Phase Contrast Imaging for medical applications with conventional sources towards laser-based medical imaging

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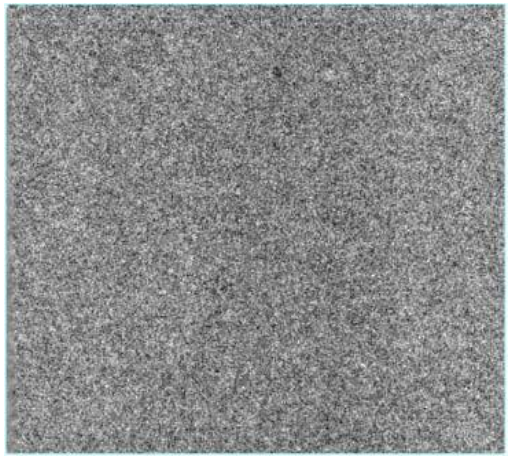
Outline of the talk:

- X-ray Phase Contrast Imaging – Overview and Theoretical background
- Talbot Lau Interferometer
- Phase Contrast X-ray Imaging (PXI) on mammography phantom
- Phase Contrast X-ray Imaging (PXI) on artery
- Laser driven X-ray sources for PXI

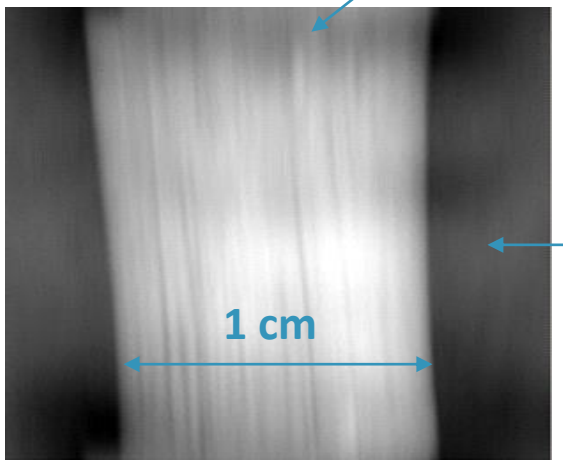
Why X-ray Phase Contrast Imaging

- Was developed in 1930 by Frits Zernike - in 1953 winner of the Nobel Prize in Physics for his invention of the phase-contrast microscope;

Frits Zernike
(1888-1966)



Attenuation



Stutman et al. 2013

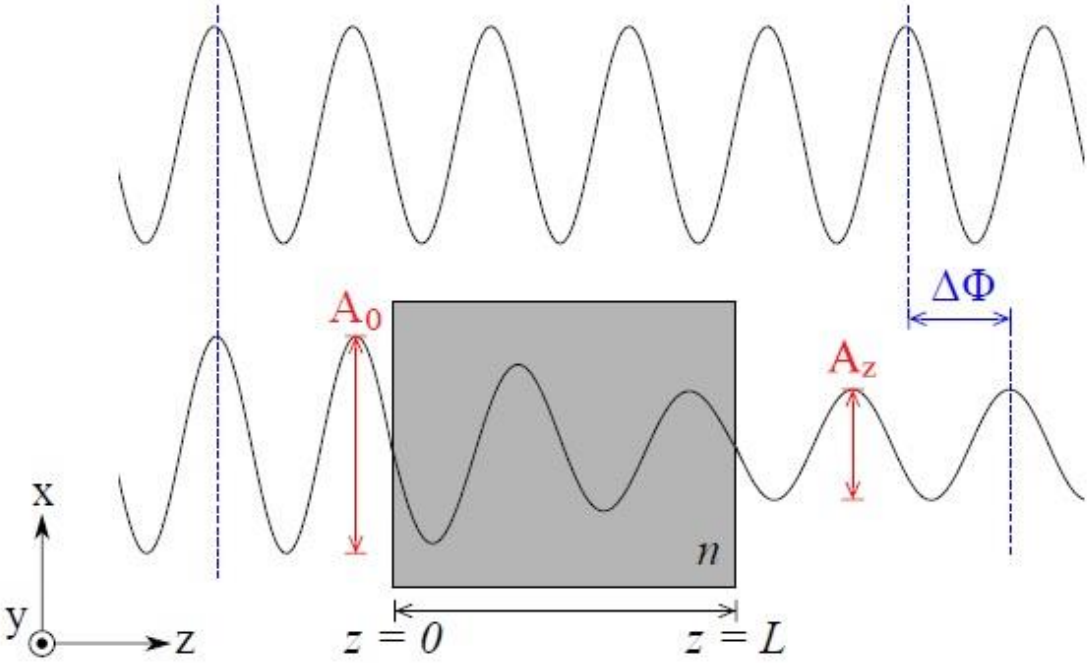
Phase Contrast

- A promising approach based on refraction of radiation and not on the attenuation, like in classical methods;
- A better visualization of materials with low Z - tissue, biological materials;
- High quality images with enhanced contrast and very high spatial resolution;
- Potential to reduce dose in tissue (the dose is still an issue in conventional techniques);

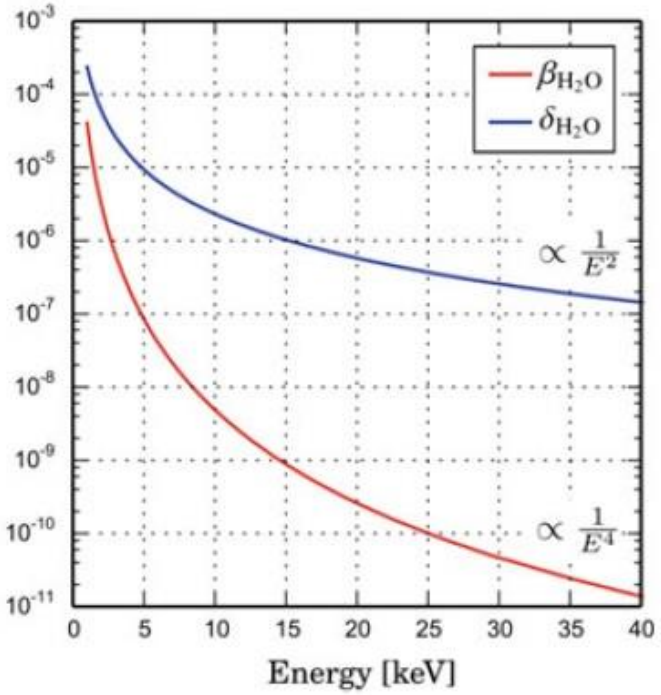
Interaction of X-rays with matter

$$n = \underbrace{1 - \delta}_{\text{elastic}} + \underbrace{i\beta}_{\text{inelastic}}$$ **Complex index of refraction**

Where, δ - refractive index decrement
β - absorption index



- For low-Z matter (tissues) refraction coefficient bigger than attenuation one

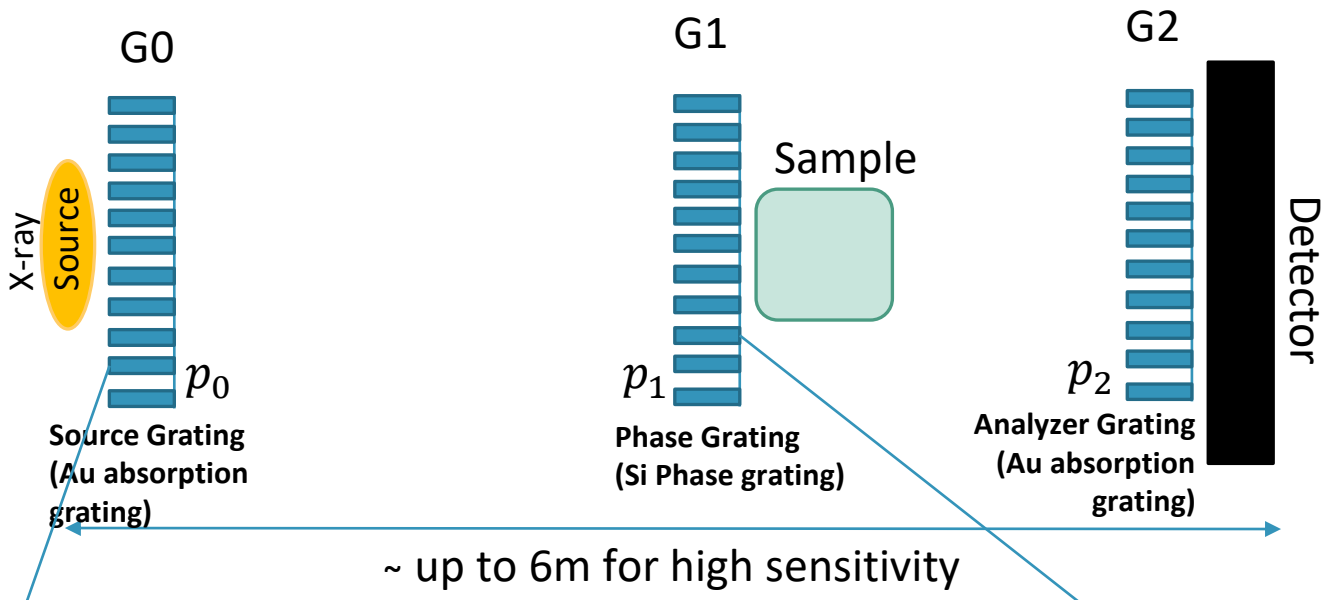


Stampanoni, M., et al. (2011)

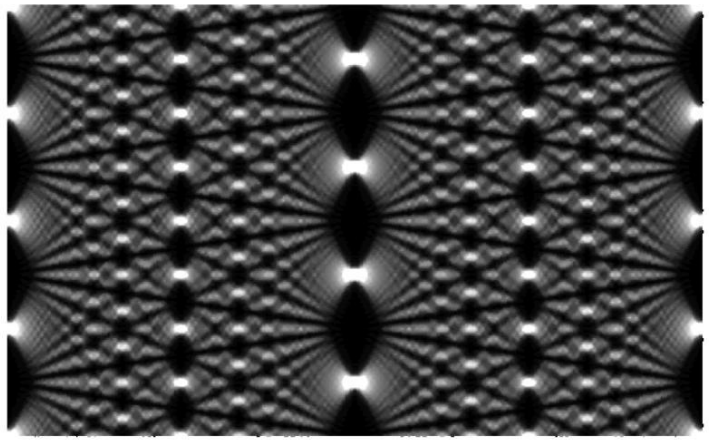
- A plane monochromatic wave that traverses a material of complex refractive index n experiences an amplitude decrease $\Delta \boldsymbol{A} = \boldsymbol{A_0} - \boldsymbol{A_z}$ and a phase shift $\Delta \boldsymbol{\Phi}$ compared to an unperturbed wave traveling in vacuum.

X-ray Phase Contrast Imaging

Talbot-Lau Interferometer

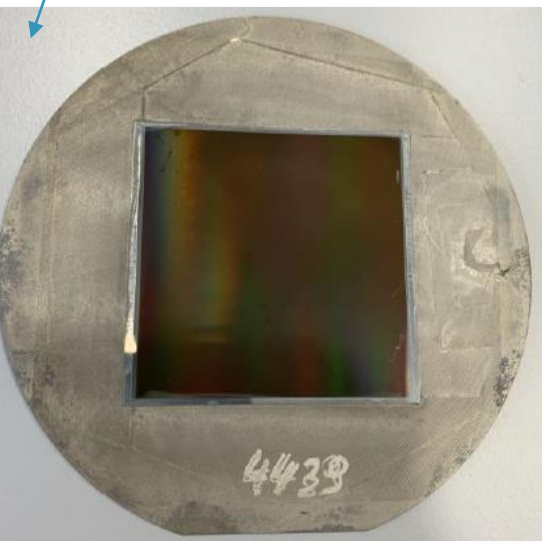


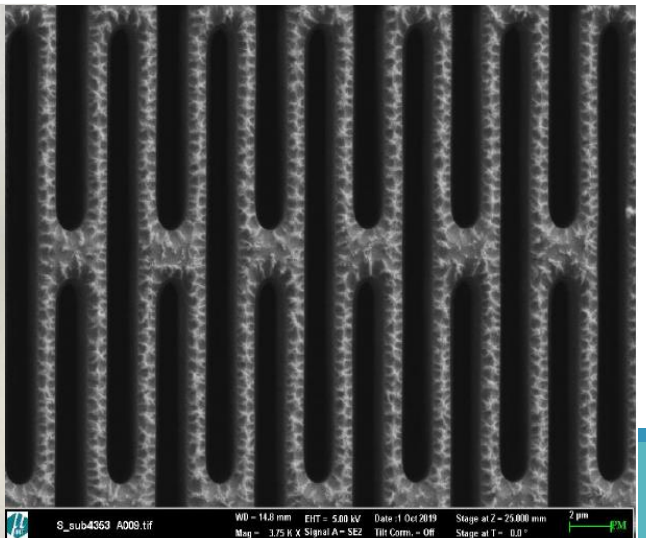
TALBOT EFFECT

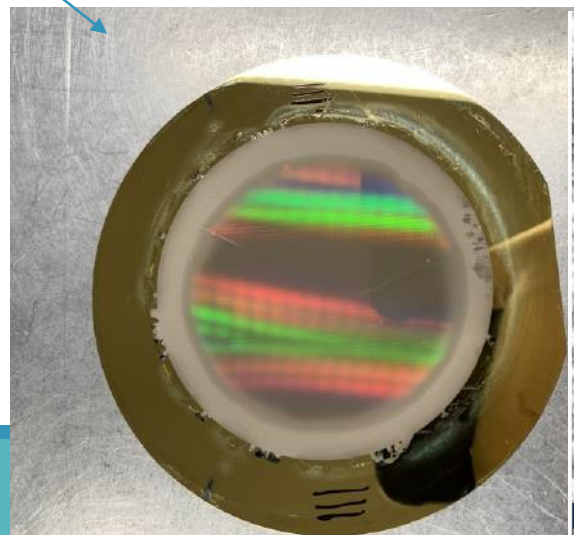


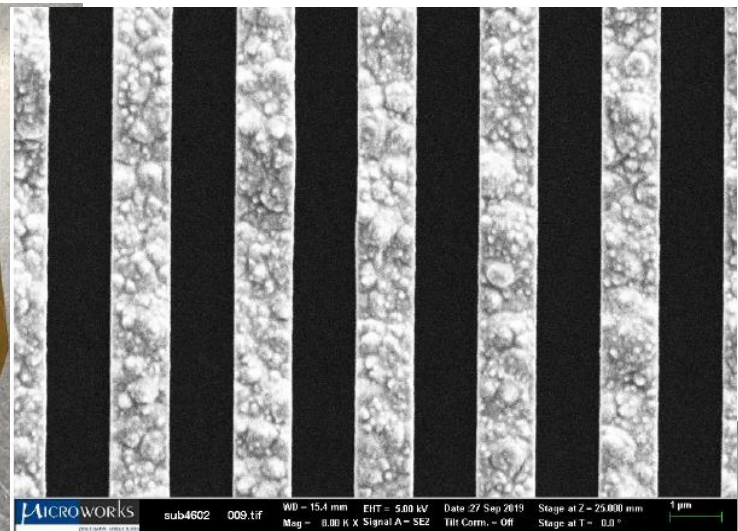
$$d_T = m\frac{2p^2}{\lambda}$$

m – Talbot order
p – period of the grating
λ - wavelength









Phase Contrast X-ray Imaging (PXI) on mammography phantom

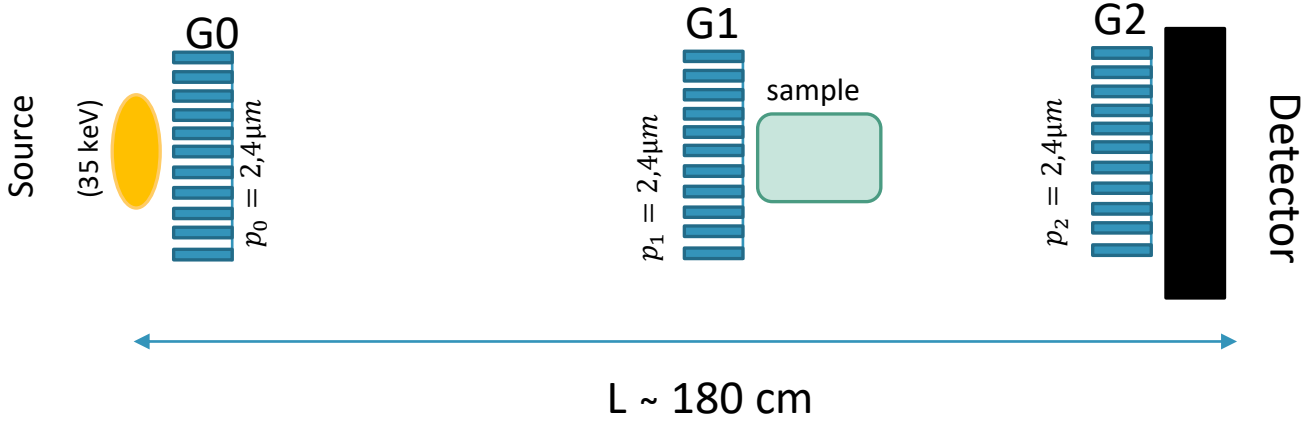
Purpose:

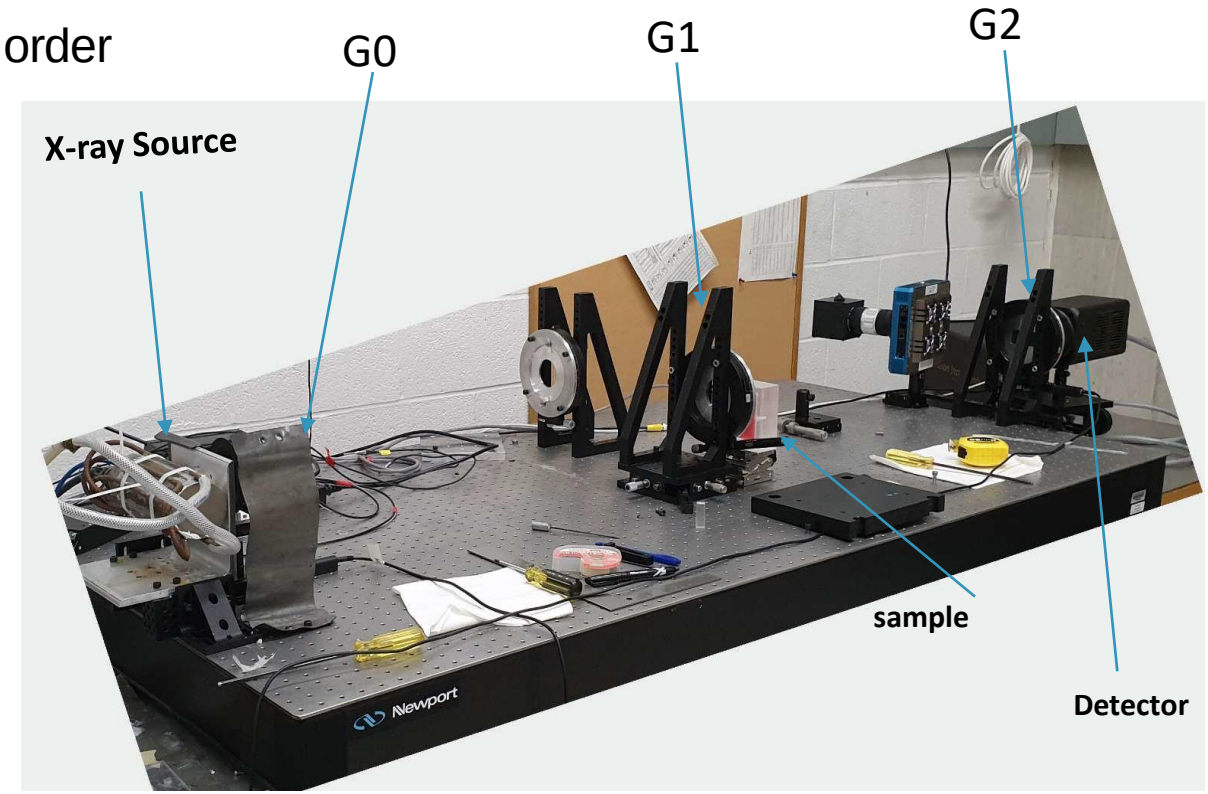
- to demonstrate ultrahigh sensitivity of phase contrast x-ray imaging at 20-40 keV, towards laser-based mammography;

Means:

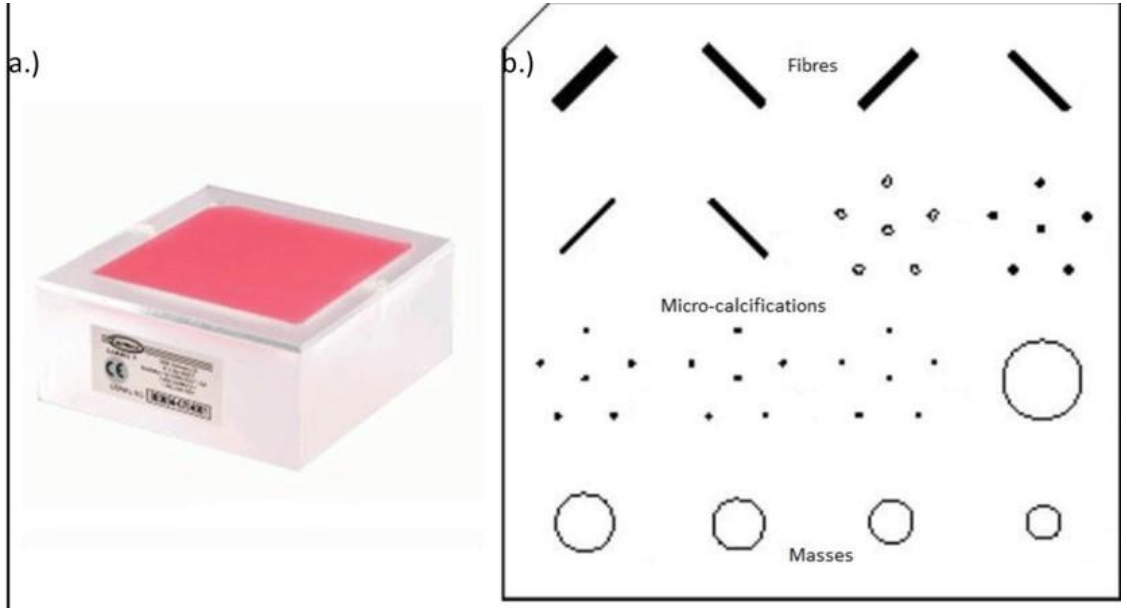
- very small period Talbot gratings operated in very high Talbot order

Set-up:



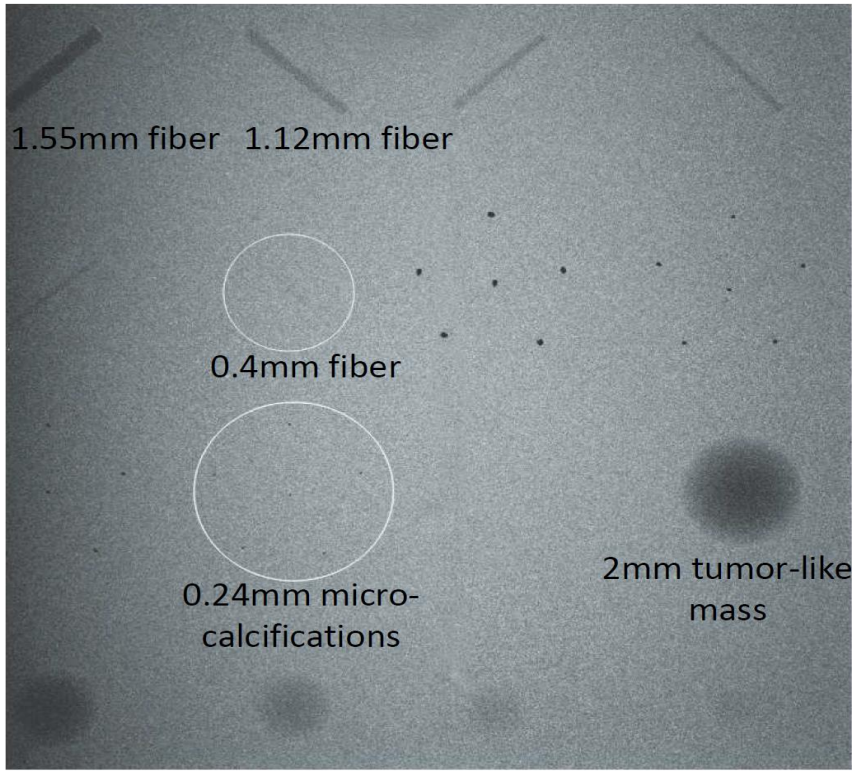


The object used for the experiment: mammography phantom



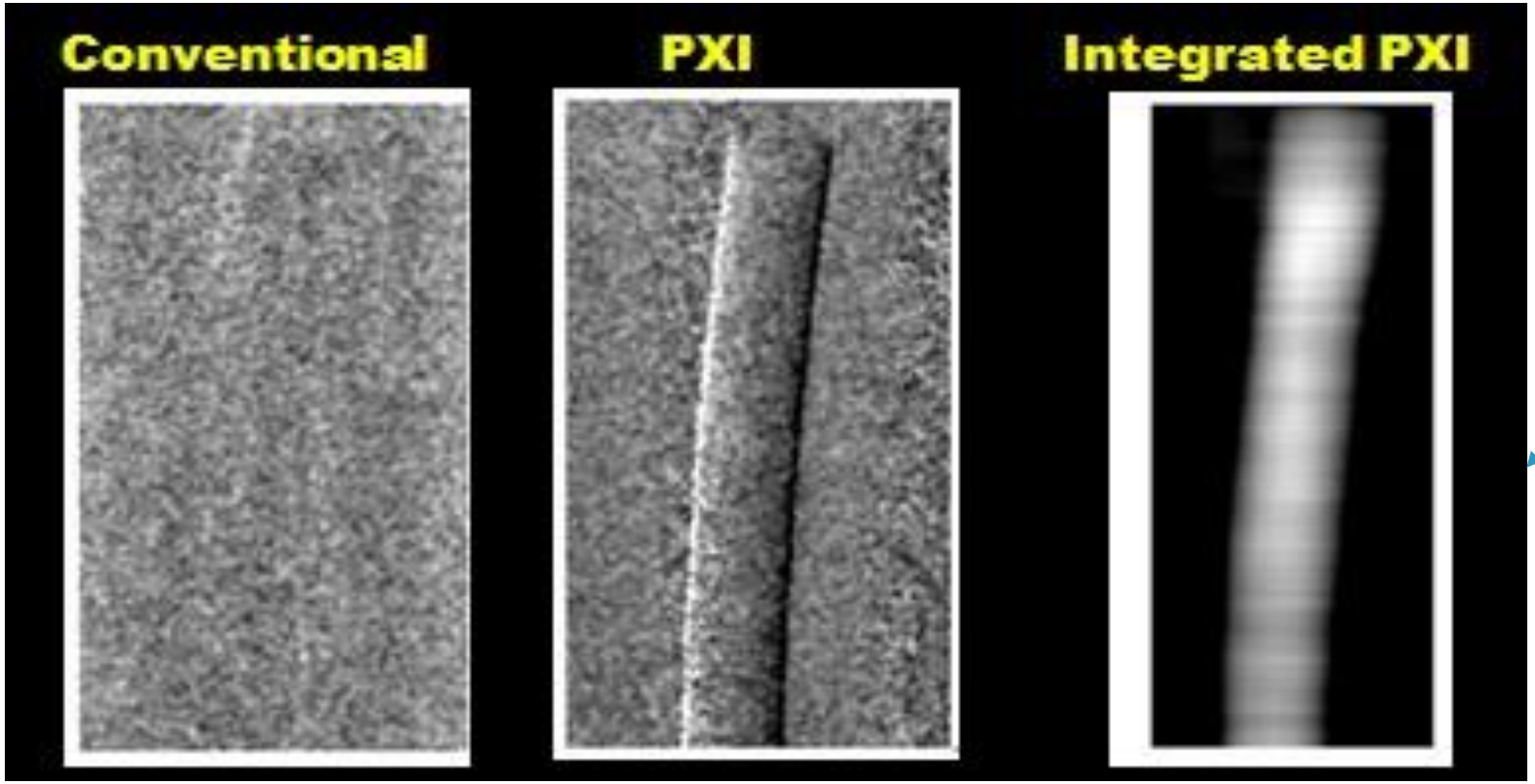
Mamography Phantom: Location of the target object

(nylon fibers, microcalcifications, tumor-like masses)

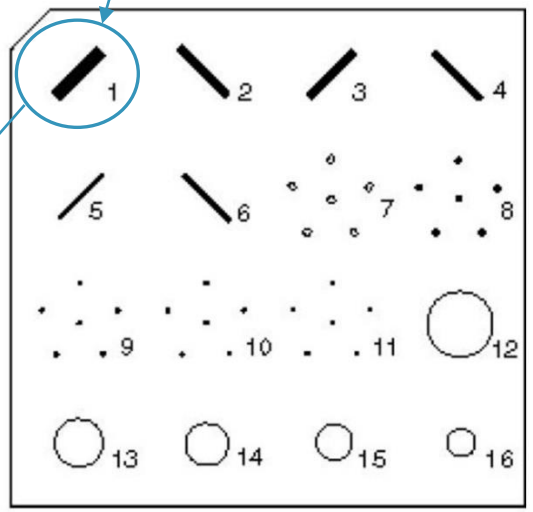


Reference image with full-field digital mammography, 75um pixel CdTe detector, very high sensitivity, low energy

Phase Contrast X-ray Imaging (PXI) on mammography phantom



1.55 mm nylon fiber

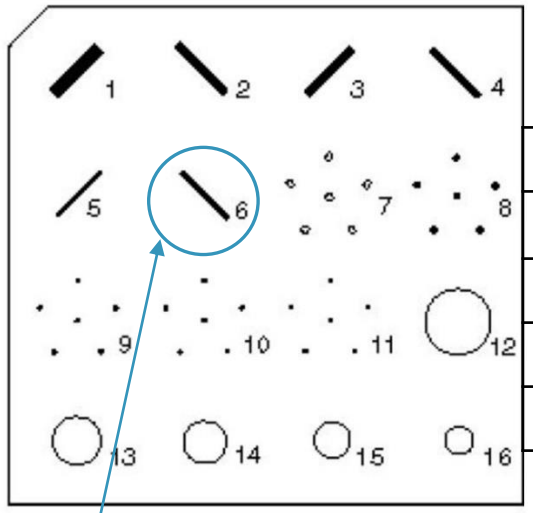


Results

Tube voltage	35 kVp
Filtering	1 mm Al, 0.065 mm Cu
Source-Object	950 mm
Object-Detector	850 mm
Exposure	650 s at 1 mA

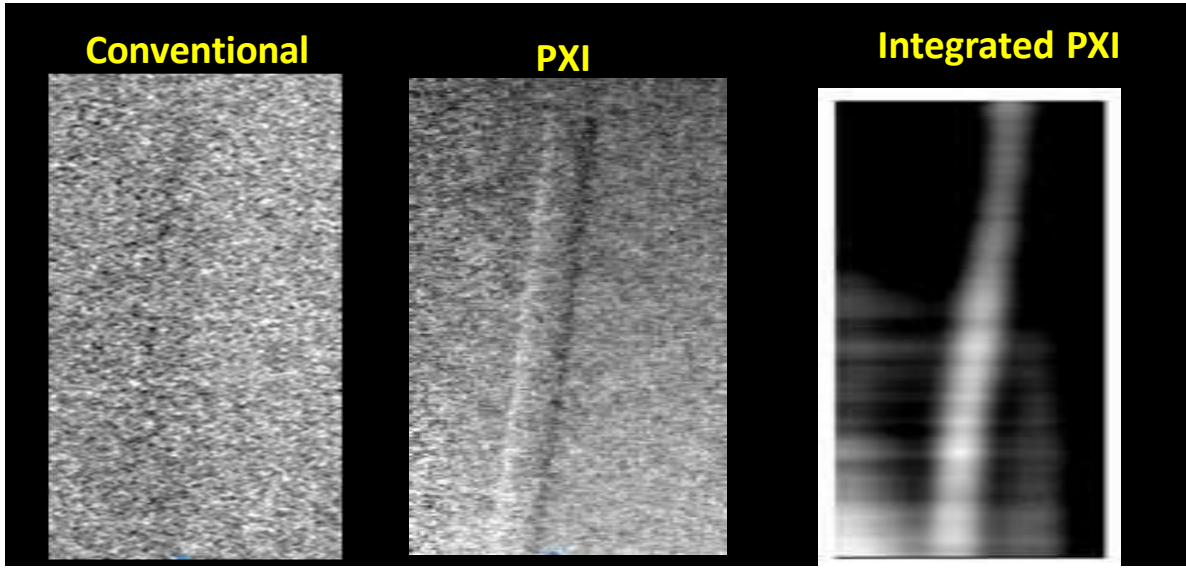
Phase Contrast X-ray Imaging (PXI) on mammography phantom

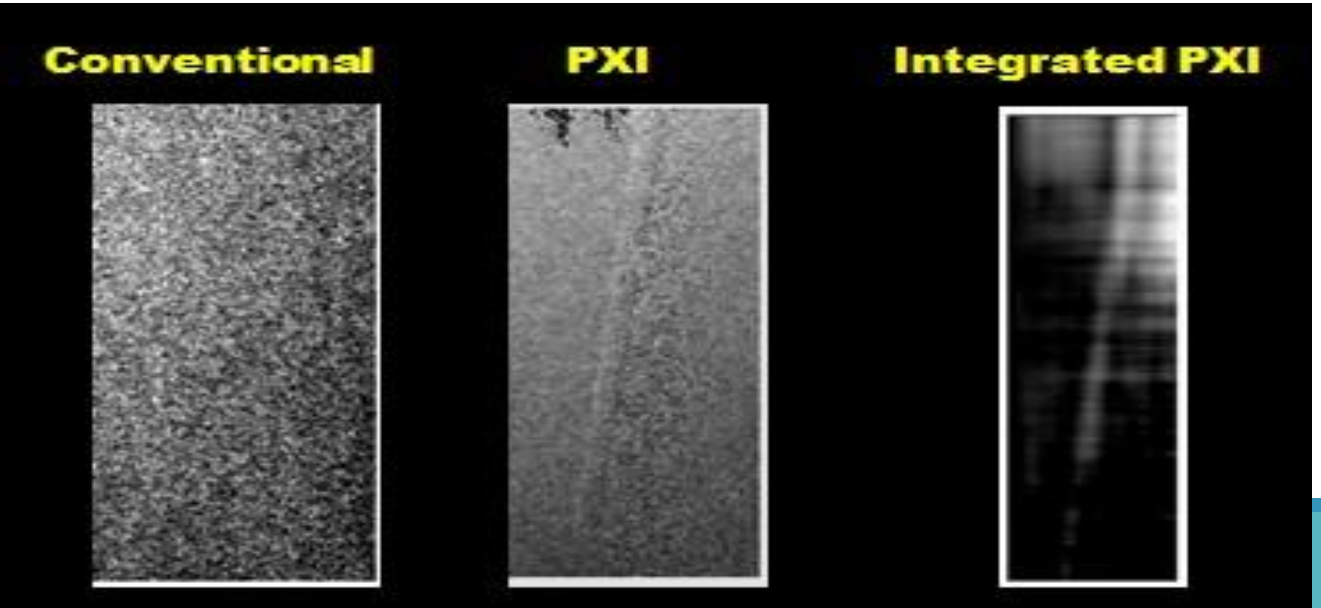
Results



0.4 mm nylon fiber

Tube voltage	35 kVp
Filtering	1 mm Al, 0.065 mm Cu
Source-Object	950 mm
Object-Detector	850 mm
Exposure	650 s at 1 mA





Tube voltage	35 kVp
Filtering	1 mm Al, 0.065 mm Cu
Source-Object	950 mm
Object-Detector	850 mm
Exposure	16 s at 1 mA

M.O. Cernaianu, D. Stutman

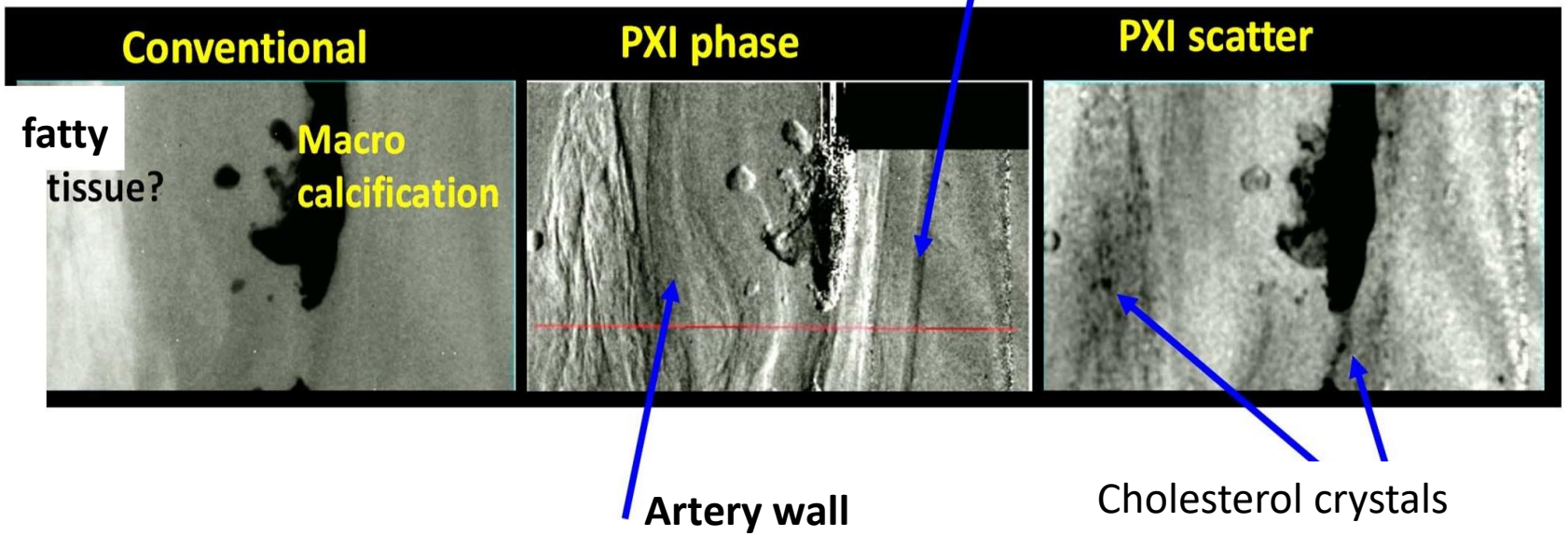
Phase Contrast X-ray Imaging (PXI) on artery

Set-up

Phase Contrast X-ray Imaging (PXI) on artery

Results

atherosclerotic iliac artery



Results to be published in UPB Buletin: Perspective on using Talbot-Lau X-ray phase contrast imaging for atherosclerosis diagnosis

Laser driven X-ray sources for PXI

Dose efficiency ratio of grating PXI CT vs attenuation CT

$$\eta \approx \lambda^2 \cdot [L/G]^2 \cdot V^2 \cdot [\Delta\phi/\Delta\mu]^2 \cdot a^{-2}$$

L = inteferometer length

G = grating period

V = Talbot fringe contrast

a = spatial resolution

Raupach & Flohr 2012

for η=10, G=5 μm, V=25%, a=50 μm, E= 50 keV (clinical CT)

L~ 5 meters

Why laser driven X-ray sources for PXI?

- PXI needs coherent, bright, and directional X-ray sources
- X-ray flux of conventional X-ray tubes too low at long distances
- Synchrotrons too expensive and large for practical applications
- X-ray sources driven by high power lasers may be ideal solution: directional, quasi-coherent and bright

Summary of the talk:

- **PXI performance with conventional X-ray tubes nevertheless limited;**
- **Bright, coherent and directional X-ray sources driven by high power lasers will improve performance PXI;**
- **The Talbot method uses X-ray grating optics to increase the sensitivity of phase-contrast imaging, in particular at X-ray energies of interest for medical imaging (20-40 keV);**
- **Talbot Method with betatron Source is a novelty;**
- **The experiment will open the way towards further laser medical imaging applications at ELI-NP;**

Acknowledgments:

- Dr. Dan Stutman - Johns Hopkins University, Baltimore, Maryland
- Dr. Petru Ghenuche - Extreme Light Infrastructure (ELI-NP), and Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH)
- Dr. M.O. Cernaianu - Extreme Light Infrastructure (ELI-NP), and Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH)

Thank you!