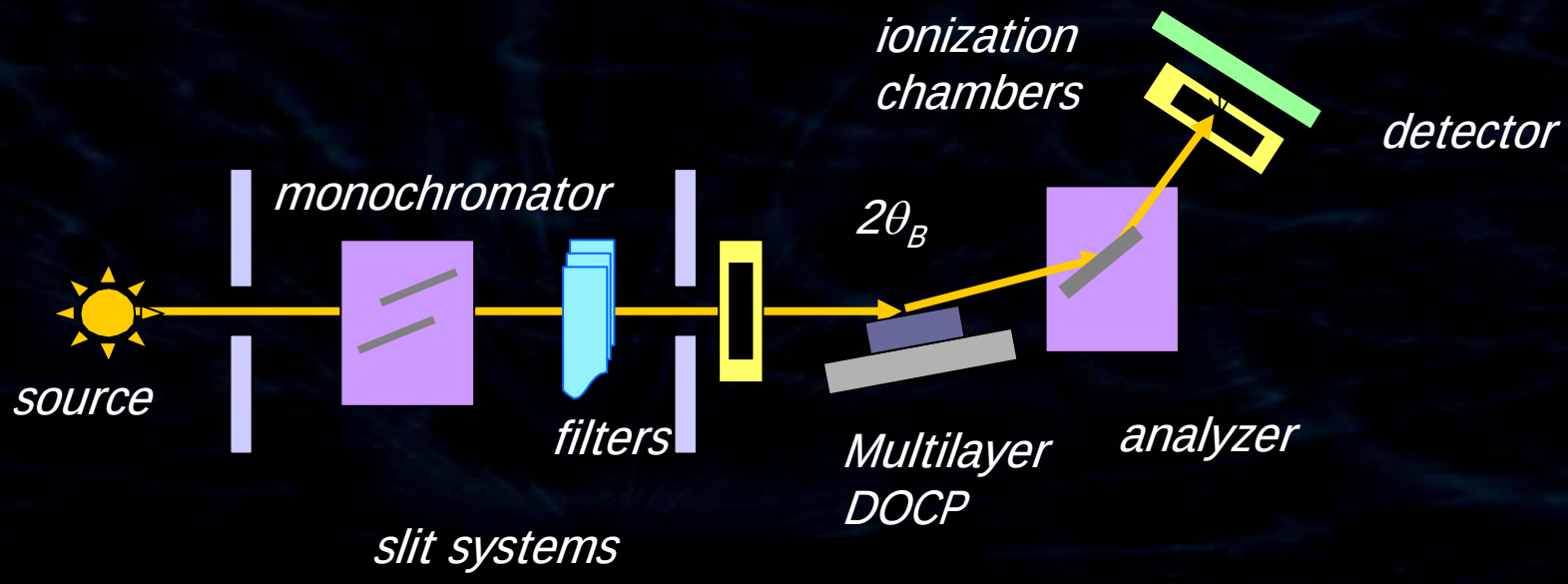

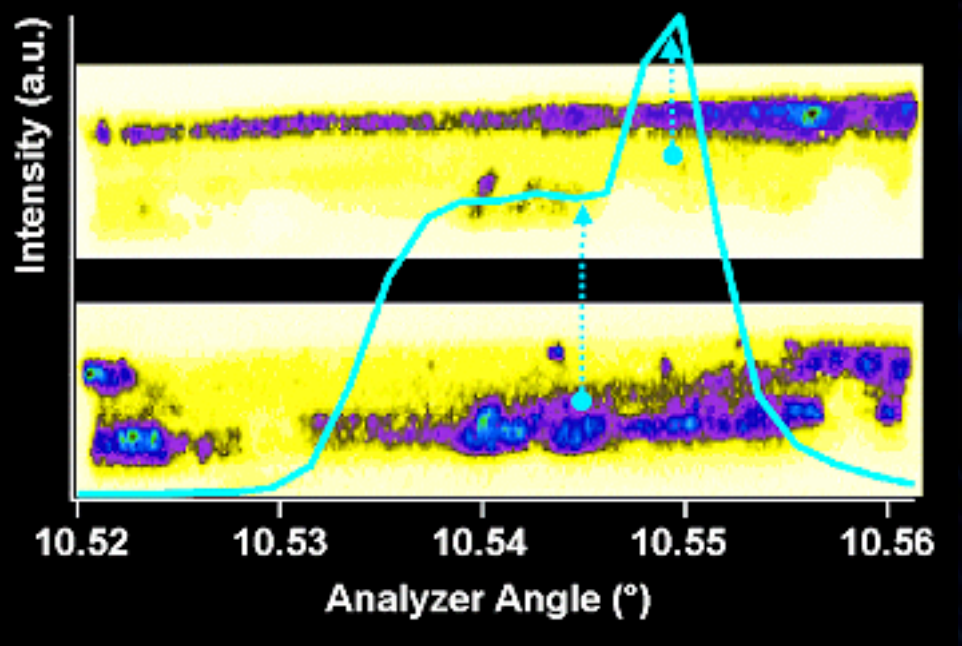

Multi layer reflection
0.25 nm^{-1}

Amenitsch et al Elettra

Limitations and Wish-list

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Limitations

- multiple scattering
- time consuming procedure

Study of dynamic processes

- new detectors
- new optics

Hasnah M., Oltulu O., Zhong Z., Chapman D. "Single-exposure simultaneous diffraction-enhanced imaging" NIM A 492 (2002) pp.236 -240

Wernick M. Wirjadi O., Chapman D., Oltulu O., Zhong Z. Yang Y. "Preliminary investigations of a multiple image radiography method" Proceedings 2002 IEEE International Symposium on Biomedical Imaging (ISBI 2002), pp. 565-568.

Pagot E, Cloetens P, Fiedler S, Bravin A, Coan P, Baruchel J, Hartwig J, Thomlinson W, "A method to extract quantitative information in analyzer-based x-ray phase contrast imaging", Applied Physics Letter 82 (2003)(20): pp.3421-3423

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