TU Delft

Delft University of Technology

PHOTONIS

Scientific Detectors

Neutron Imaging and Tomography at Low Flux Sources

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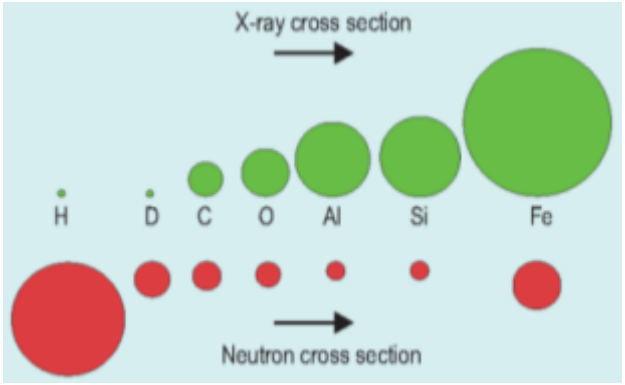
ATTRACT-NL meeting, 12 January 2018, Nikhef, Amsterdam

Neutron Imaging vs X-ray imaging

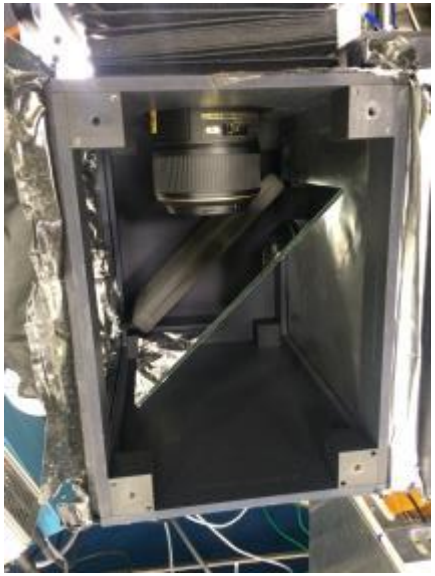
- Difference in contrast: X-rays interact with electrons, neutrons with nuclei
- X-ray cross-section increases steeply with Z, neutron cross-section less predictable, and depends on isotope

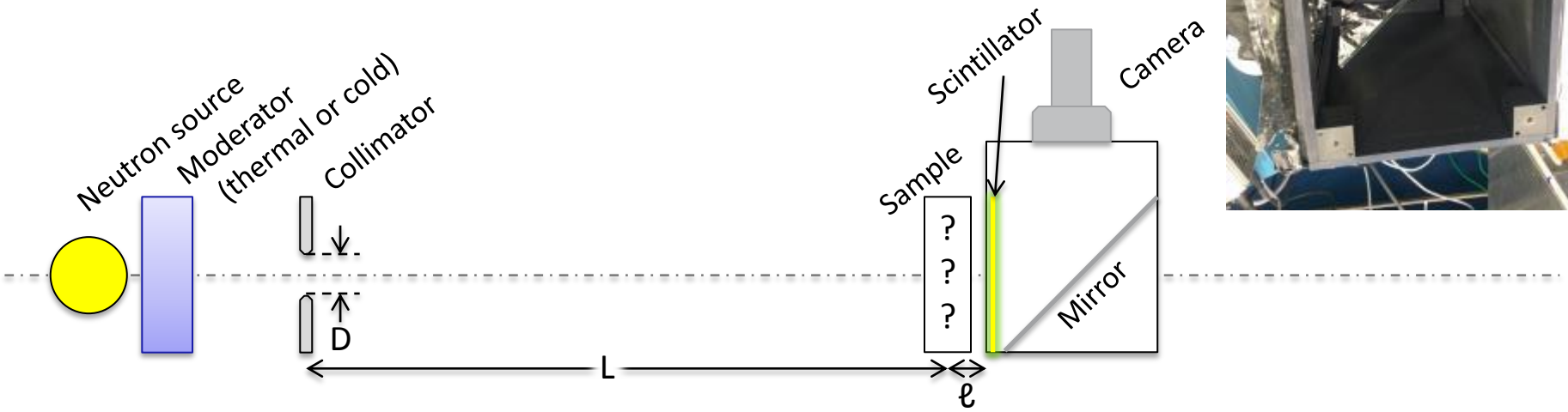


Source: PSI

Neutron Imaging simplified setup

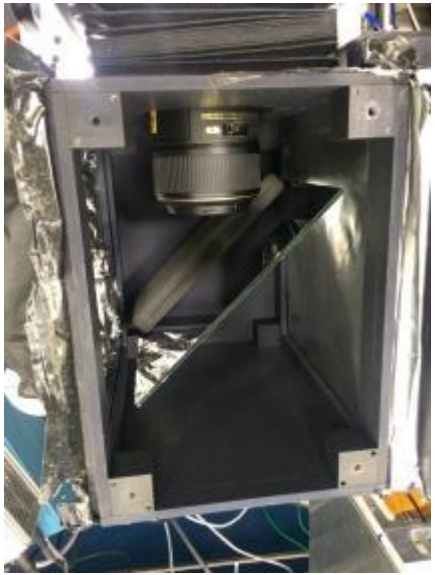
- Tomography possible with a rotating sample stage
- L/D of a beamline often limits spatial resolution to ℓ×L/D
- Scintillator/mirror/camera detector trades off resolution with detection efficiency. **Efficiency ~1% is common**





Neutron Imaging challenges

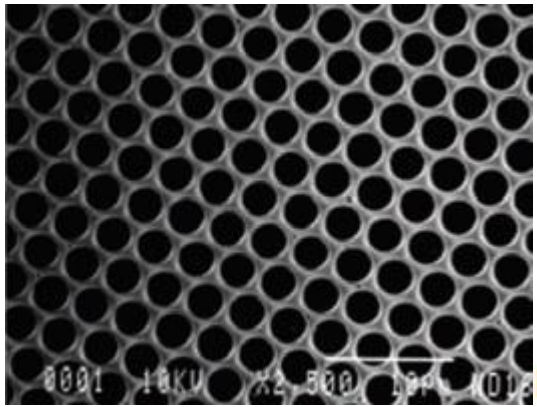
- Intensity is limiting final resolution for reasonable exposure time
- The higher the desired resolution the thinner the scintillator needs to be thus the lower the efficiency
- Neutron beam exposure may activate sample which is usually unwanted in these cases avoid inefficient exposures.

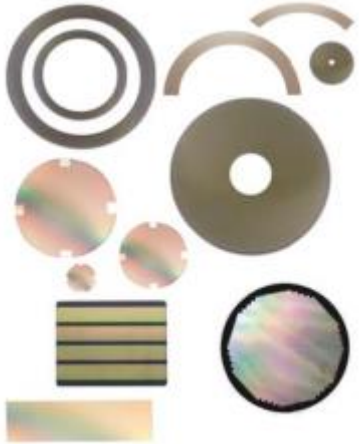


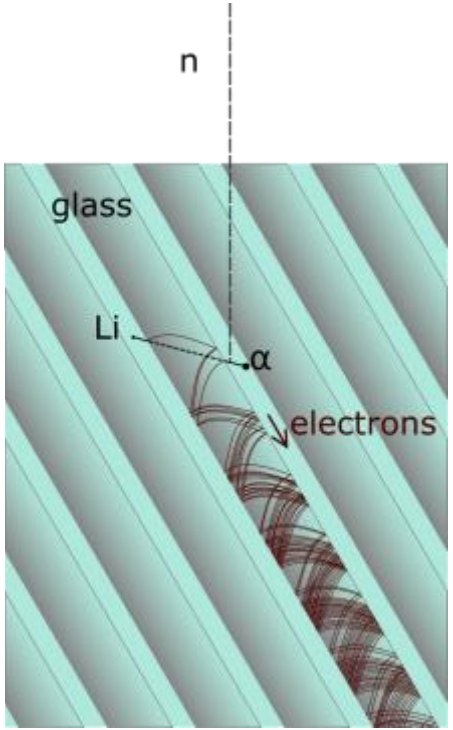
In practice only a handful of reactor/spallation sources worldwide is bright enough for tomography with reasonable exposure times and high resolution.

Microchannel Plates loaded with ^{10}B and Gd

- Glass capillary structures with millions of microscopic pores, each of which acts as an electron multiplier
- Can be made in almost any size and shape
- If the glass is doped with ^{10}B and Gd, it becomes neutron sensitive
- Detection efficiency ~50% for thermal neutrons (~70% cold)

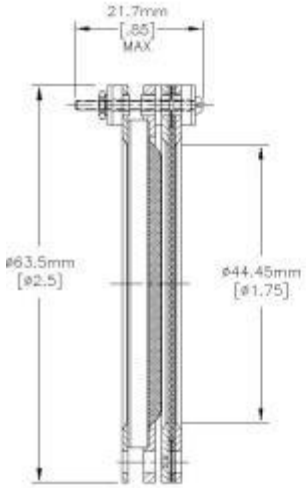


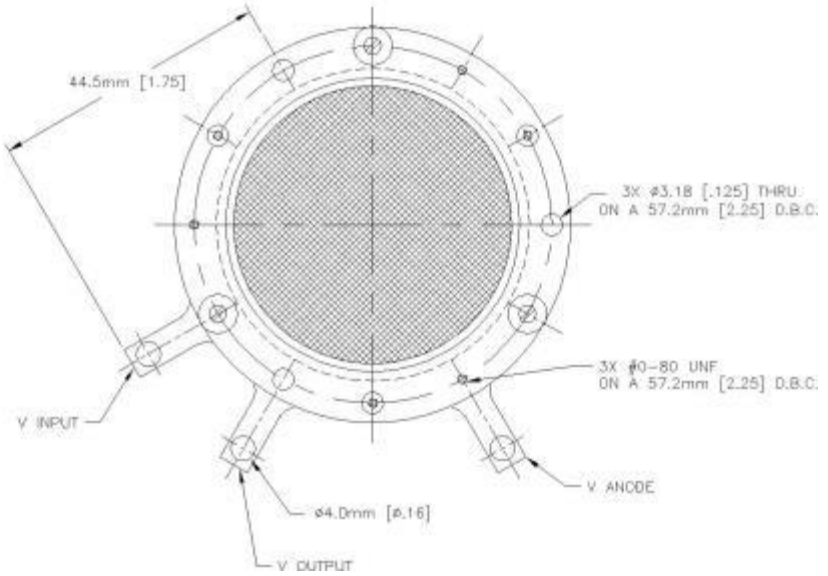




Neutron-sensitive phosphor screen imager

- An assembly of one or more MCPs with a phosphor screen
- Mounted in a vacuum enclosure, screen observed through a viewport by a camera
- 2 MCPs high gain, wider PSF
- 1 MCP lower gain
- First tests with 40 mm round FoV
- 100x100 mm^2 unit in progress

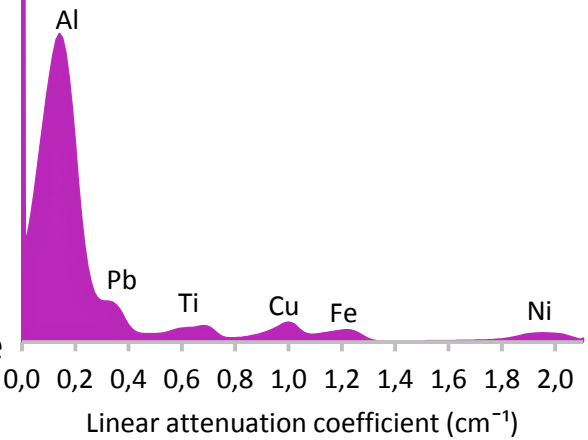


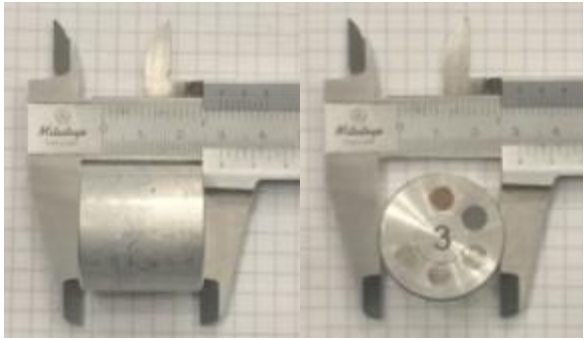


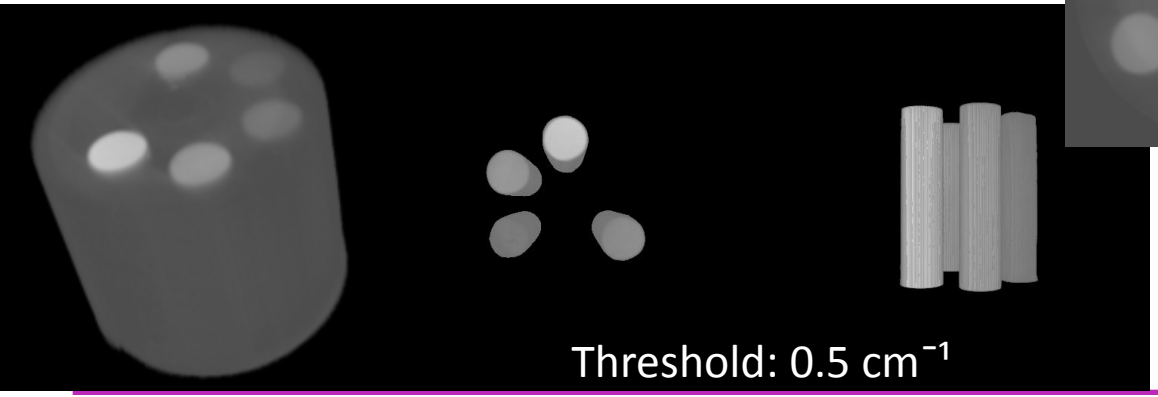
Tomography

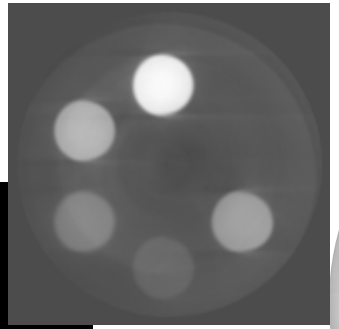
Test sample from: A.P. Kaestner et al., *Phys. Proc.* 43 (2013) 128–137.

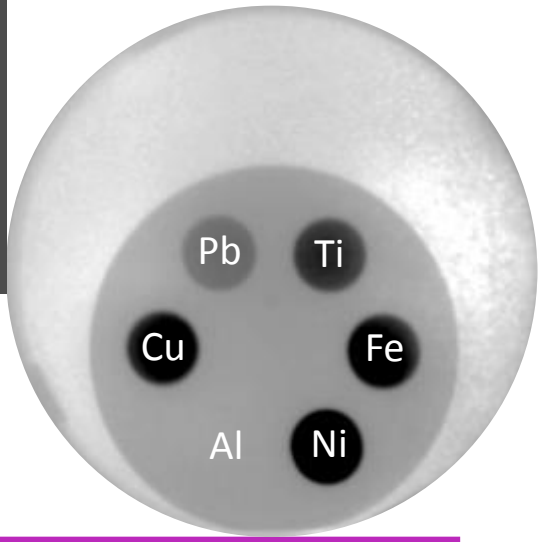
- Tomography of multi-metal sample
- 900 projections in <2 hours
- Shadows due to uncorrected beam hardening →
- By adjusting the attenuation coefficient threshold metals can be in- or excluded











Improved design

Improved design

Attains a 50 µm spatial resolution
Over the full 100x100 mm² active area.

Trends

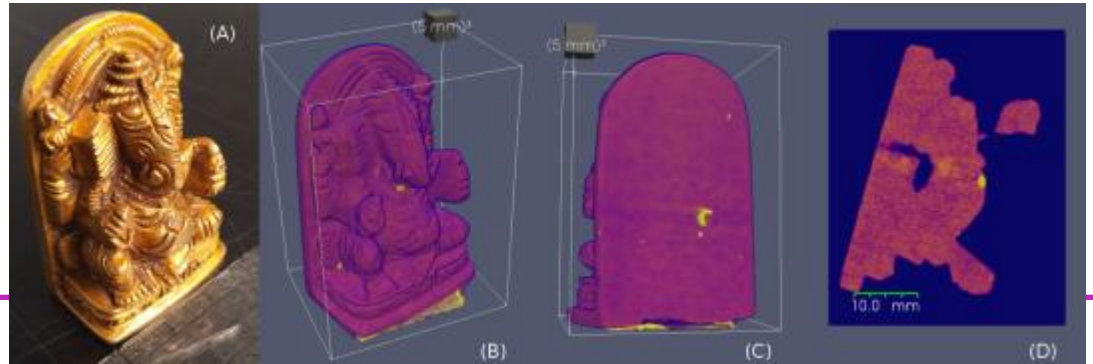
- Efficient, high resolution neutron imaging is becoming possible
- The imager is still based on a commercial camera, greatly reducing complexity
- Plenty of applications both in research and industry

Wishes

- Set up an imaging and tomography beamline at a low-power research reactor
- Experiment with imaging using portable sources (neutron generators, even isotopes)

Dreams

- Neutron tomography on countless research reactors would make this technique available to local universities and industry
- Lower flux means lower sample activation, opening possibilities with rare artefacts
- Beyond that: neutron imaging based on portable or lab-size sources could make it a mainstream non-destructive testing method many companies and universities have available in-house



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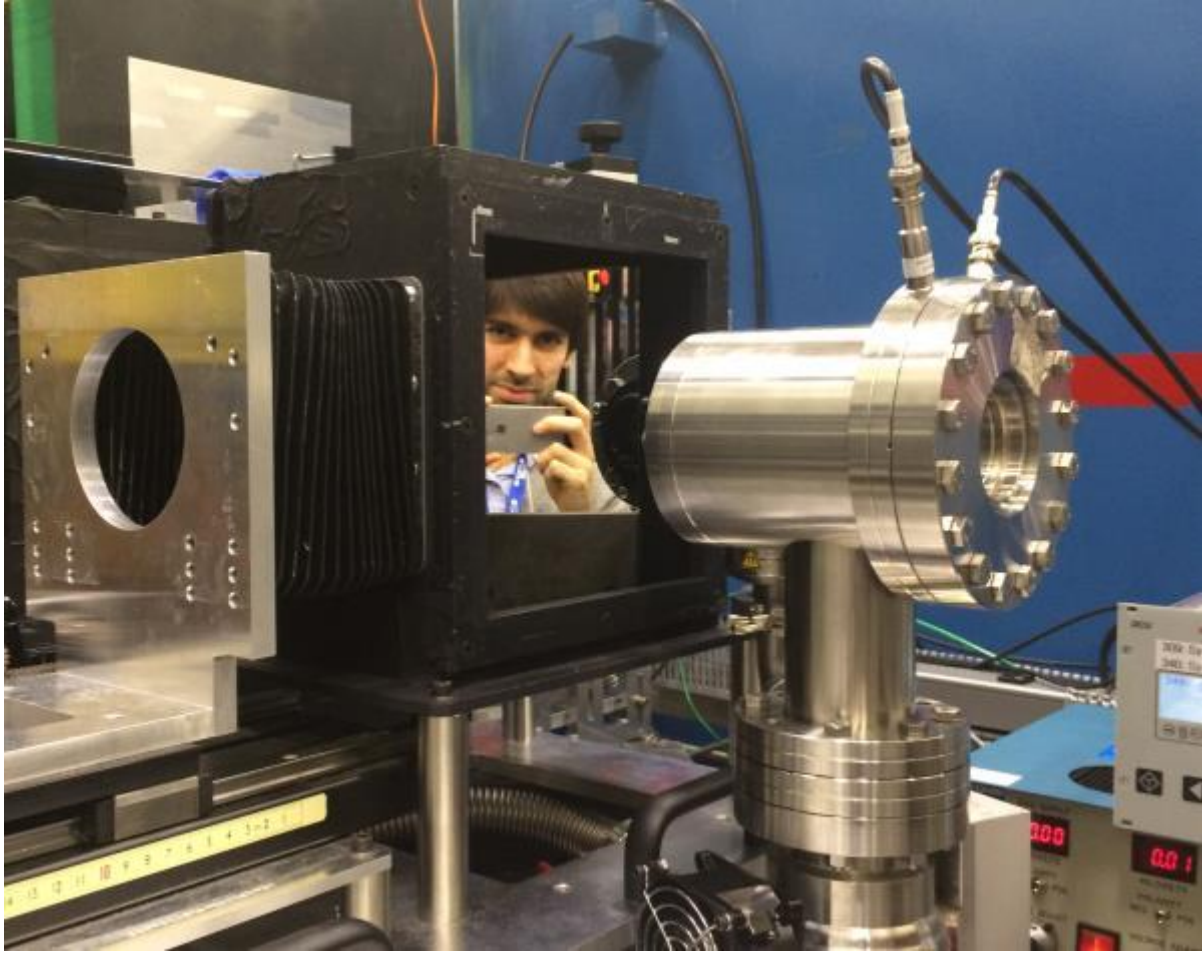
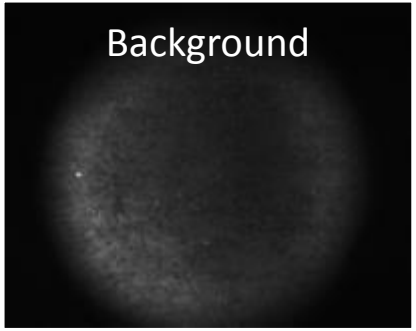
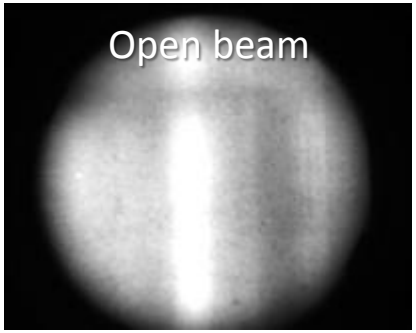
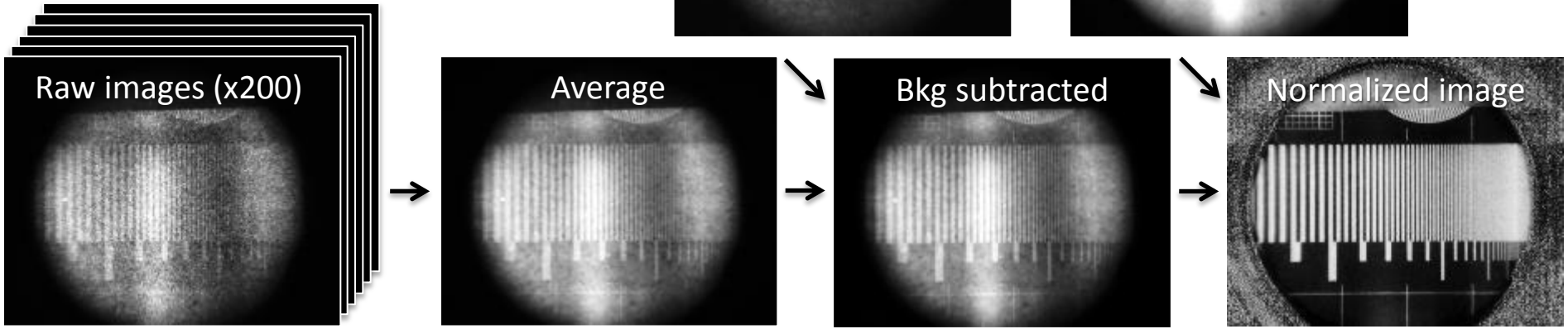


Taking Images and processing them

- Raw images are taken until sufficient exposure
- Background subtracted from the average raw image
- Normalization with open beam image

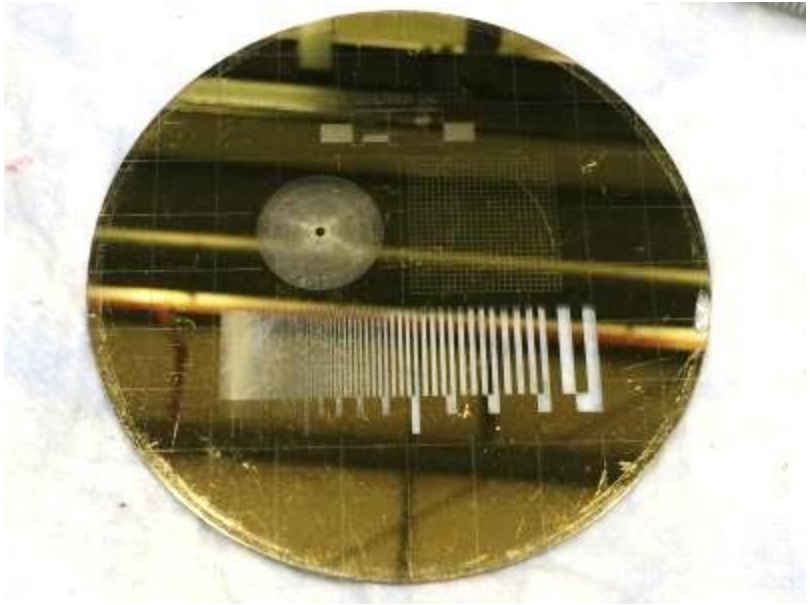


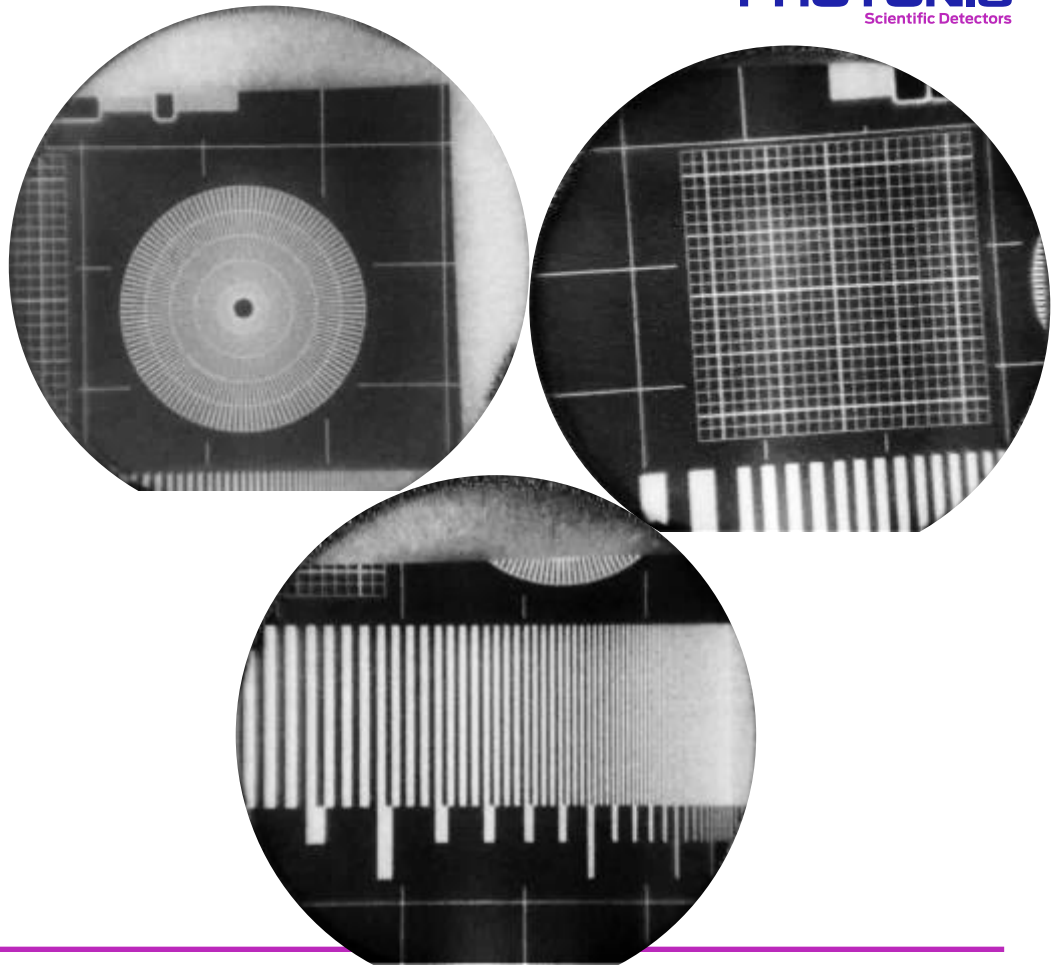




Gadolinium test mask

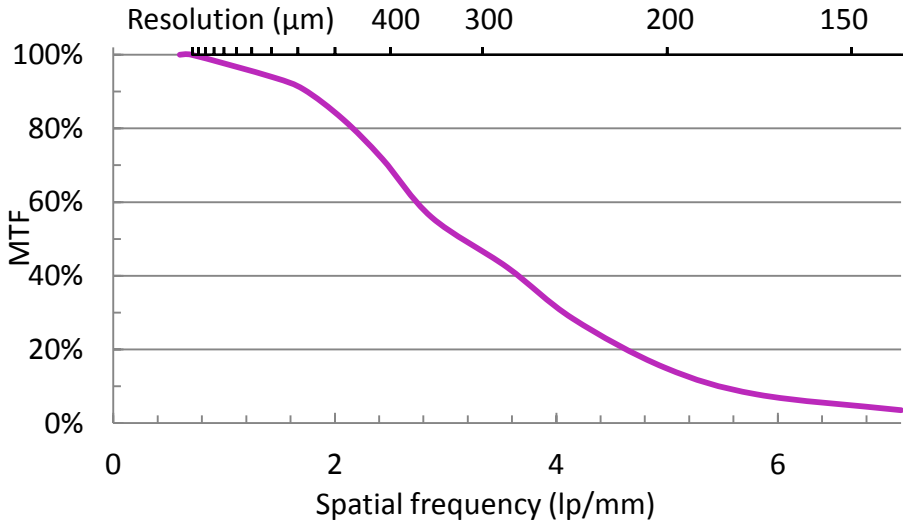
Made at PSI: C. Grünzweig et al., *Rev. Sci. Instrum.*, vol. 78, no. 5, p. 53708, May 2007.

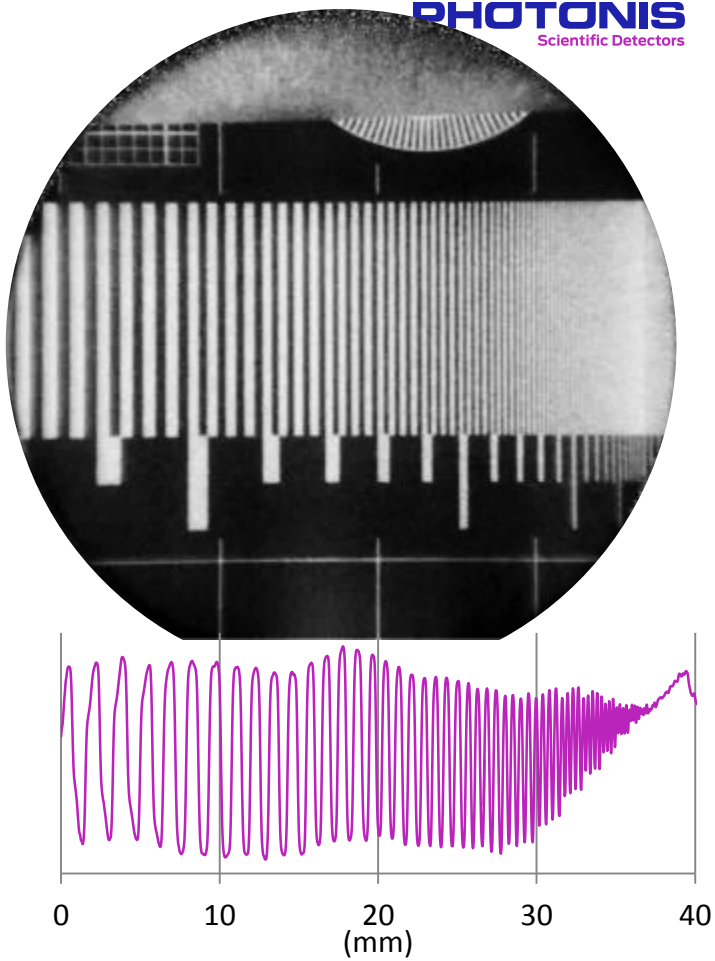




Gadolinium test mask

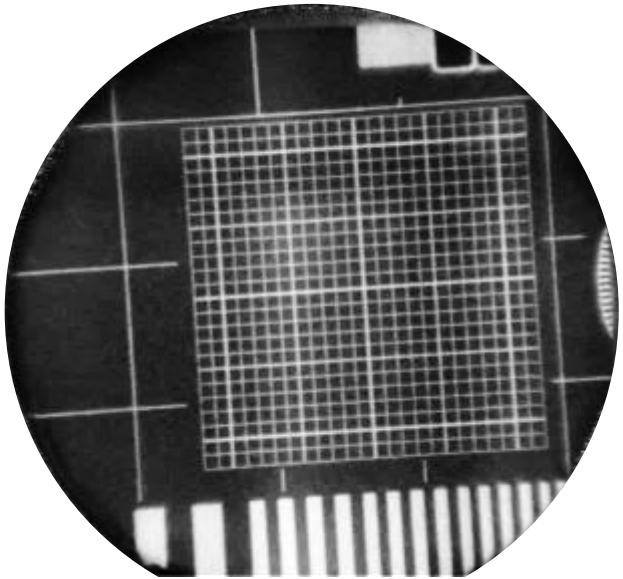
- Resolution line grid can be used to calculate *modulation transfer function* (MTF) curve
- *Limiting resolution* is often defined @ 10% or 5% MTF
- This means 6-10 lp/mm, or 100-170 µm for our imager



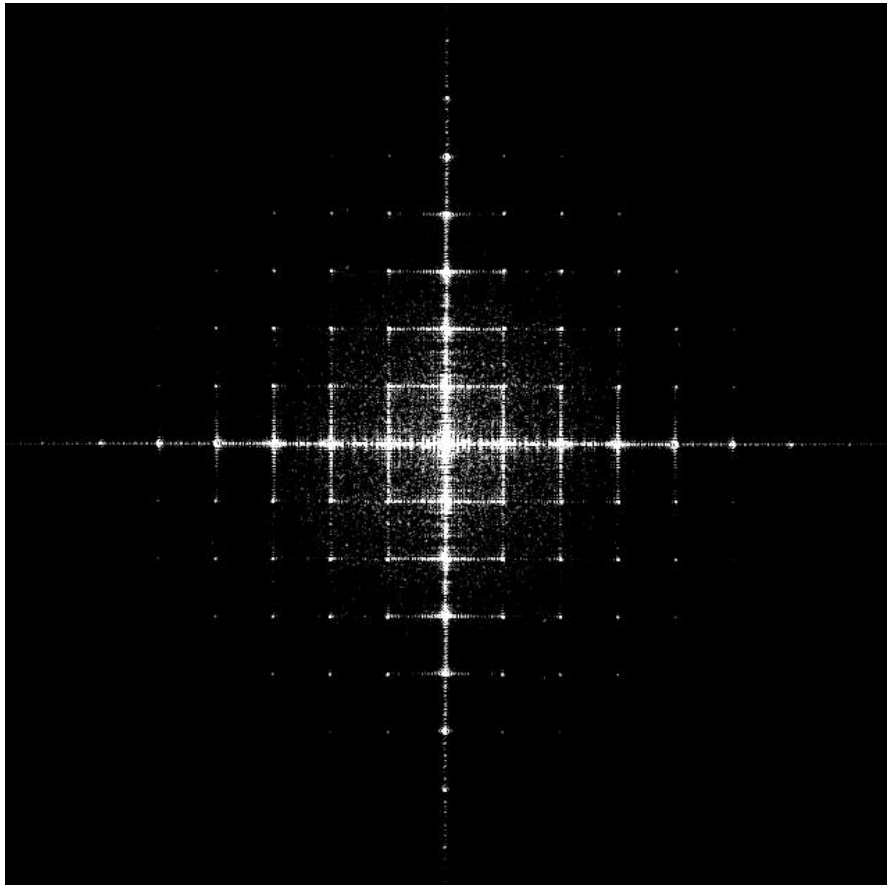


Gadolinium test mask

The square line grid can reveal pincushion or barrel distortions. A 2D Fourier transform is particularly sensitive to such distortion.



2D FFT



Some more images