Novel 3-D Differential Phase Contrast Imaging

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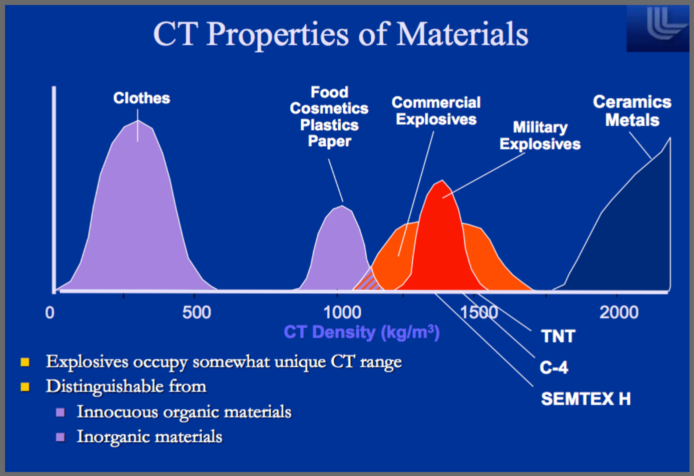
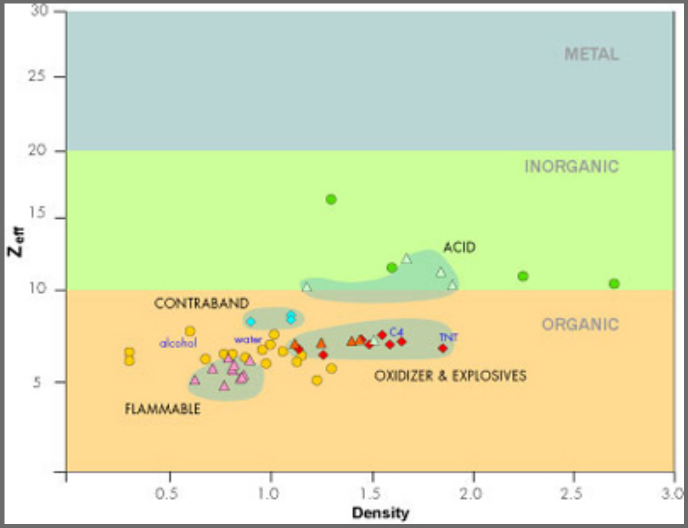
Introduction: Problem Statement

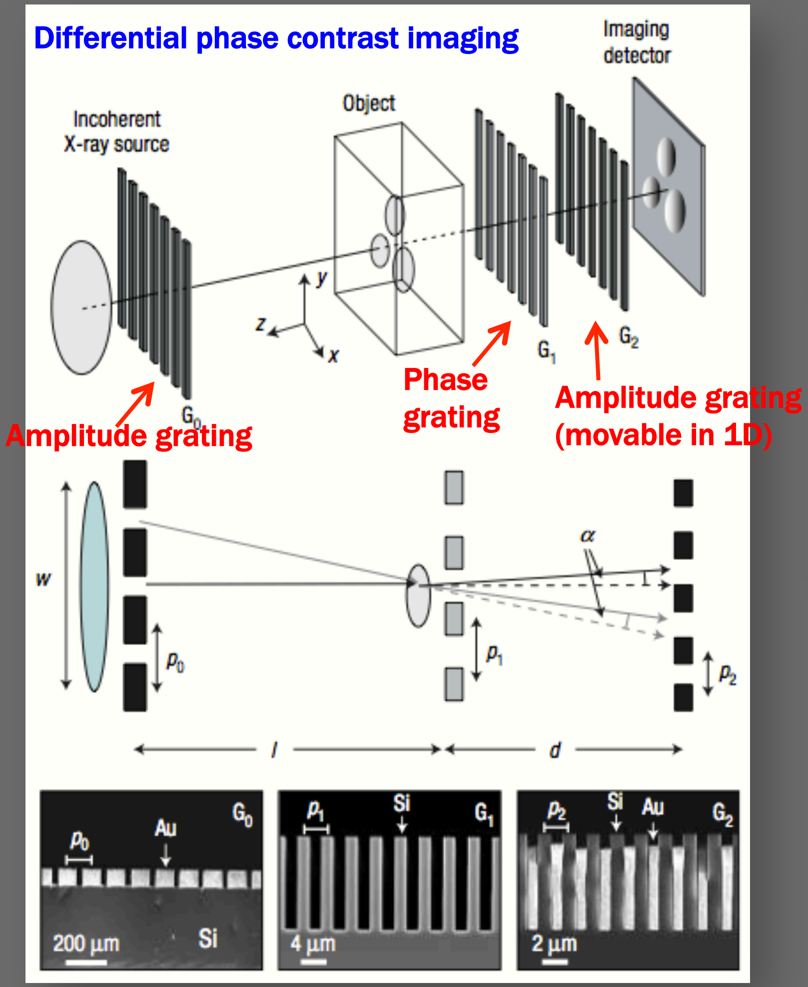


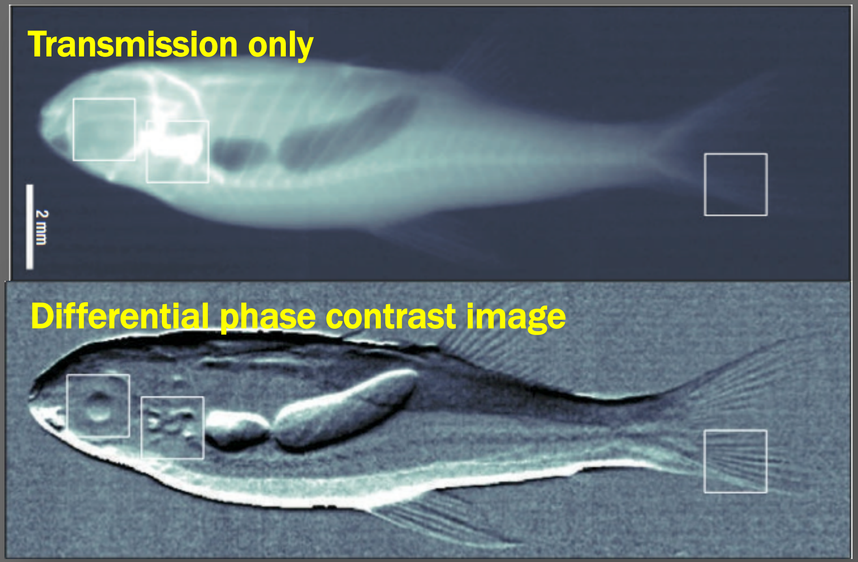
H. Martz, C. Crawford, Explosives detection in aviation applications using CT, LLNL, June 2010



- Improve discrimination through:
  - Improved data collection by measuring additional material's parameters:
    - Phase in addition to density and effective atomic number
    - Better 3-D reconstruction data

X-ray Differential Phase-Contrast Imaging



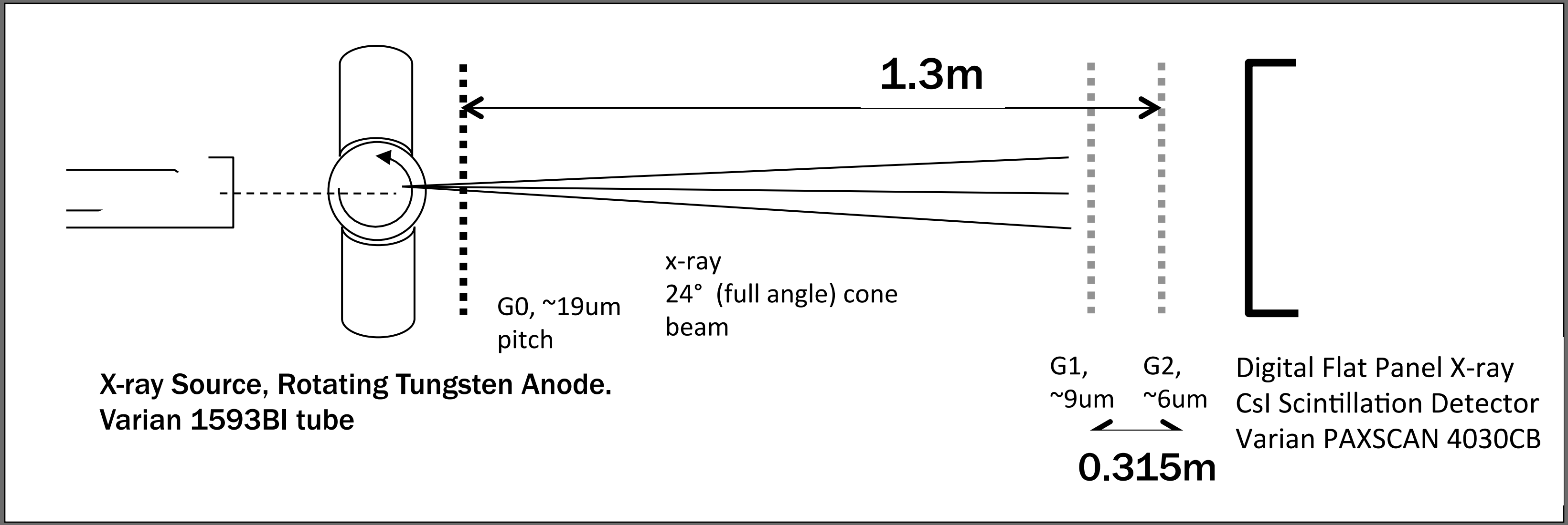


Pfeiffer et al., Nature Phys.. (2006)

Challenges:

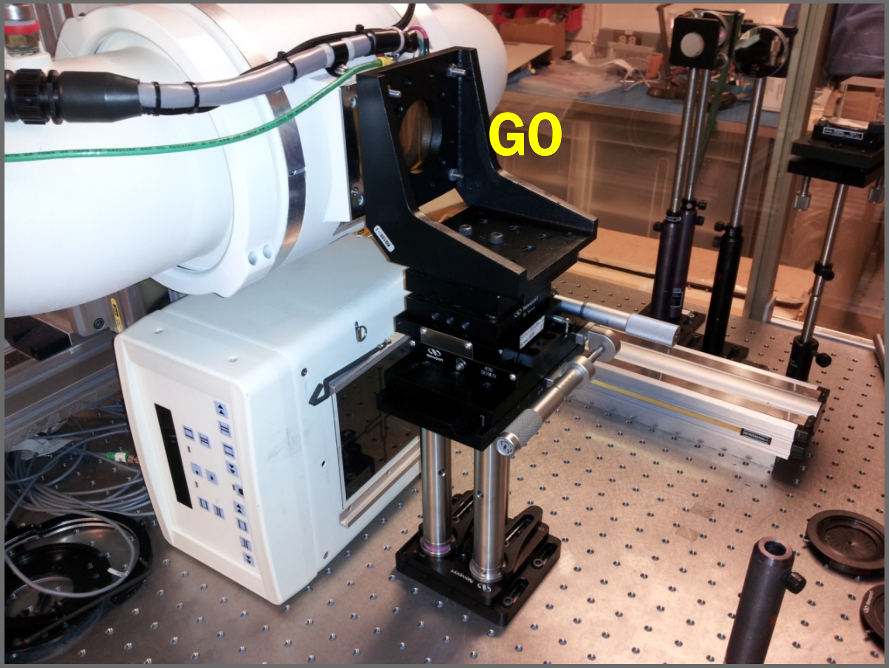
- Need high aspect-ratio (> 100X) amplitude grating for high energy (> 100 keV) X-ray design.

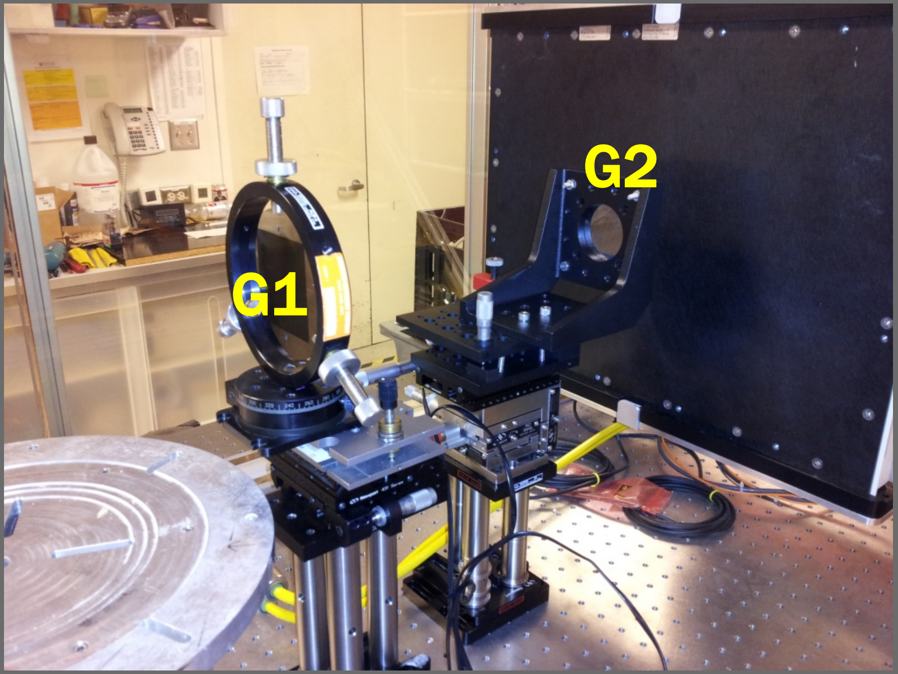
Experimental Schematic



- Incoherent, polychromatic source is made partially coherent by grating G0.
- G1 and G2 form a phase grating/amplitude grating interferometer analyzer pair.
- G0-G2 distance = 1.3m, G1-G2 distance 0.315m, G0=19um, G1=9um, G2=6um.
- Phase contrast signal is detected at the digital flat panel detector.
- X-ray parameters: 60kVp, 10mA, 7.5pps. Detector: 1x1 0.5pF Gain 2

Photos of the Setup





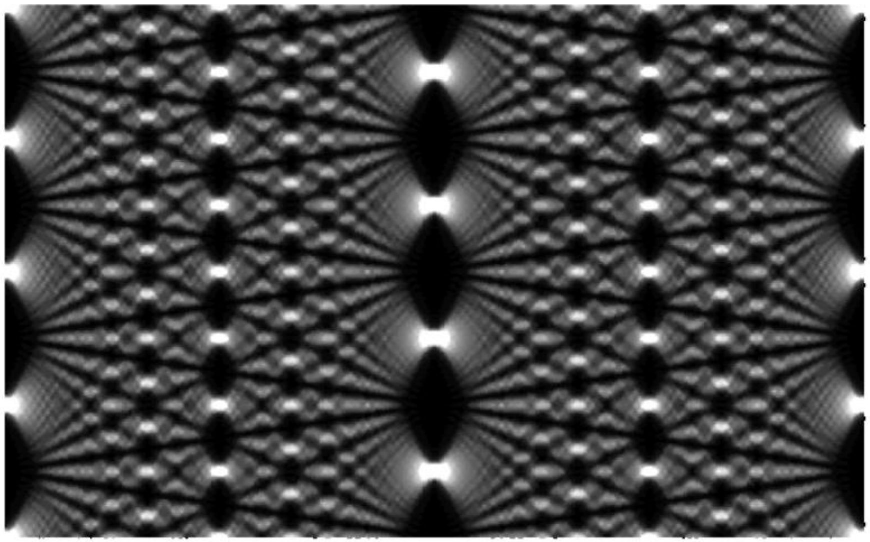
G0, on x-y stage

G1, on x-y and tilt/rotation stage
G2, on x-y-z and tip/tilt/rotation stage+ pico motor drive

X-ray Talbot Interferometry

- Uses Talbot effect for G1 and G2 gratings.
- Moiré Pattern detection at detector.
- Partial Coherence needed, G0 provides this via van Cittert-Zernike Theorem (Think Ducks).
- G1 can be Phase or Amplitude.
- Works with polychromatic sources.

The Talbot Effect

Z=0  Z_T

$$E(x,z) = C\int e^{i\frac{k}{2z}(x-x')^2} E(x',0)dx'$$

$$E(x,0) = T(x) = \sum_n a_n e^{i\frac{2\pi}{p_0}nx}$$

$$E(x,z) = C\sum_n a_n \int e^{i\frac{k}{2z}(x'-x)^2} e^{i\frac{2\pi}{p_0}nx'} dx'$$

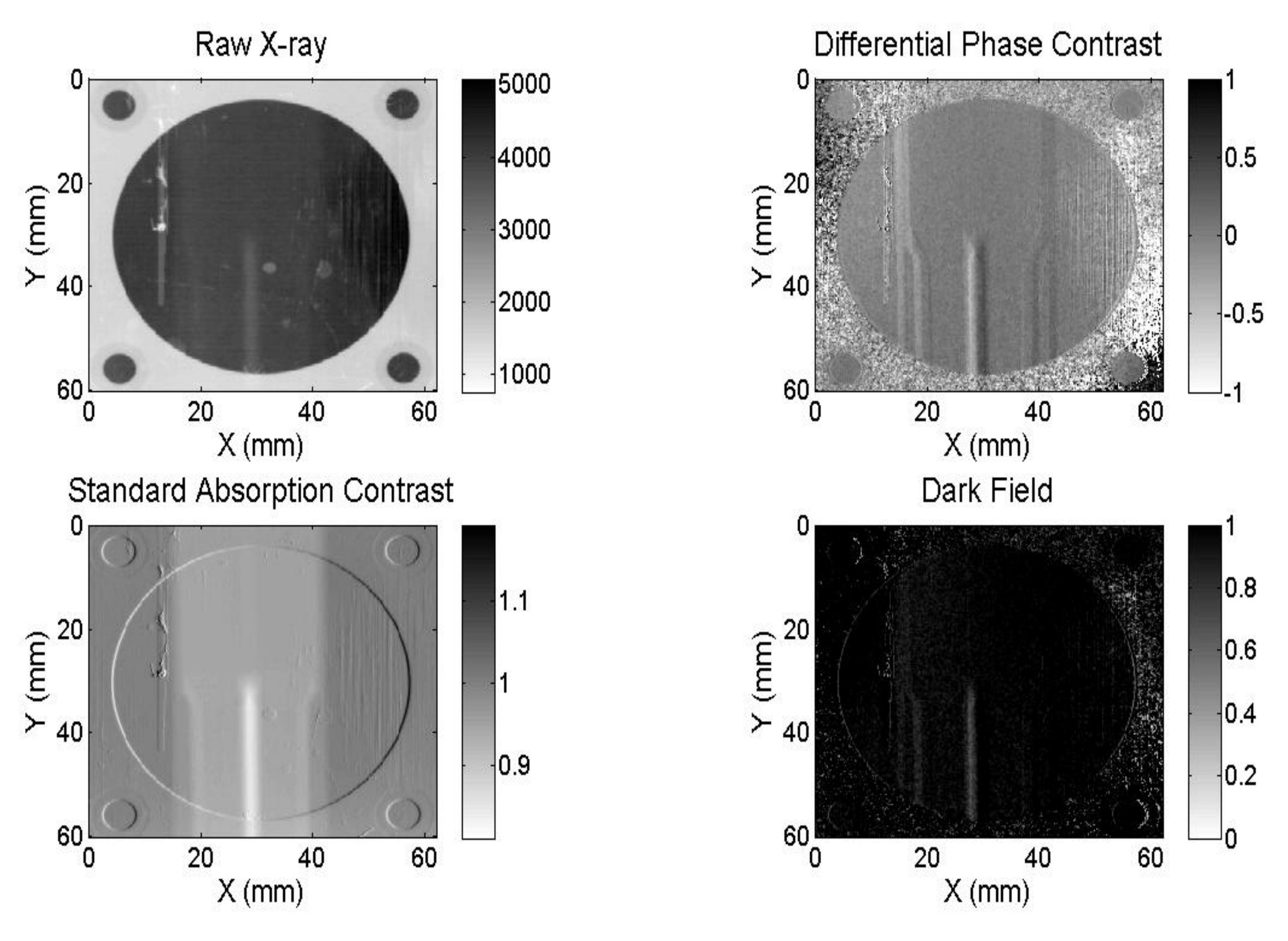
$$E(x,z) = C'\sum_n a_n e^{i\frac{2\pi}{p_0}nx} e^{-i\frac{\pi\lambda z}{p_0^2}n^2}$$

$$2\pi m = \frac{\pi\lambda z}{p_0^2}$$

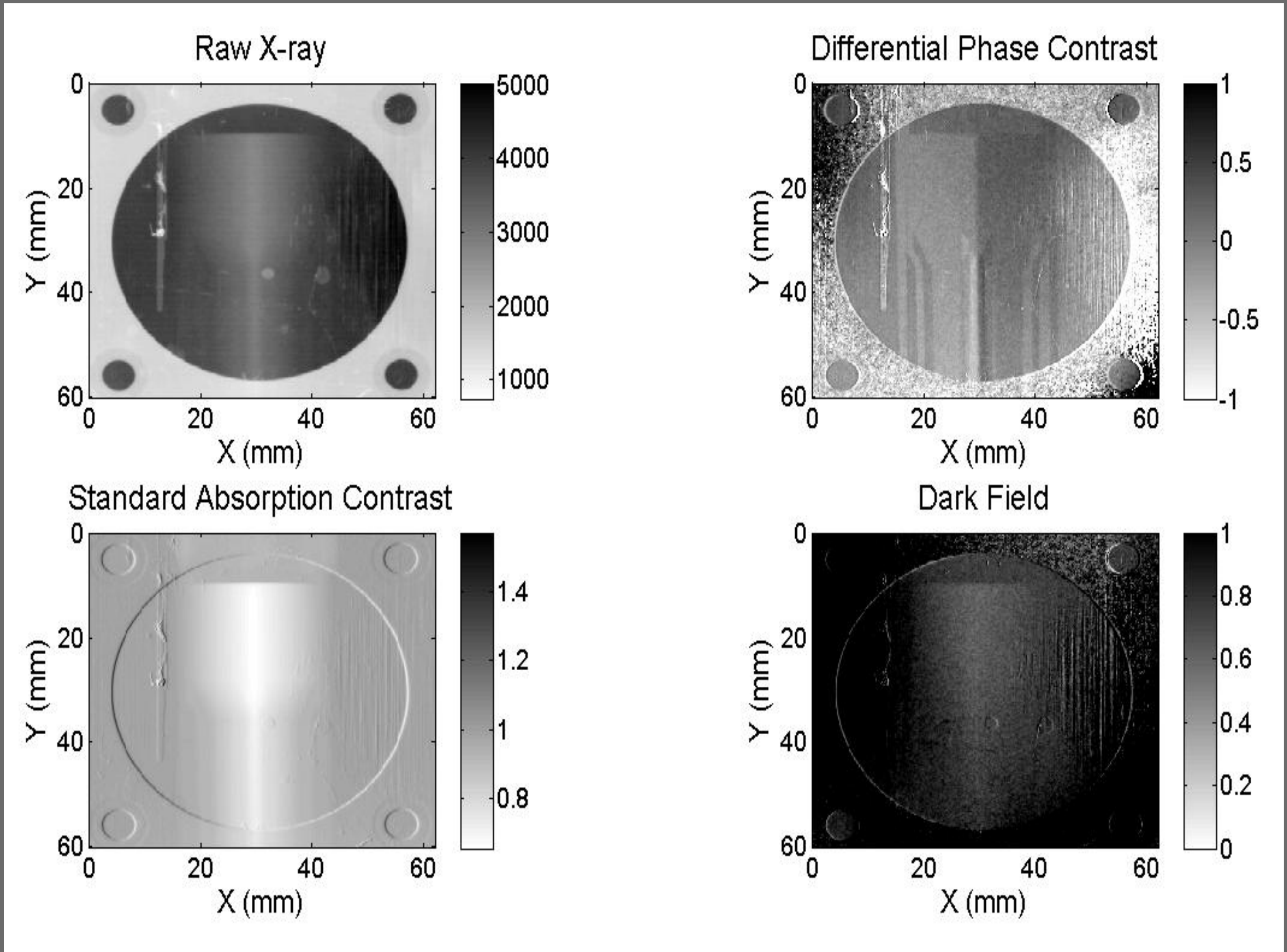
$$z = mz_T$$

$$\boxed{z_T = \frac{2p_0^2}{\lambda}}$$

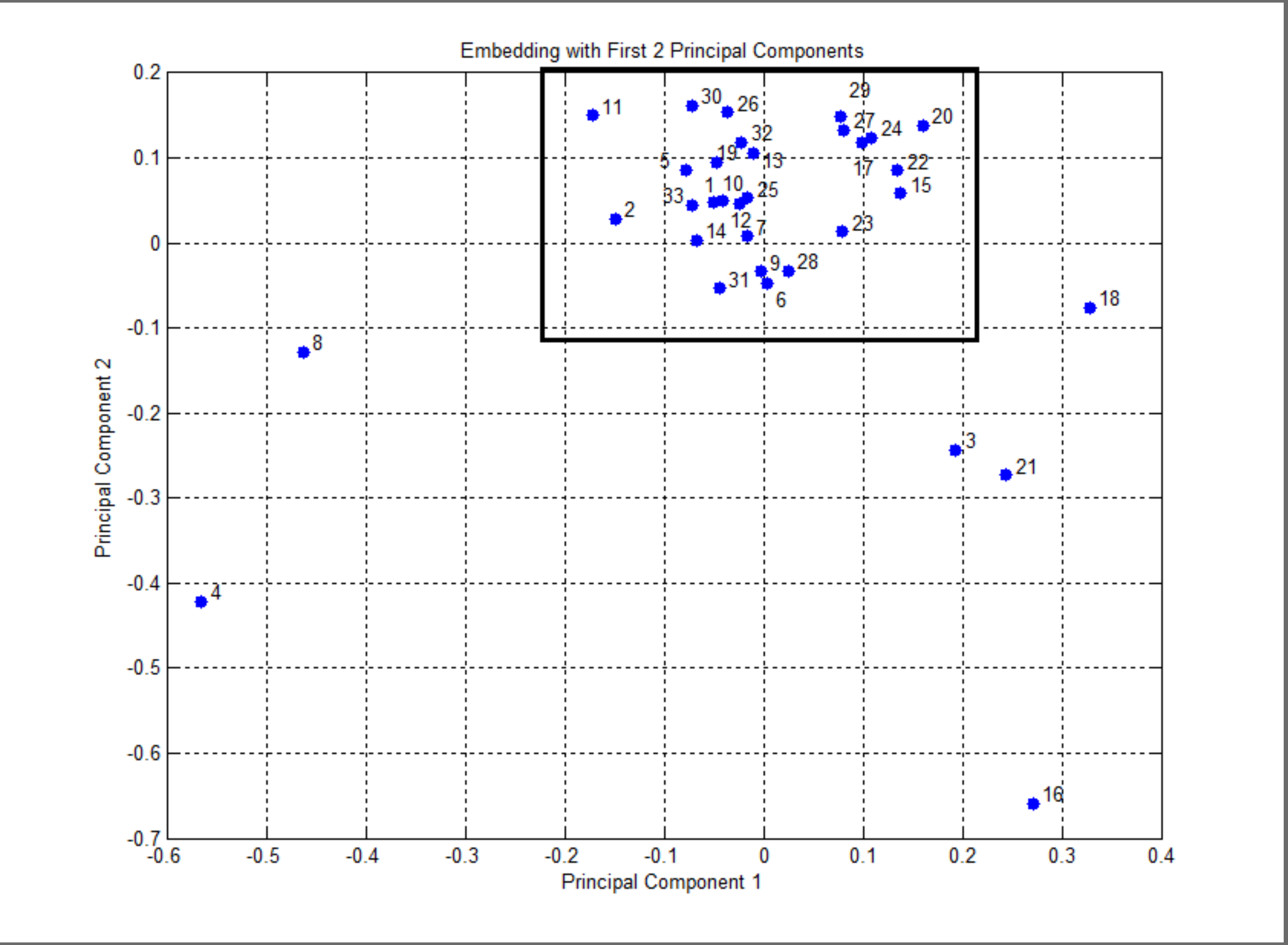
X-ray Absorption, DPC, and Dark Field Contrast Images of Empty Cuvette



X-ray Absorption, DPC, and Dark Field Contrast Images of Water + Cuvette

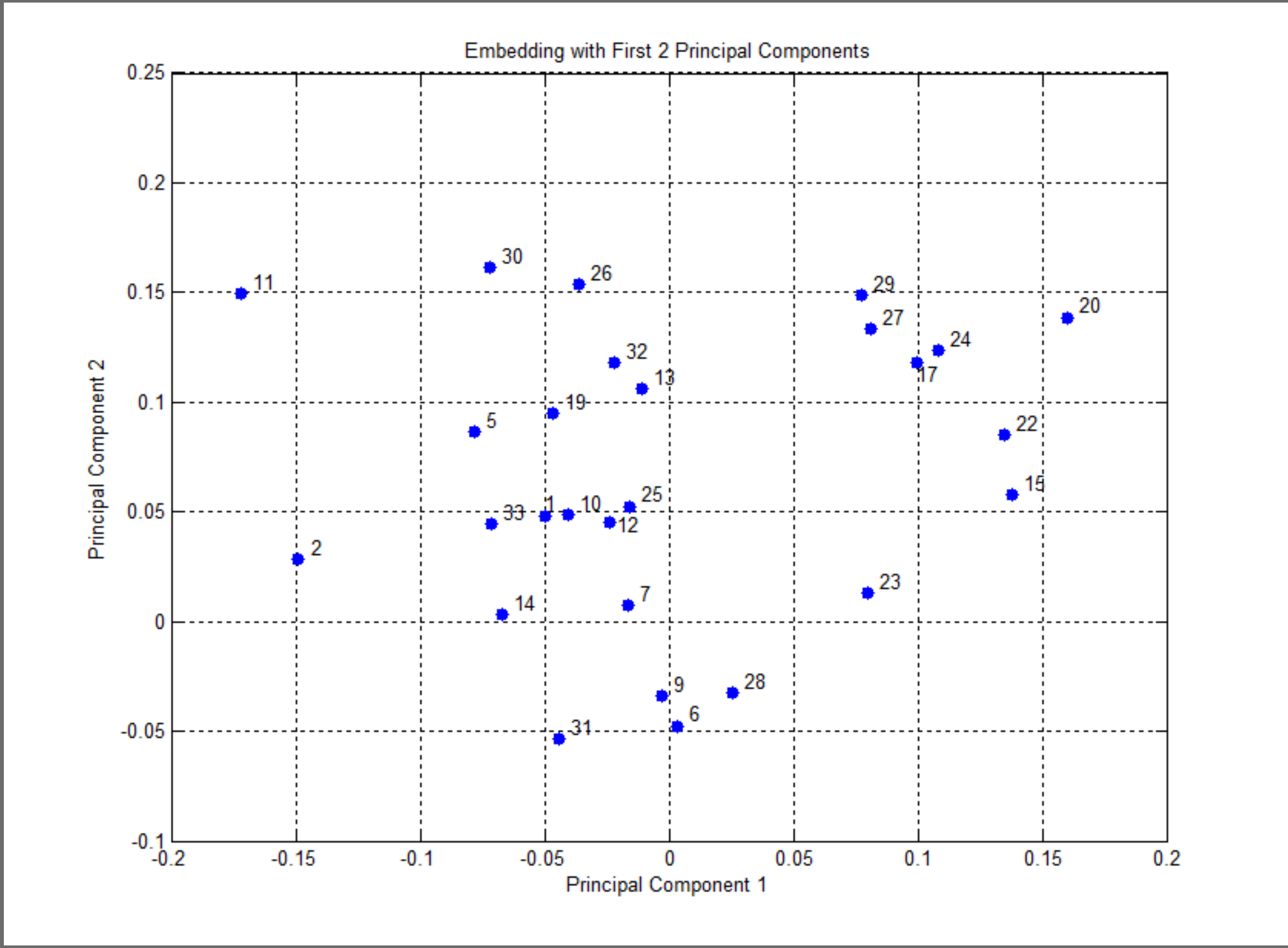


Principal Component Analysis

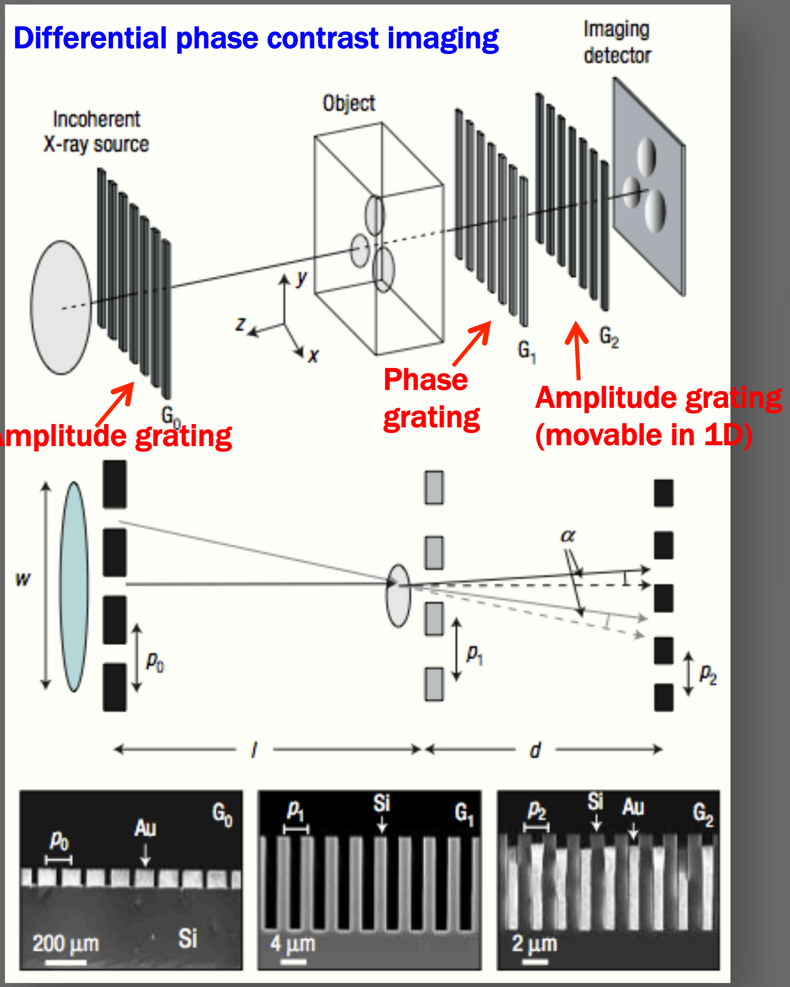


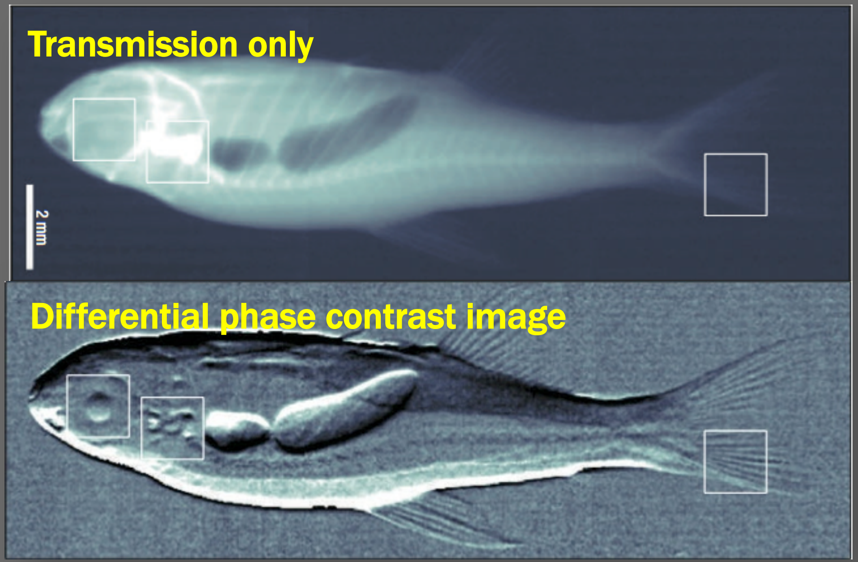
Squared area shows in next figure

Principal Component Analysis



X-ray Differential Phase-Contrast Imaging





Pfeiffer et al., Nature Phys.. (2006)

Problems:

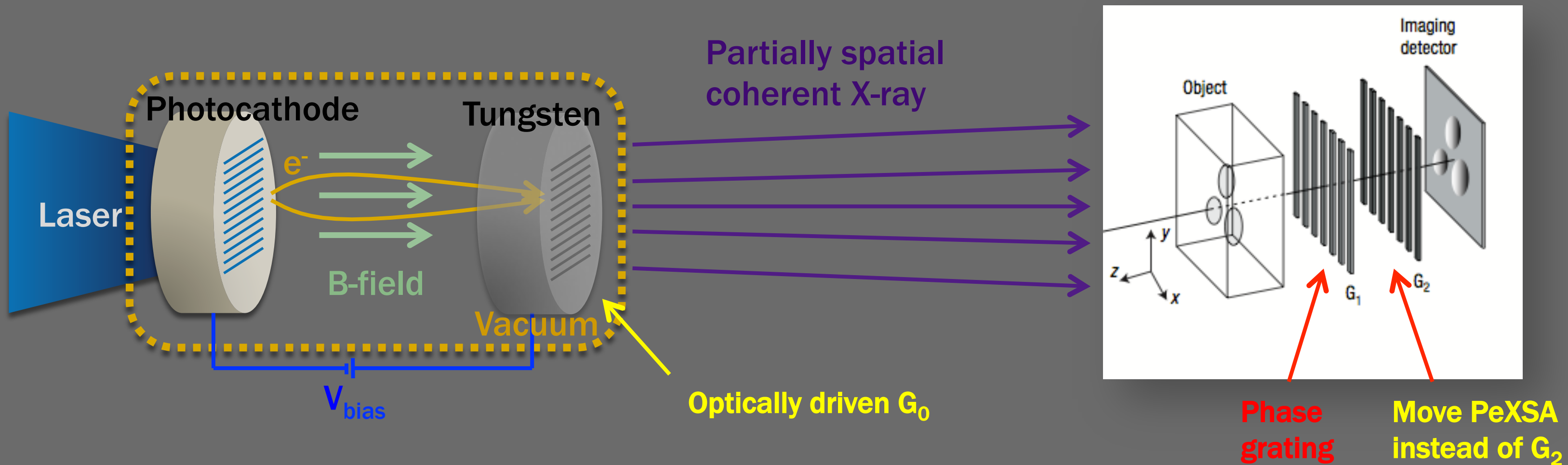
- Amplitude grating G_0 blocks > 75% of incident X-rays (for spatial coherence).
- Need high aspect-ratio (> 100X) amplitude grating for high energy (> 100 keV) X-ray design.

Solution

Optically Driven Patterned X-ray Source

Photoelectron X-ray Source Array (PeXSA)

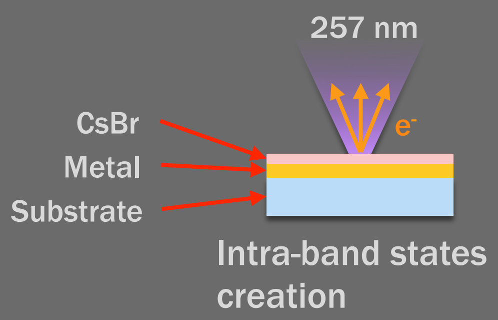
We can reduce the wasted X-ray power > 4X and replace the tricky high aspect ratio amplitude grating

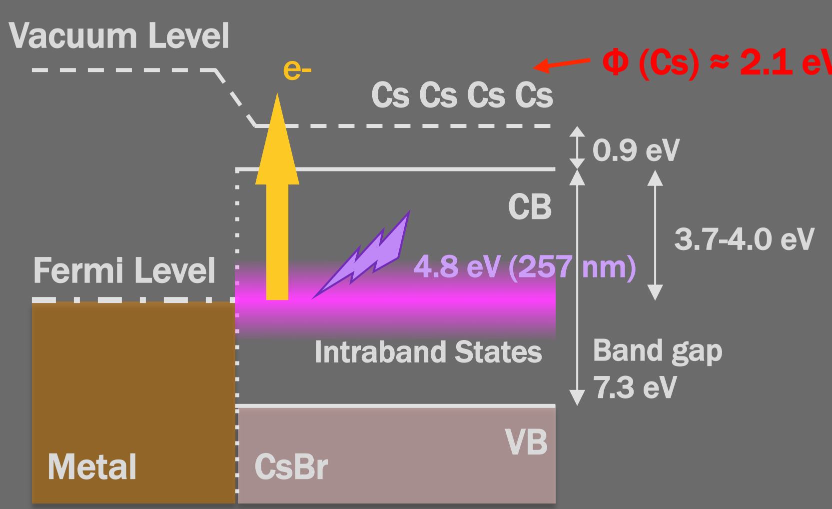


A spatial light modulator now generates the optical pattern
... hence the e-beam pattern
... hence the X-ray pattern
G2 grating does not need to move!

Ongoing research

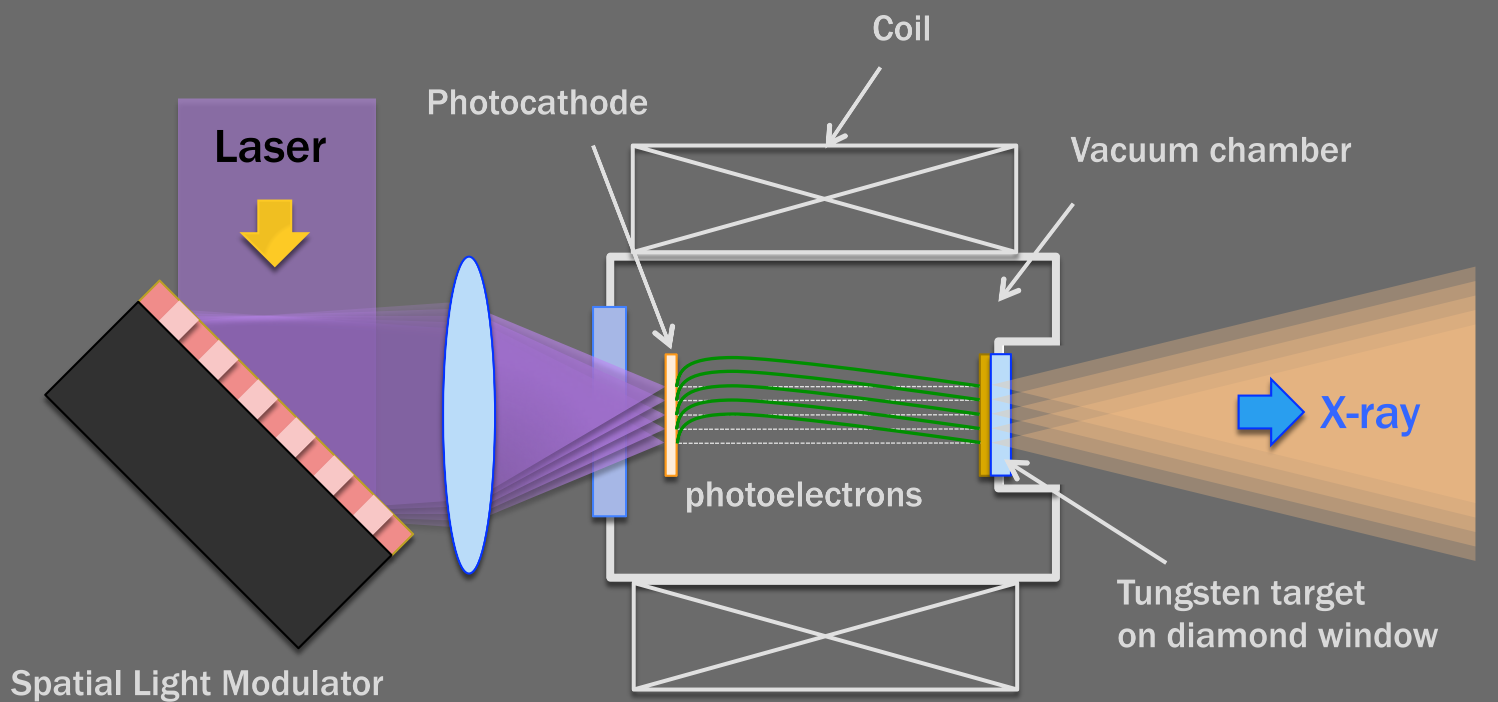
Photoelectron Source
UV activated intraband states in CsBr





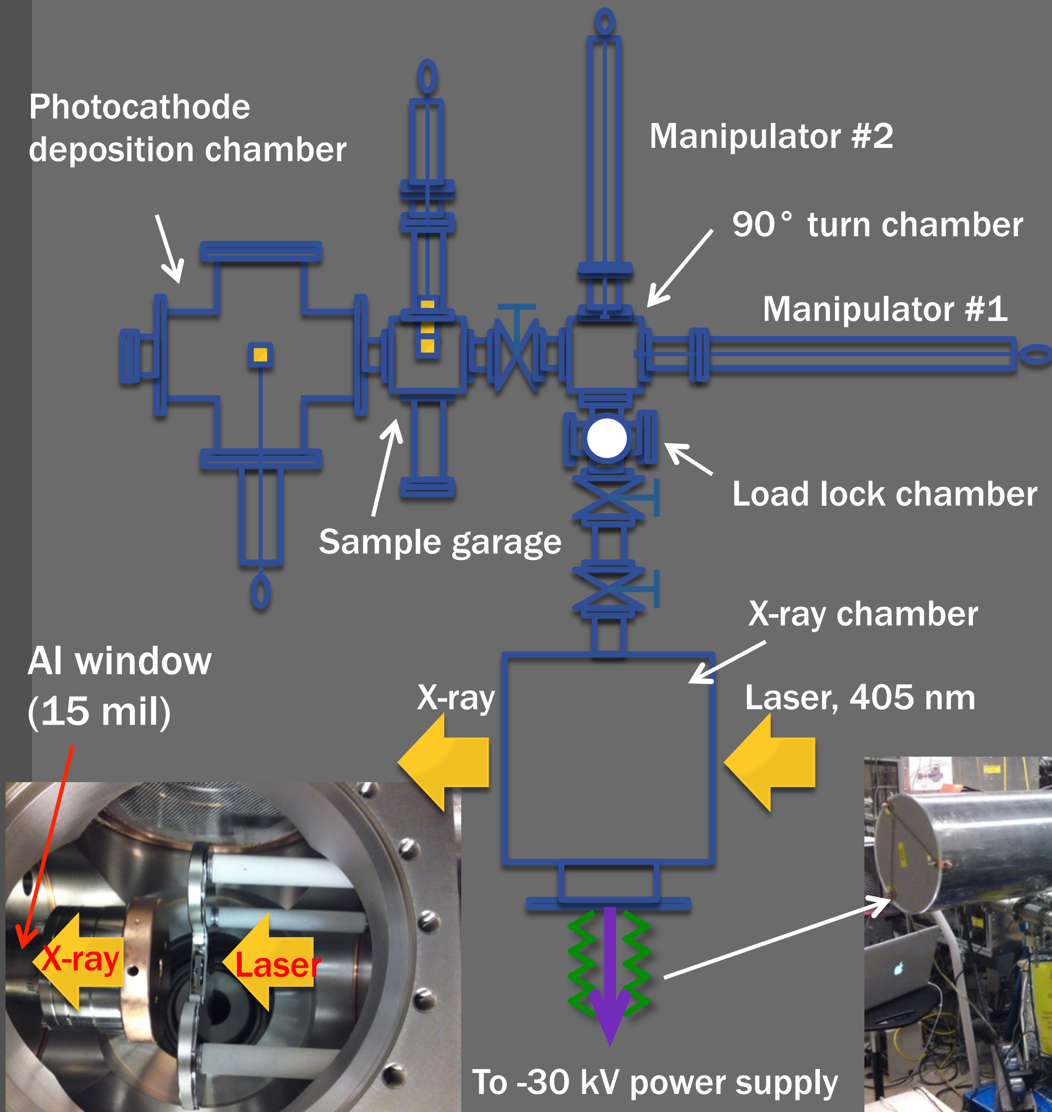
Use UV to activate intra-band states first.

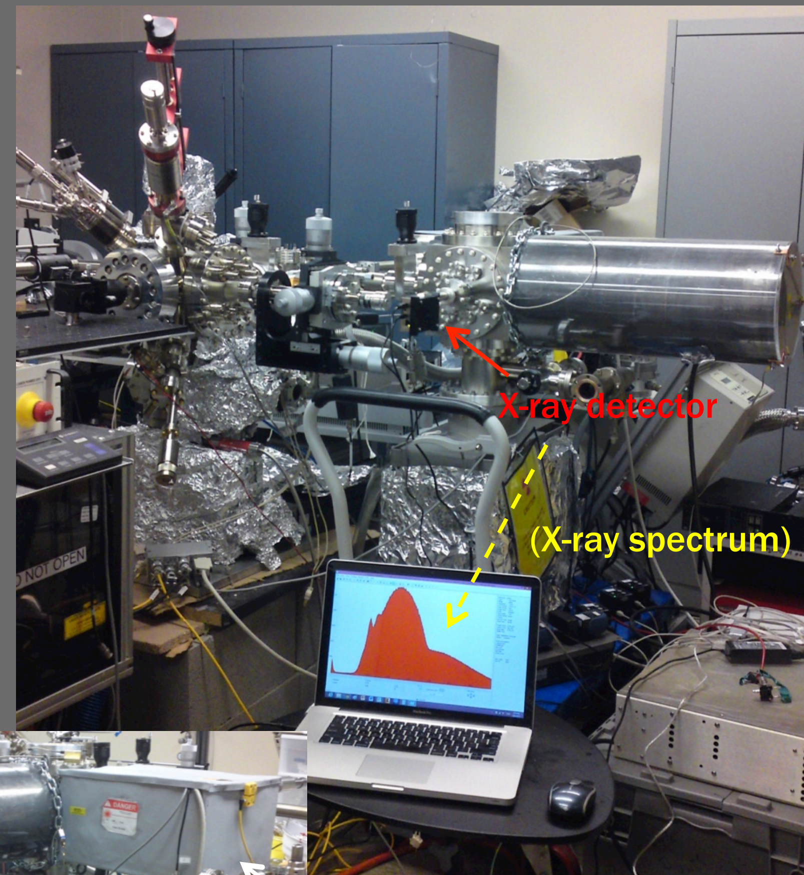
Photoelectron X-ray Source Array

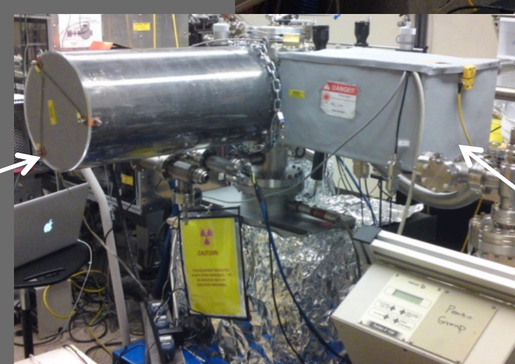


Laser + SLM → Optical pattern → electron pattern → Spatial coherent X-ray

PeXSA Setup



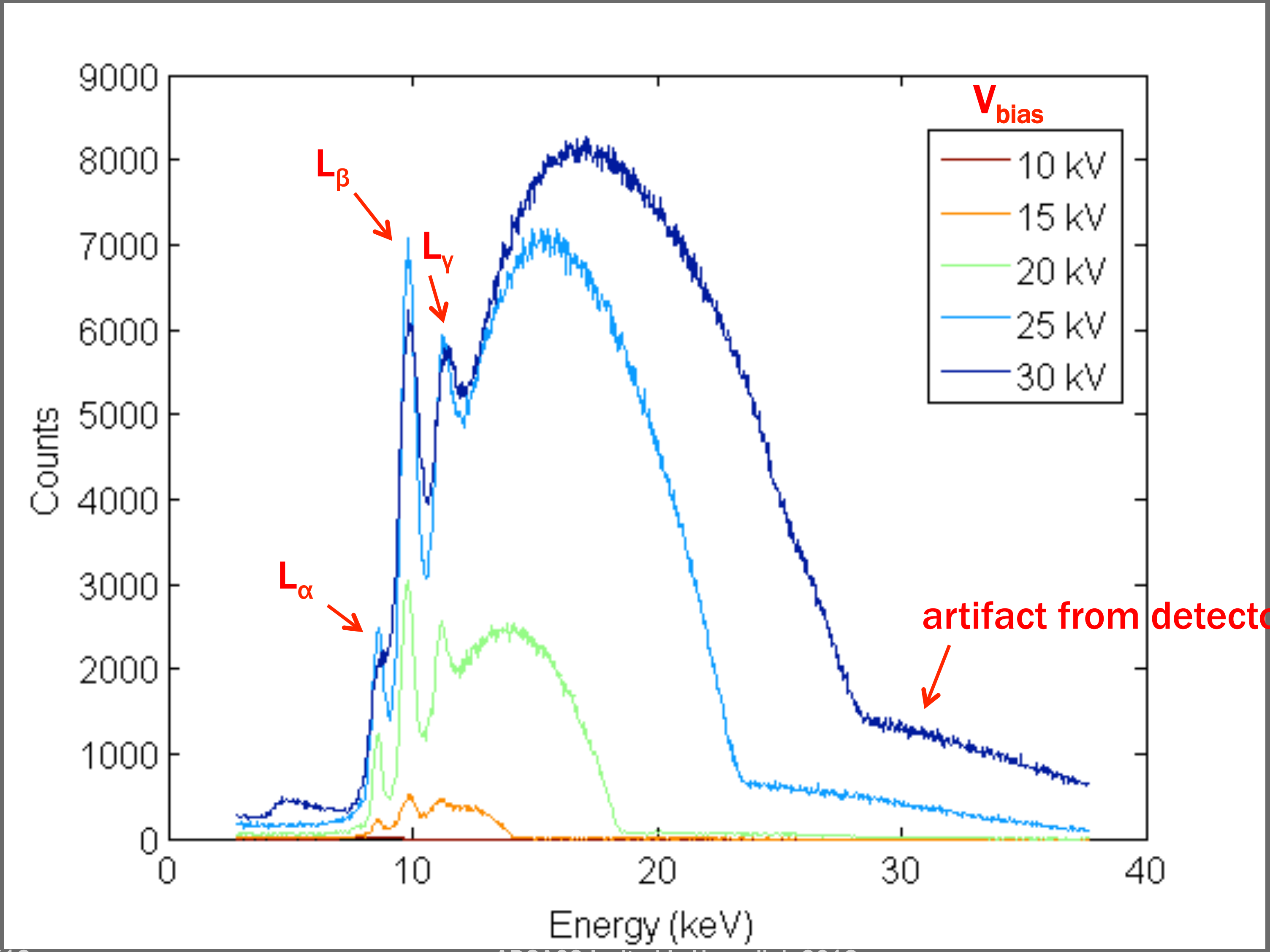




Laser input with lead enclosure

Photoelectron Excited X-ray

Transmission W target, Laser power 5 mW, V_{bias} 10 kV-30 kV



Summary

- DPC measurements provide richer detection signatures
  - *More work to be done to determine effectiveness within cluttered bag*

- *Photo Electron X-ray Source Array (PeXSA) enables simpler and more sensitive DPC system with large FoV*
  - *Gratings severely limit FoV for high energy system*