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Gratings-based x-ray imaging for explosives detection

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ADSA14 May 10, 2016

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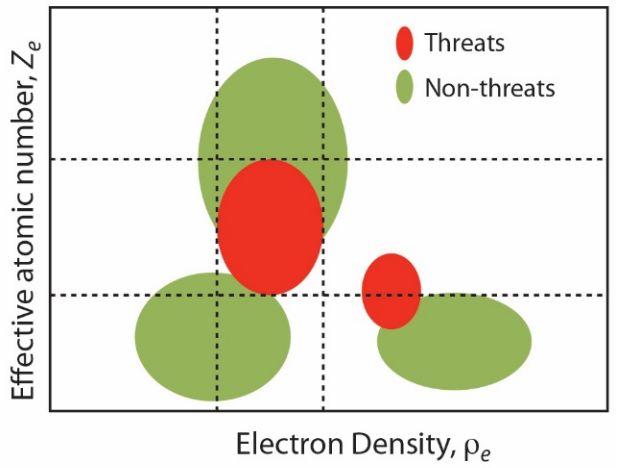
The point

- X-ray imaging is a mainstay of checkpoint screening, but has limited material discrimination
- Gratings-based x-ray imaging provides 3 distinct contrast mechanisms: improved detection? what about material discrimination?
  - phase contrast has been seen to improve contrast for small biological samples
  - scatter is a unique signature
  - no systematic study of explosives and benign materials at energies relevant to checkpoint screening
- Complex interplay between system design and detection characteristics



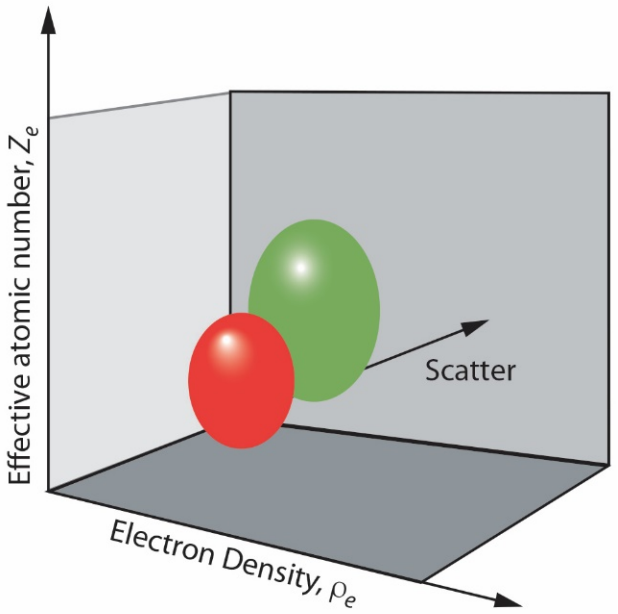
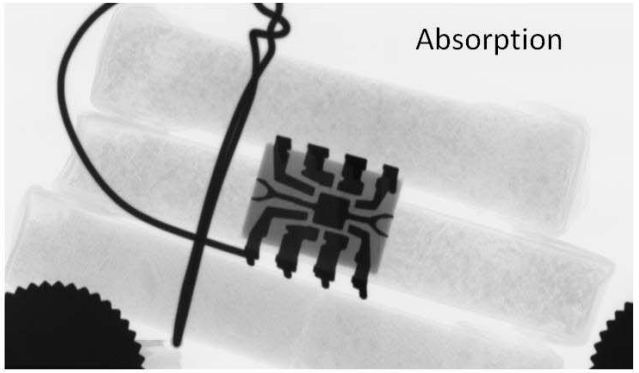
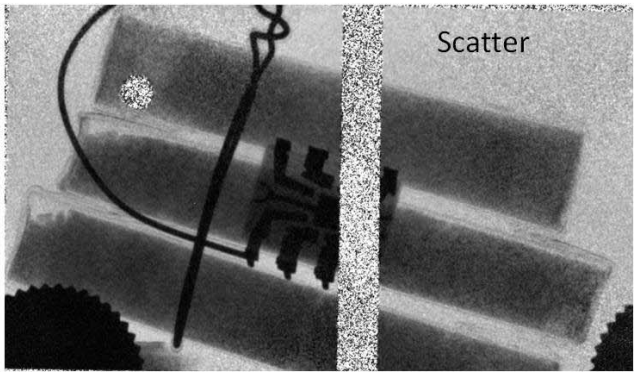


Figure courtesy of H. Martz, LLNL

Gratings-based x-ray imaging





Powdered explosives simulants; sections 6mm in diameter. Images acquired with PNNL's Talbot-Lau system.

- Gratings-based phase contrast provides three physically distinct contrast mechanisms, which may improve detection limits and material discrimination
  - Absorption contrast is strongly dependent on *effective Z*
  - Phase contrast is sensitive to variations in *electron density* and can give enhanced contrast for low-*Z* materials
  - Scatter contrast is sensitive to electron density variations (*texture*) on length scales smaller than the imaging resolution

What does this mean for explosives detection?

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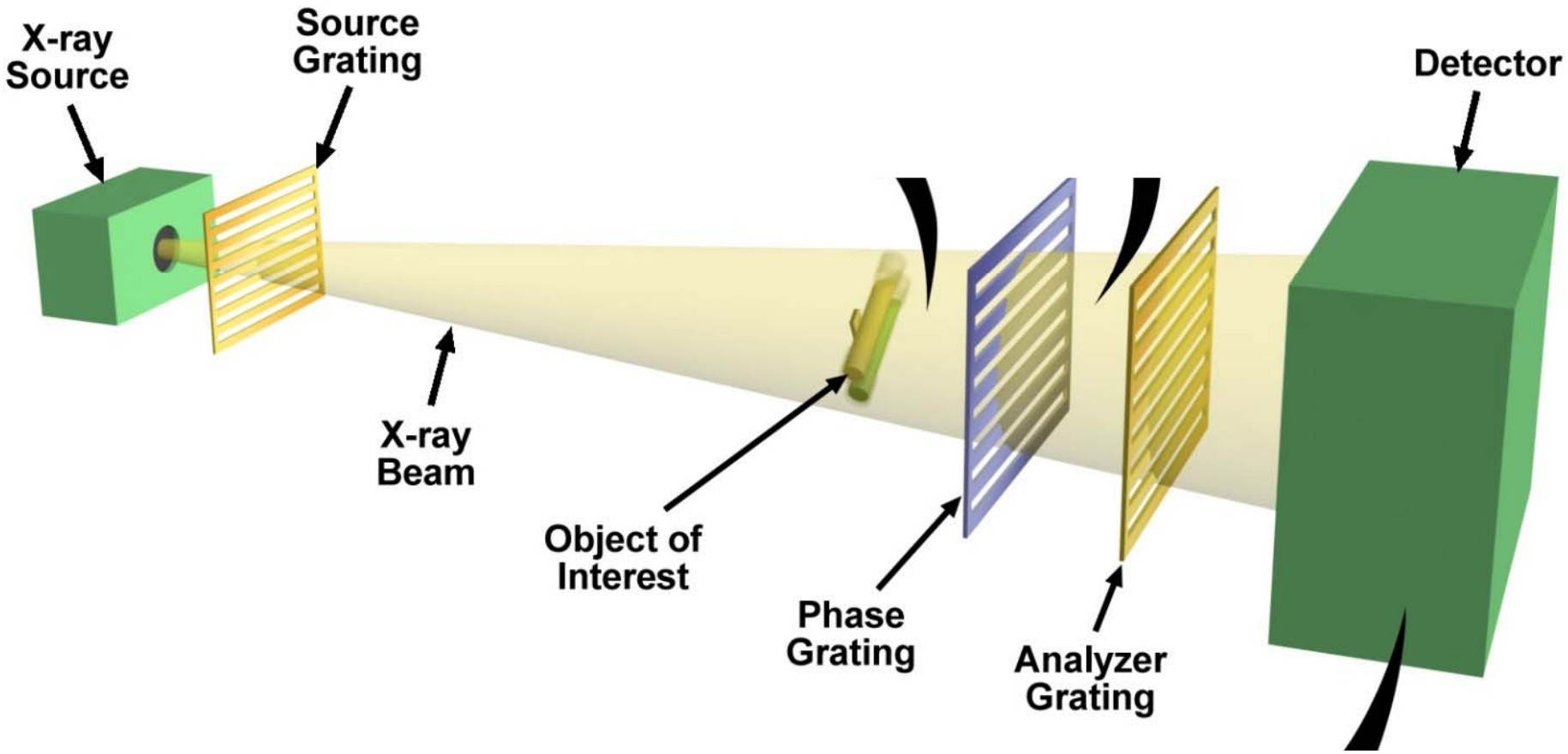
- Many explosives have sub-resolution texture
  - prior work at LLNL to characterize microscale structure

…but…

- We need to be able to scale up to relevant energies
- The system must be sufficiently robust to operate in a checkpoint environment (and affordable)
- Changing system design and energy change not only cross sections but also the length scales to which the scatter measurement is sensitive

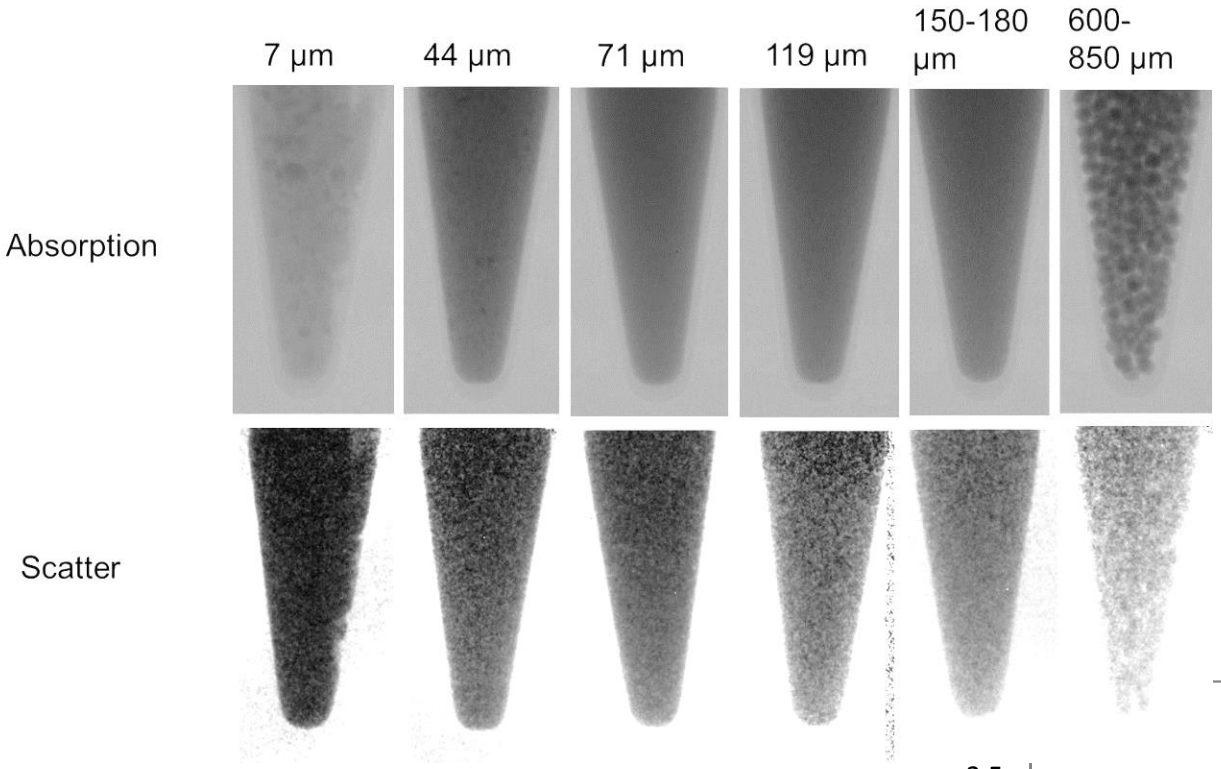
Gratings-based phase contrast:
Talbot-Lau Interferometer



Gratings-based x-ray imaging approaches

Number of Gratings	Grating Characteristics	Considerations
3 (Talbot-Lau/F. Pfeiffer)	High aspect ratio Demonstrated as high as 183 keV	High resolution, sensitive to small density variations. Sensitive to relatively large length scales for scatter
2 (Talbot/ A. Olivo, Z.F. Huang)	(Phase /absorption) and absorption	Stronger constraint on either source size or grating period; easier alignment than 3-grating system.
1 (H. Wen)	Usually absorption; may be commercially available	Simple and inexpensive; grid pattern is imaged directly and processed image resolution is reduced to grid period. Scatter sensitive to smaller length scales.
0 (propagation based)	N/A	Simplest x-ray optics; requires very small source focal spot; works best for high resolution imaging of small objects. No scatter information.

Scatter and Length Scales (1)



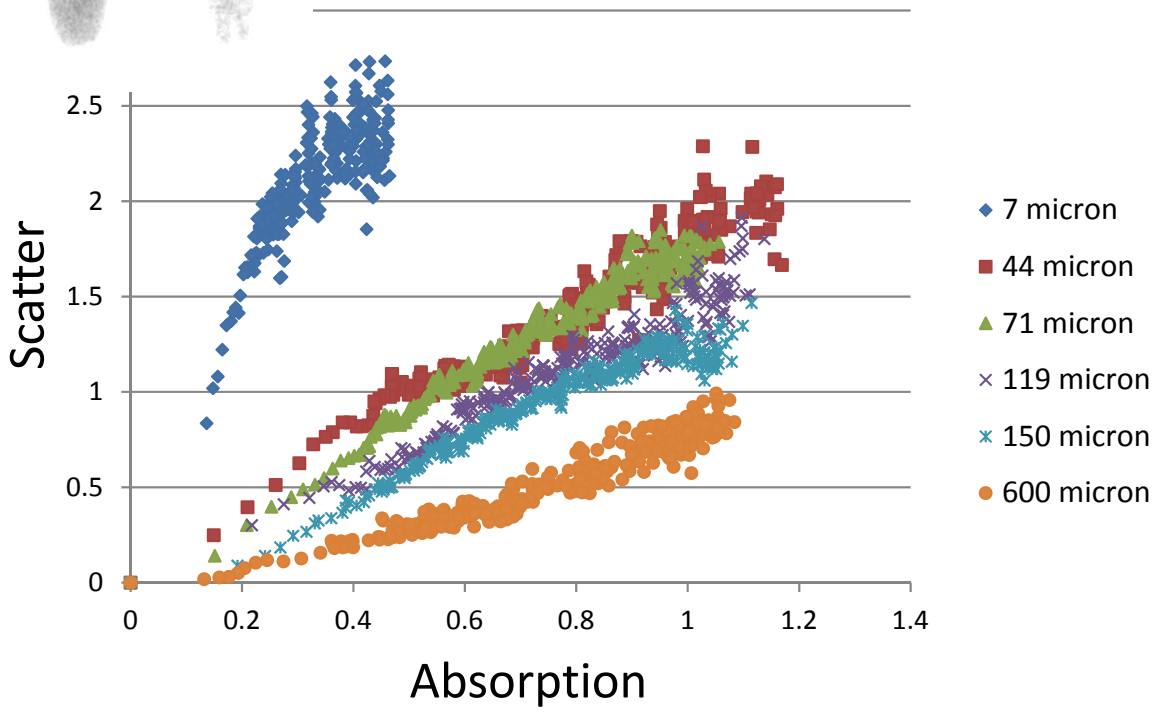
- 3-grating system; glass beads 7-850 µm (dry and wet); 40 kVp
- Scatter intensity changes with sample length scale
  - Packing fraction also varies
- Miller et al., IEEE Trans Nuc Sci 2013

- Absorption is uncorrelated with particle size
- Scatter intensity increases as particle size is reduced

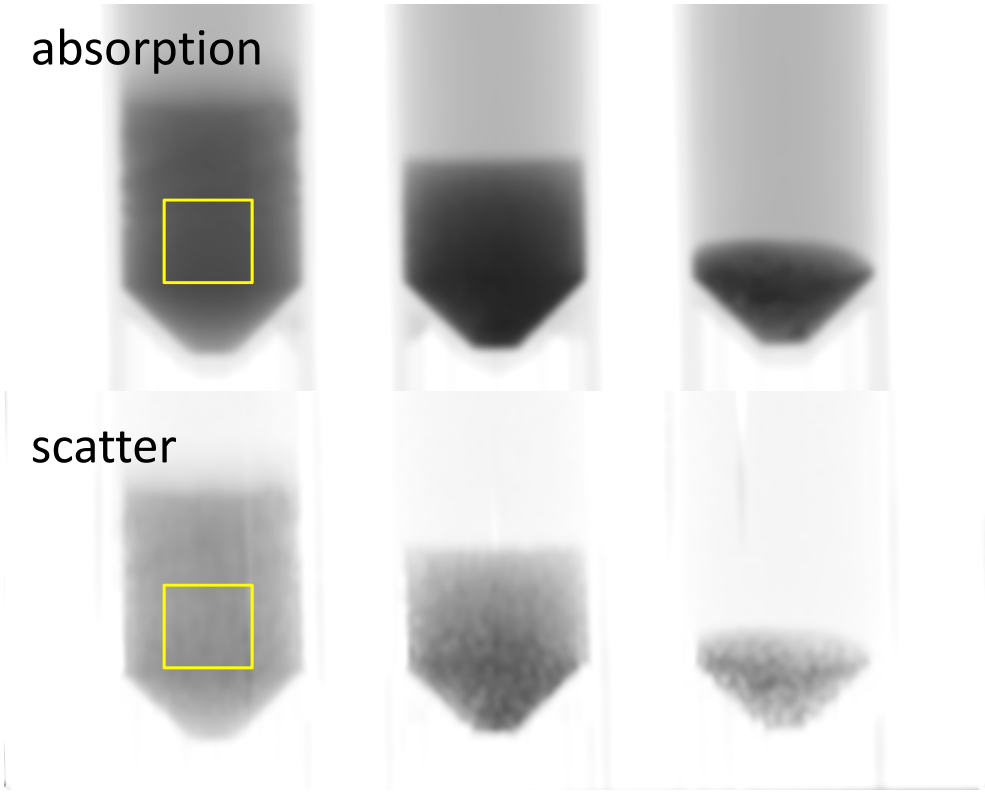
IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 60, NO. 1, FEBRUARY 2013

Phase Contrast X-Ray Imaging Signatures for Security Applications

Erin A. Miller, Timothy A. White, Benjamin S. McDonald, and Allen Seifert



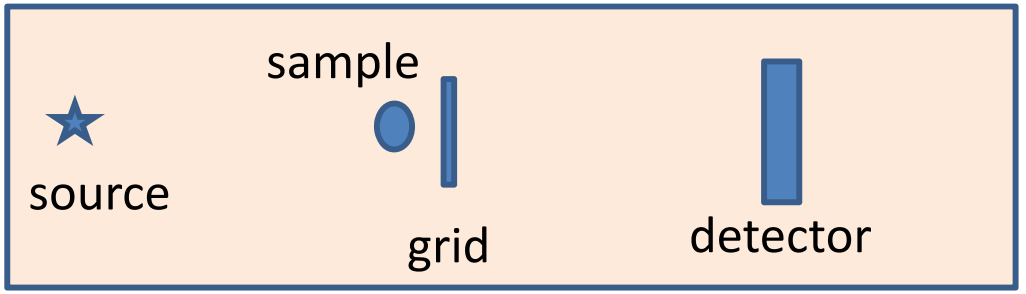
Scatter and Length Scales (2)

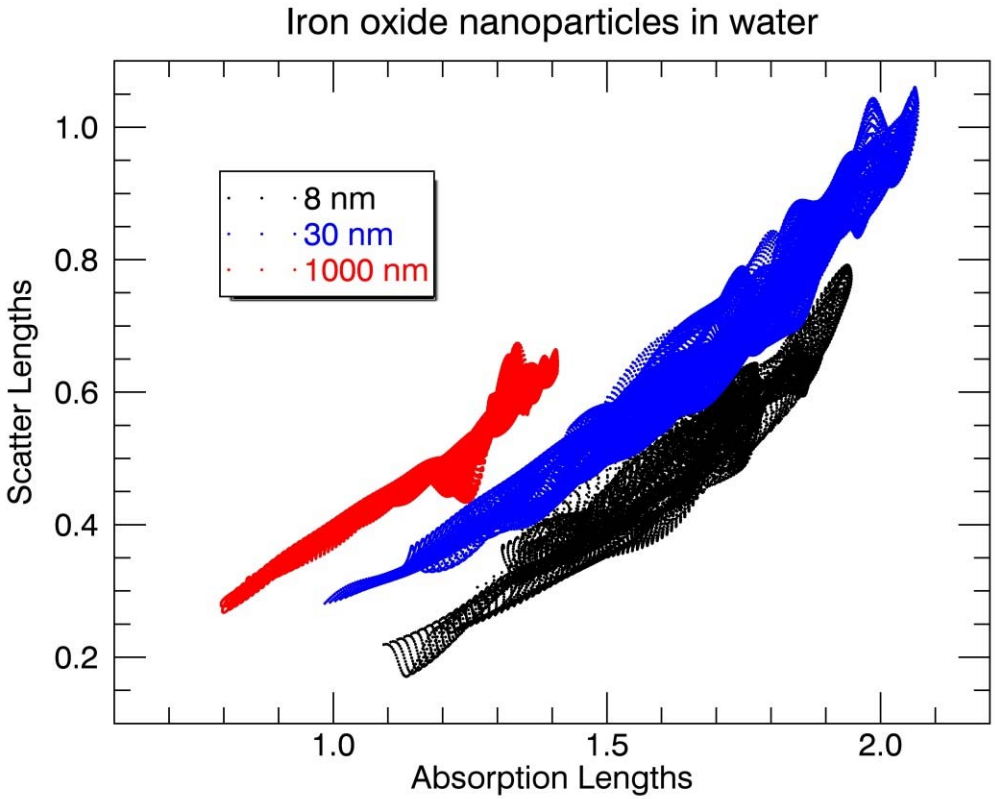


1000 nm 30 nm 8 nm

Iron oxide nanoparticles in water

Single grating: 2m working distance, grid and sample near center; 40 kVp
d=76 nm





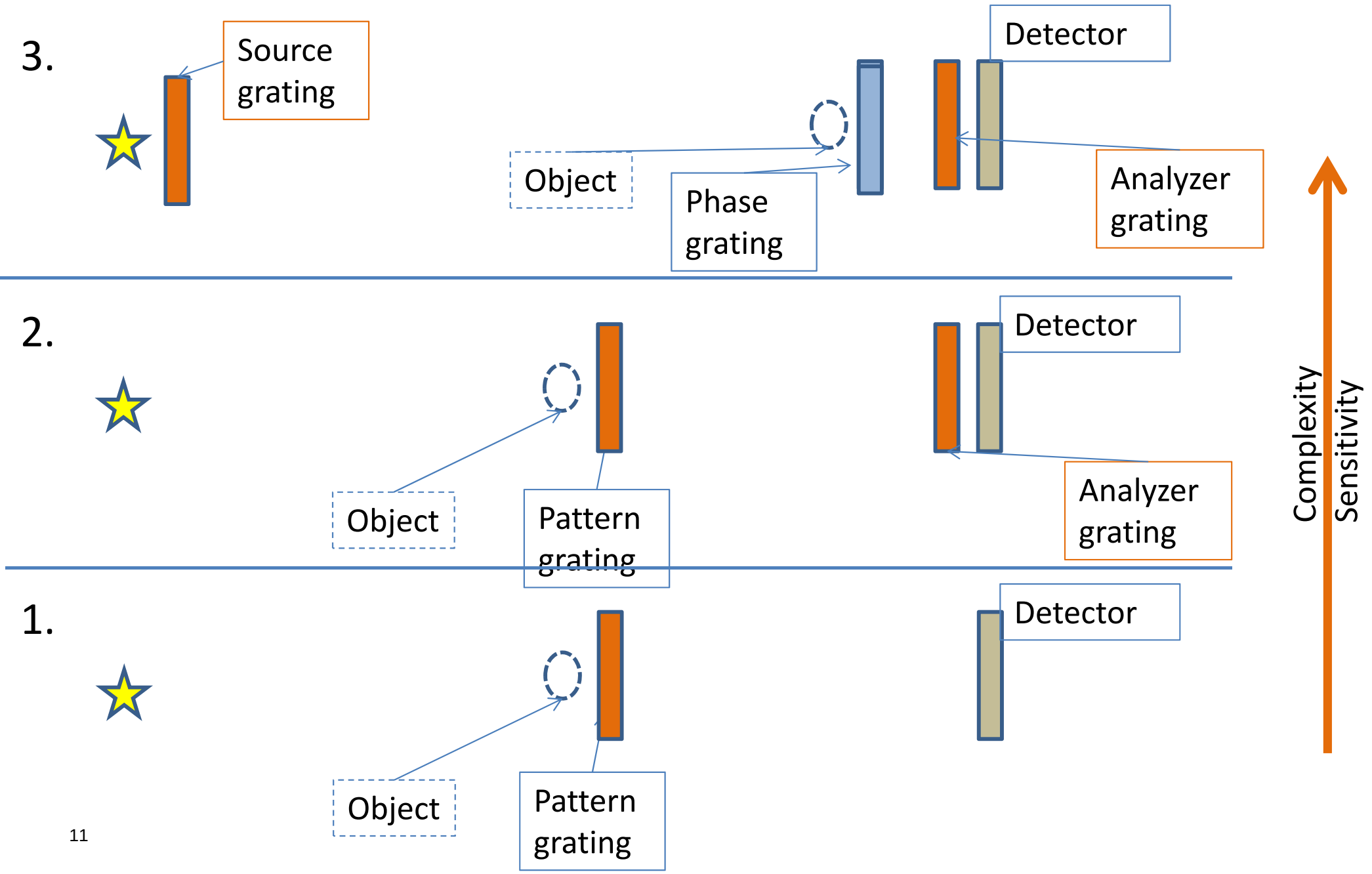
Same three contrast modes, but different signal intensity and length scale sensitivity

The point

- Scatter offers a new signature which may be relevant for explosives
- Highly attenuating bags
  - Approaches exist which scale readily to baggage energies
  - Interaction cross sections and length scales change – can this align with the properties of real explosives and benign interferents?
- The signatures of threat materials and common interferents in scatter have not been well explored -- and should be

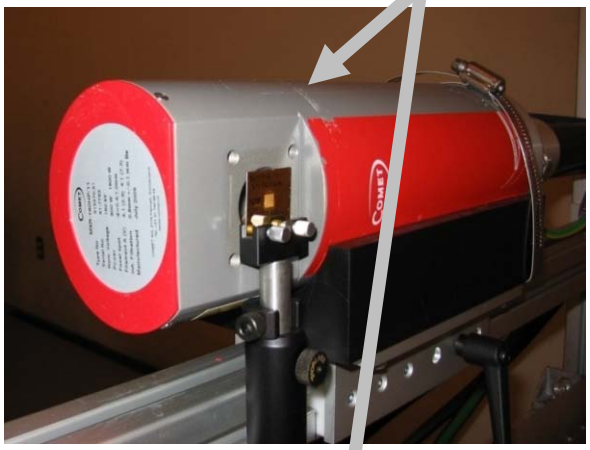
Backup slides

Gratings-based phase contrast:



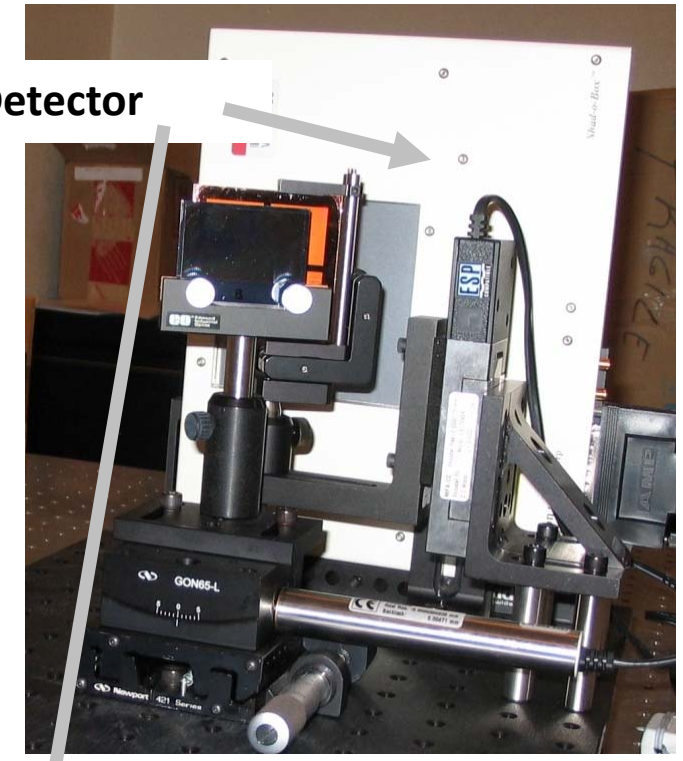
Talbot-Lau System

X-ray source

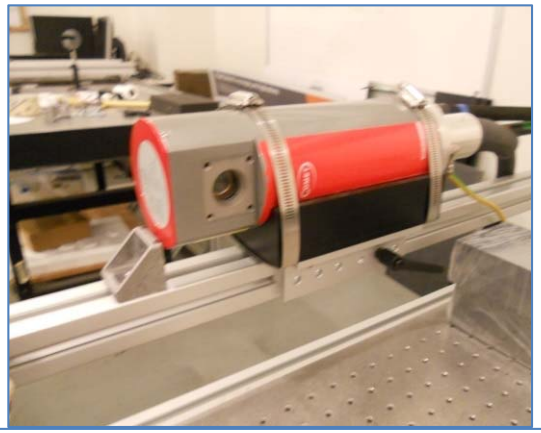


- PNNL system has been used for investigations of:
  - sensitivity to texture
  - geochemistry, fish biology
  - explosives detection
  - synchrotron version has been used to investigate biofilm structure
- Multiple iterations on gratings fabrication

Detector



Single-Grid Setup



Source: Comet MXR/HP-11
40-160 kVp; 400 µm spot size

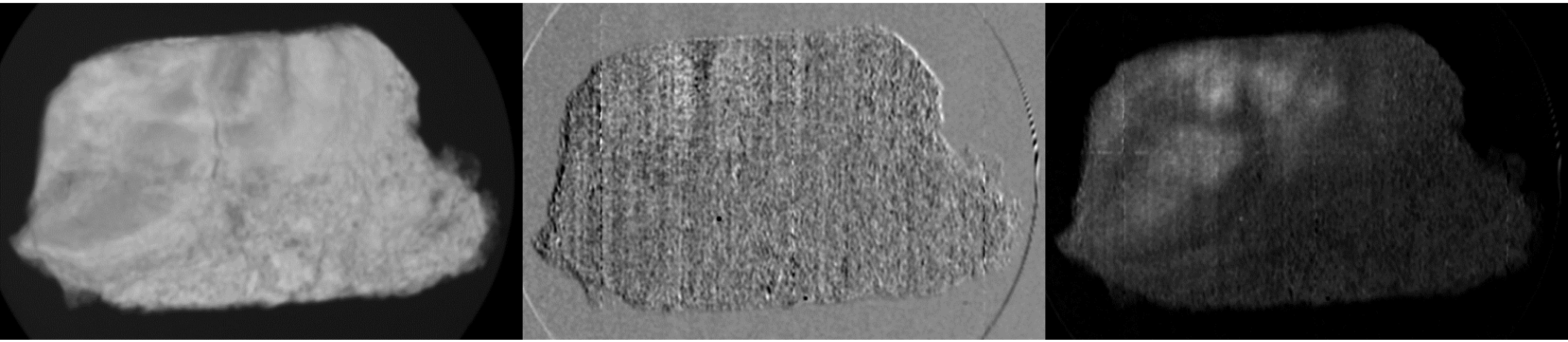
Grid, held in mount with set screws

Sample: pen, pencil, folded paper

Detector: Shad-o-box 4k; 10 cm active area, 50 µm pixel size

- Approx. 2m working distance, with grid near center (~2x magnification)
- Sample is near the grid, but can be upstream or downstream (~2x magnification)
- Tube Focal Spot size limits the ability to resolve grid features

Mineralized biofilm (fixed slice)



~4 cm

Abs

Phase

Scatter

- 2m working distance; 230 lpi (110 micron) 40 kVp; 0.4 mm fs

Hot lake biofilm (fixed slice)

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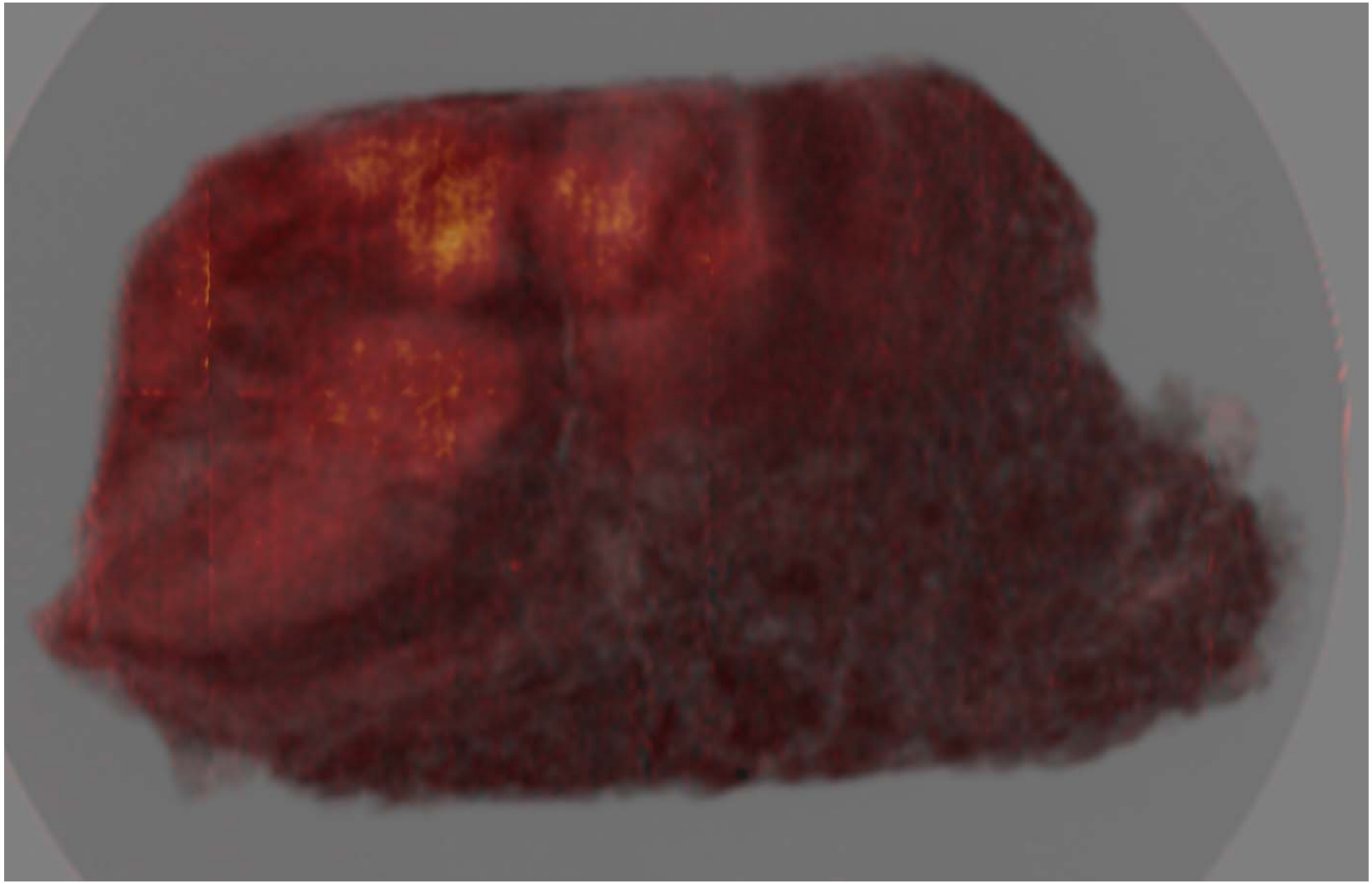
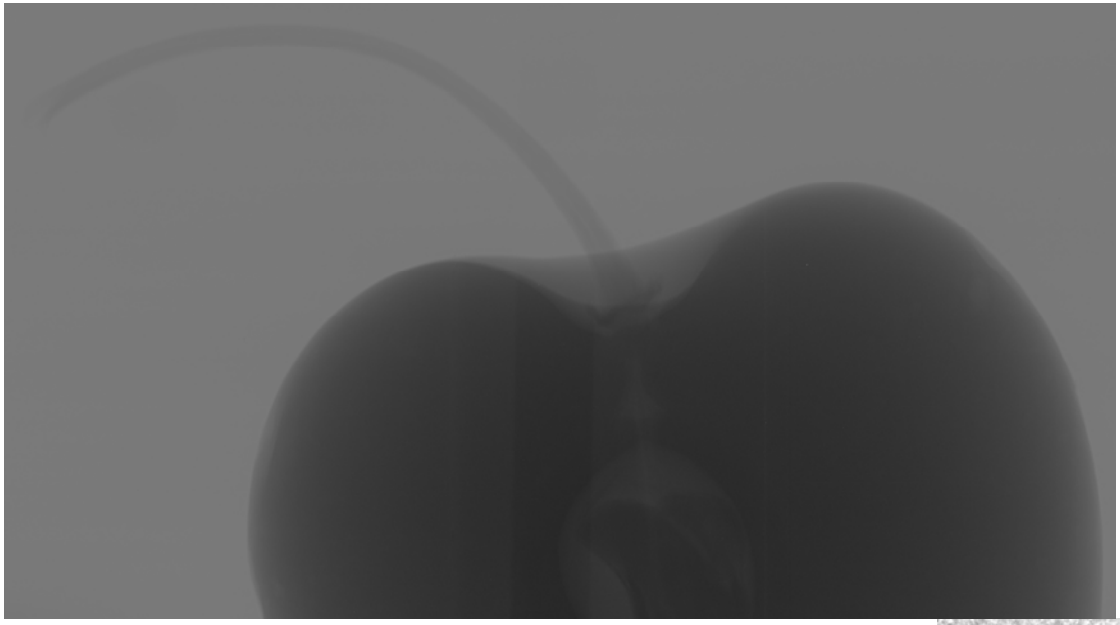


Abs: gray scale
Scatter: red scale

- 2m working distance; 230 lpi (110 micron) 40 kVp; 0.4 mm fs



Cherry

E47-cherry

correction E48-flat

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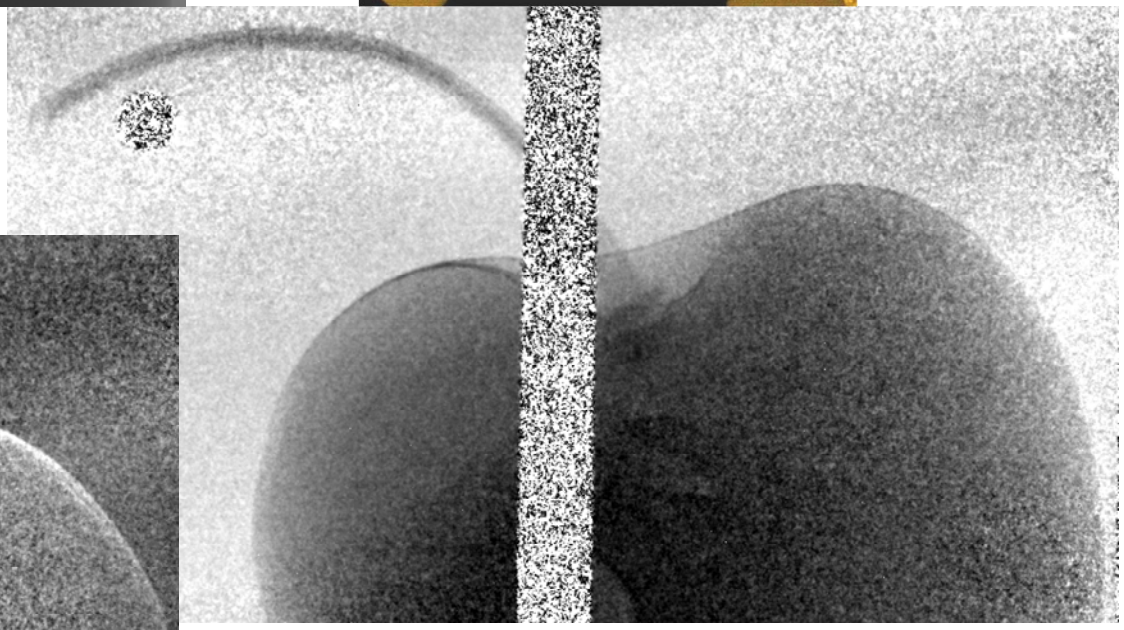

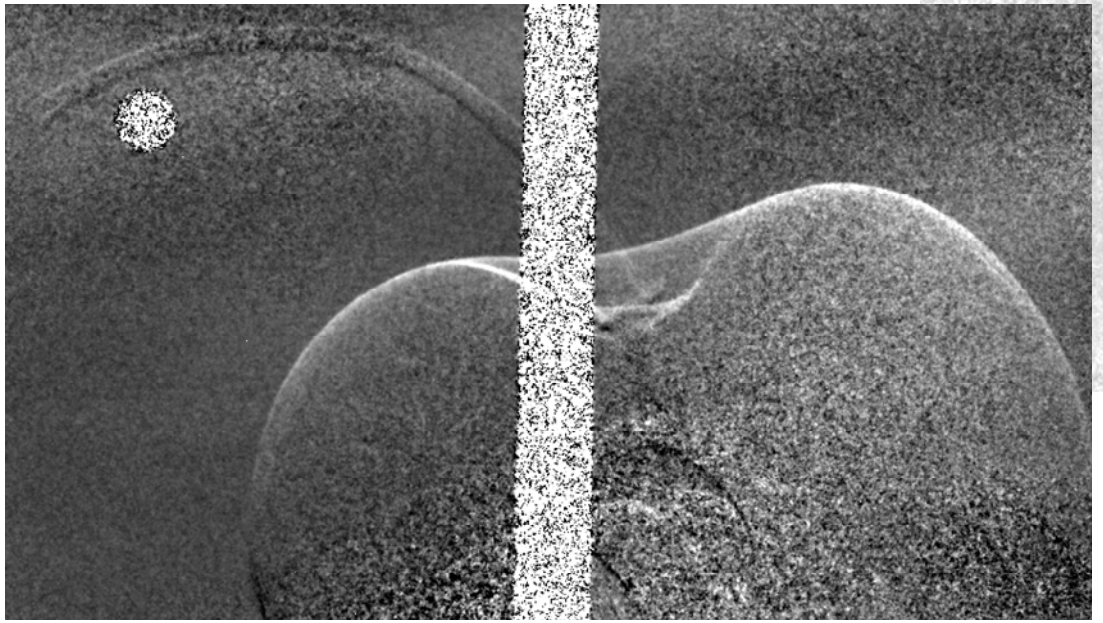

Paper – wet and dry

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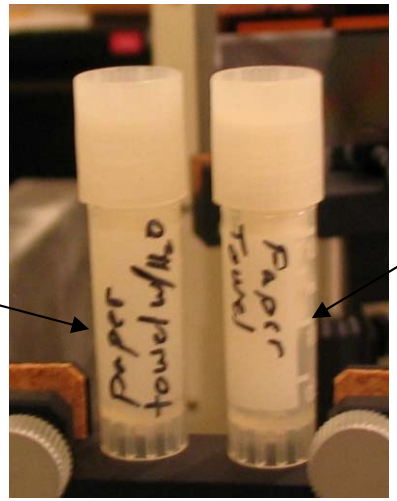
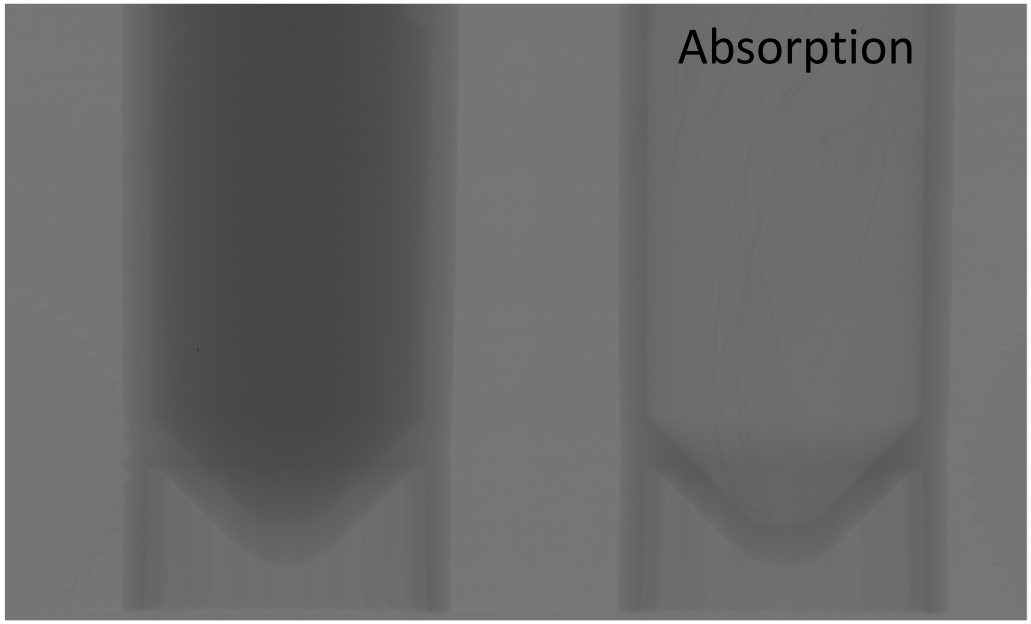
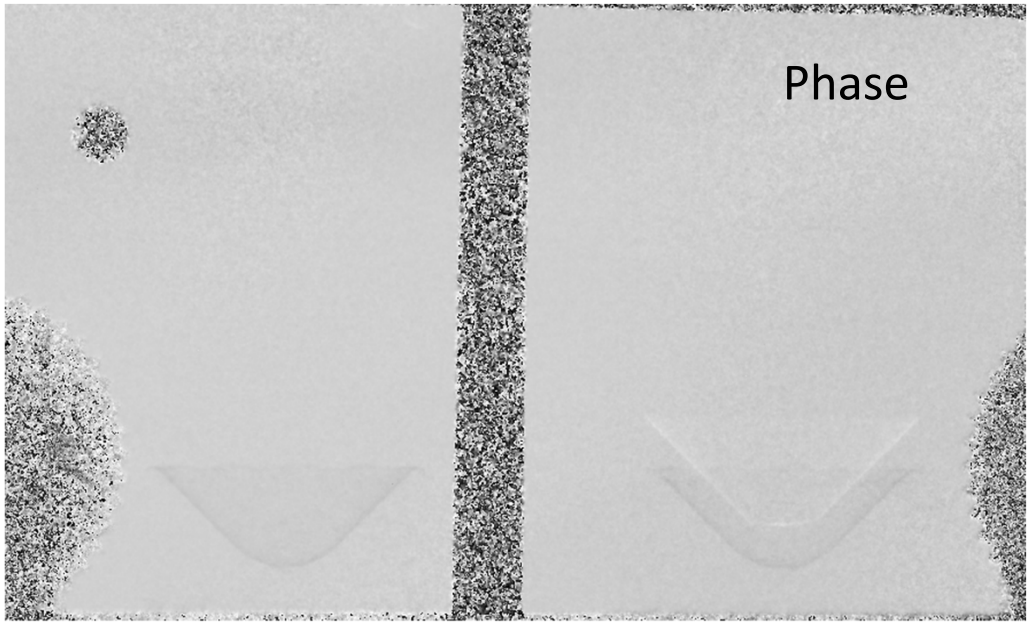
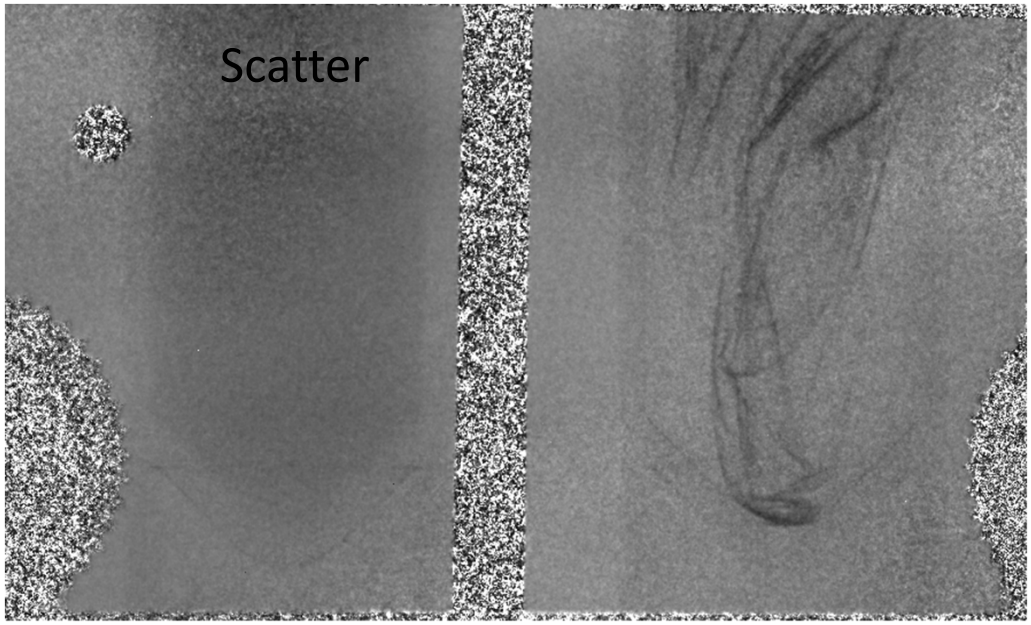
Water +
Paper



Dry Paper







Scatter Anisotropy

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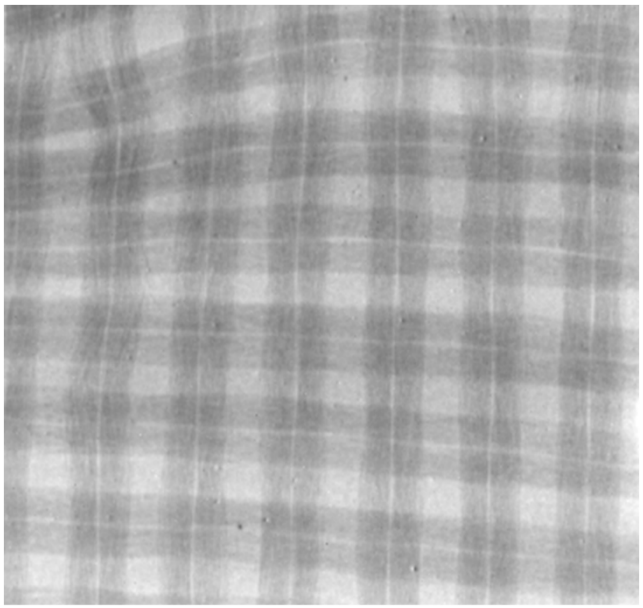
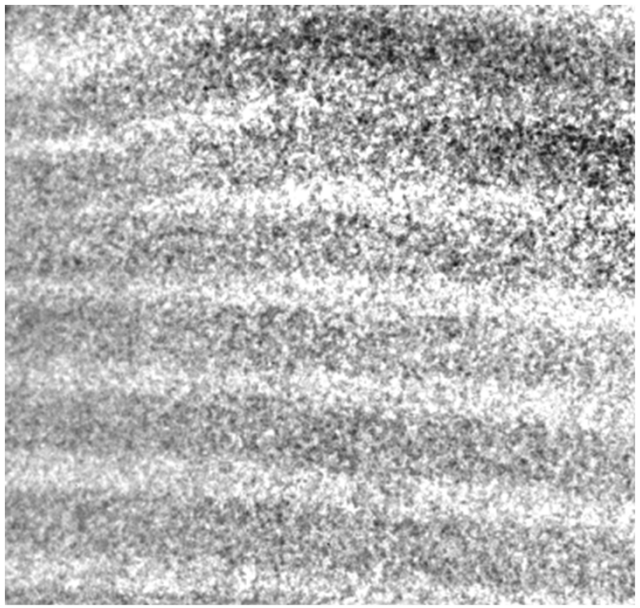
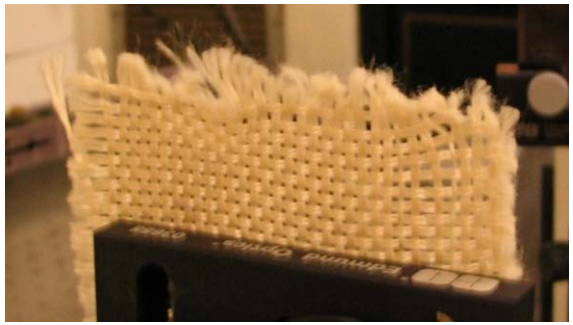
Absorption

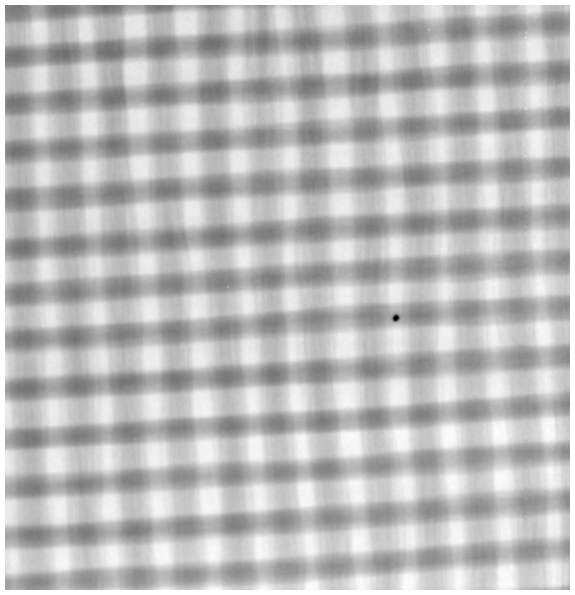


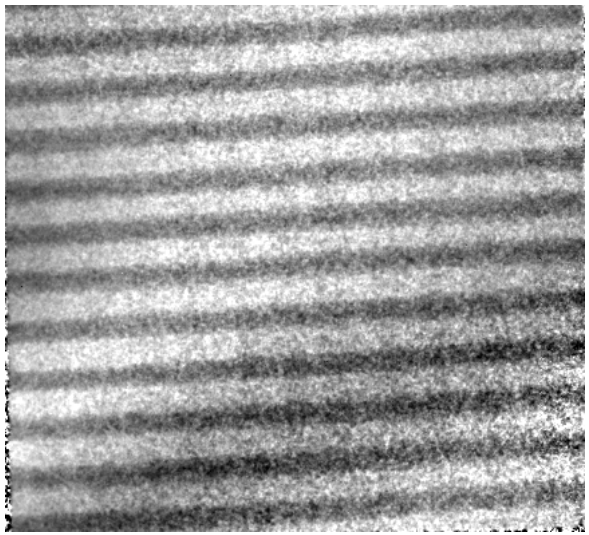
Scatter



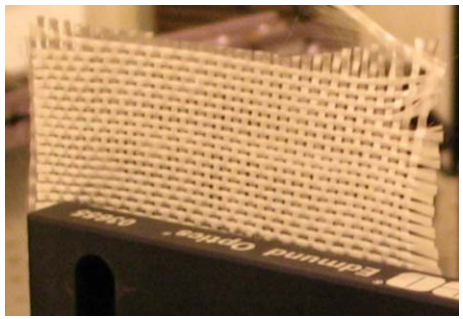
Vectran fabric



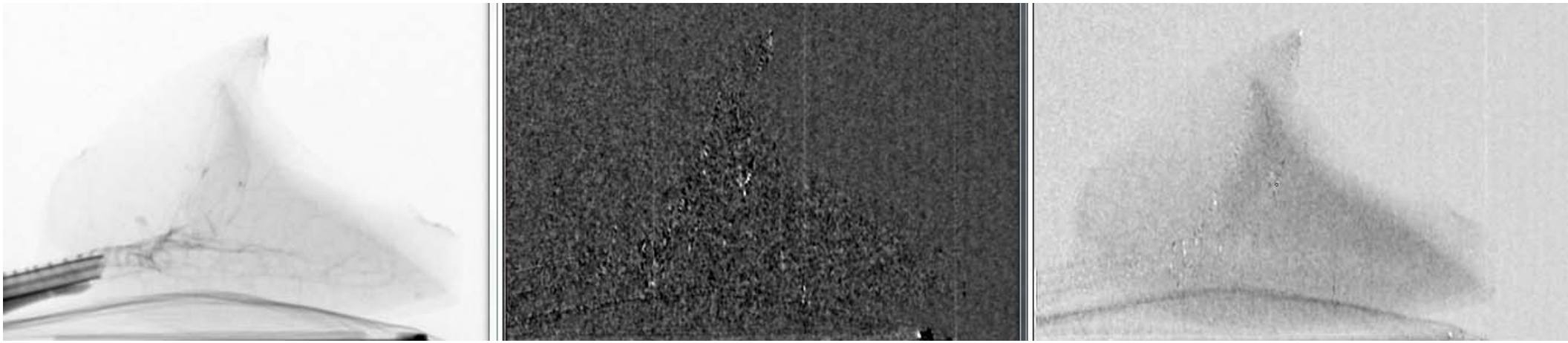




Glass fiber fabric



Rat Lung (dried)



Abs Phase Scatter

- 2m working distance; 230 lpi (110 micron) 40 kVp; 0.4 mm fs

Rat Lung (dried)

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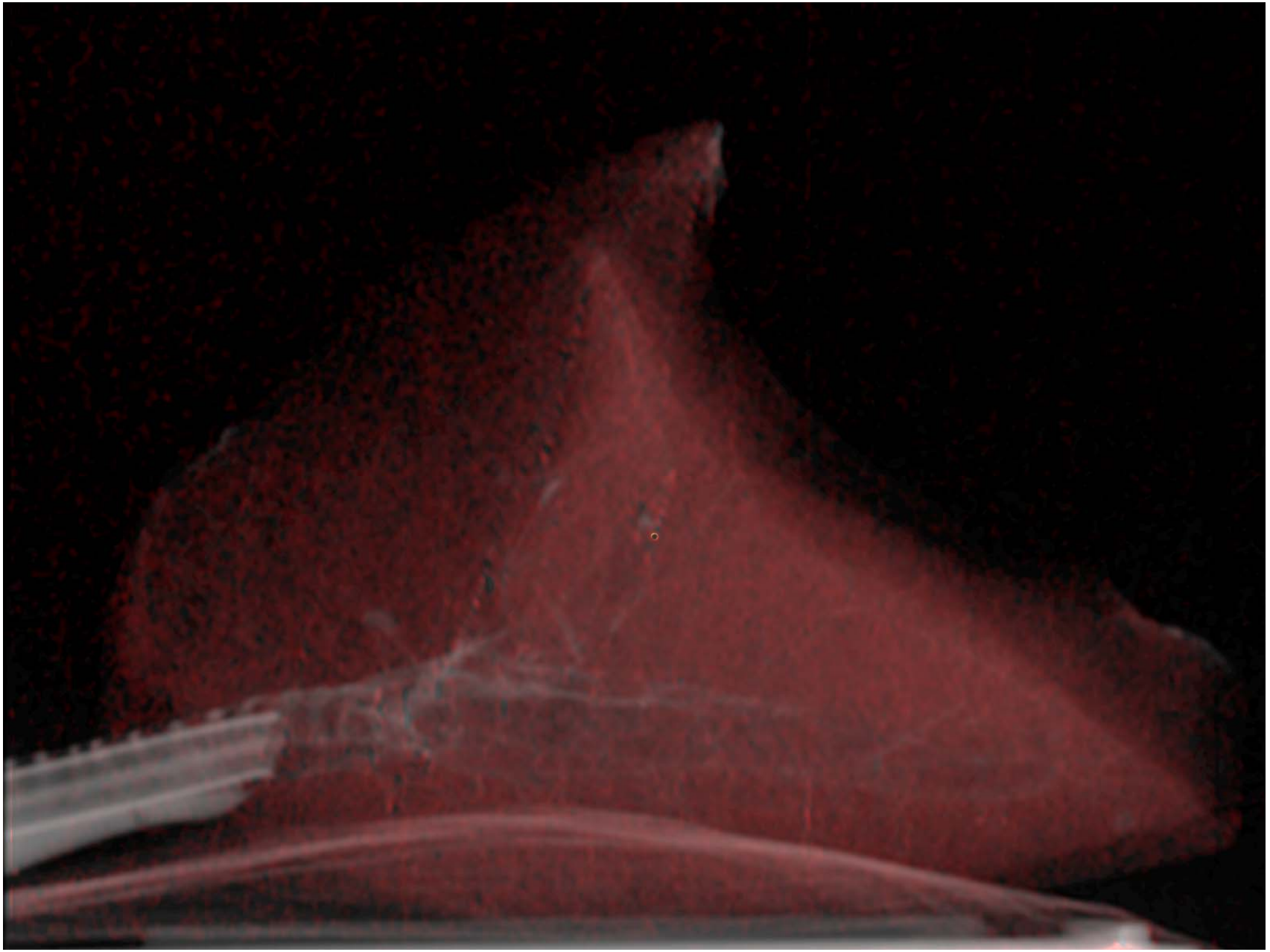

Abs: gray scale
Scatter: red scale

- 2m working distance; 230 lpi (110 micron) 40 kVp; 0.4 mm fs

Dandelions

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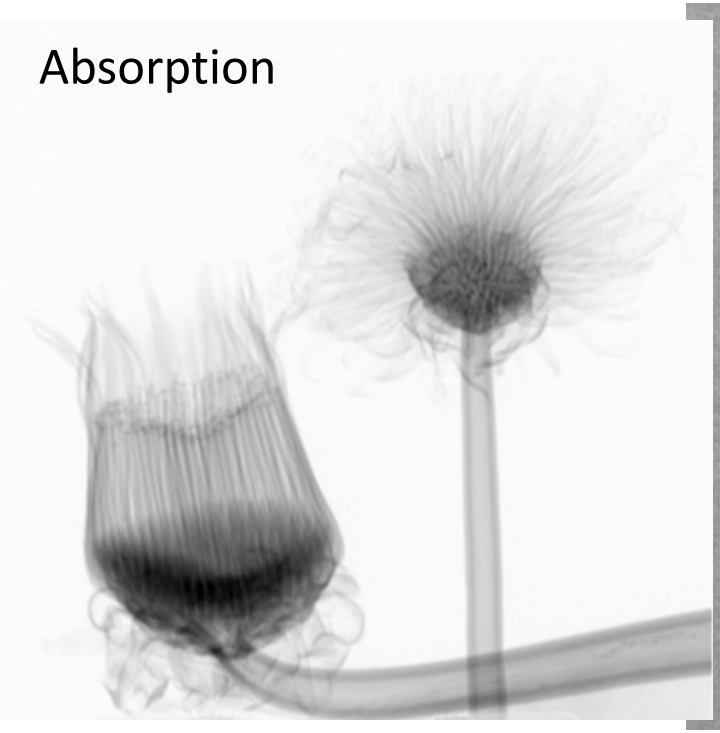

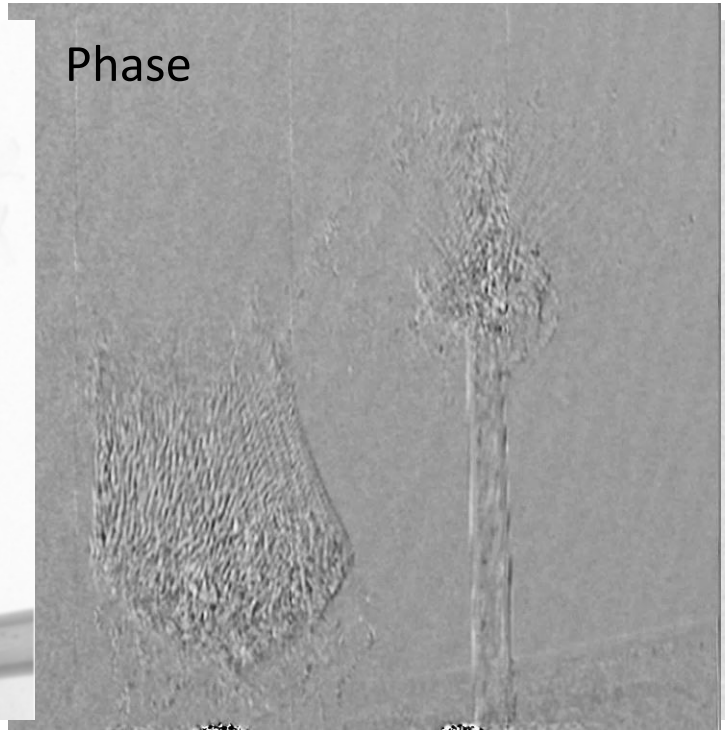

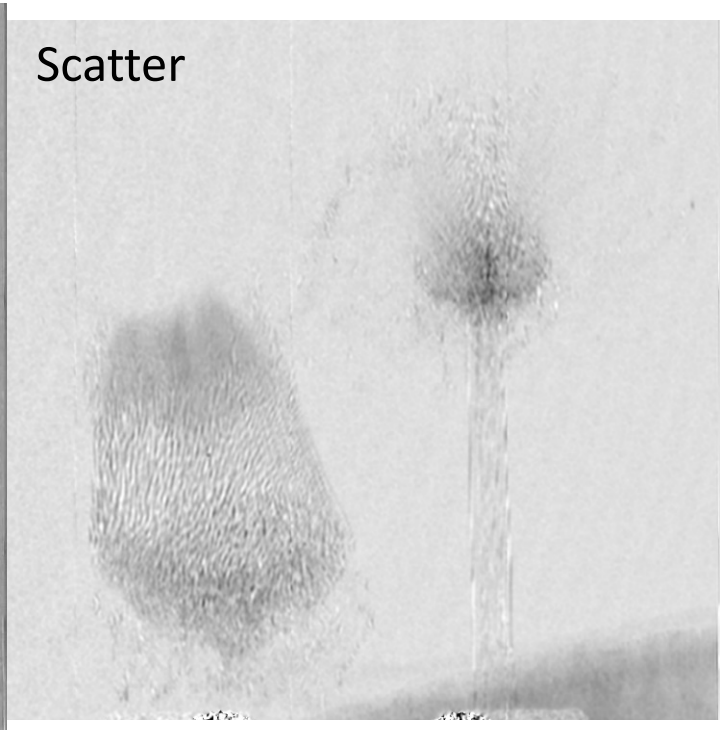

2m working distance; 230 lpi (110 micron) 40 kVp; 0.4 mm fs