

*14.06.2016, MPP COLLOQUIUM, MUNICH*

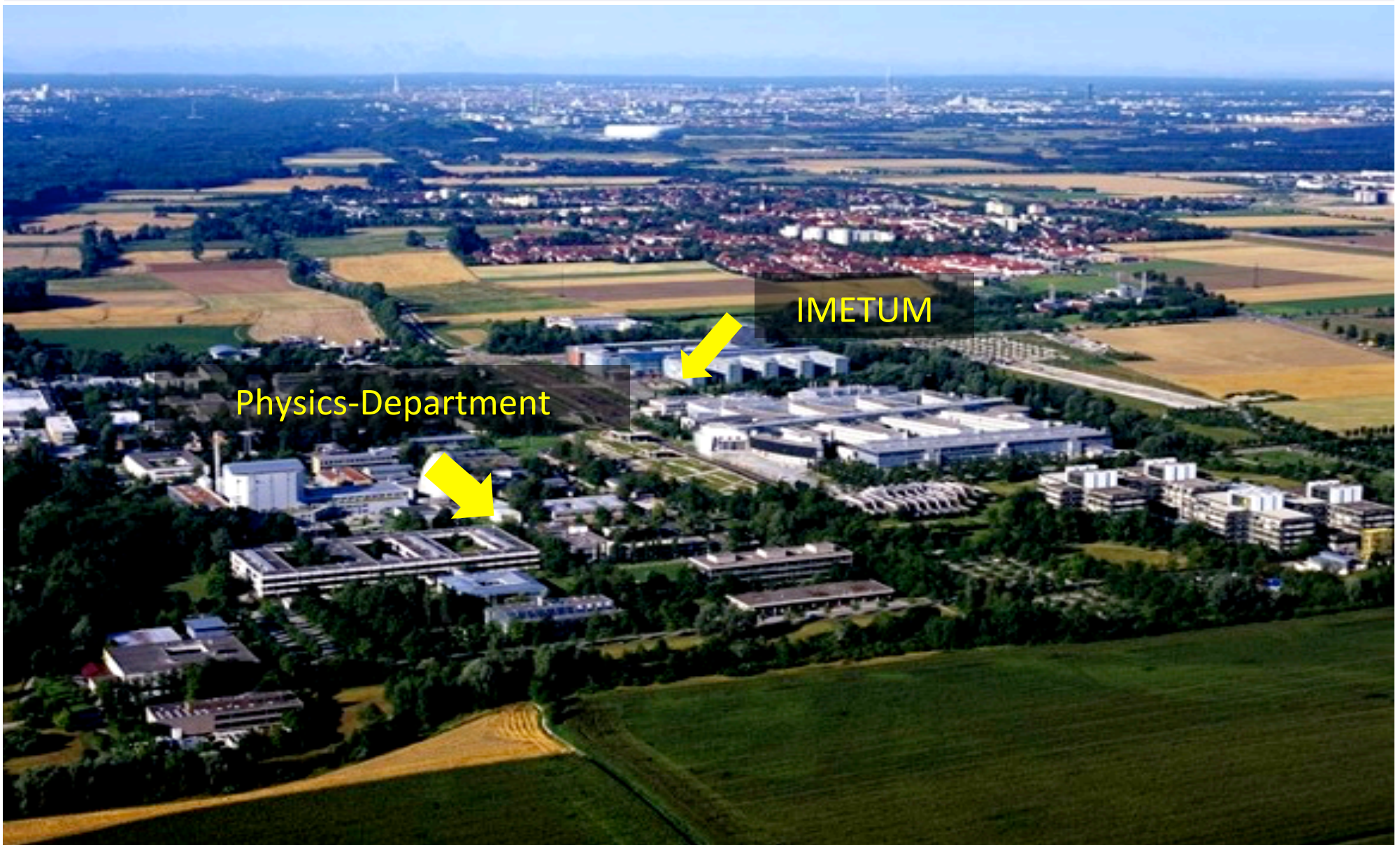
# GRATING-BASED X-RAY IMAGING

**JULIA HERZEN**

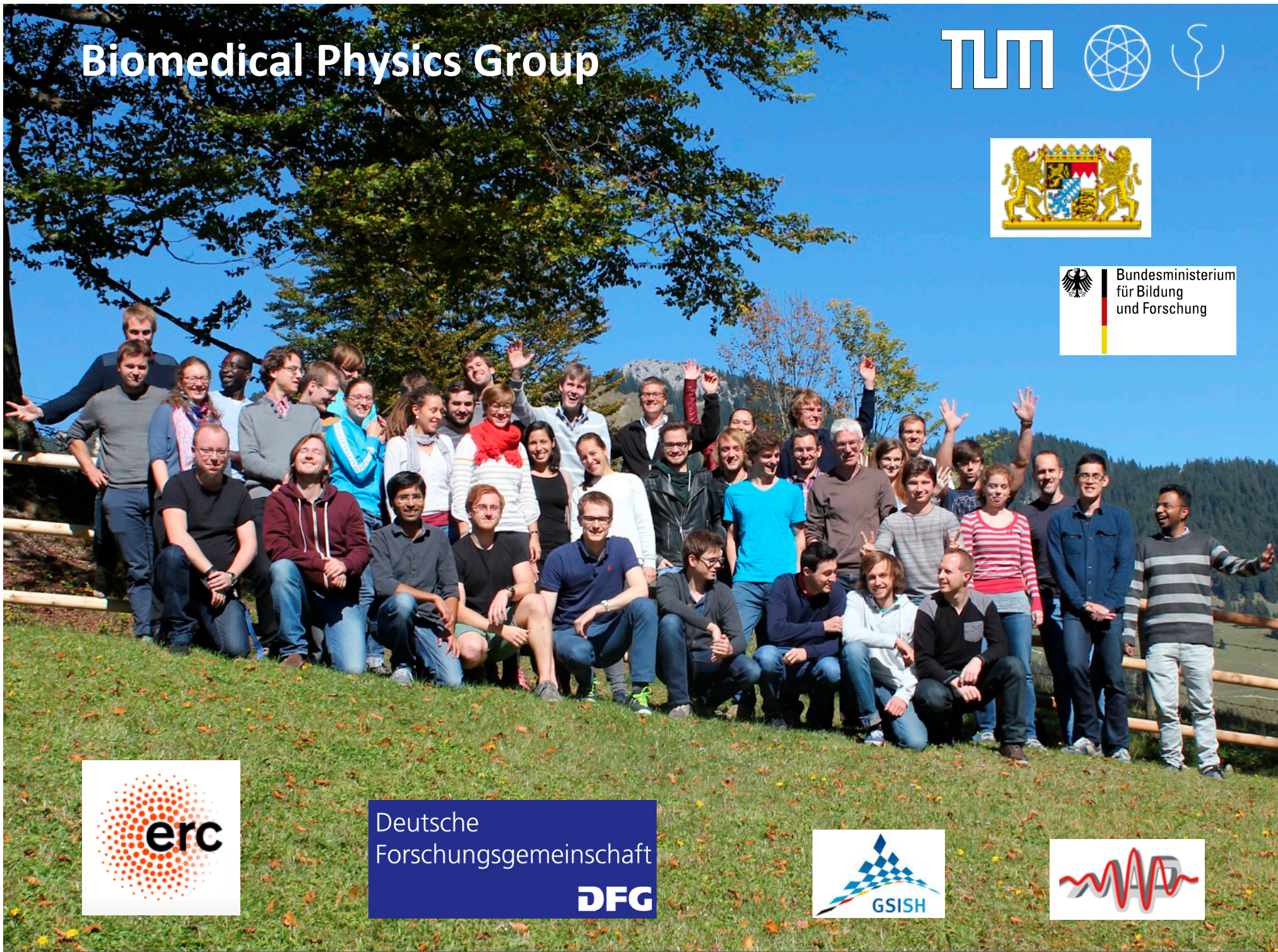
*PHYSICS DEPARTMENT & INSTITUTE FOR MEDICAL ENGINEERING*

*TECHNISCHE UNIVERSITÄT MÜNCHEN*

# TUM Garching Campus



# Biomedical Physics Group

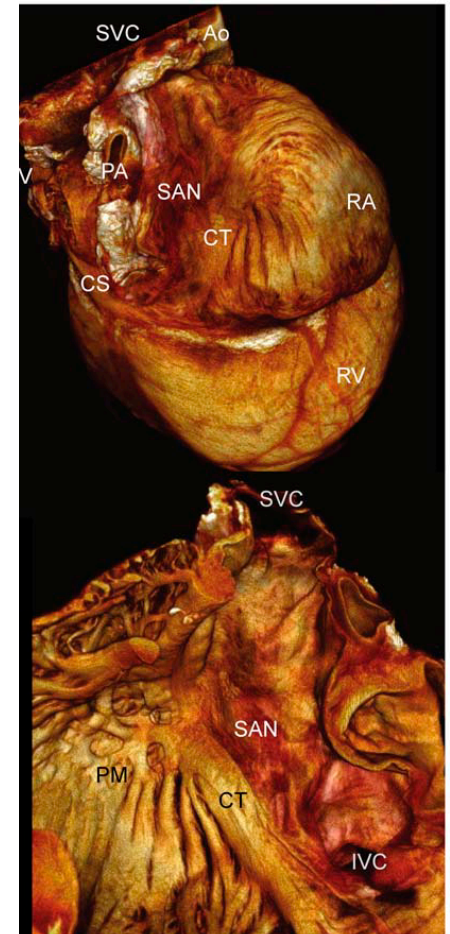
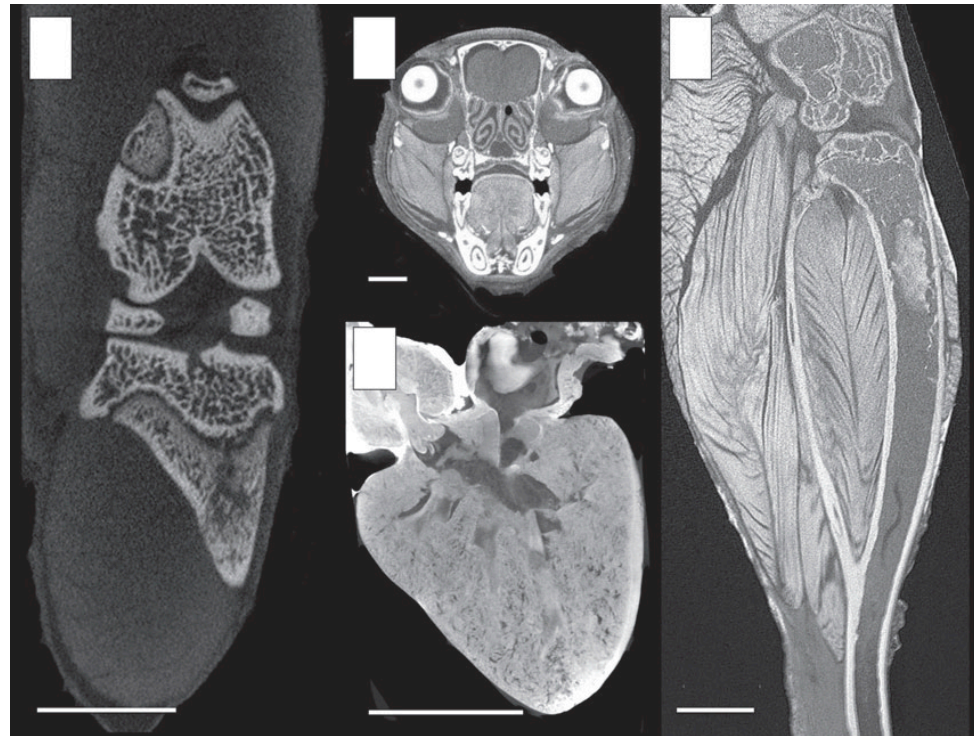


# ,State-of-the-art' *ex-vivo* micro CT



Chicken heart, stained with IKI  
M. Zdora | unpublished | 2011

Mouse knee and organs, stained with I<sub>2</sub>KI  
Vickerton et al. | J. Anat. 223 | 2013

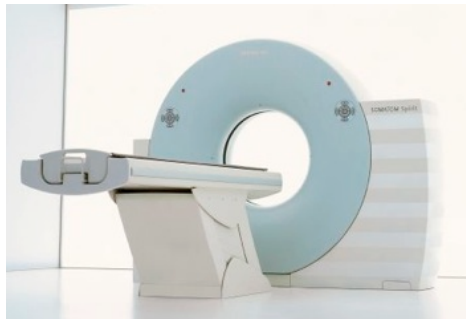
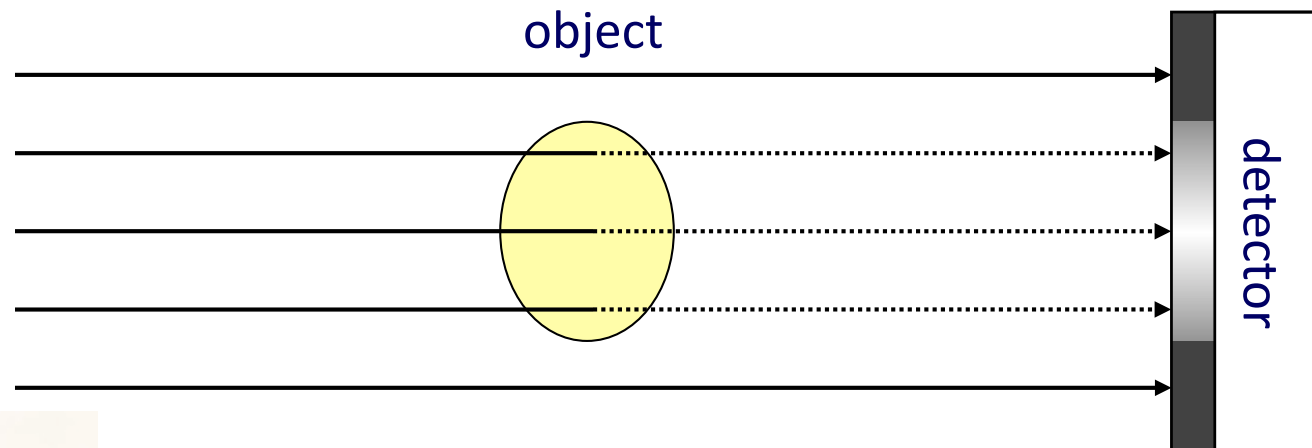


Rabbit heart, stained with IKI  
Stephenson et al. | Plos One 7(4) | 2012



## Attenuation Contrast

$$n = 1 - \delta + i\beta$$



### X-ray interaction:

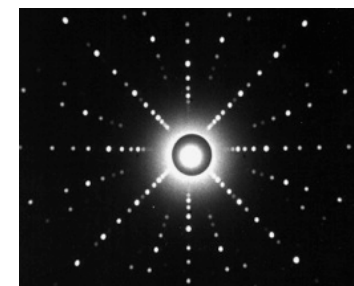
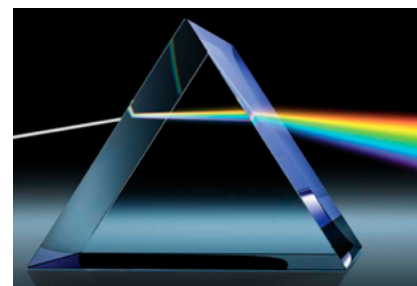
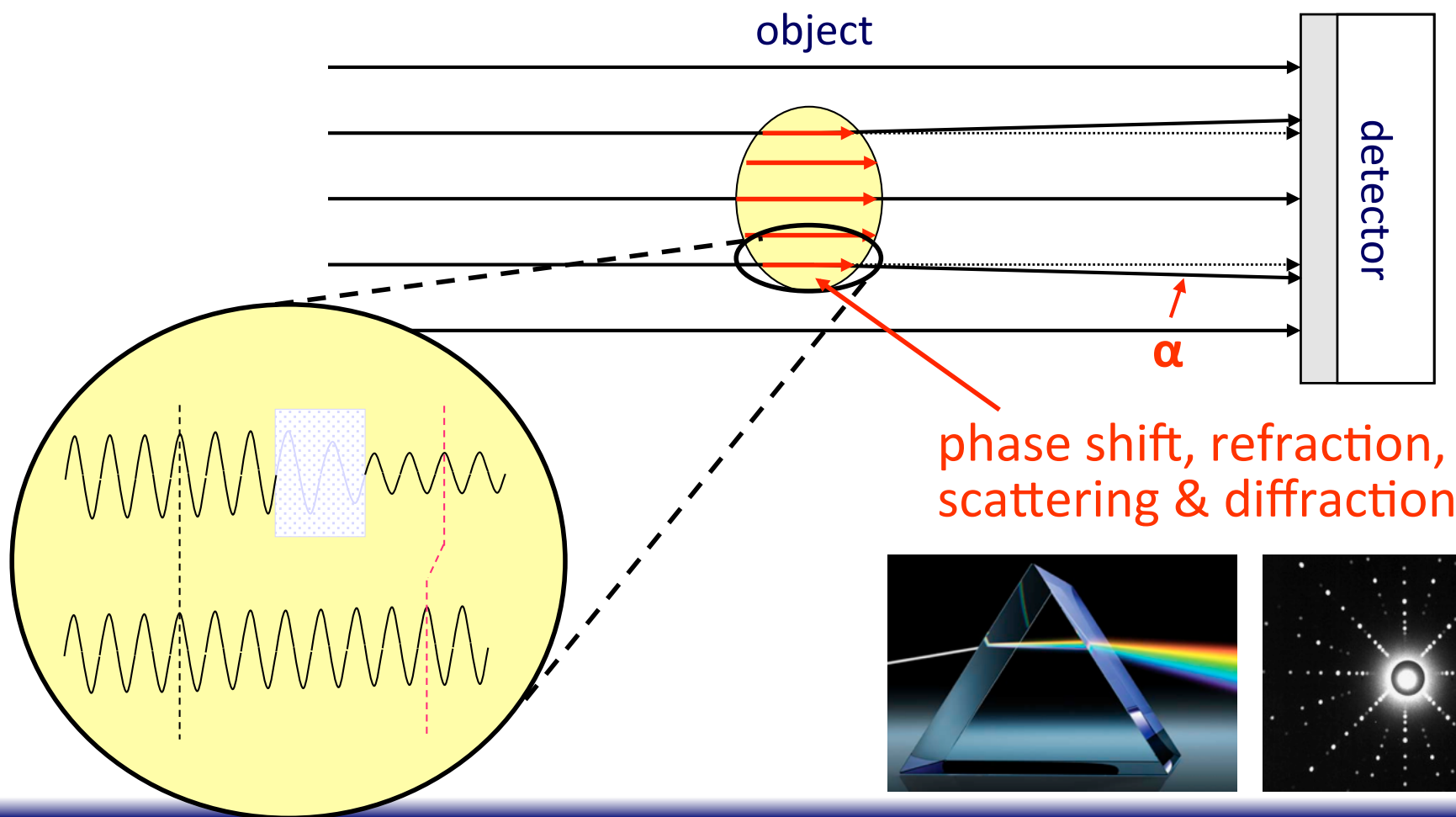
- Compton Scattering
- Photo-electric absorption

# 'Wave-Optical' X-ray Radiography



## Phase Contrast

$$n = 1 - \delta + i\beta$$



# Synchrotron Sources



**ESRF, Grenoble**



Conventional  
MicroCT

Phase-contrast  
MicroCT



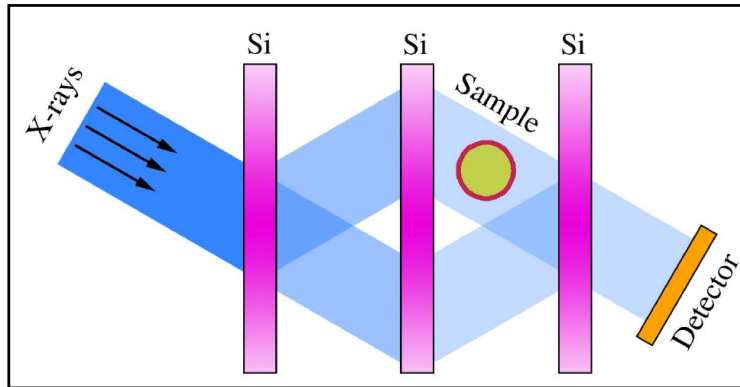


# Phase-contrast methods



$\Phi$

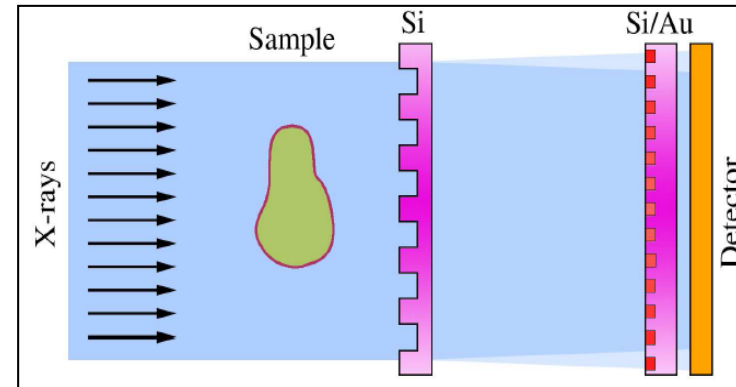
## Crystal Interferometer



Bonse & Hart 1965

$d\Phi/dx$

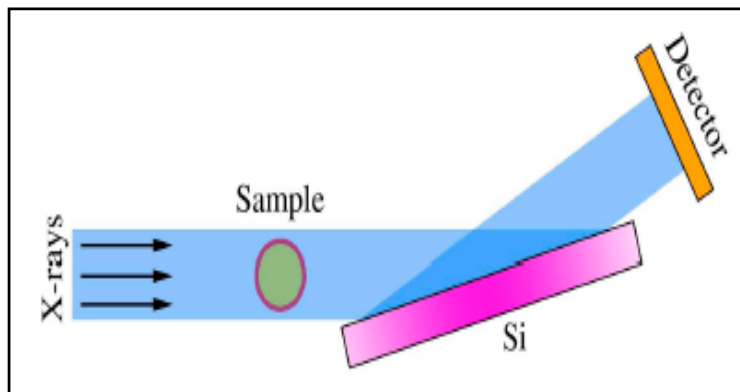
## Grating-based Methods



Momose 2003 & David 2002

$d\Phi/dx$

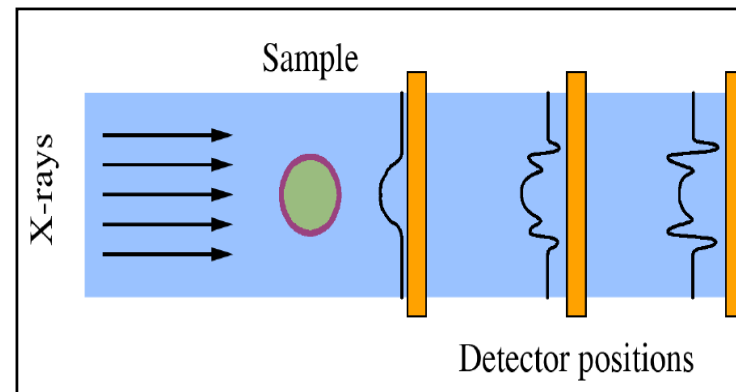
## Crystal Analyzer



Förster 1980 & Davis 1995

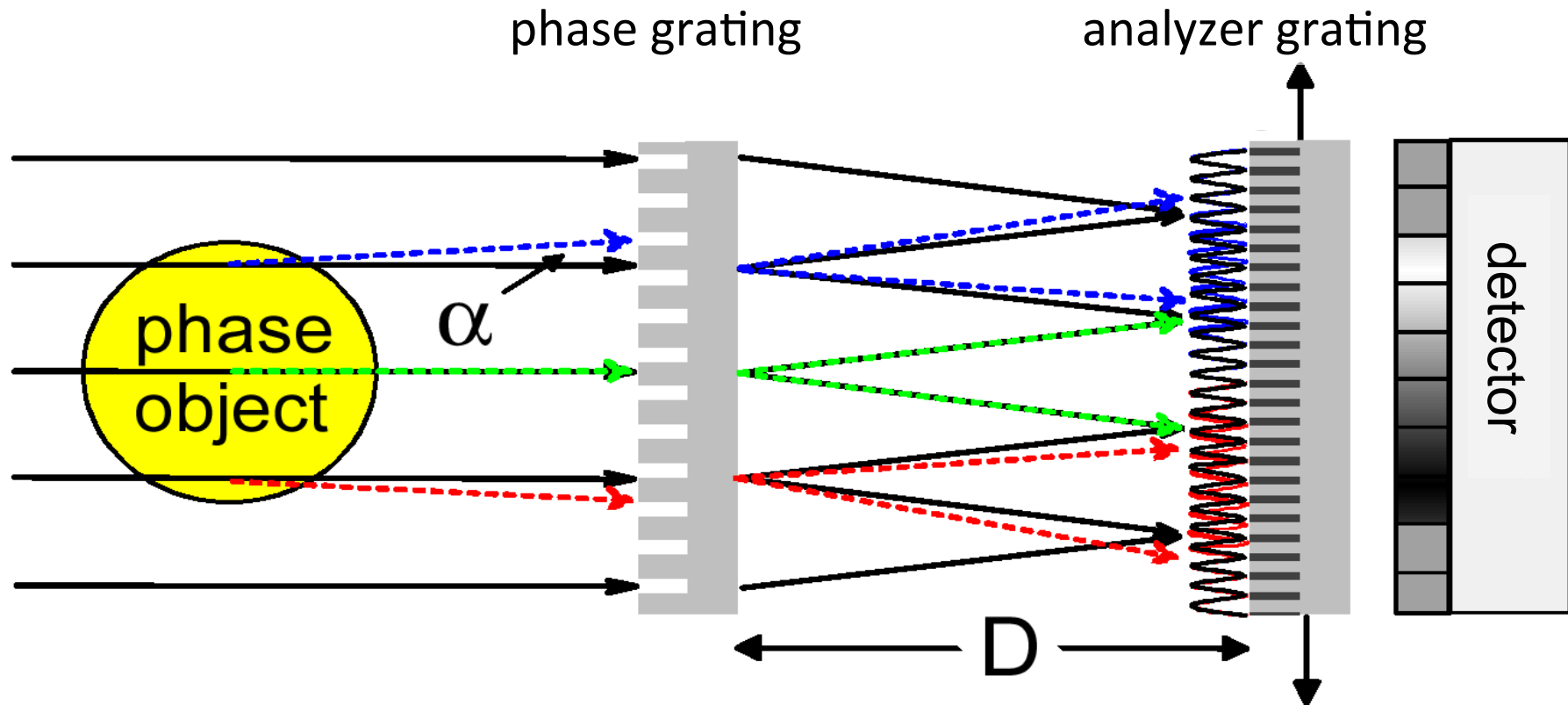
$\Delta\Phi$

## Propagation-based Imaging



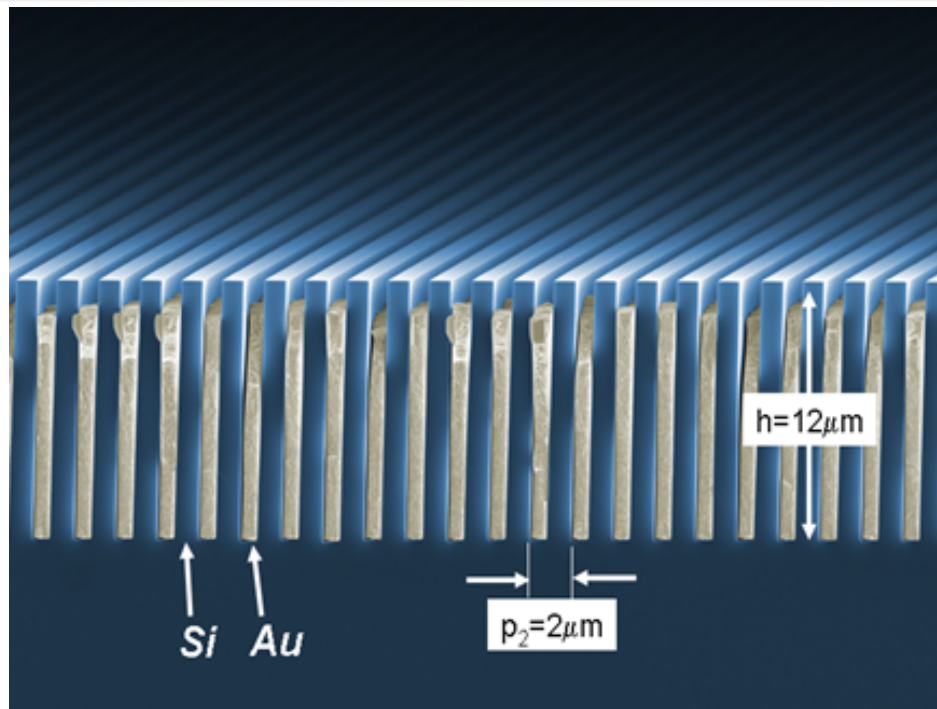
Snigirev 1995, Cloetens & Wilkens 1996

# Grating-Based Phase-Contrast Imaging



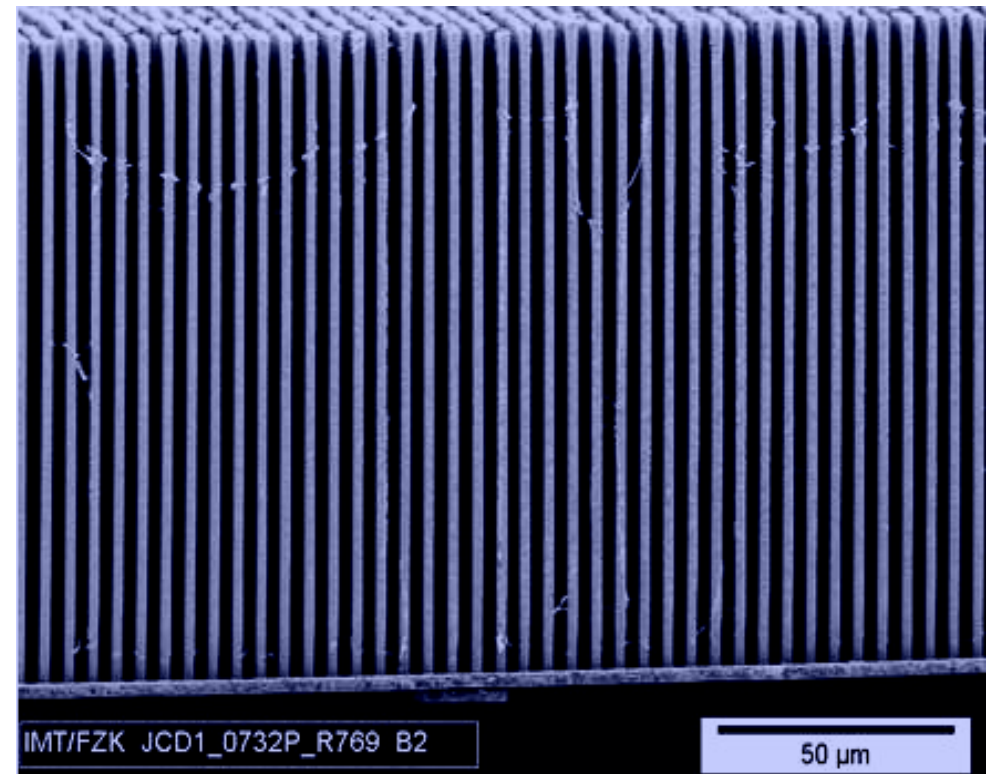
$$\alpha = \frac{\lambda}{2\pi} \nabla \Phi$$

# X-Ray Optical Transmission Gratings



**anisotropic wet etching & electroplating**  
C. David et al.,  
Paul Scherrer Institut/ CH

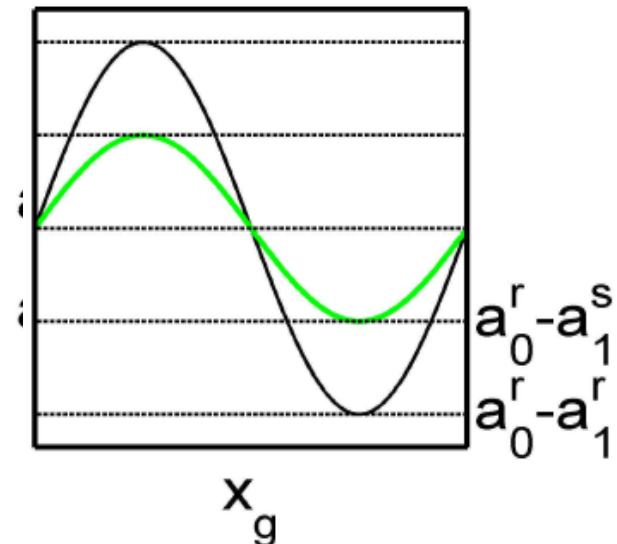
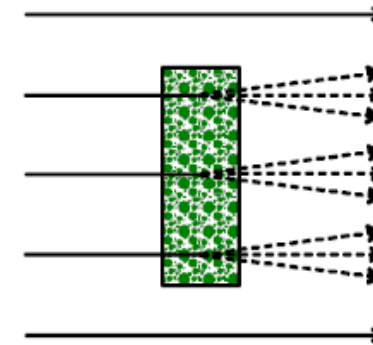
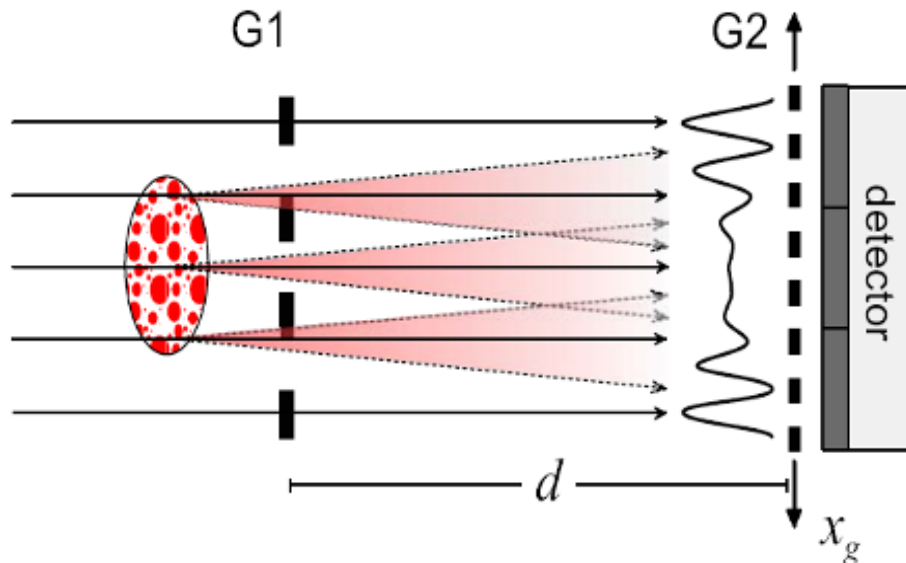
**LIGA (X-ray lithography)**  
J. Mohr & J. Schulz,  
Karlsruhe Institute of Technology  
& microworks/ DE



# Extraction of Three Image Signals



via 'fringe scanning' or 'phase stepping'



$$I(m, n, x_g) = \sum a_i(m, n) \cos(ikx_g + \phi_i(m, n))$$

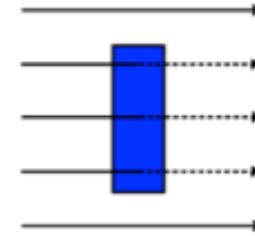
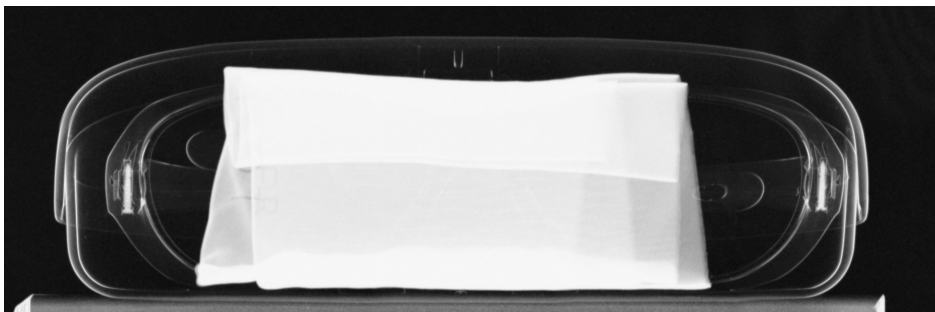
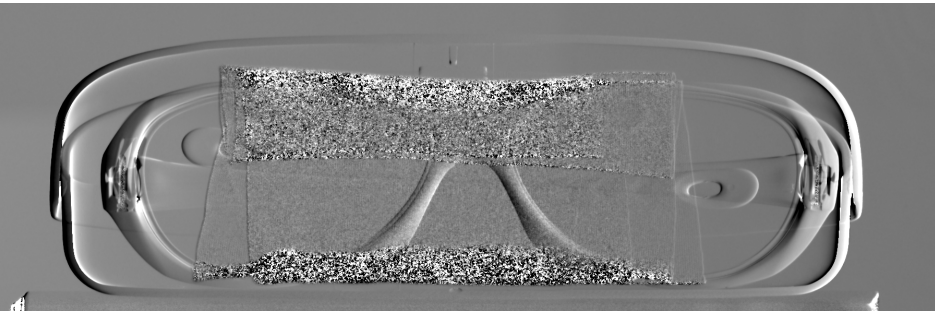
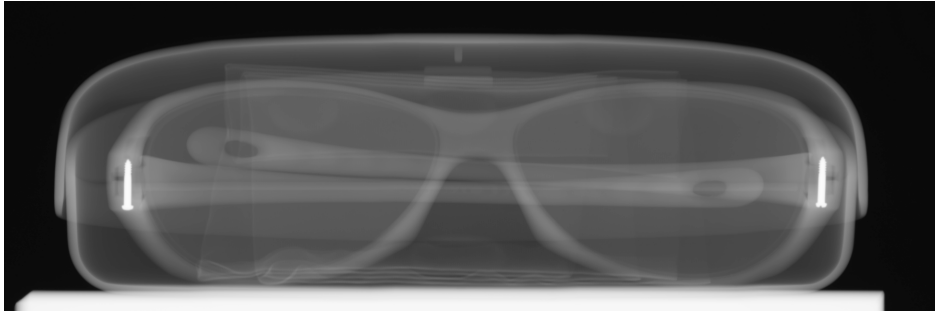
$$\approx a_0(m, n) + a_1(m, n) \cos(kx_g + \phi_1(m, n))$$

transmission

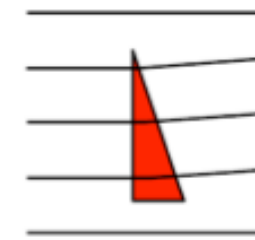
scattering/  
dark-field

phase  
gradient

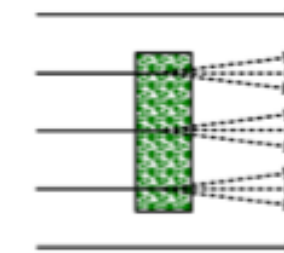
# Multi-modal X-ray Imaging



**Absorption contrast**

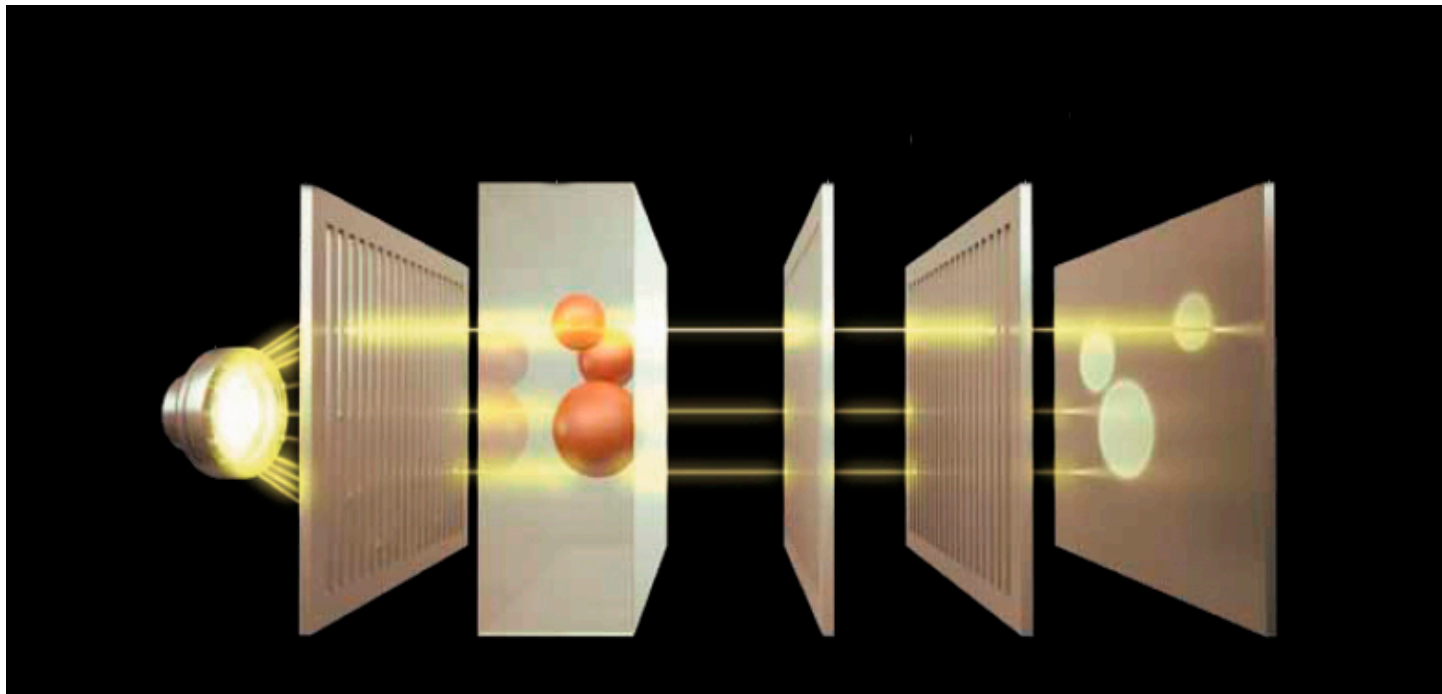
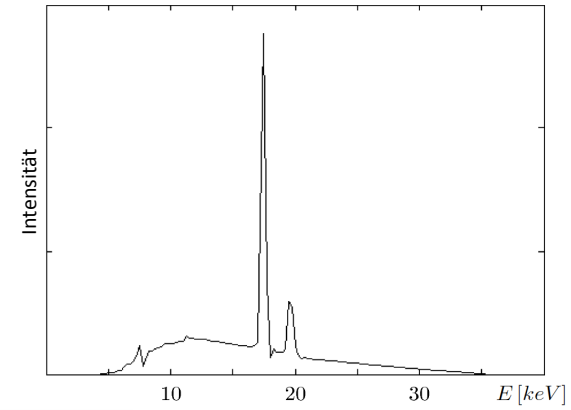
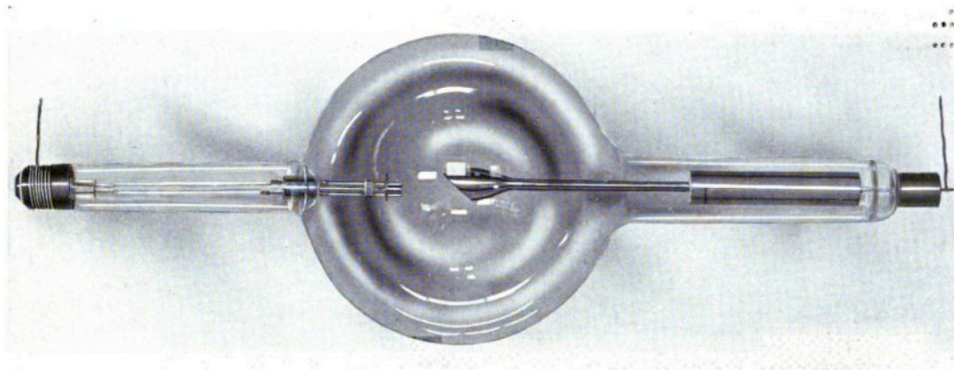


**Phase contrast**

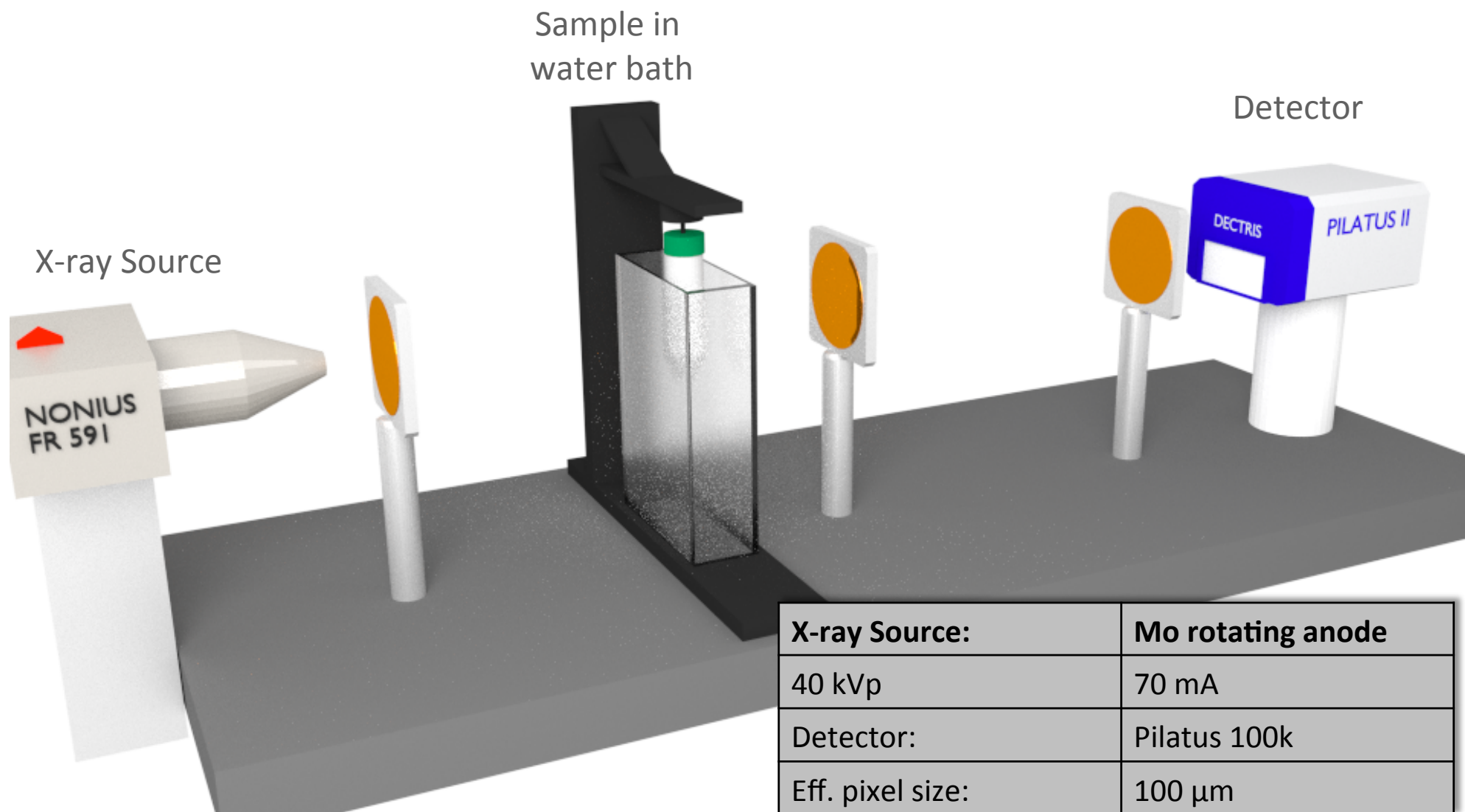


**Dark-field contrast**

# Extending to Laboratory Sources



# Table-top Talbot-Lau Interferometer



# Improving Image Quality

## Less Noise – Higher Sensitivity for Phase Shifts

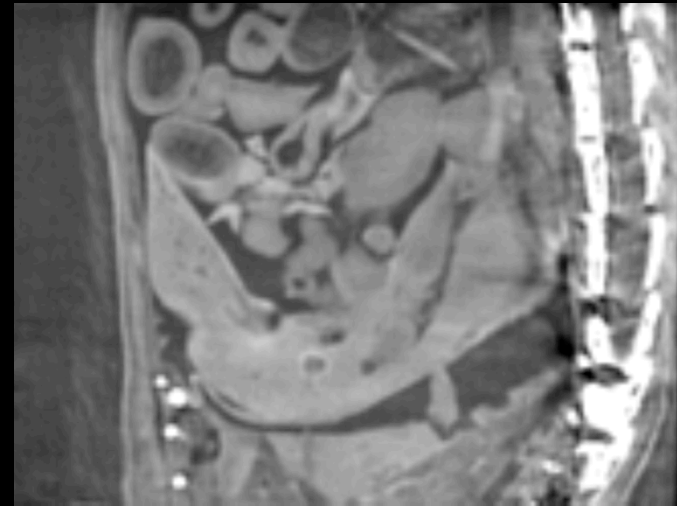
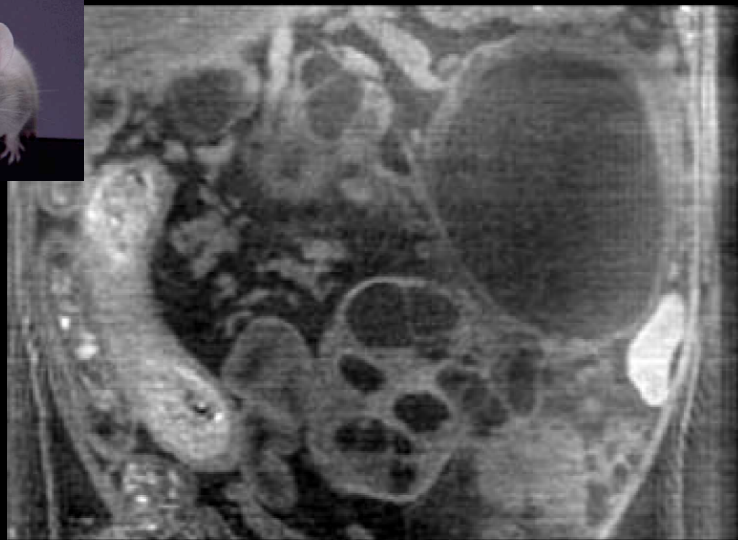
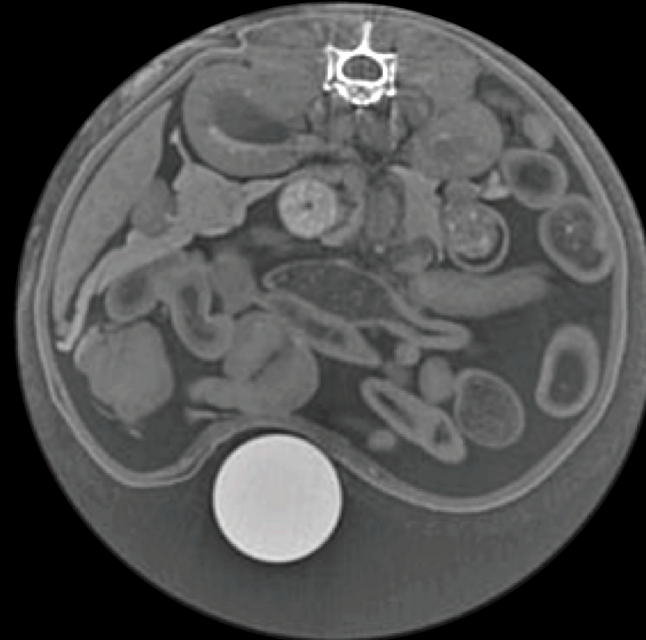
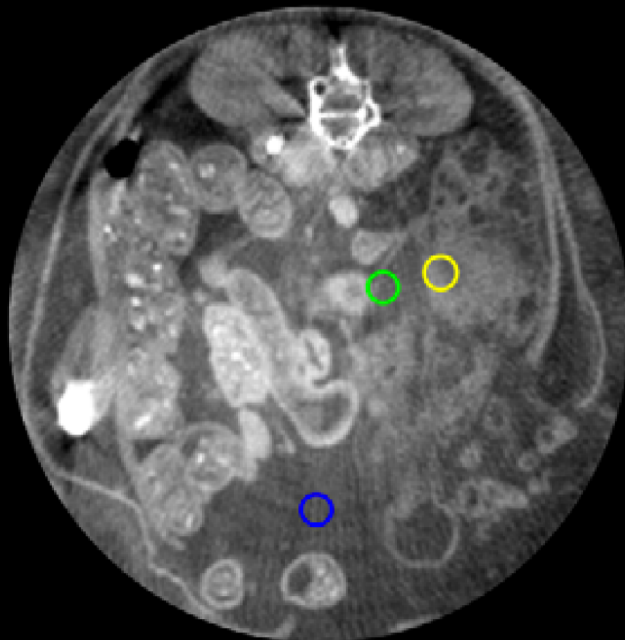


Image Quality 2012

Image Quality 2015



Tapfer et al | PLoS ONE | 2013

Birnbacher et al | in preparation | 2016



# Improving Image Quality Comparison Synchrotron vs. X-ray tube



Synchrotron



20  $\mu\text{m}$

3 h

Tapfer et al | PLoS ONE | 2013

Resolution:

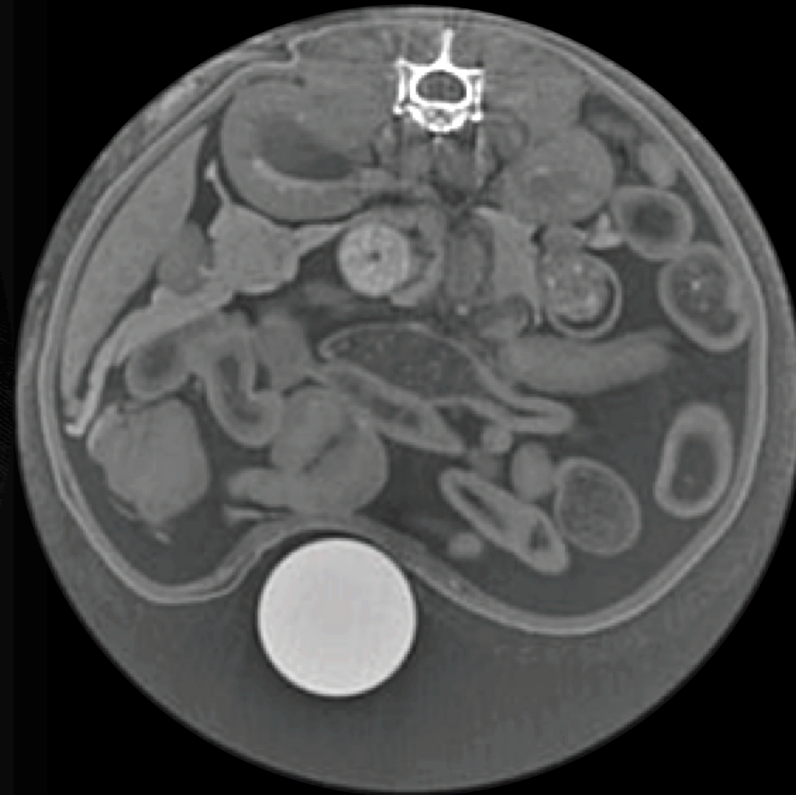
100  $\mu\text{m}$

Scan time:

12 h

Birnbacher et al | in preparation | 2016

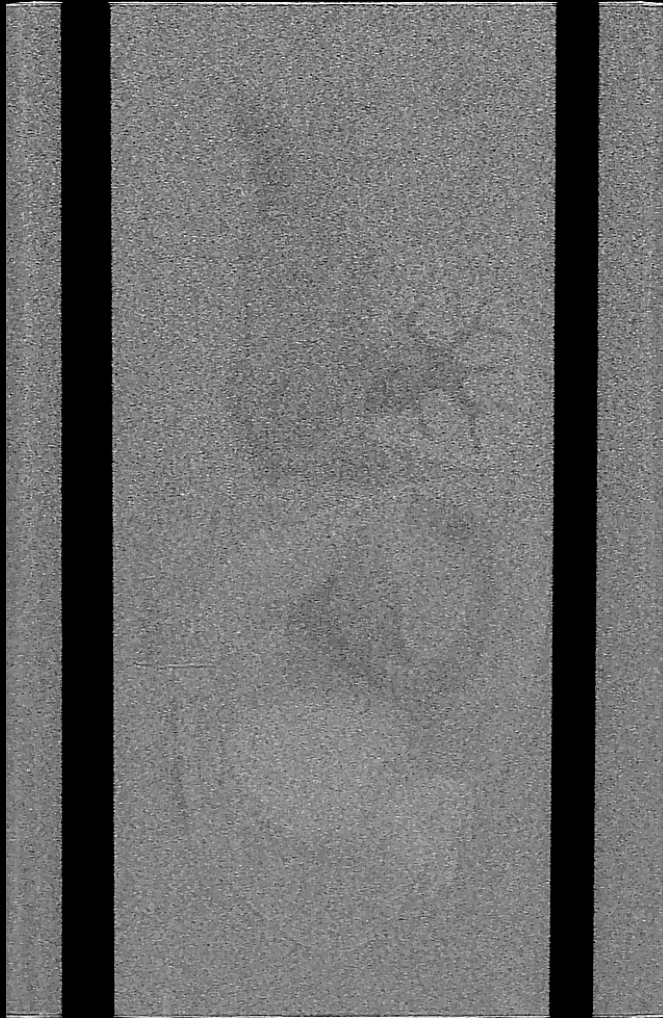
X-ray Tube



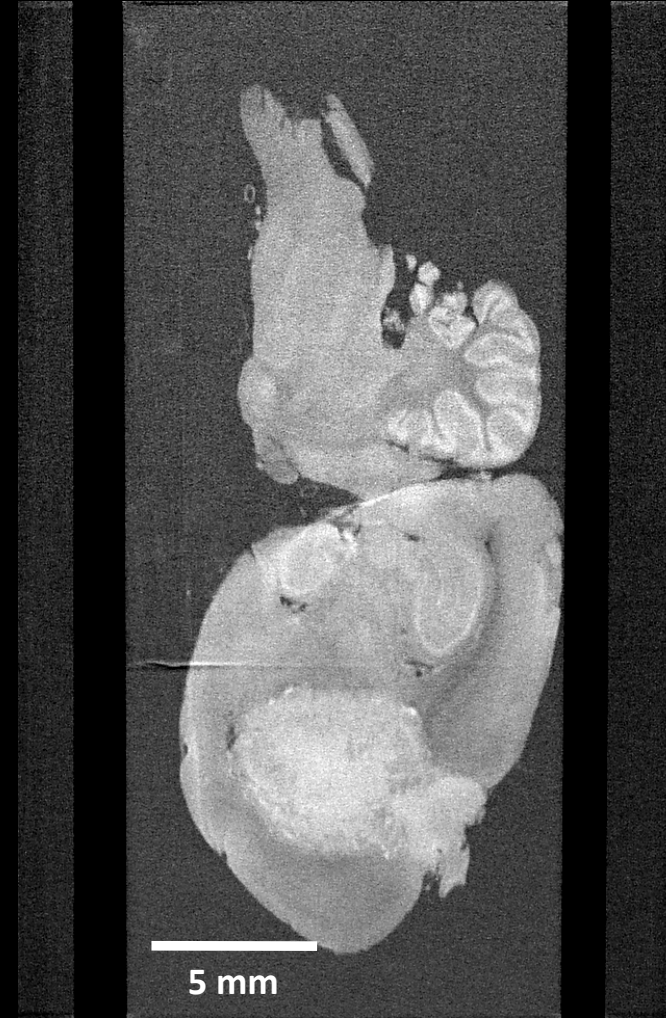
# Improving Image Quality

## High Resolution & High Sensitivity (Rat Brain)

Absorption contrast

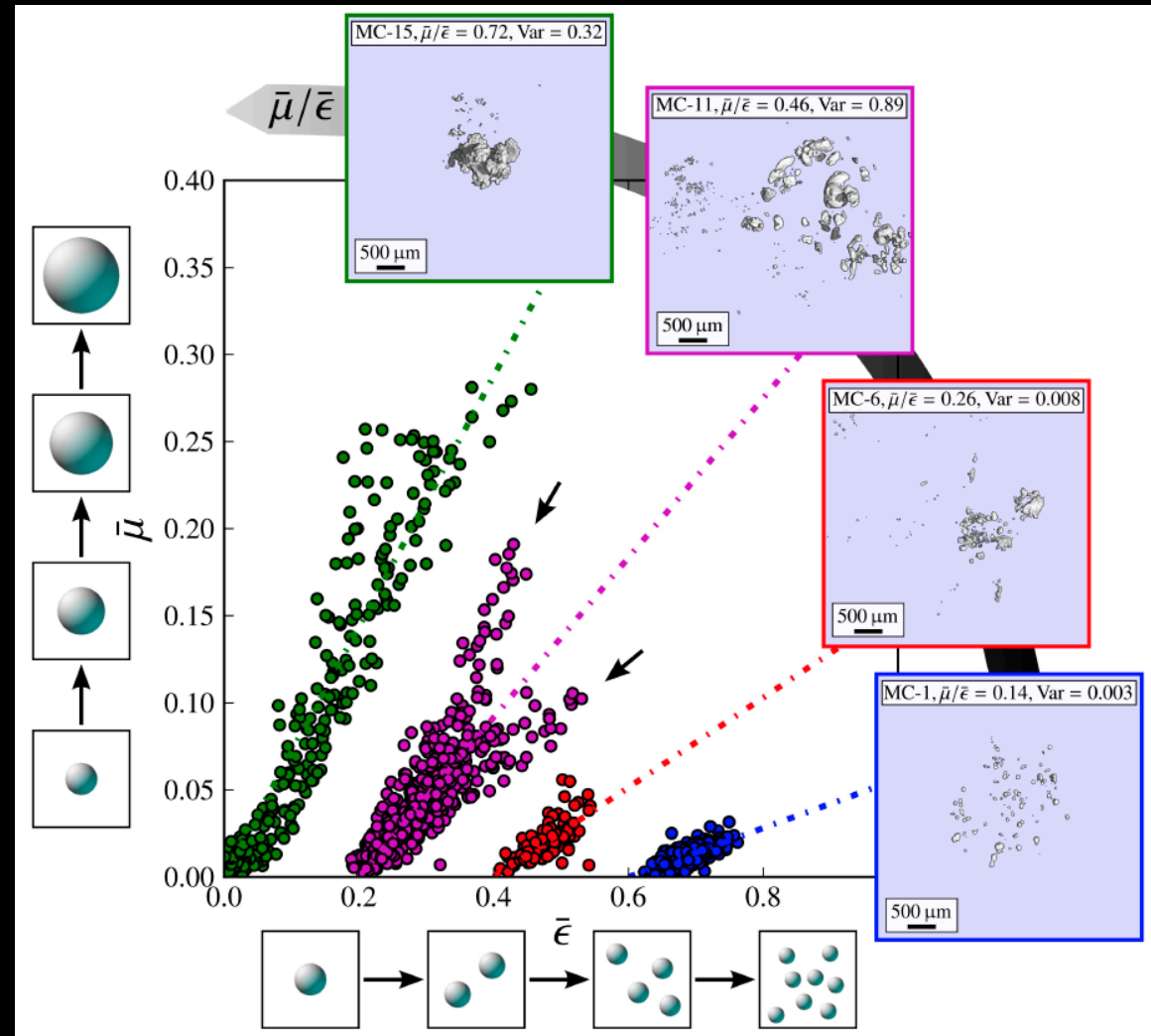
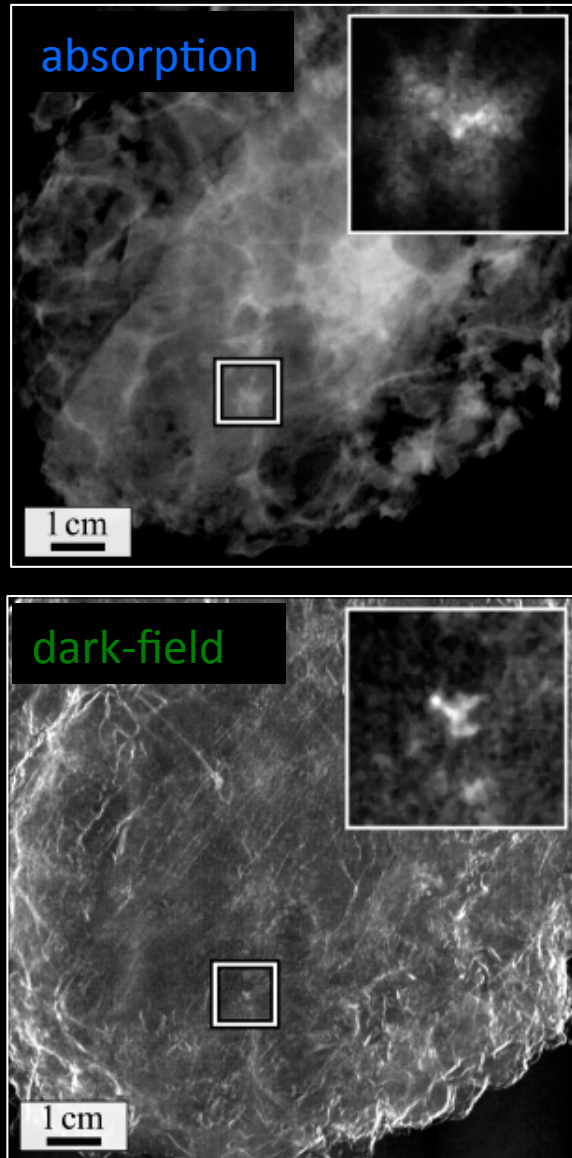


Phase contrast

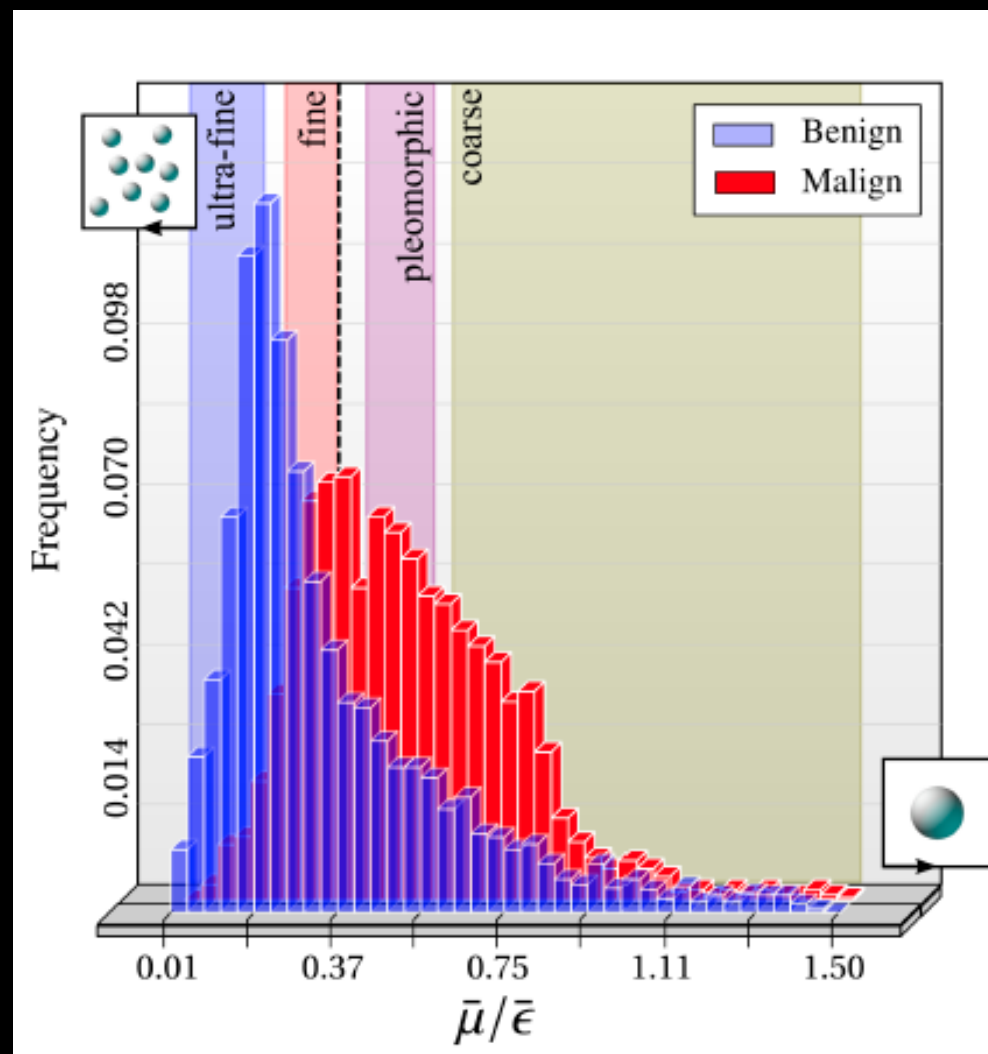
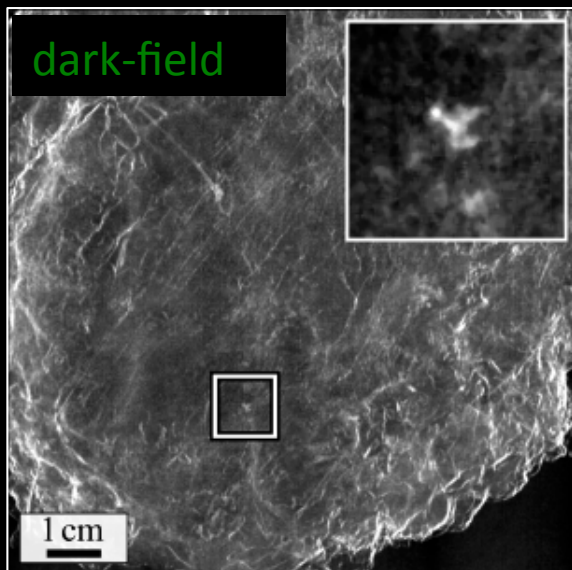
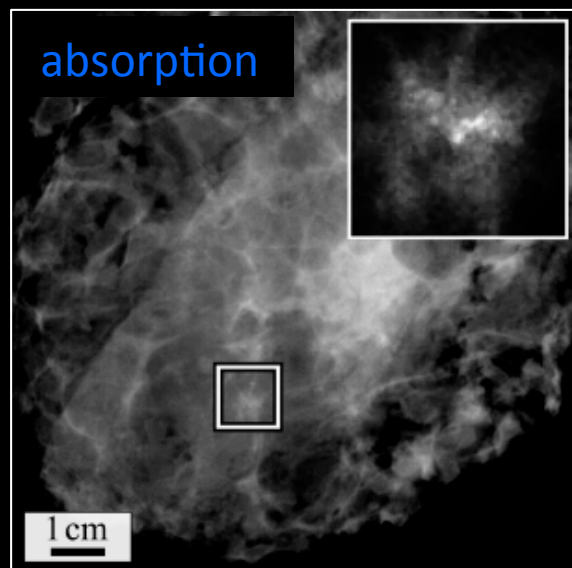


Resolution: 29  $\mu\text{m}$ , photon-counting Detector; Viermetz et al | in preparation | 2016

# dark-field contrast mammography for classification of micro-calcifications

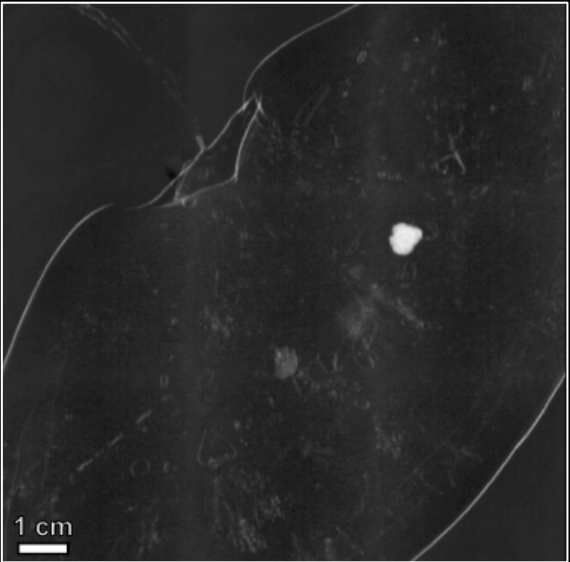
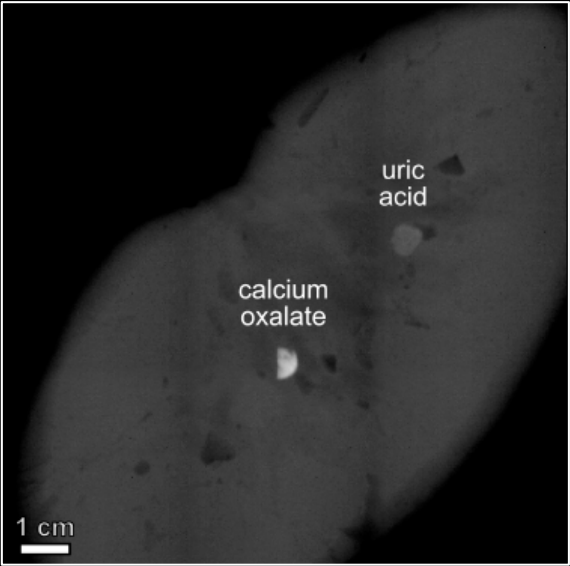


# dark-field contrast mammography for classification of micro-calcifications

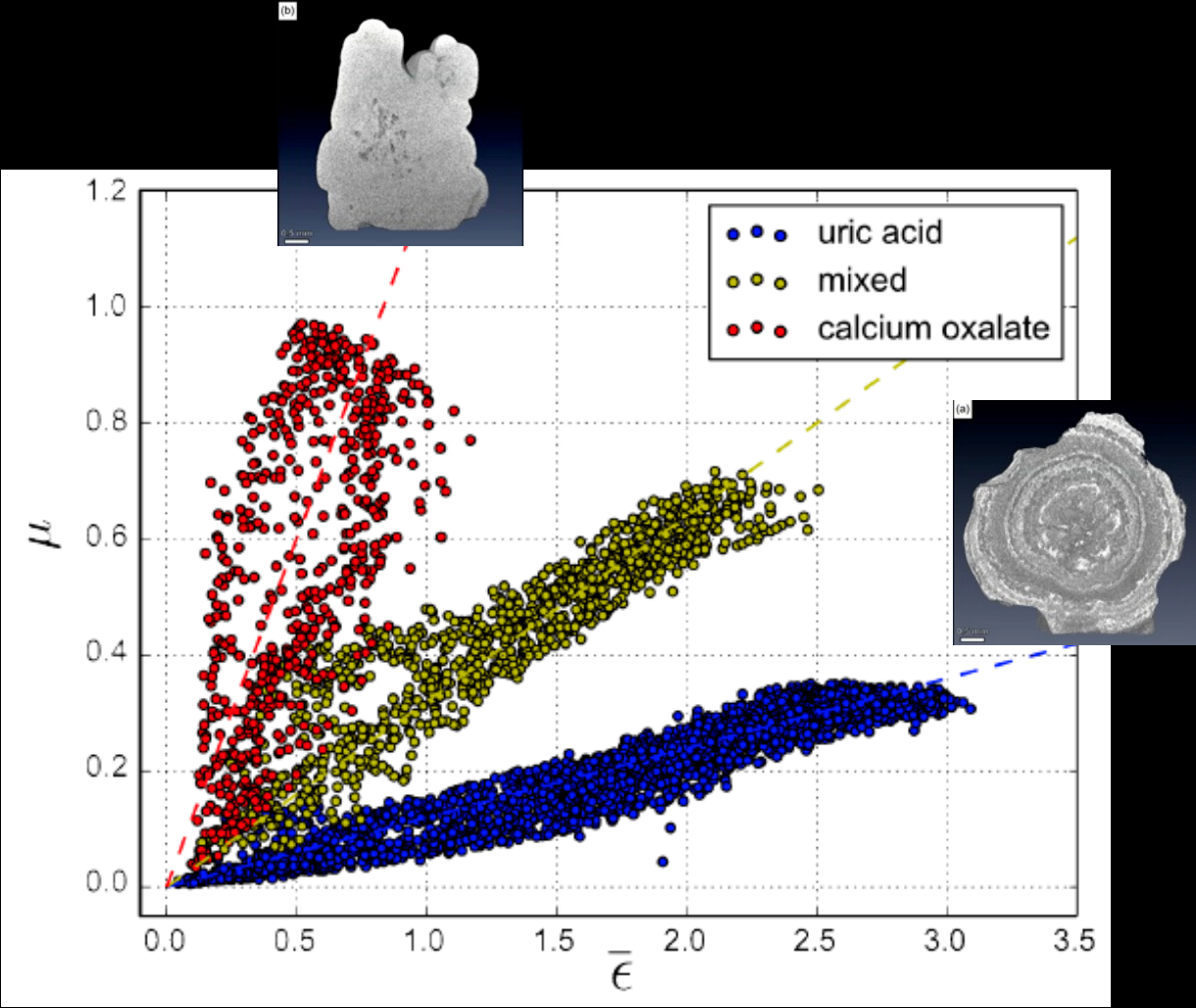


# dark-field contrast imaging for classification of kidney stones

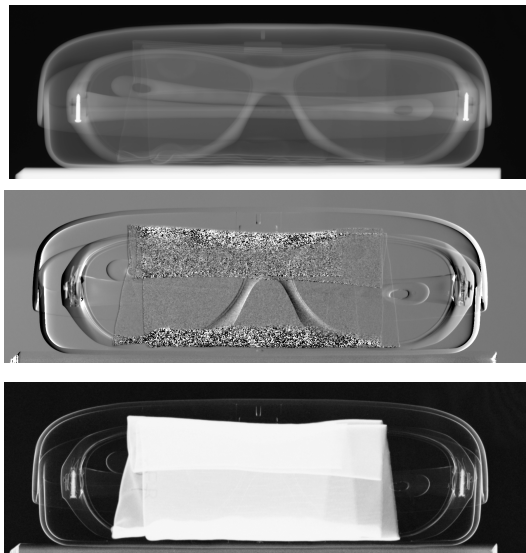
absorption



dark-field



# Our Dream: Better Clinical X-Ray Diagnostics



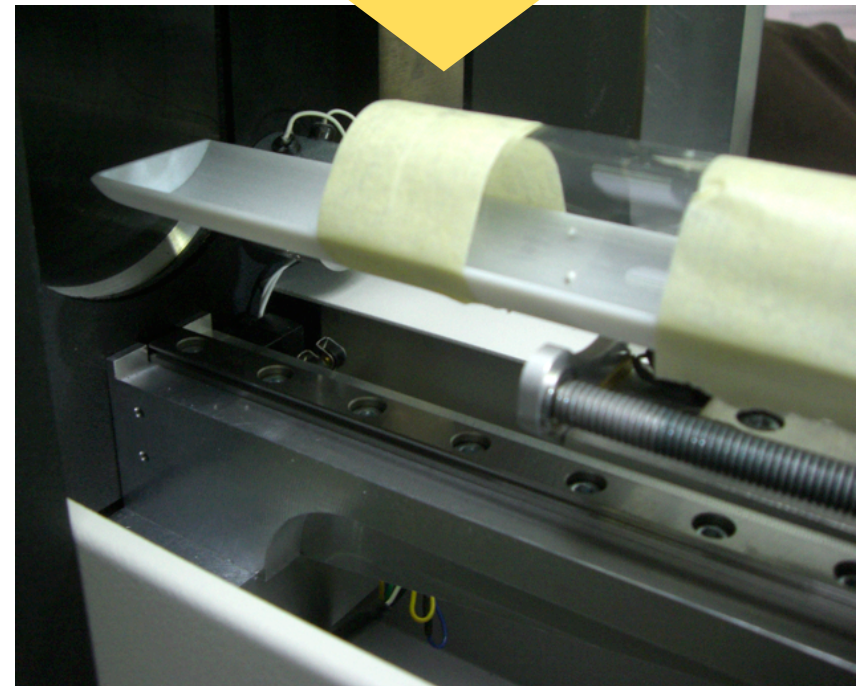
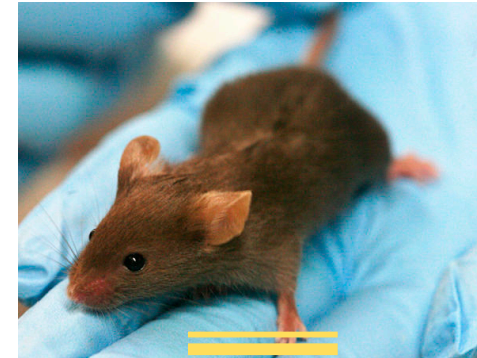
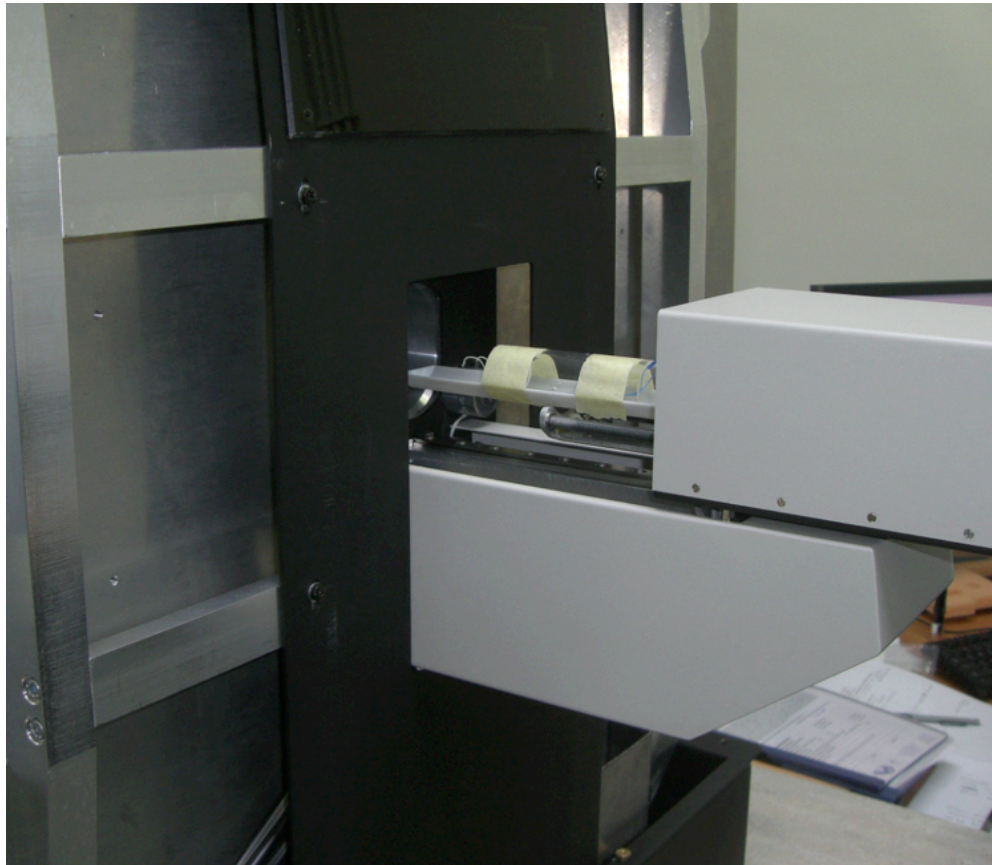
X-ray tube results

Clinical X-ray CT

# First small-animal phase-contrast CT scanner



# From bench to (mouse) bed-side...



includes life support:

- temperature stabilization
- breathing detection (CCD)



# Translation to in-vivo experiments



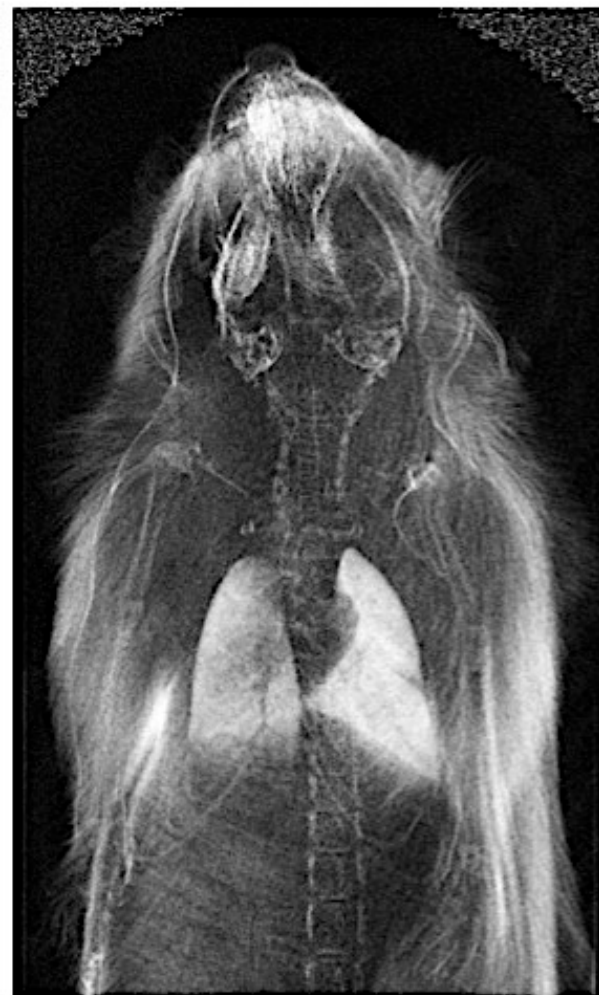
absorption image



phase-contrast image



dark-field image

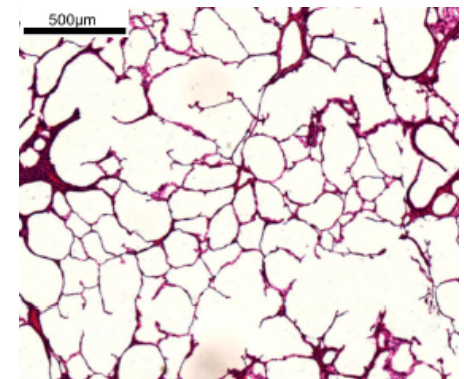
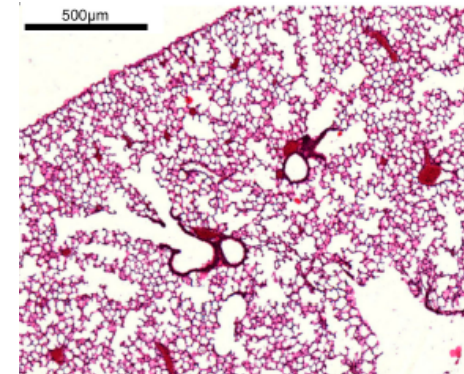
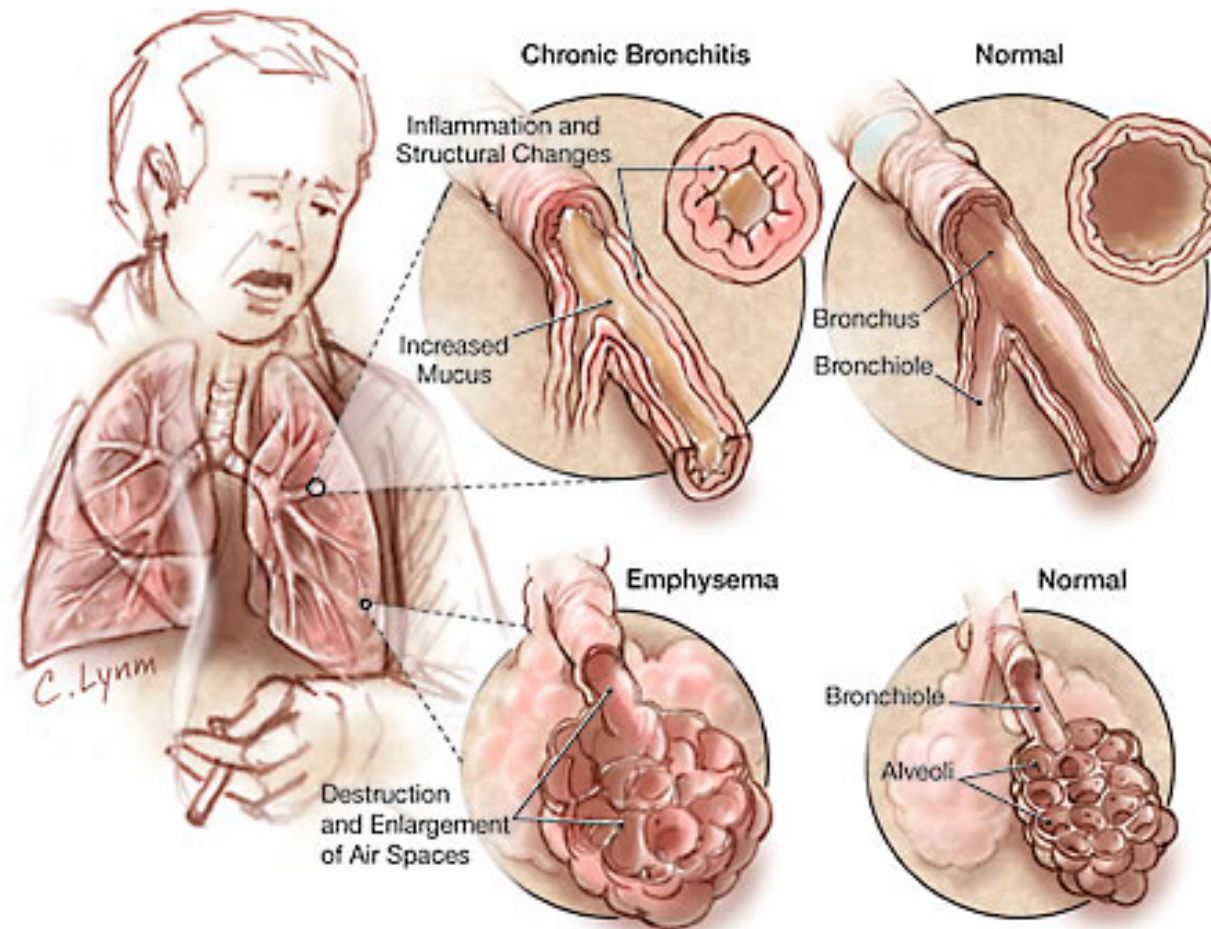


total exposure time: 20 sec, total dose: approx. 3.5 mGy

# X-ray Dark-Field Imaging & Lung Diseases

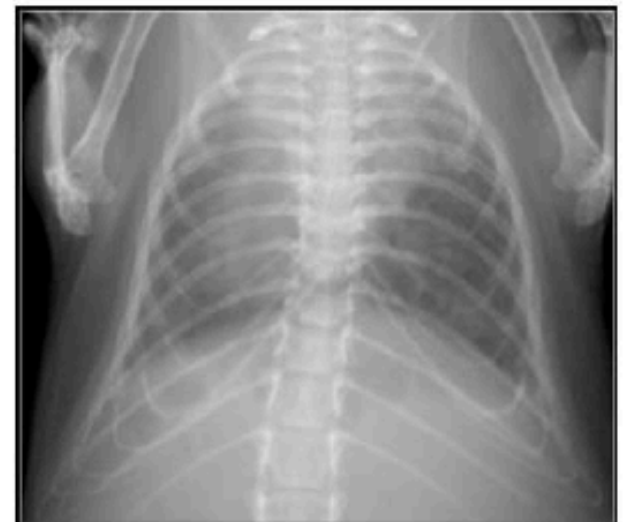


COPD: „Chronic obstructive pulmonary disease”

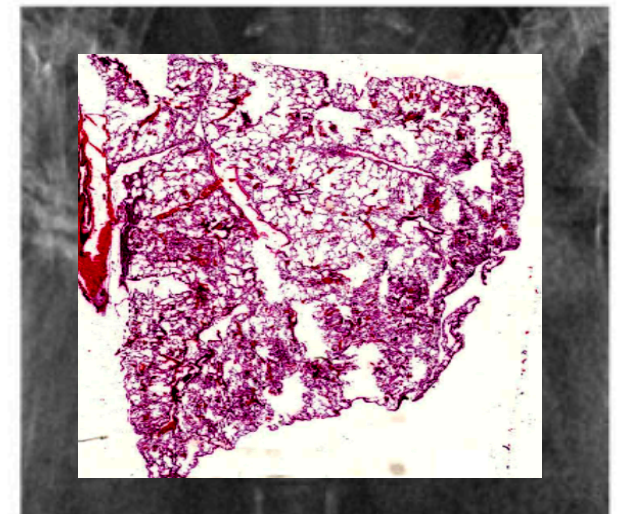
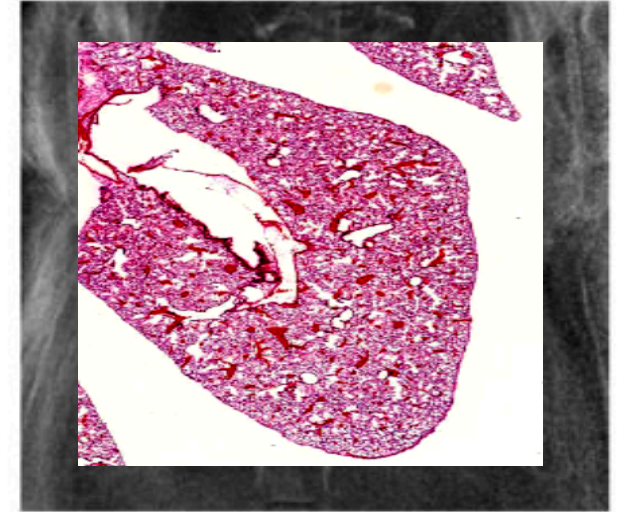
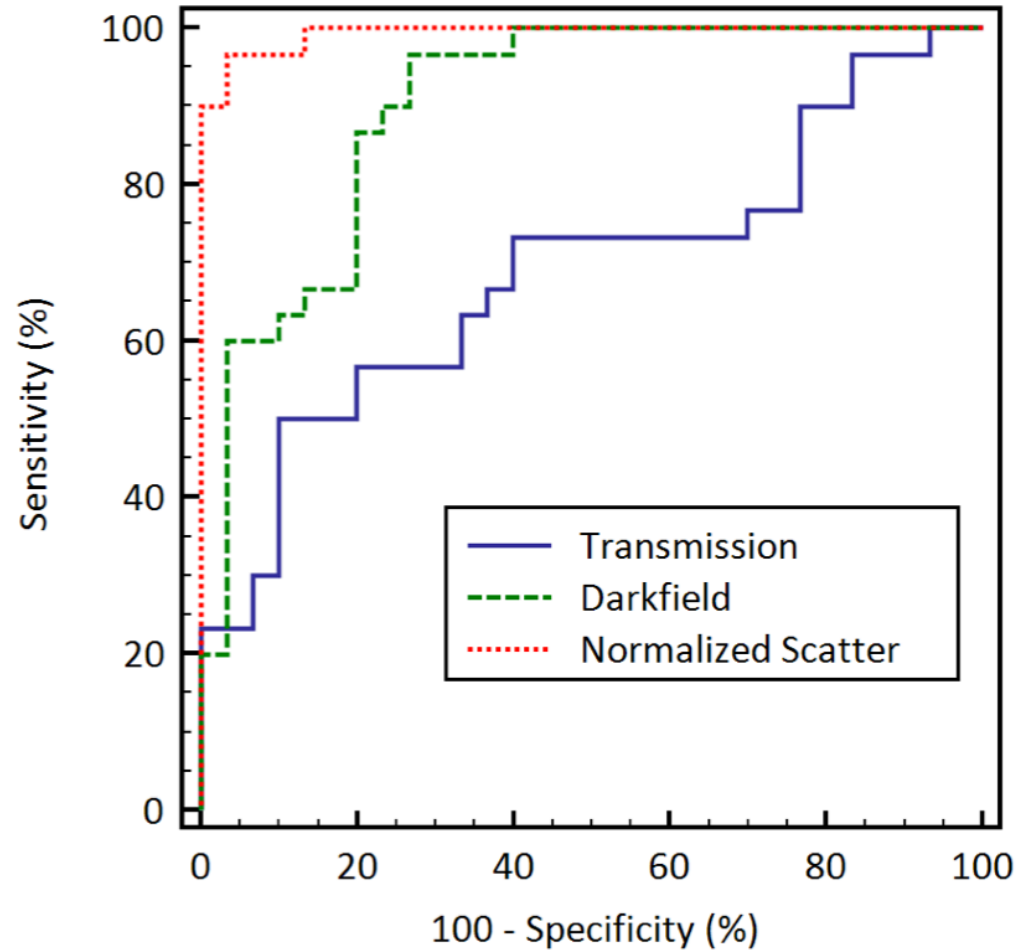


ranked as the fourth/ fifth leading cause of death, with tendency to increase

# emphysema diagnostics in in-vivo mouse models



# emphysema diagnostics in in-vivo mouse models



## staging of emphysema in in-vivo mouse models

None



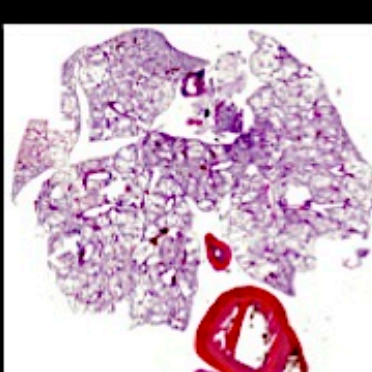
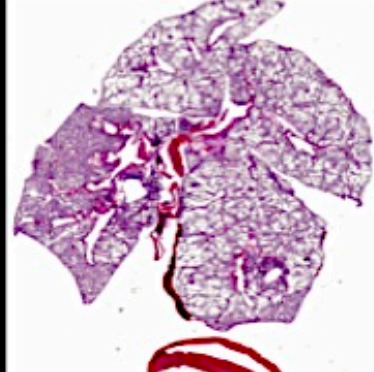
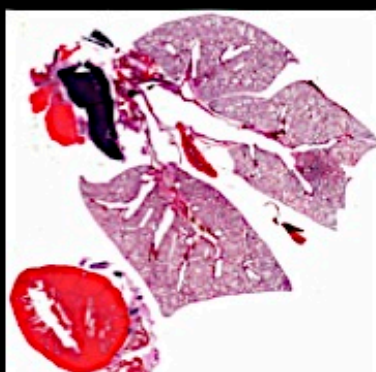
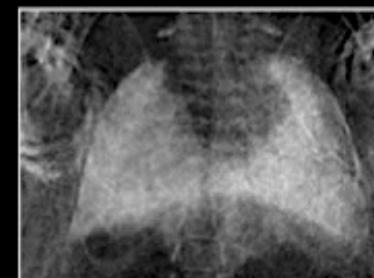
Mild



Moderate



Severe



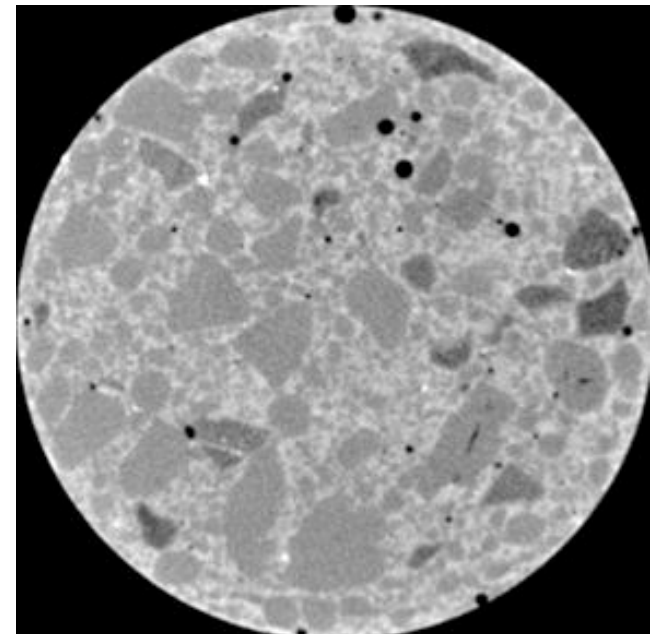
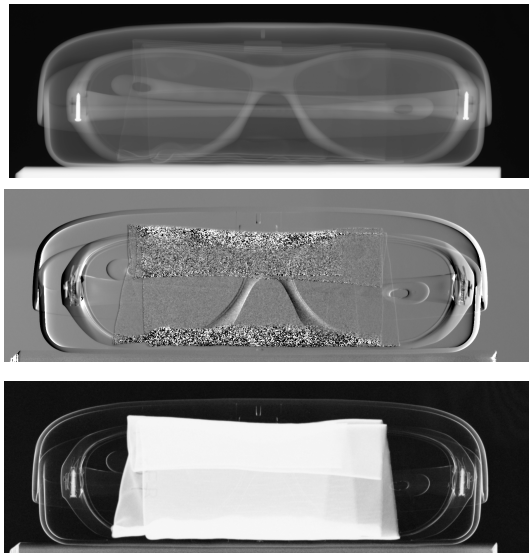
# first in-vivo small-animal dark-field CT images



# Multimodality for materials science



Damage in cement/mortar

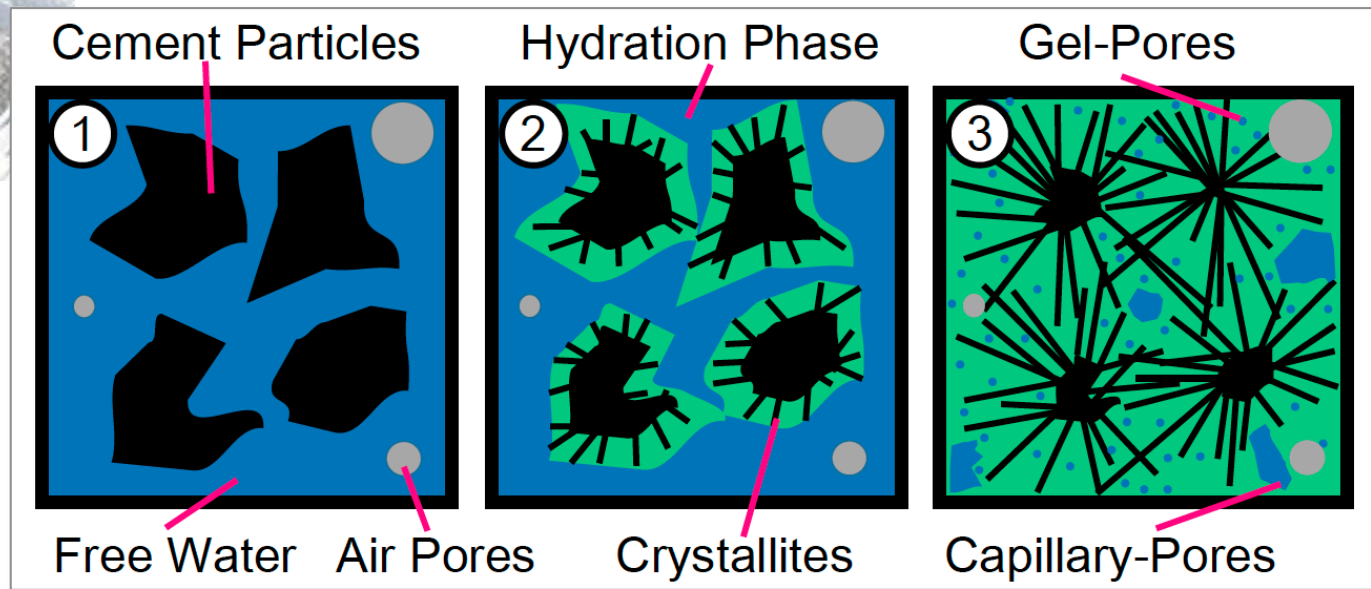


Structure of concrete

# Cement/ Concrete Hardening



Collaboration with Prof. C. Grosse/Chair for Non-destructive Testing (TUM)

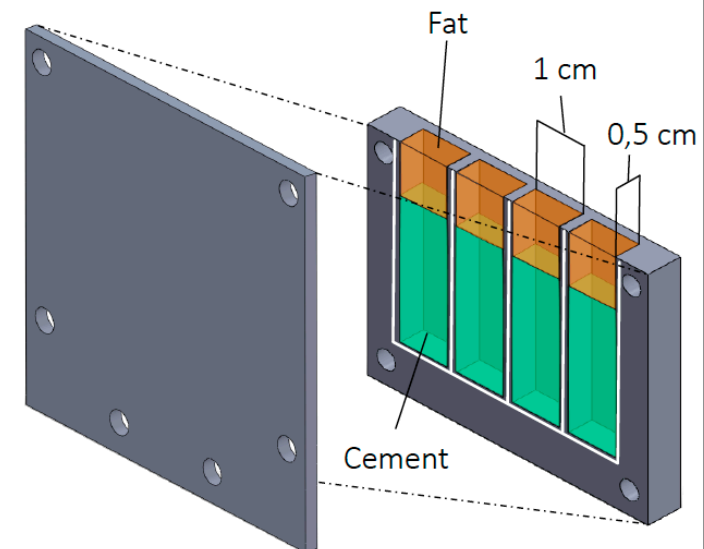




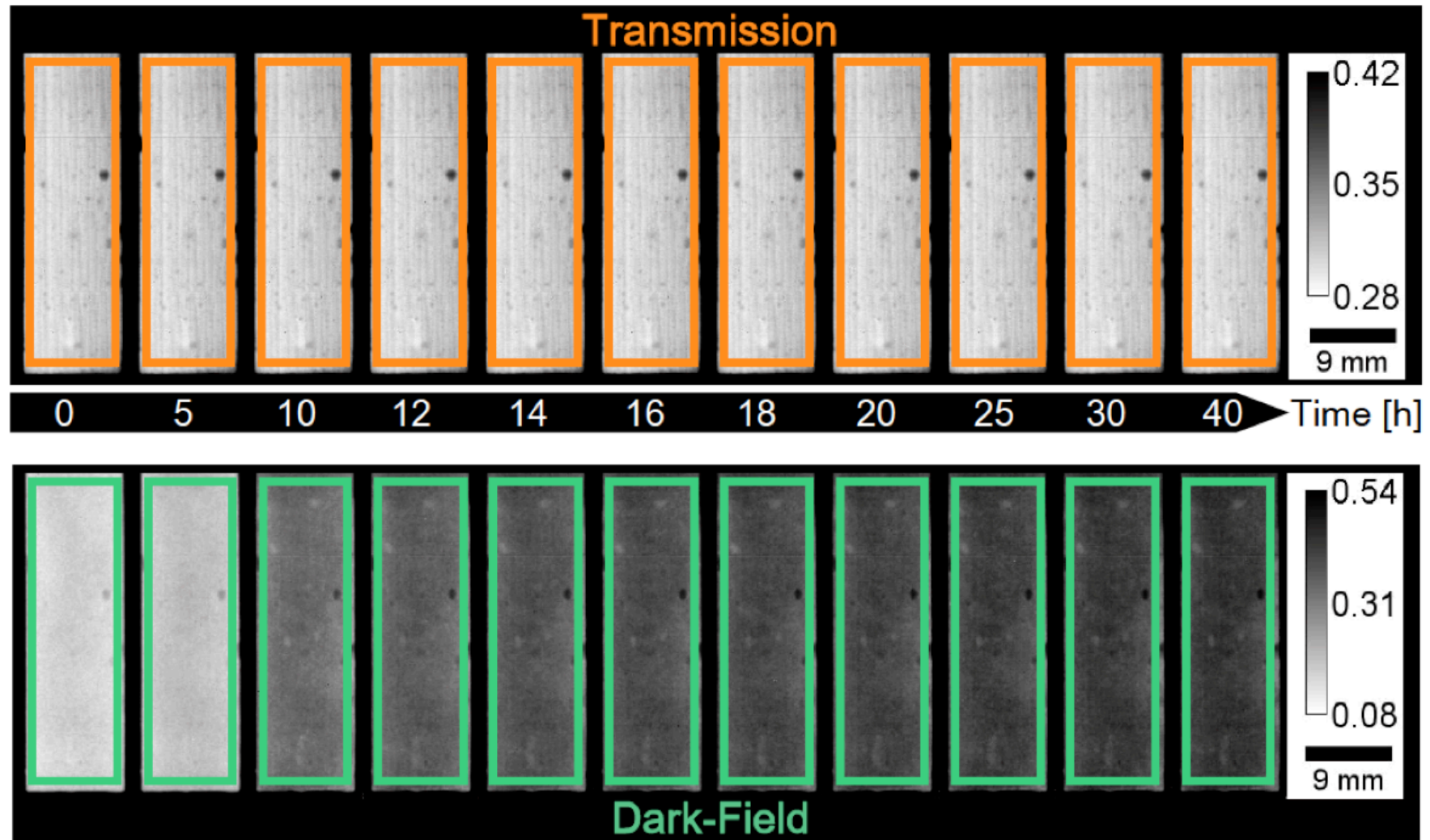


Collaboration with Prof. C. Grosse/Chair for Non-destructive Testing (TUM)

- Portland cement (CEM 42.5R) with  $w/c=0.3125$
- Acquiring images every 15 min over 60 hours @ 60 kVp
- Measurement was repeated 3 times



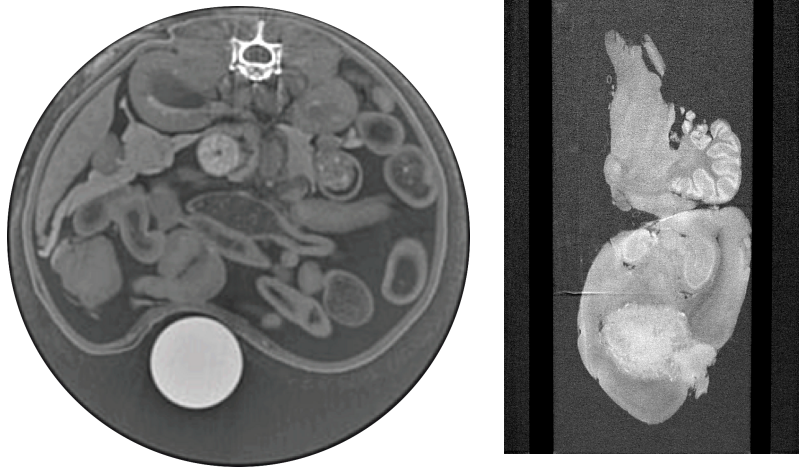
# Cement/ Concrete Hardening



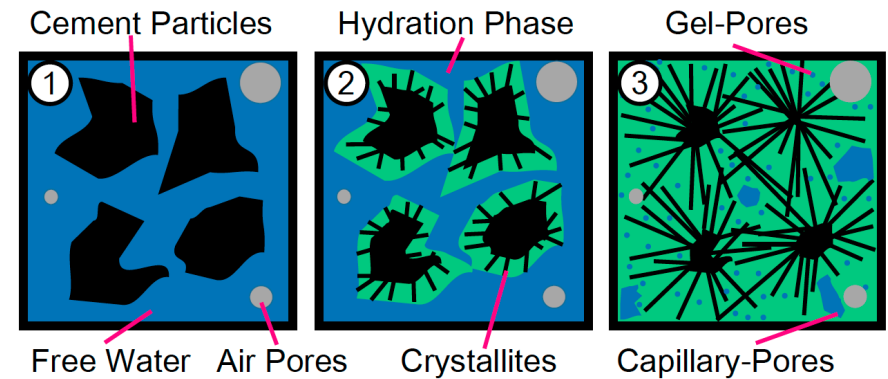
# Conclusions



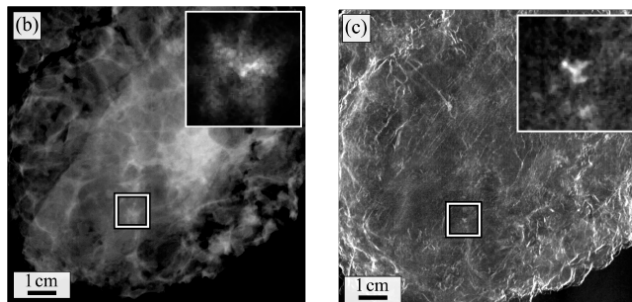
## Phase-Contrast CT for Biomedical and Materials Research



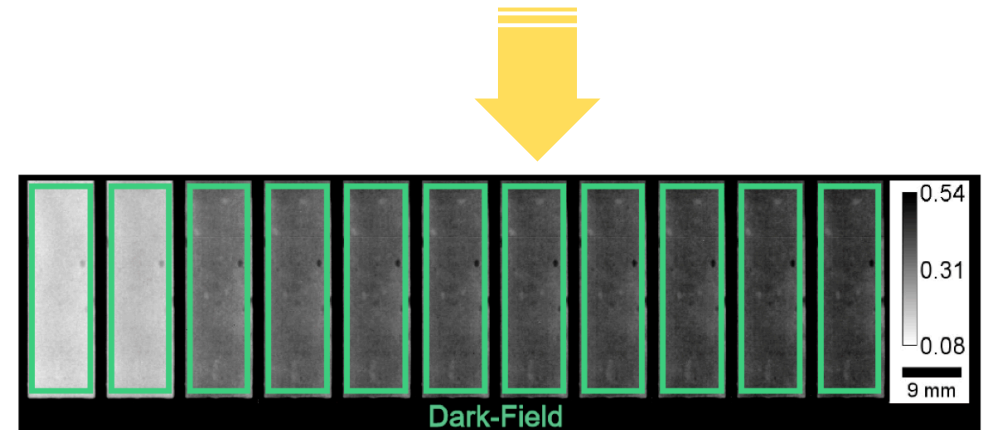
## Dark-Field Radiography for Materials Characterization



## Dark-Field for better Diagnostics



Classification of calcifications in Breast and Kidney!



Resolving internal structures below the image resolution!

# Acknowledgements



...E17 group @ TUM, especially Marian Willner, Lorenz Birnbacher, Manuel Viermetz, Kai Scherer, Friedrich Prade and Franz Pfeiffer



# Acknowledgements



**P. Noel, T. Baum, R. Braren, J. Bauer, A. Fingerle, D. Muenzel, E. Rummeny**  
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**S. Auweter, H. Hetterich, F. Meinel, S. Grandl, K. Hellerhoff, F. Bamberg, K. Hellerhoff, B. Ertl-Wagner, T. Saam, M. Reiser**  
*Institute for Clinical Radiology, Klinikum Grosshadern & LMU Munich*



F. Koch, J. Meiser, T. Schroeter, D. Kunka, M. Amberger, M. Walter,  
J. Schulz, **J. Mohr**  
J. Maisenbacher, **J. Gibmeier, A. Wanner**  
*Karlsruhe Institute for Technology & microworks, Karlsruhe*



**F. Yang, R. Kaufmann, M. Griffa**  
*Empa - Swiss Federal Laboratories for Materials Science and Technology*

Funding by:



European Research Council  
Established by the European Commission

**THANK YOU VERY MUCH  
FOR YOUR ATTENTION !**