

# Structured Light for Surpassing Optics and Detector Limitations

Doga Gursoy (Argonne)

(Coded apertures, coded exposures, ...)

# Structured Light for Surpassing Optics and Detector Limitations

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How can we encode beam (in time, space, ...) to improve certain performance characteristic (resolution, acquisition time, data volume, ...)?

# 1. Basics of Coded Imaging

# Imaging in a general context

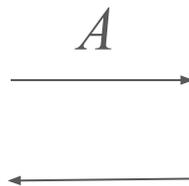


Light source



Object

$x$



Measurements

$d$

$$\arg \min_x \|Ax - d\|_2^2$$

# Imaging in a general context



Light source



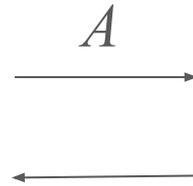
Object

$x$



Measurements

$d$



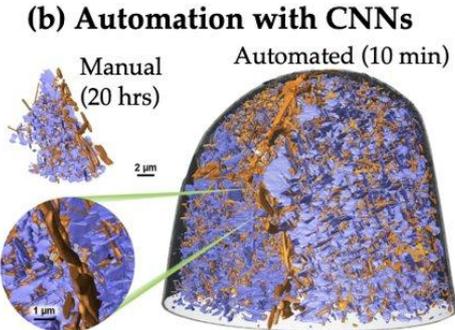
$$\arg \min_x \|Ax - d\|_2^2$$

Goals:

- increase the resolution
- reduce the observations
- make it robust to noise
- make it computable in reasonable time

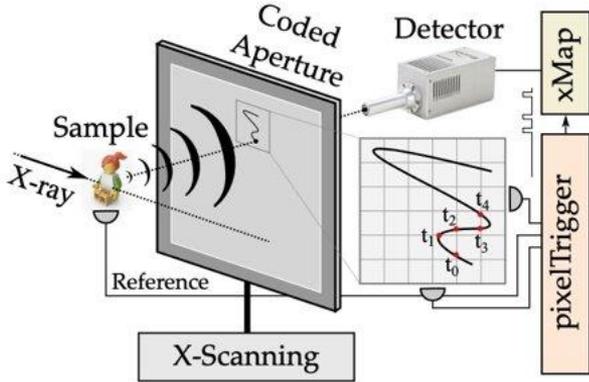
# Different shades of imaging

## Inverse problems

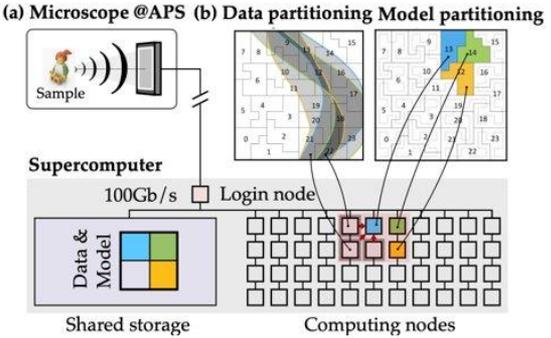


$$\min_x \|Ax - d\|_2^2$$

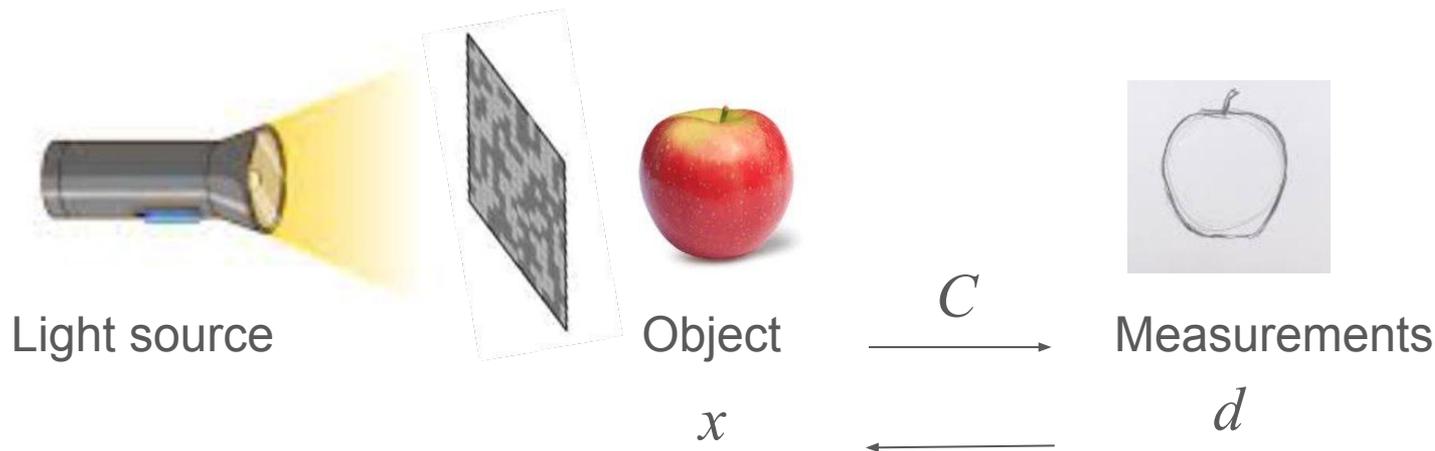
## Computational Imaging



## Scientific Computing



# Imaging in a general context



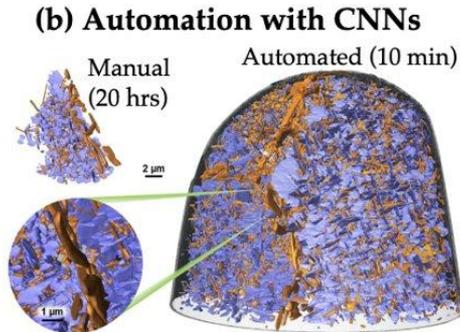
Goals:

- increase the resolution
- reduce the observations
- make it robust to noise
- make it computable in reasonable time

$$\arg \min_x \|Cx - d\|_2^2$$

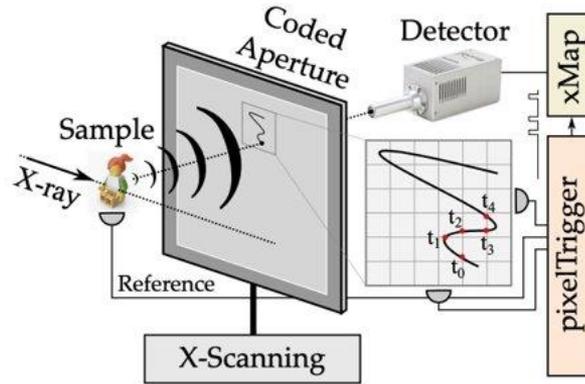
# Different shades of imaging

## Inverse problems



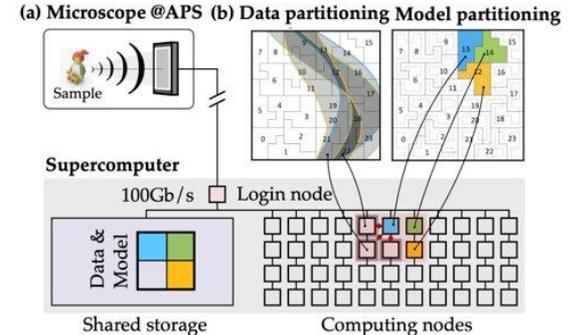
$$\min_x \|Ax - d\|_2^2$$

## Computational Imaging



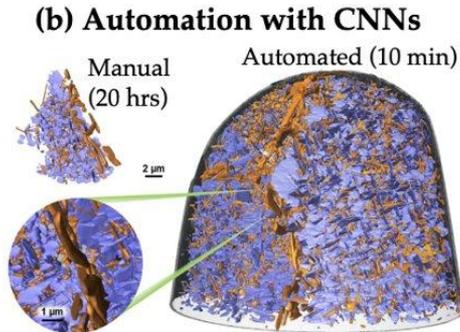
$$\min_x \|Cx - d\|_2^2$$

## Scientific Computing



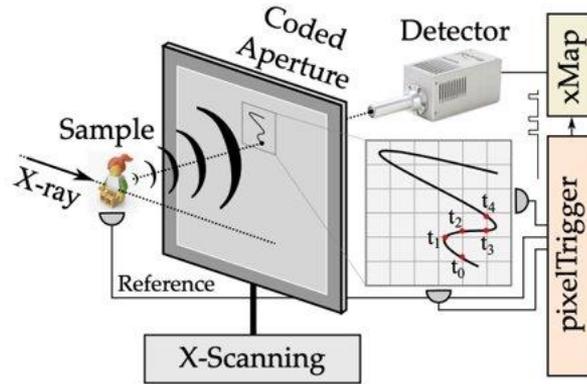
# Different shades of imaging

## Inverse problems



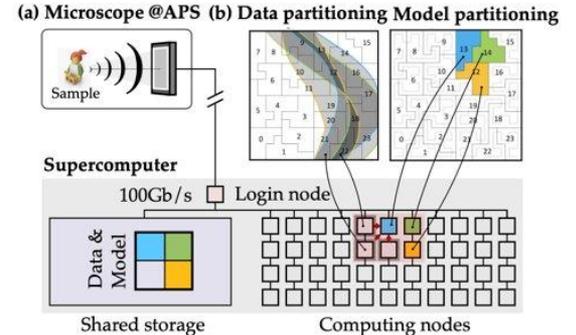
$$\min_x \|Ax - d\|_2^2$$

## Computational Imaging



$$\min_x \|Cx - d\|_2^2$$

## Scientific Computing



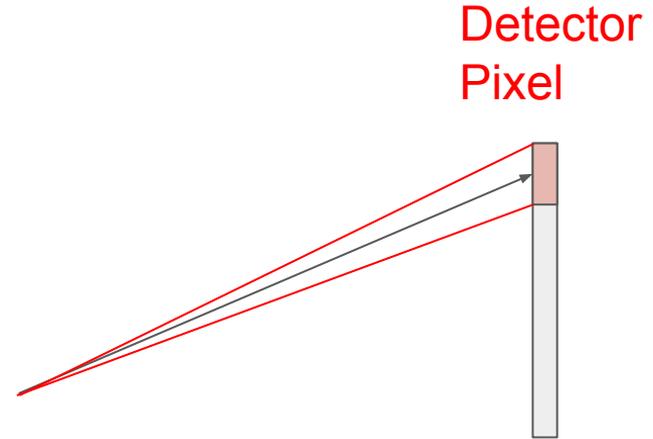
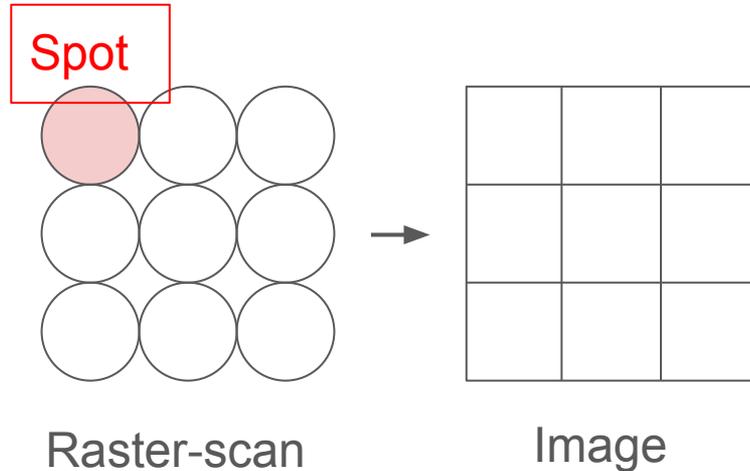
$$\min_{x, u_1, \dots, u_M} \frac{1}{2} \|A_i u_i - d_i\|_2^2$$

$$\text{subject to } u_i = x, \quad i = 1, 2, \dots, M,$$

# Let's talk about "better"?

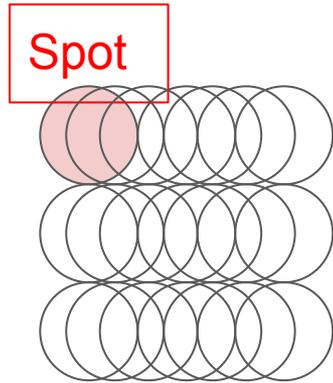
Limitations (from instrument perspective):

- Focal spot size or illumination area (optics related)
- Detector size and FOV (detector related)
- Exposure times (detector related)



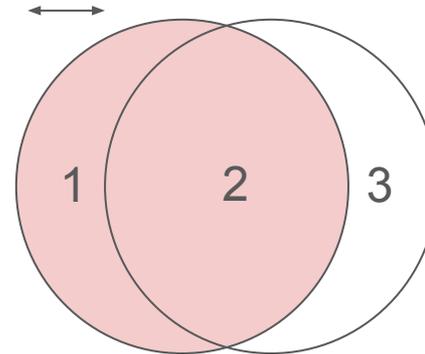
# Beginnings: Differential imaging

Remember:  
Ptychography=Large  
probe+small steps!



Raster-scan  
with overlapping  
regions

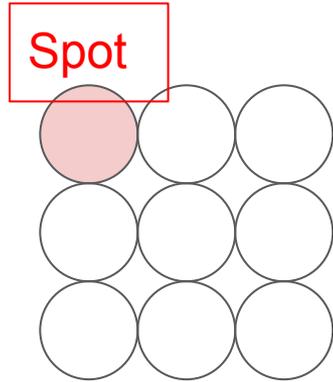
The larger the overlap, the  
better the resolution\*



$$(1+2) - (2+3) = 1-3$$

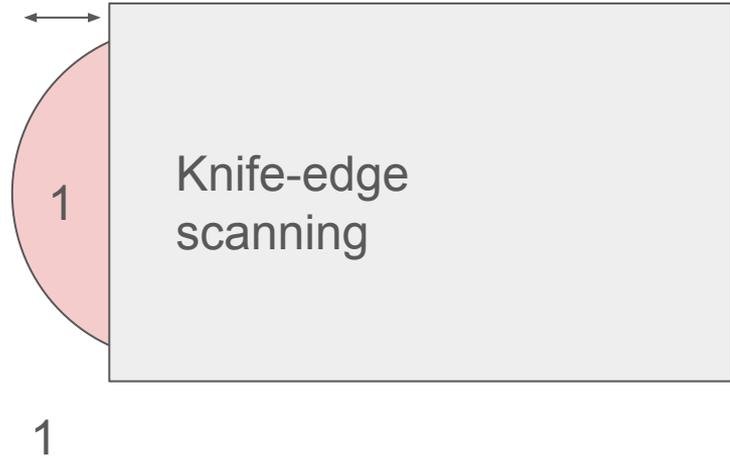
\*under ugly conditions. if you know the probe; if the probe is constant, etc.

# Beginnings: Differential imaging



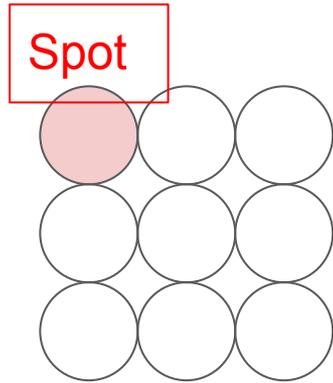
Raster-scan  
with overlapping  
regions

The larger the overlap, the  
better the resolution\*



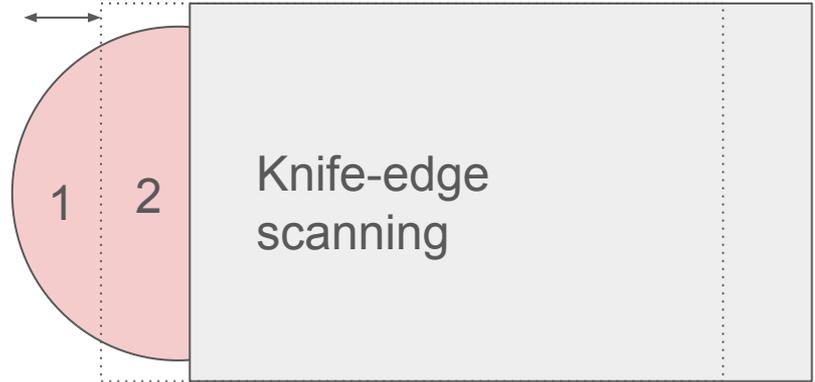
\*under ugly conditions. if you know the probe; if the probe is constant, etc.

# Beginnings: Differential imaging



Raster-scan  
with overlapping  
regions

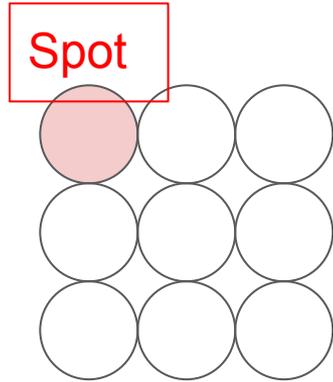
The larger the overlap, the  
better the resolution\*



$$(1+2) - 1 = 2$$

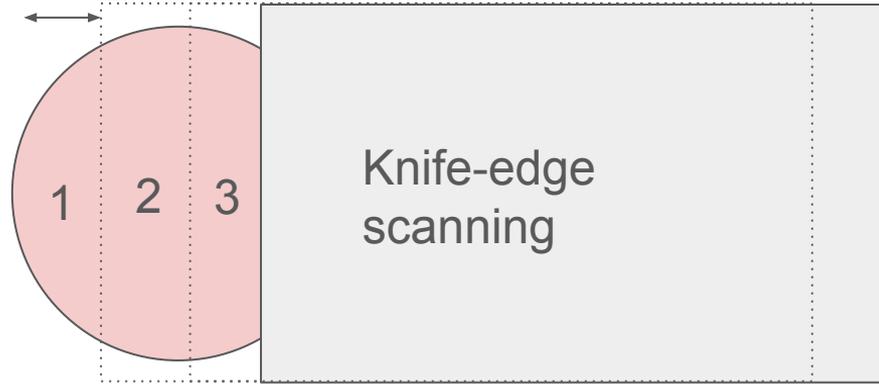
\*under ugly conditions. if you know the probe; if the probe is constant, etc.

# Beginnings: Differential imaging



Raster-scan  
with overlapping  
regions

The larger the overlap, the  
better the resolution\*



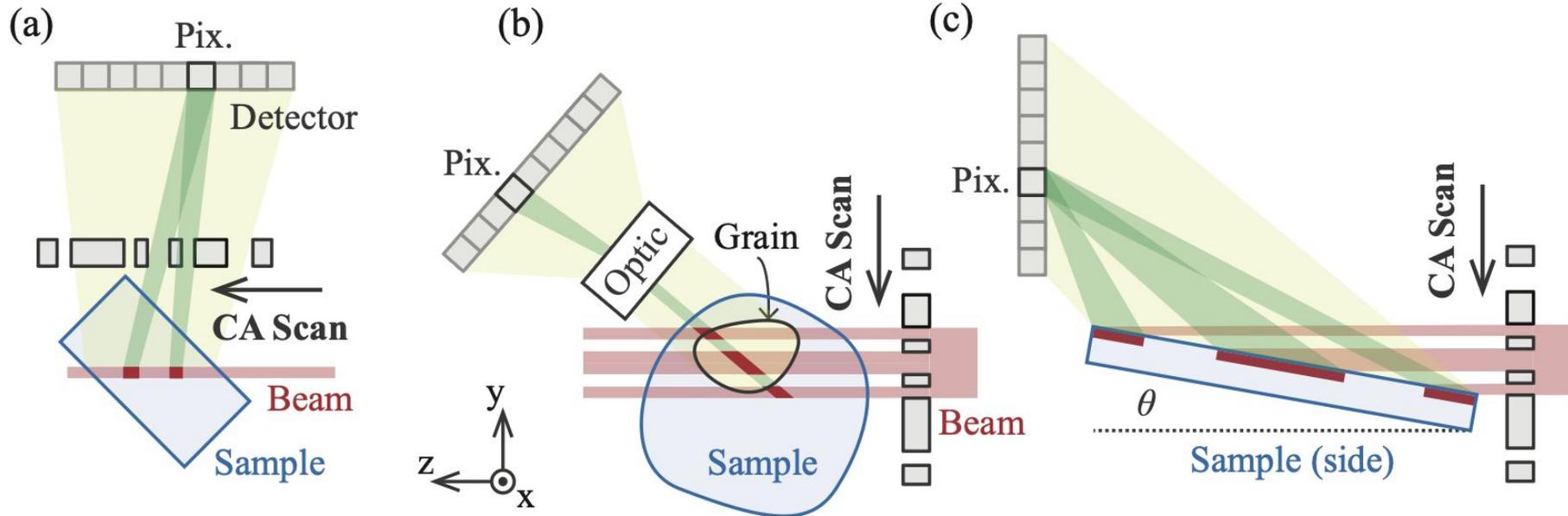
$$(1+2) - 1 = 2$$

$$(1+2+3) - (1+2) = 3$$

...

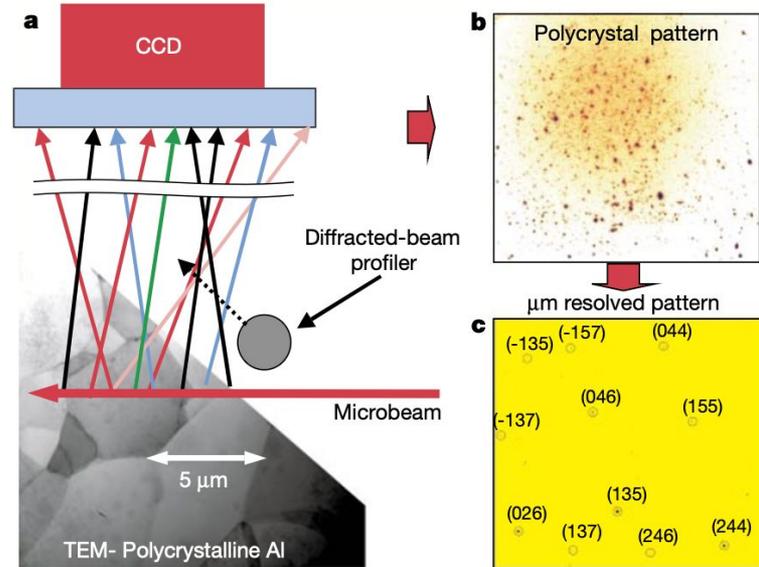
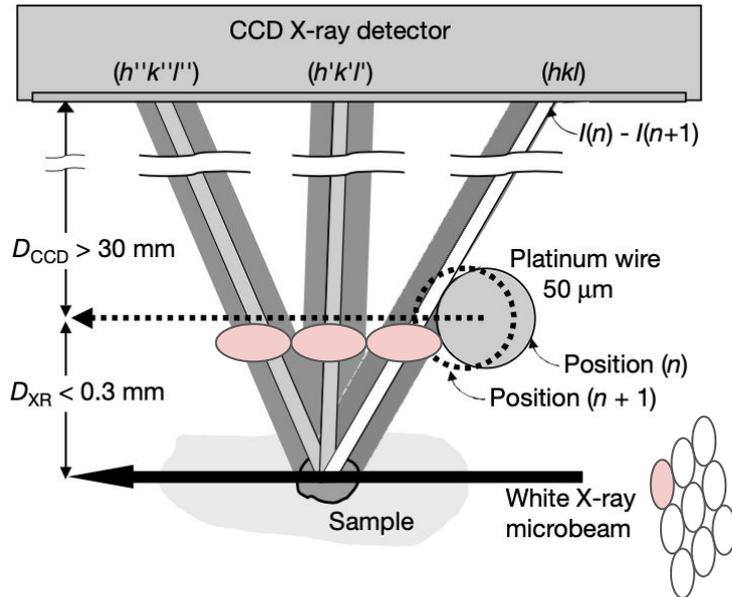
\*under ugly conditions. if you know the probe; if the probe is constant, etc.

The message: Find a method to control where (and when) the illumination beam interacts with the sample.

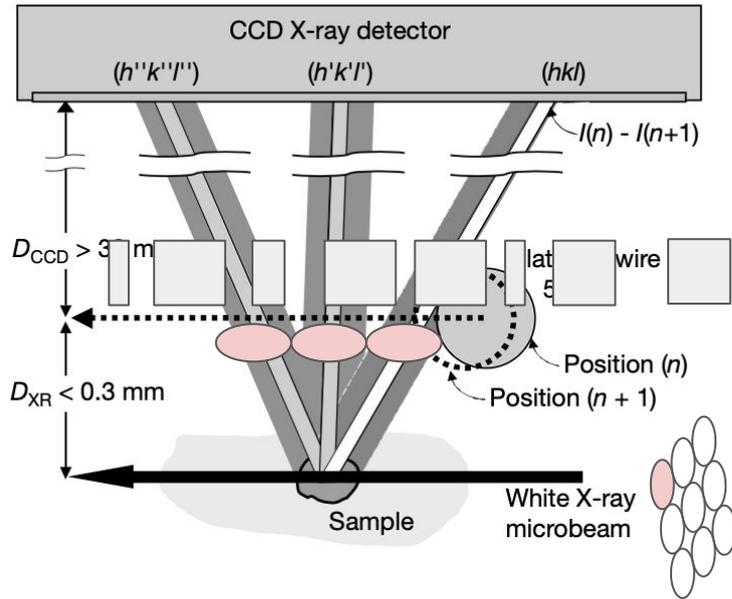


## 2. Applications

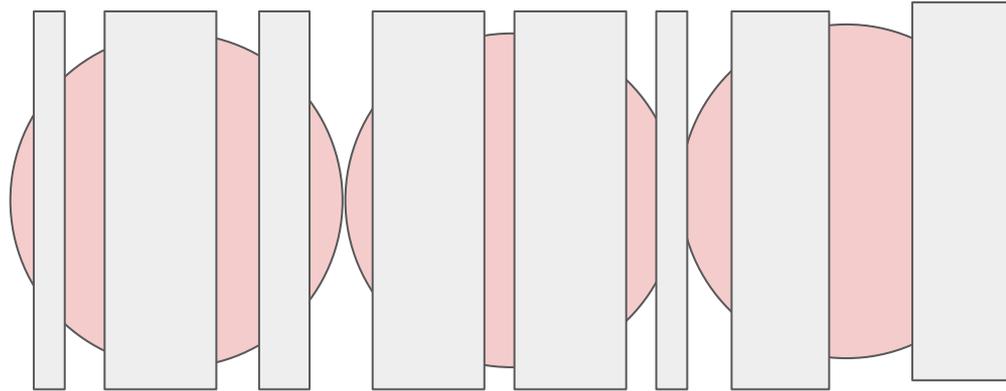
# Example: Differential-Aperture Depth-resolved Diffraction



# Example: Coded-Aperture Depth-resolved Diffraction

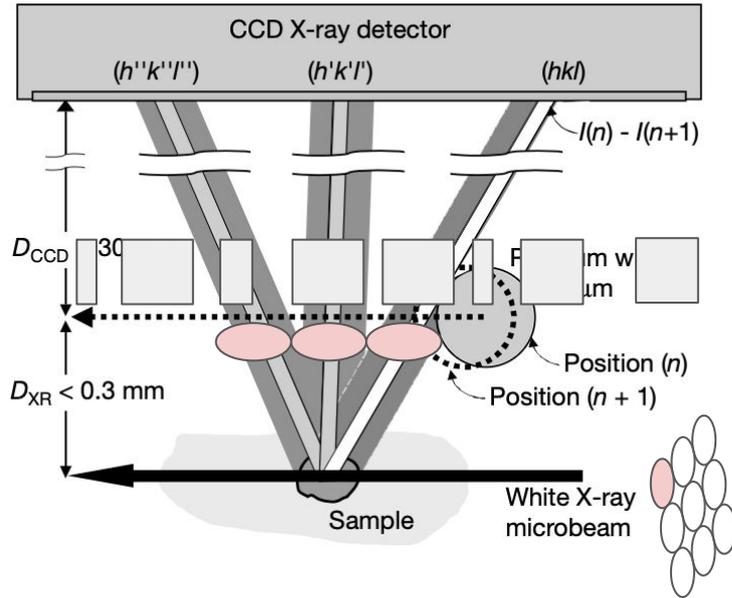


## Coded-aperture scanning

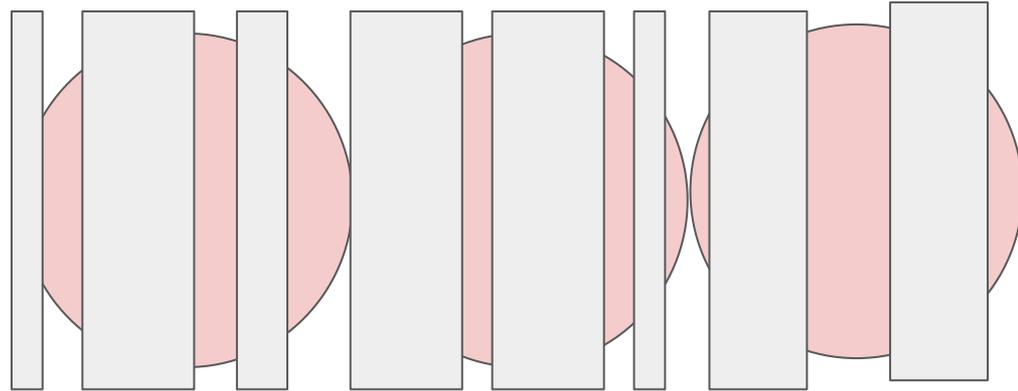


- Gürsoy, Doğa, et al. "Depth-resolved Laue microdiffraction with coded apertures." *Applied Crystallography* 55.5 (2022): 1104-1110.  
Gürsoy, Doğa, et al. "Digital autofocusing of a coded-aperture Laue diffraction microscope." *Review of Scientific Instruments* 94.1 (2023).  
Gürsoy, Doğa, et al. "Optimizing Coded-Apertures for Depth-Resolved Diffraction." arXiv preprint arXiv:2405.12813 (2024).

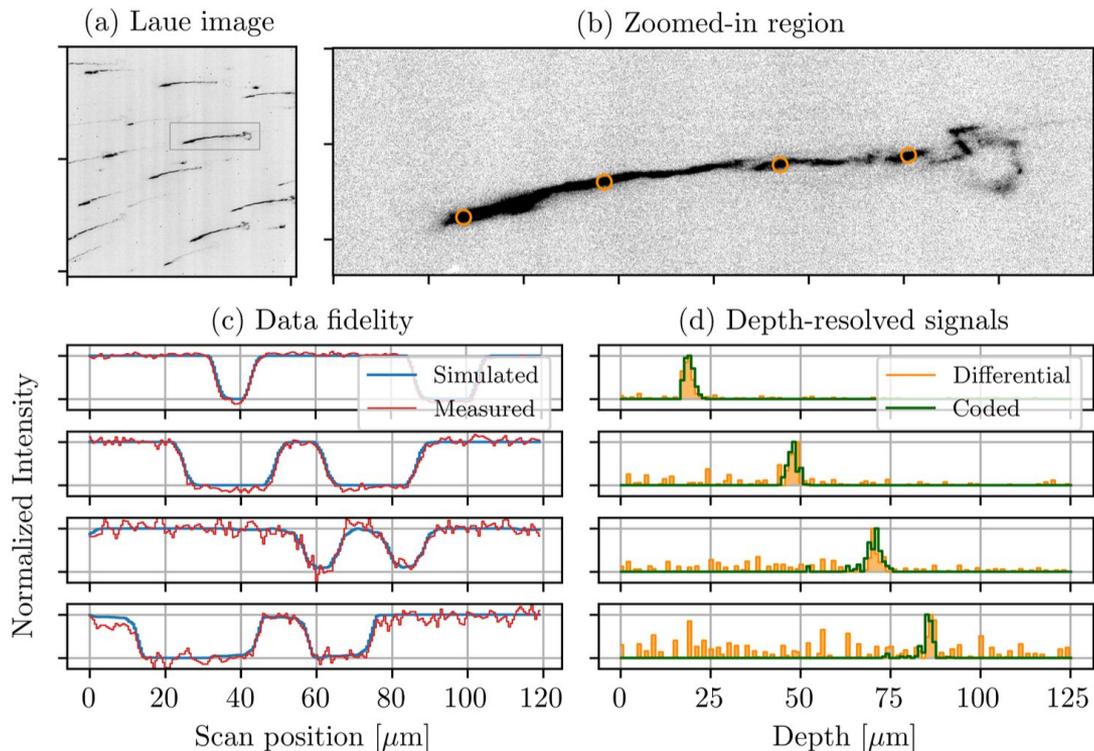
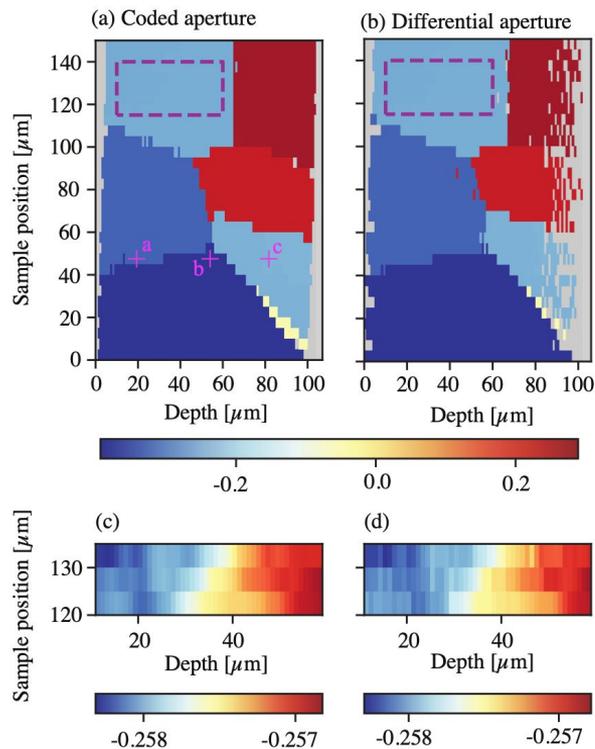
# Example: Coded-Aperture Depth-resolved Diffraction



## Coded-aperture scanning



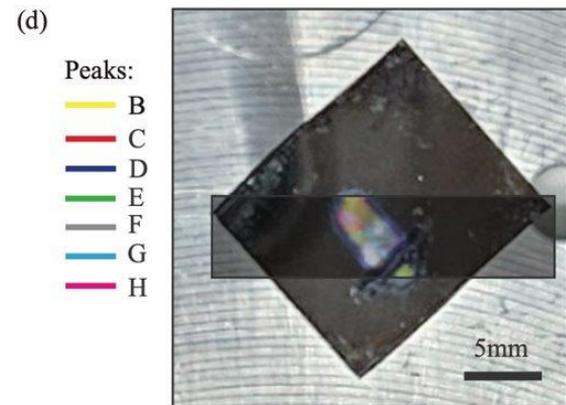
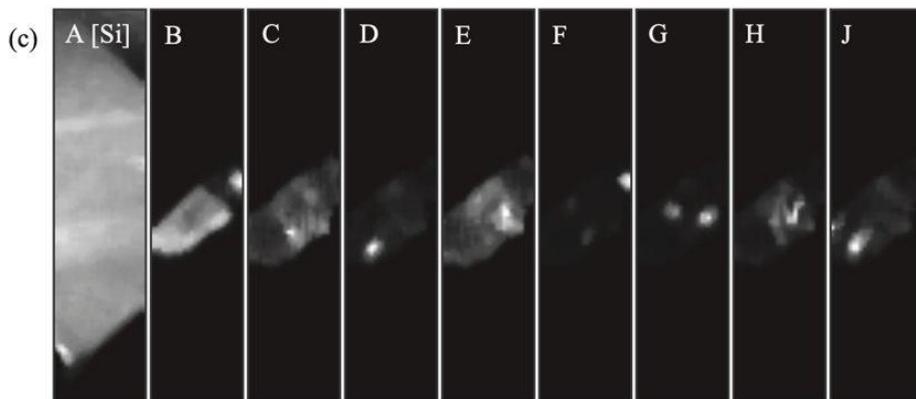
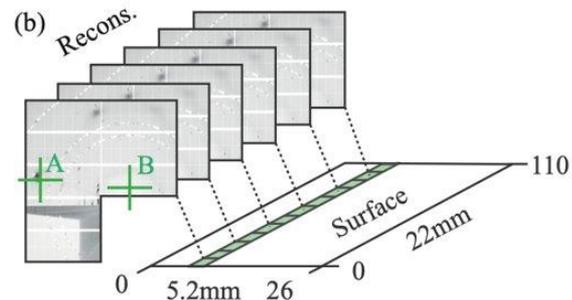
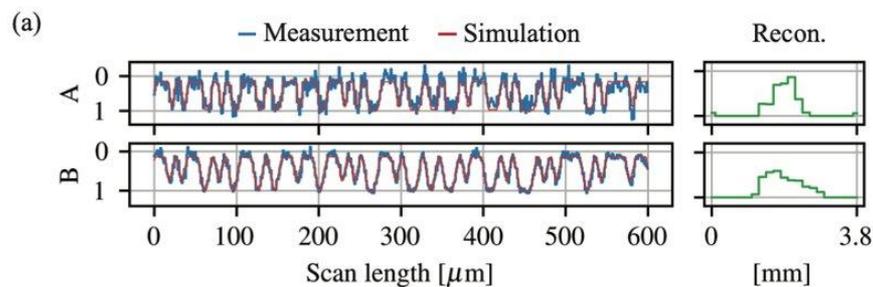
- Gürsoy, Doğa, et al. "Depth-resolved Laue microdiffraction with coded apertures." *Applied Crystallography* 55.5 (2022): 1104-1110.  
Gürsoy, Doğa, et al. "Digital autofocusing of a coded-aperture Laue diffraction microscope." *Review of Scientific Instruments* 94.1 (2023).  
Gürsoy, Doğa, et al. "Optimizing Coded-Apertures for Depth-Resolved Diffraction." arXiv preprint arXiv:2405.12813 (2024).



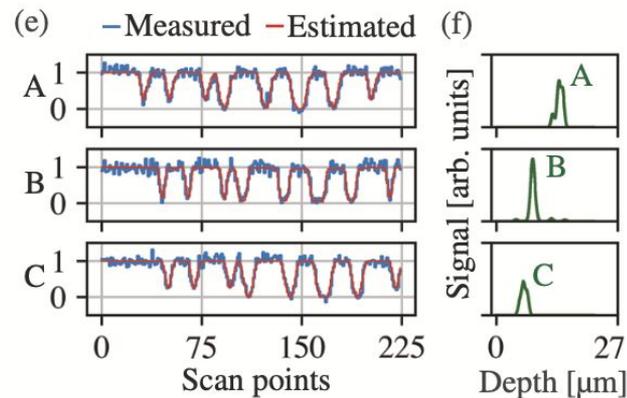
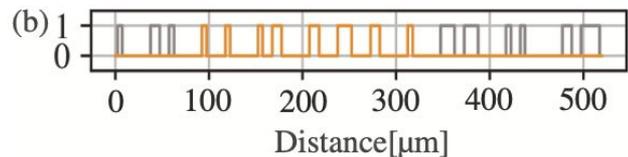
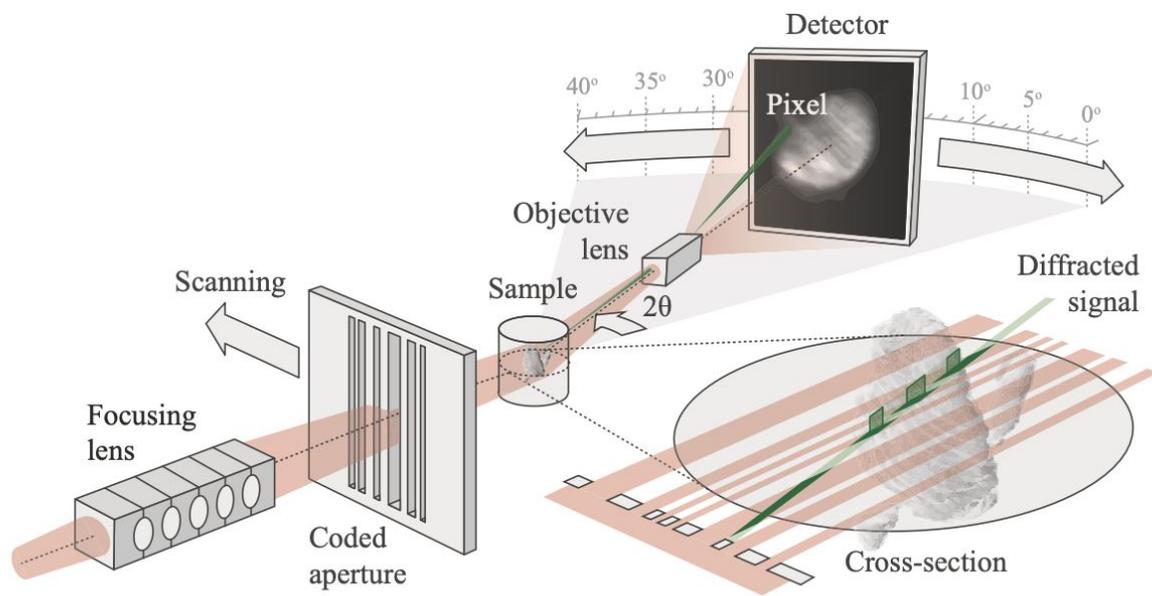
Gürsoy, Doğa, et al. "Depth-resolved Laue microdiffraction with coded apertures." *Applied Crystallography* 55.5 (2022): 1104-1110.  
 Gürsoy, Doğa, et al. "Digital autofocusing of a coded-aperture Laue diffraction microscope." *Review of Scientific Instruments* 94.1 (2023).  
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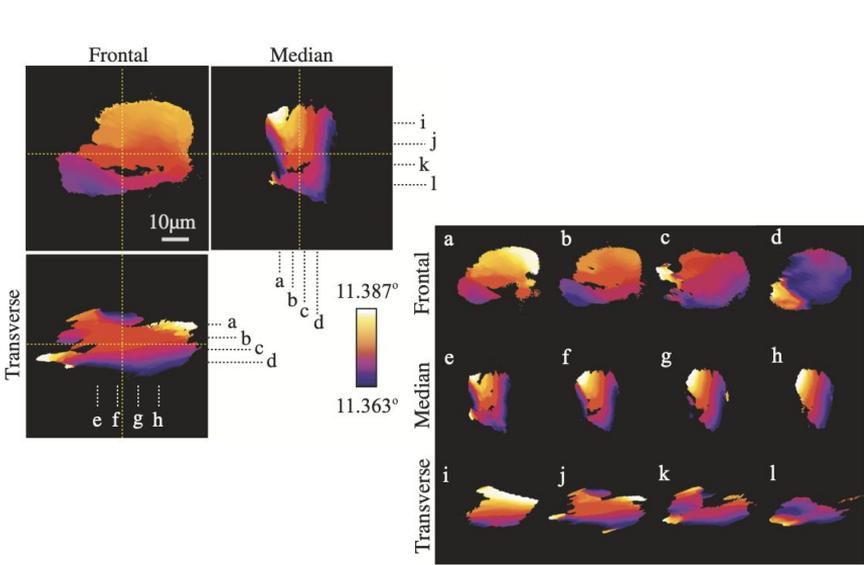
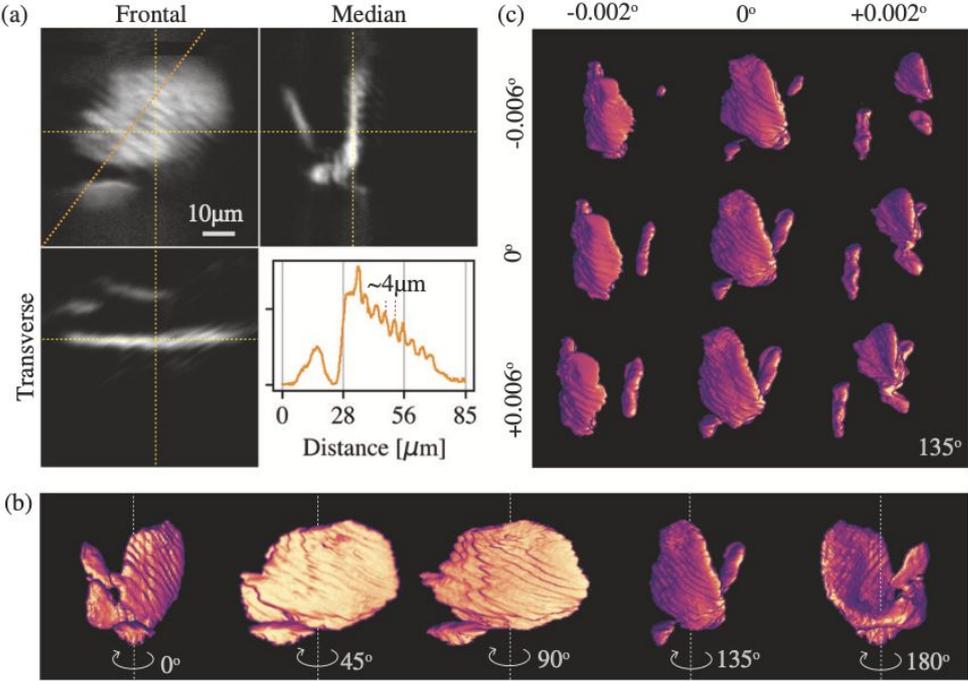
# Example: Depth-resolved Diffraction @ Grazing Angles



# Example: Depth-resolved Dark-Field X-ray Microscopy

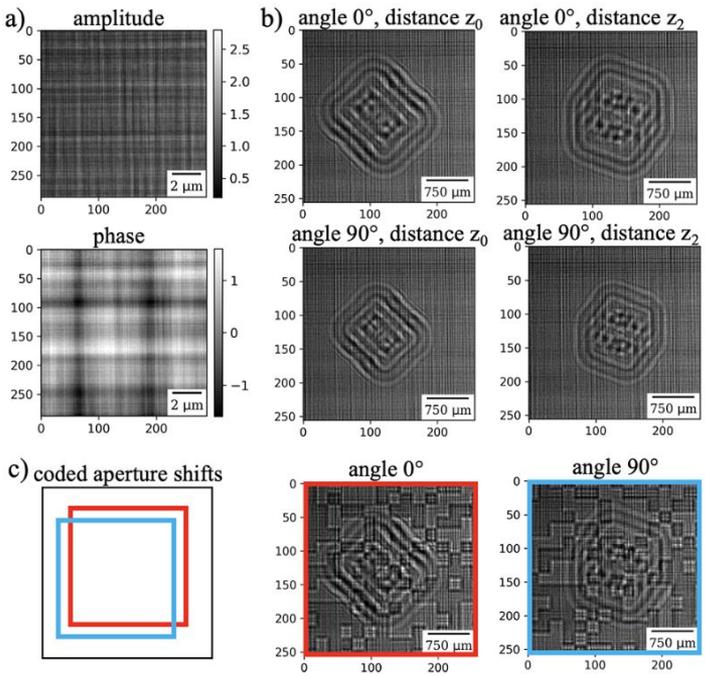
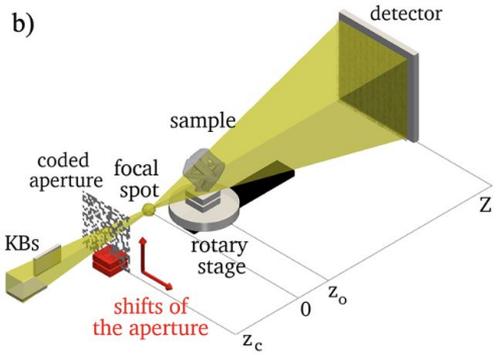
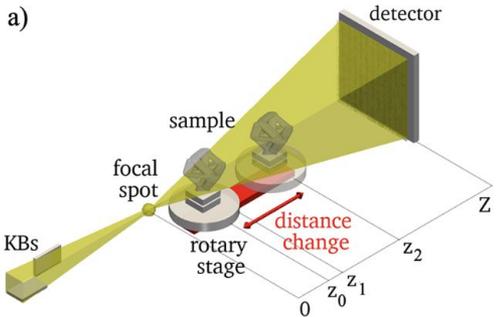


# Example: Depth-resolved Dark-Field X-ray Microscopy

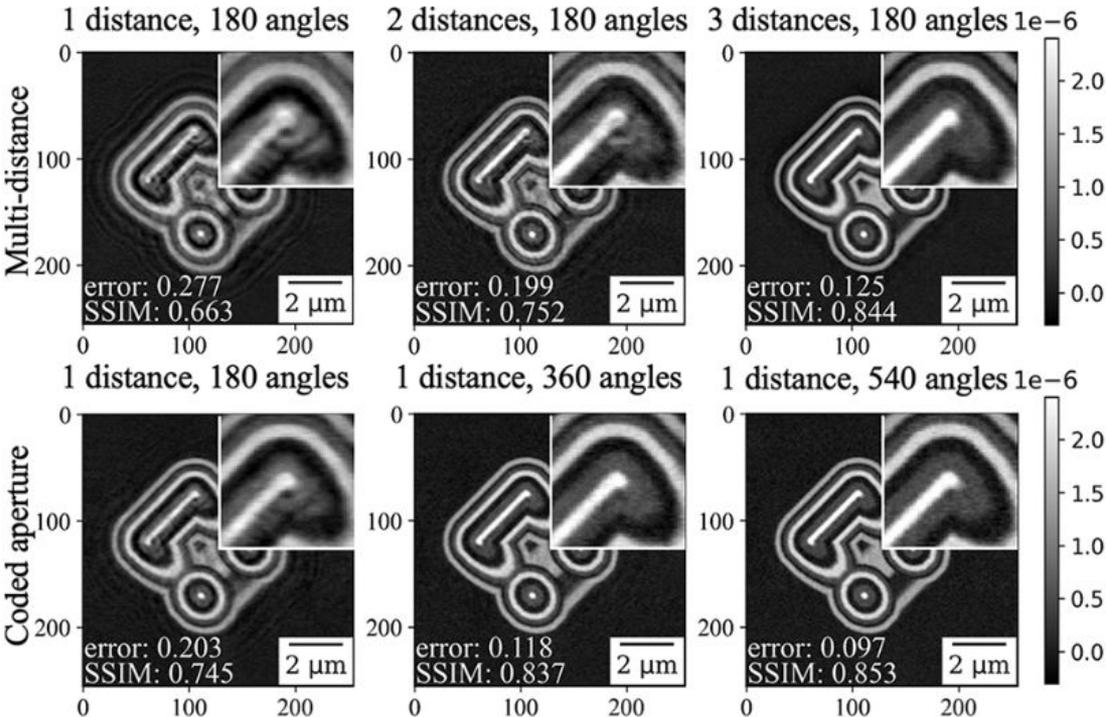


Gürsoy, Doğa, et al. "Dark-field X-ray microscopy with structured illumination for three-dimensional imaging." Communications Physics 8.1 (2025): 34.

# Example: Single-Distance Holo-Tomography

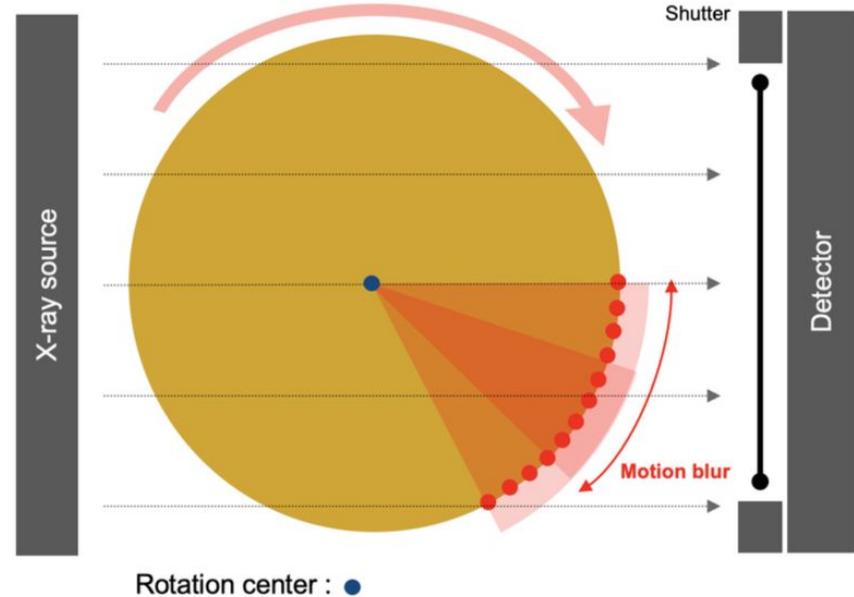
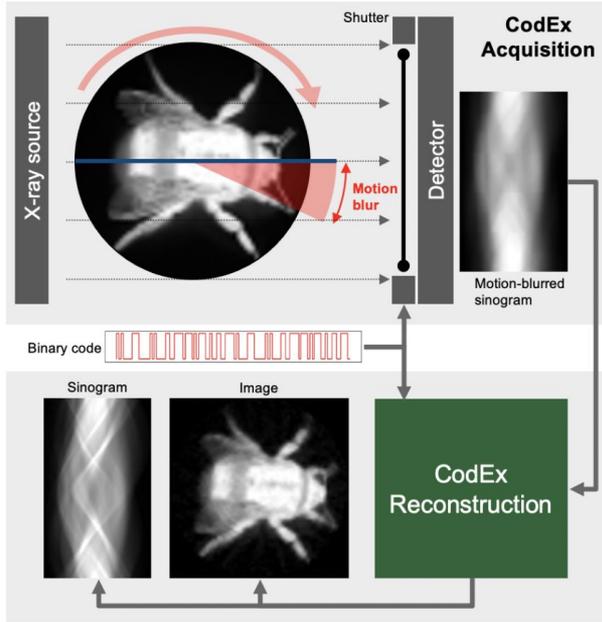


# Example: Single-Distance Holo-Tomography



# Example: Time-coded imaging

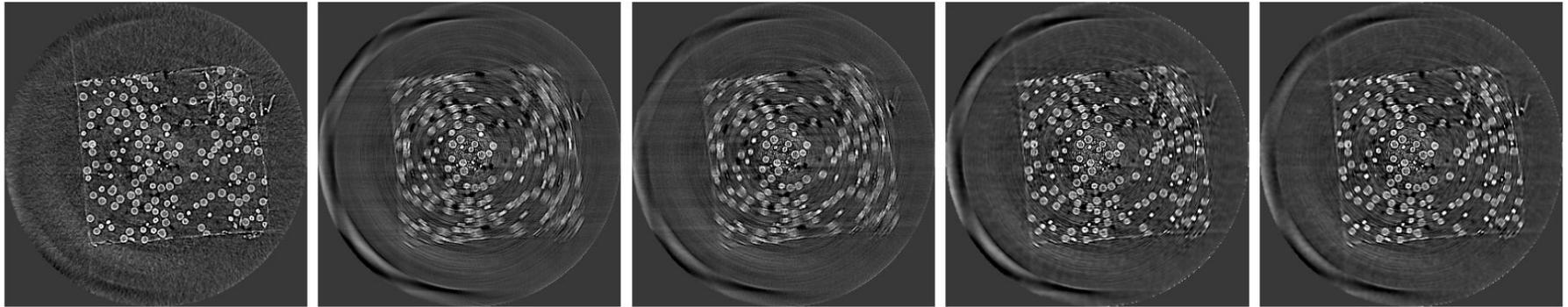
Rotation speed is fast and exposure is longer than covering arc resolution



Ching, Daniel, et al. "Time-coded aperture for x-ray imaging." *Optics Letters* 44.11 (2019): 2803-2806.

Majee, Soumendu, et al. "CodEx: a modular framework for joint temporal de-blurring and tomographic reconstruction." *IEEE Transactions on Computational Imaging* 8 (2022): 666-678.

# Example: Time-coded imaging



(a) Pseudo phantom

(b) MBIR-boxcar

(c) MBIR-Raskar

(d) CodEx-boxcar

(e) CodEx-Raskar

Ching, Daniel, et al. "Time-coded aperture for x-ray imaging." *Optics Letters* 44.11 (2019): 2803-2806.

Majee, Soumendu, et al. "CodEx: a modular framework for joint temporal de-blurring and tomographic reconstruction." *IEEE Transactions on Computational Imaging* 8 (2022): 666-678.

# Conclusions and looking ahead

- There is still untapped potential of **designing illumination** to overcome current system bottlenecks
- Ensuring **compatibility of illumination designs** with existing instruments and hardware constraints
- **Expanding coherence-based methods** beyond current imaging modes (e.g., CDI, ptychography) toward broader algorithmic and system-level integration
- Designing structured illumination and coherence to **compress information before measurement**, reducing data volume and acquisition needs

