



**X-Ray History**

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**W. C. RÖNTGEN**

7. Nachdem ich die Durchlässigkeit verschiedener Körper von relativ großer Dicke erkannt hatte, beeilte ich mich, zu erfahren, wie sich die X-Strahlen beim Durchgang durch ein Prisma verhalten, ob sie darin abgelenkt werden oder nicht. Versuche mit Wasser und **VON STRÄHLEN**

15. Nach Interferenzerscheinungen der X-Strahlen habe ich viel gesucht, aber leider, vielleicht nur in Folge der geringen Intensität derselben, ohne Erfolg.

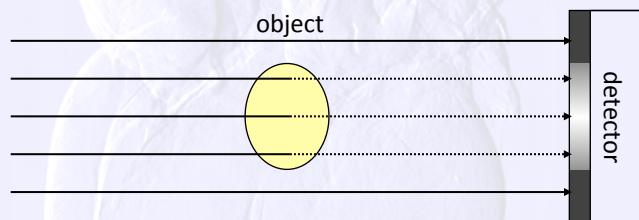
**W. C. RÖNTGEN**  
ER GESELLSCHAFT DIE ERSTE MITTEILUNG  
IM ENTDECKTEN STRÄHLEN VOR

NEUDRUCK  
ES 100JÄHRIGEN BESTEHENS  
ÄLISCH-MEDIZINISCHE  
HAFT ZU WURZBURG

RUNDET 1849 VON  
ECKER · J. SCHERER · R. VIRCHOW  
UND ANDEREN

Franz Pfeiffer

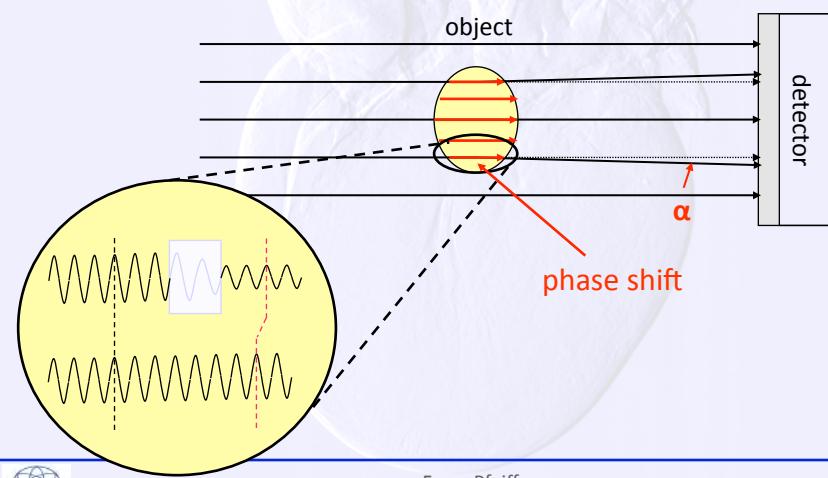
## Conventional X-Ray Radiography: Attenuation Contrast



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## New 'Wave-Optical' X-ray Radiography: Phase Contrast



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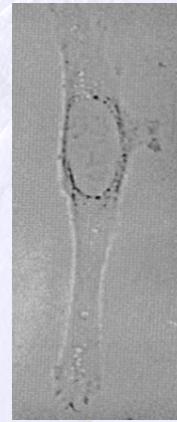


## Phase-Contrast Imaging with **Visible Light**



Frits Zernike, 1953  
Nobel Prize for  
Phase Contrast Microscopy

fibroblast  
cells



Conventional  
Bright Field



Phase  
Contrast

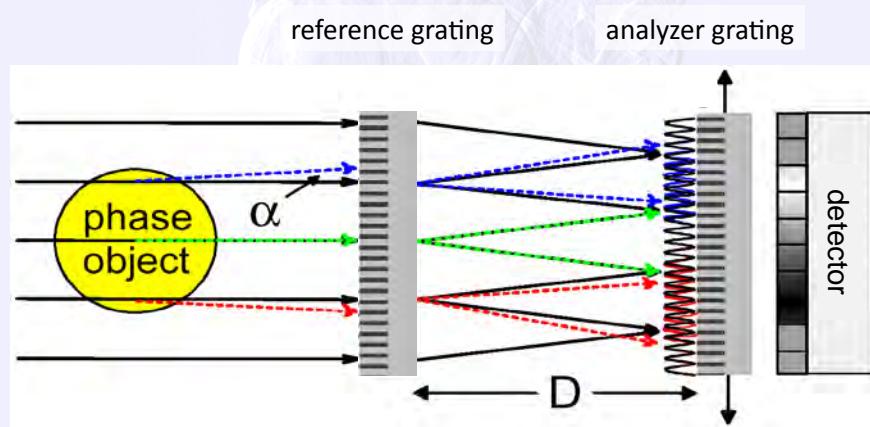
Zeiss microscope  
[www.zeiss.de](http://www.zeiss.de)



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## Phase-Contrast Imaging using **X-Ray Optical Gratings**



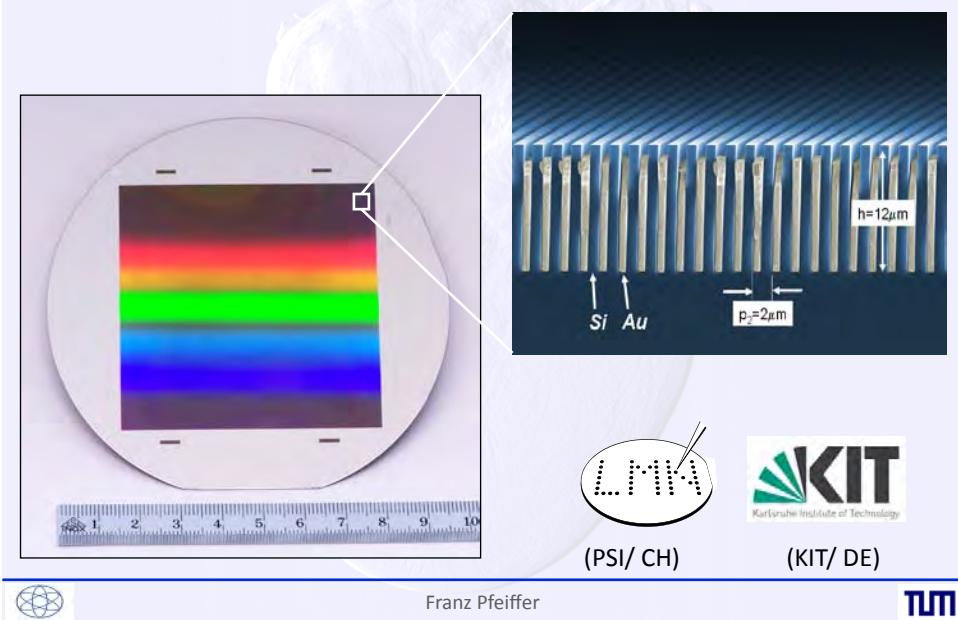
Momose et al | Optics Express | 2003  
Weitkamp et al | Optics Express | 2005  
Pfeiffer et al | Physical Review Letters | 2005



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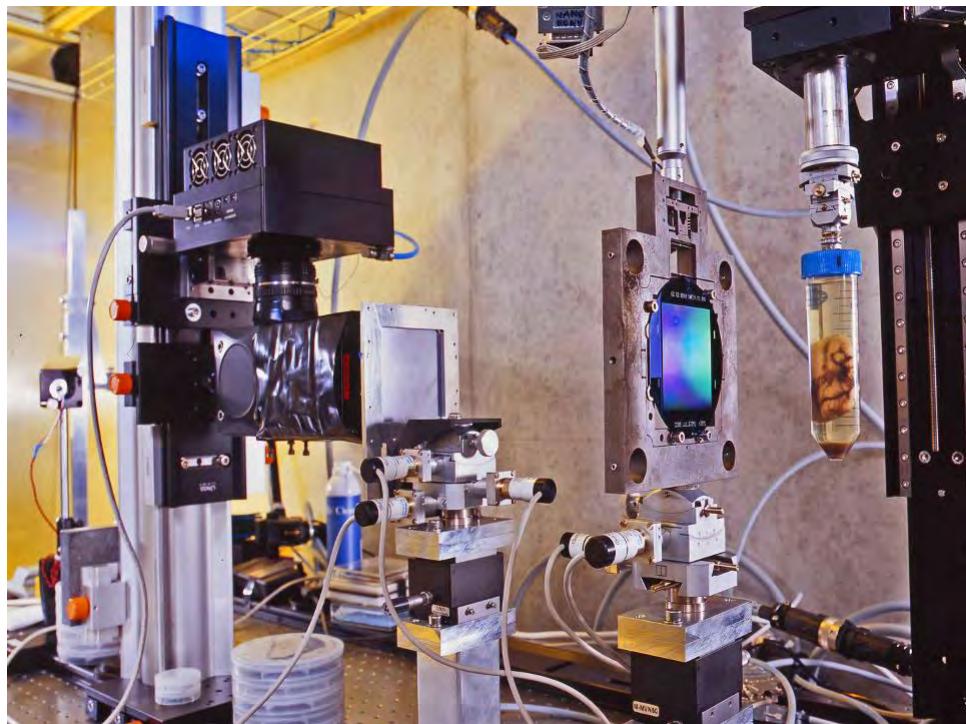


## X-Ray Optical Transmission Gratings

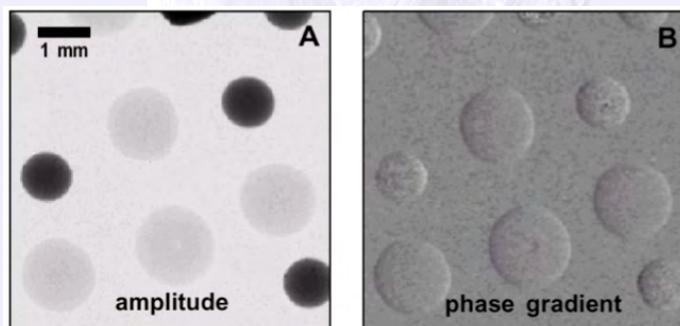


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## First Results

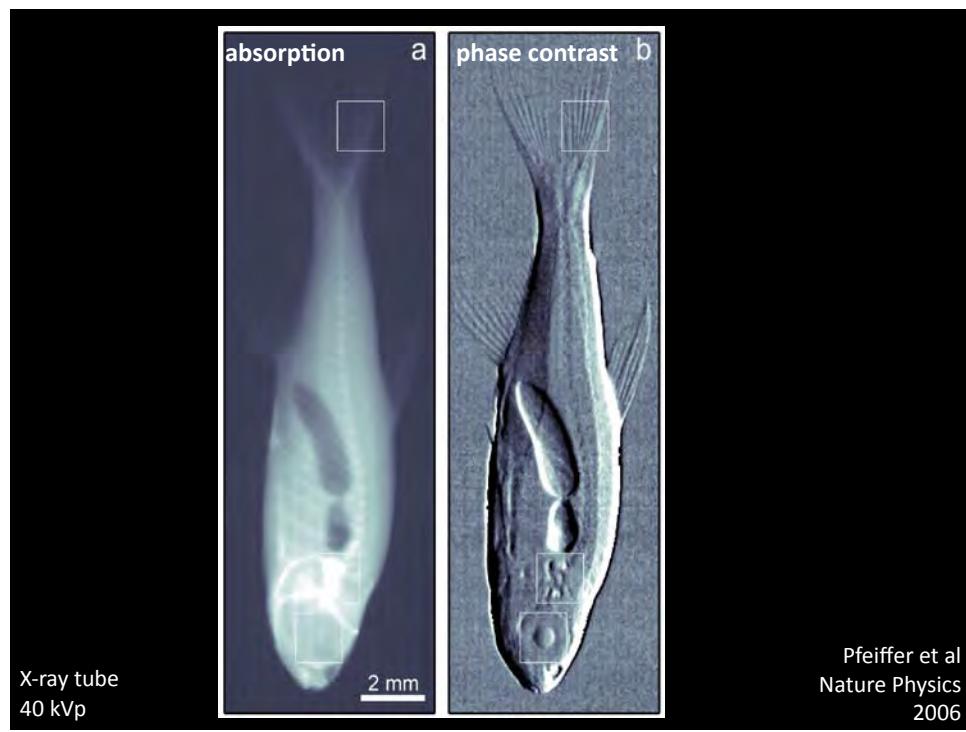
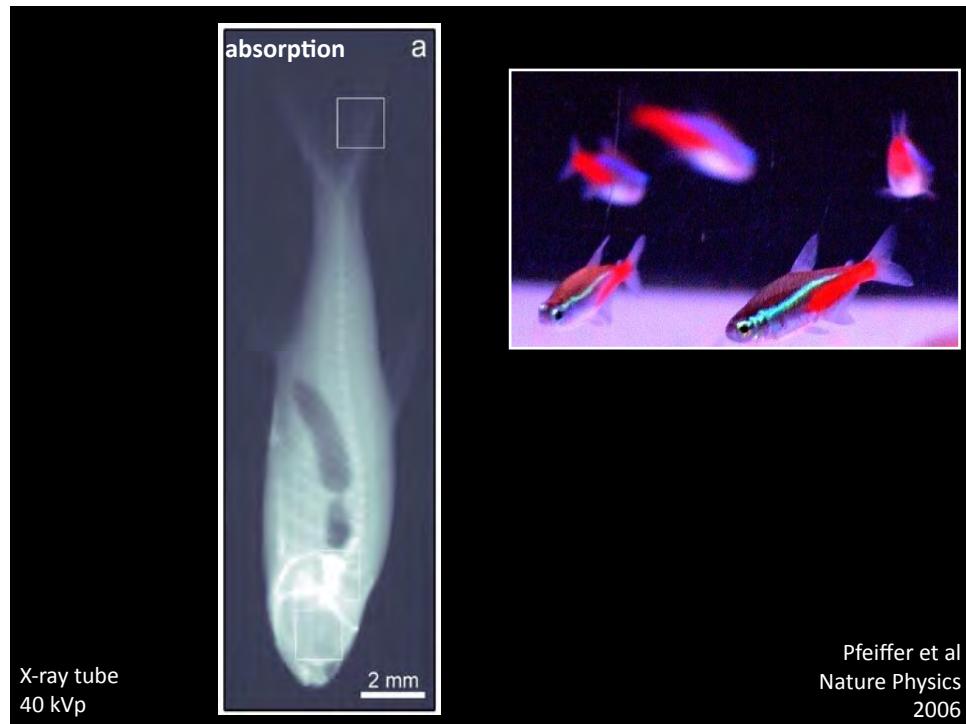


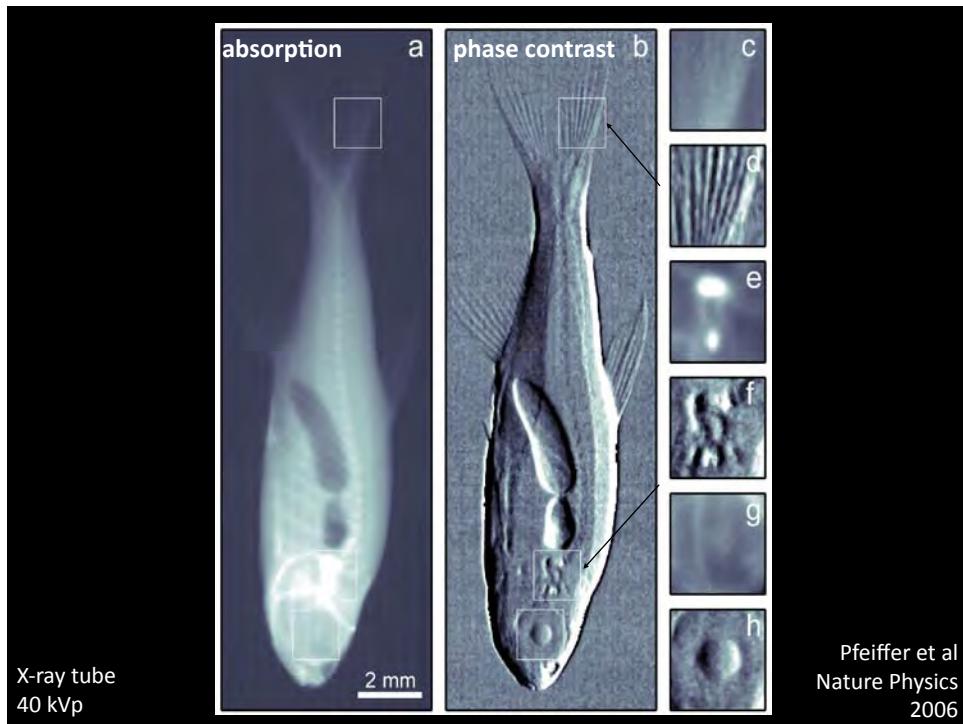
October 2004, polystyrene spheres, 35 kVp



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## Phase retrieval and differential phase-contrast imaging with low-brilliance X-ray sources

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**X**-ray noninvasive absorption imaging is an invaluable tool in medical diagnostics and materials science. Because biological tissue samples, polymer or fiber composites, have a low density, they are often difficult to image due to their weak absorption. This is resolved at high-harmonic generation (HSG) sources by using phase-contrast imaging methods to improve the contrast.<sup>1</sup> However, the requirements of the discriminating radiation mean that high-harmonic generation is currently only feasible with more readily available X-ray sources, such as X-ray lasers. In this Letter we demonstrate that the use of a sequence of phase gratings can effectively yield quantitative differential phase-contrast images with conventional X-ray tubes. Our approach provides the same resolution as HSG, but requires no spatial or temporal coherence, is mechanically robust, and can be scaled up to large fields of view. Our method provides all the benefits of phase-contrast imaging while being completely fully compatible with conventional absorption radiography. It is especially well suited for applications in medical diagnostics, testing, and to other low-brilliance radiation, such as permanent sterilization.

The conventional X-ray imaging contrast is obtained through the difference in the absorption cross-sections of the components of the object. This is often insufficient to image soft tissue against bright absorbing structures such as bones or muscle, or a mixture of relatively weakly absorbing material, like connective tissue and fat. This is particularly problematic in the case of biological tissue samples, which are often composed of many different types of tissue with similar absorption coefficients. As a consequence, the X-ray absorption contrast is relatively poor. Consequently, differential pathlength filters have previously been used to improve the contrast of X-ray images of biological tissue samples, such as breast tissue, using sequential absorption and phase-contrast imaging.<sup>2</sup> They can be

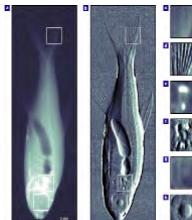


Figure 1. Left: X-ray absorption image of an angel fish. Right: X-ray phase-contrast image of the same specimen. The absorption image is easy to interpret, but it makes soft tissue difficult to distinguish from bone. The phase-contrast image, on the other hand, is much more sensitive to soft tissue. The insets show a zoomed-in view of the head region. The insets show a zoomed-in view of the head region.



## X-RAY IMAGING

### Soft focus

From Wilhelm Conrad

Röntgen's first snapshot of his wife's hand in 1895, to the security scanner that blows Arnold Schwarzenegger's cover in *Total Recall*, the use of X-rays to image dense objects has been part of common lore. Franz Pfeiffer and colleagues (*Nature Phys.* doi:10.1038/nphys265; 2006) now realign the popular view. They use X-rays to generate high-contrast images not only of bone, but also of the soft tissues that surround them. The approach could readily be used to improve the diagnostic power of existing medical-imaging equipment.

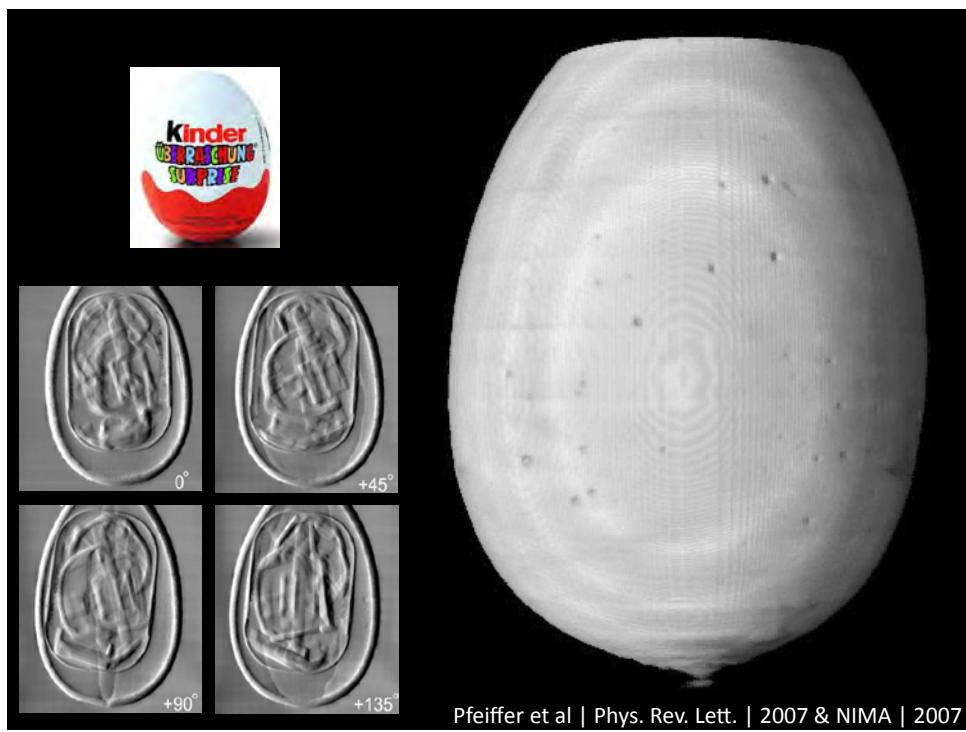
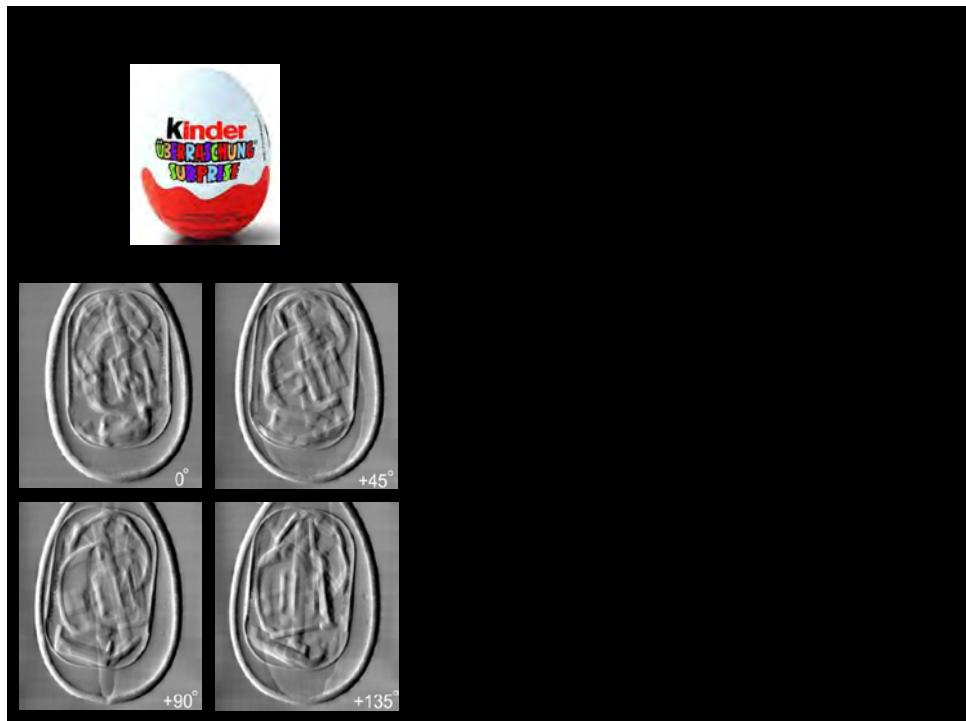
Conventional medical X-ray imaging uses the fact that the harder and denser the body tissues are, the more radiation they absorb, and the more contrast they produce on X-ray films. This makes it easy to distinguish bones and other dense bodies, such as tumours, from surrounding tissues. But discerning details of softer tissues from only the contrast in absorption is difficult. Pfeiffer et al. use a sequence of phase-contrast gratings to



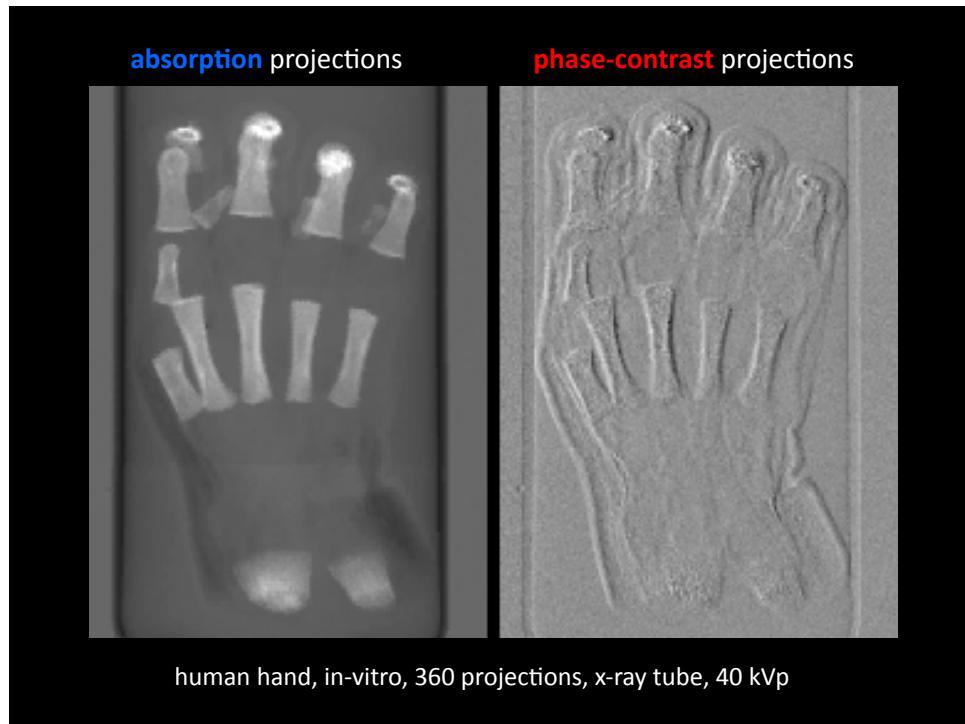
manipulate the relative phases of the X-rays that illuminate and subsequently emerge from an object. They can thus generate phase-contrast images — for example this 50-mm × 50-mm picture of an angel fish — using commercial X-ray sources at much lower intensity and cost, than has previously been possible. The authors note that, as well as improving the detail in X-ray images, their approach could be adapted for use with other low-intensity radiation sources, such as neutrons and ions.

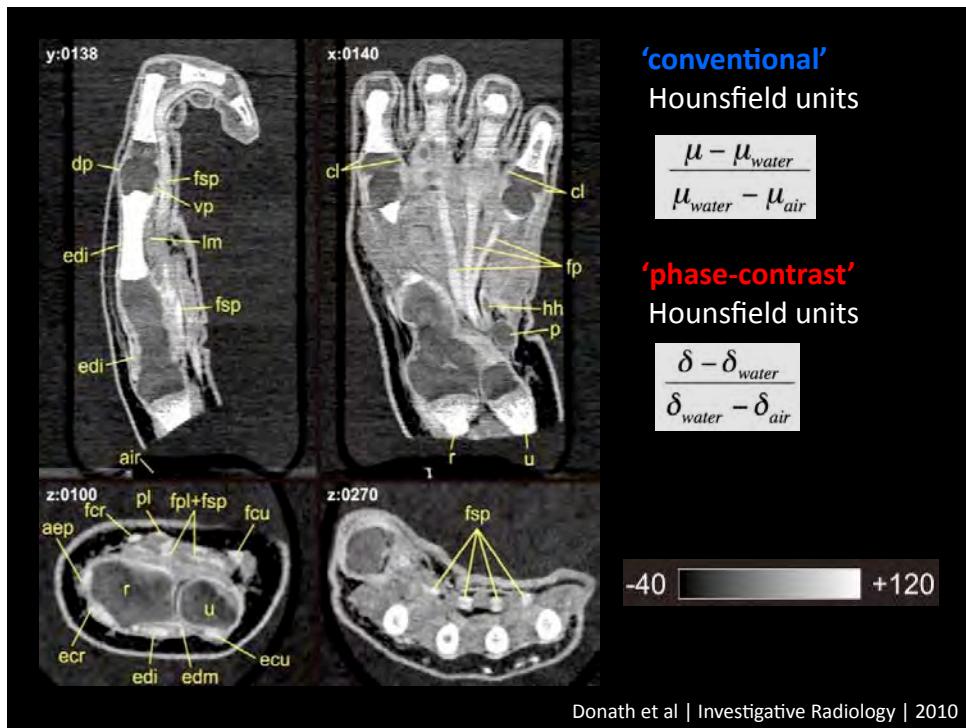
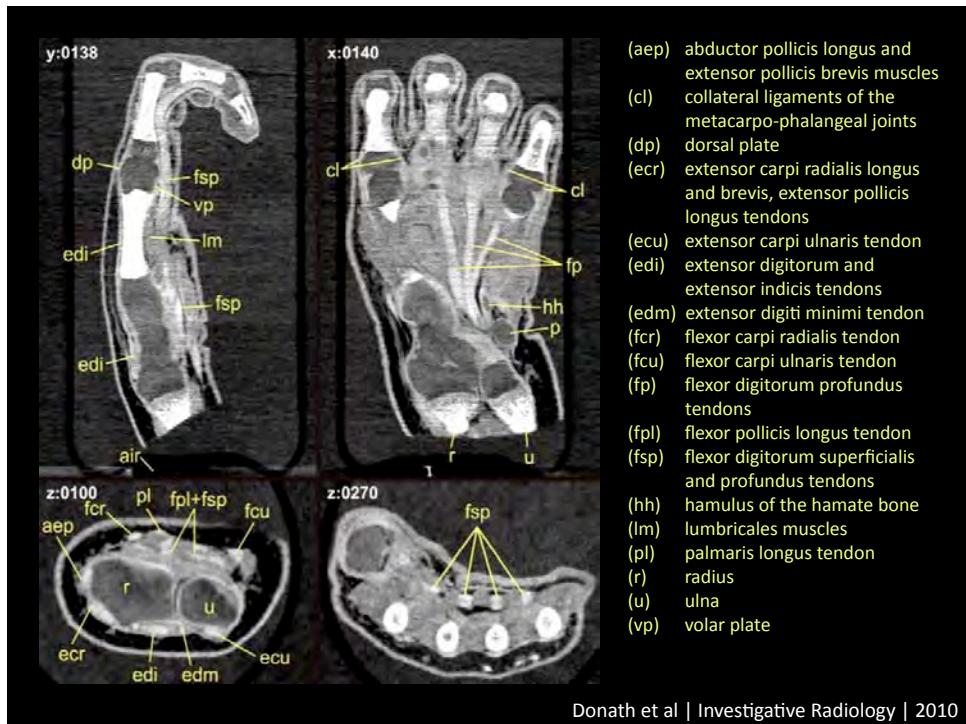
Ed Gerstner



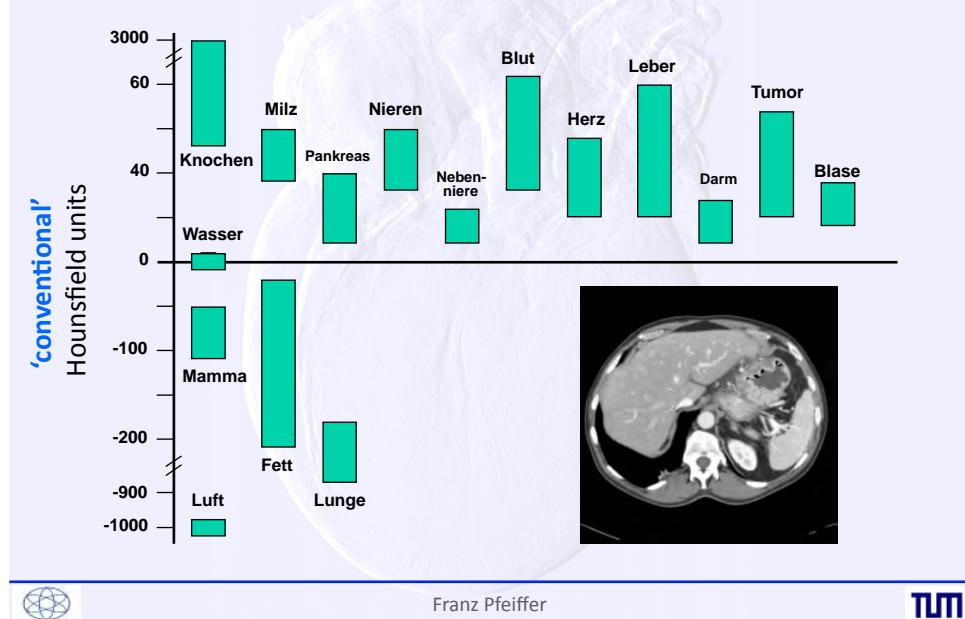


Pfeiffer et al | Phys. Rev. Lett. | 2007 & NIMA | 2007





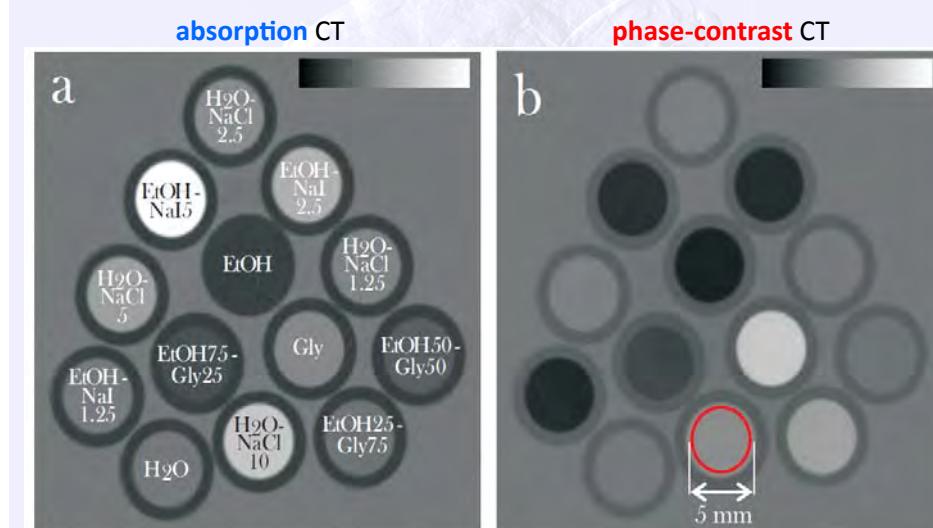
## Hounsfield Phase Units to improve Tissue Segmentation ?



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## What is better: Absorption or Phase Contrast ?



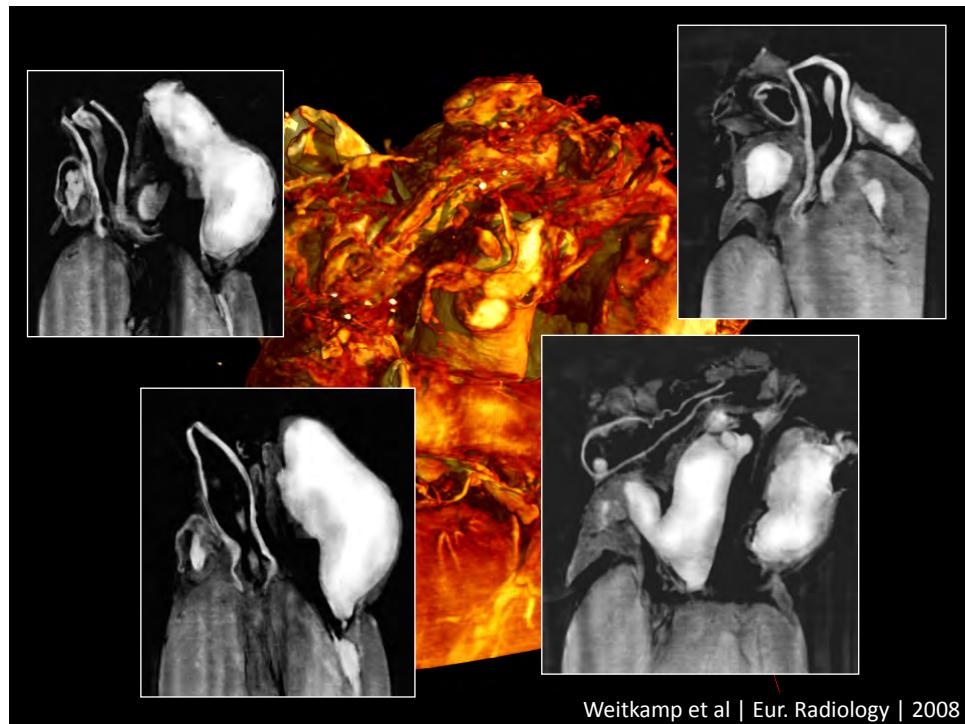
Liquid phantom, X-ray tube, 40 kVp

Herzen et al | Optics Express | 2009

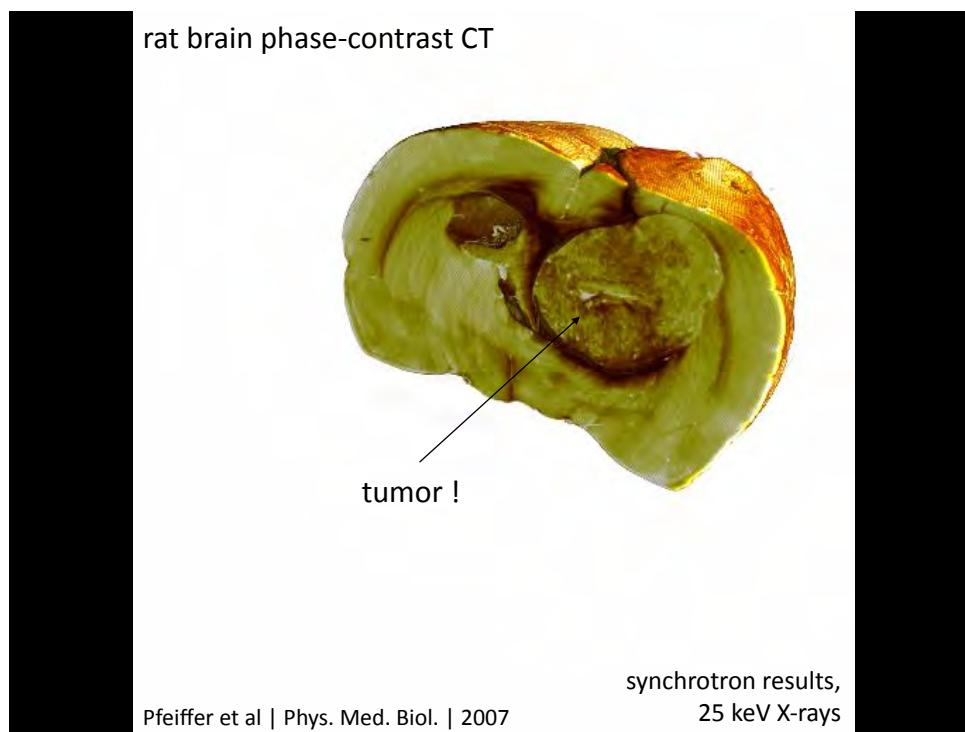


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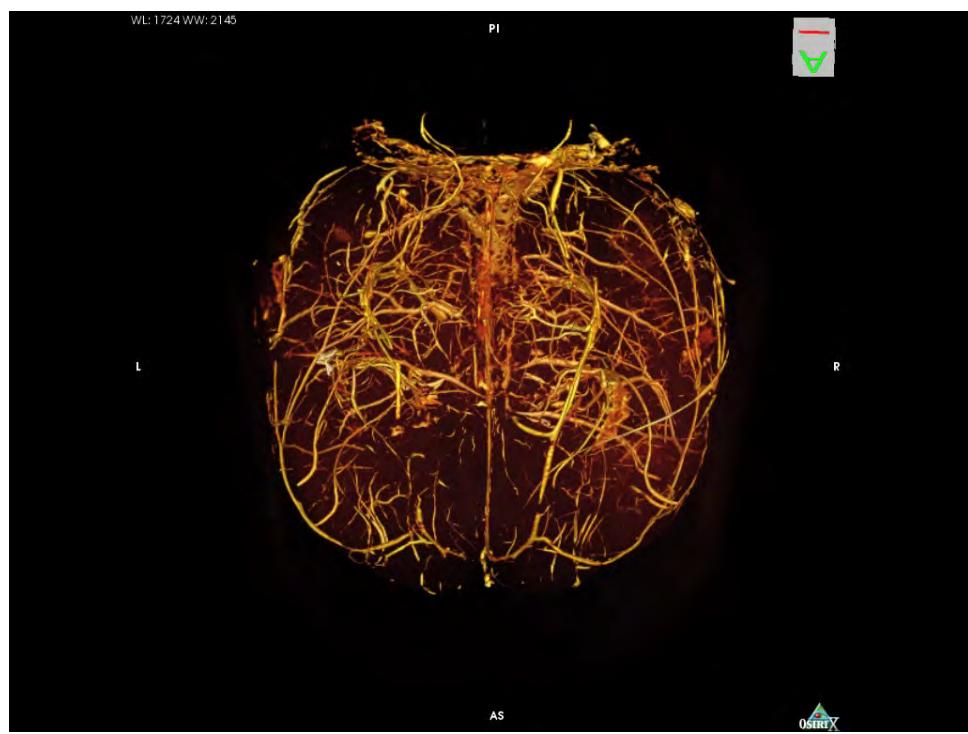


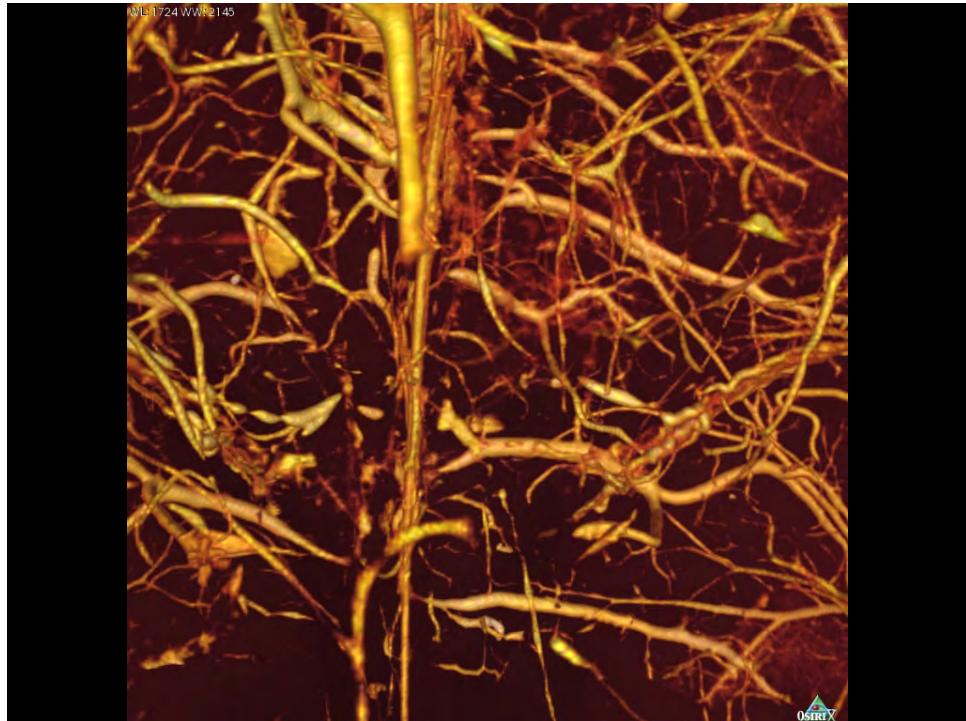
Weitkamp et al | Eur. Radiology | 2008





Pfeiffer et al  
Phys. Med. Biol.  
2007





## Acknowledgements



A. Tapfer, M. Willner, J. Herzen, M. Bech, G. Potdevin, K. Achterhold  
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