

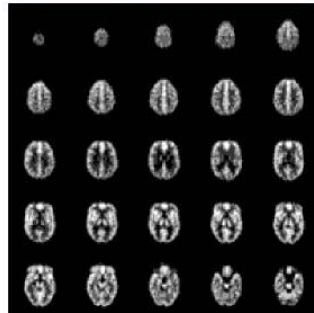
Tomography background

- Ultramicrotomy of biological specimens
- Medical imaging
- Nobel Prize awarded for back-projection algorithms
- Radon transform developed in 1917

X-ray CT scanner



CT Scan Output



The Nobel Prize in Physiology or Medicine (1979)



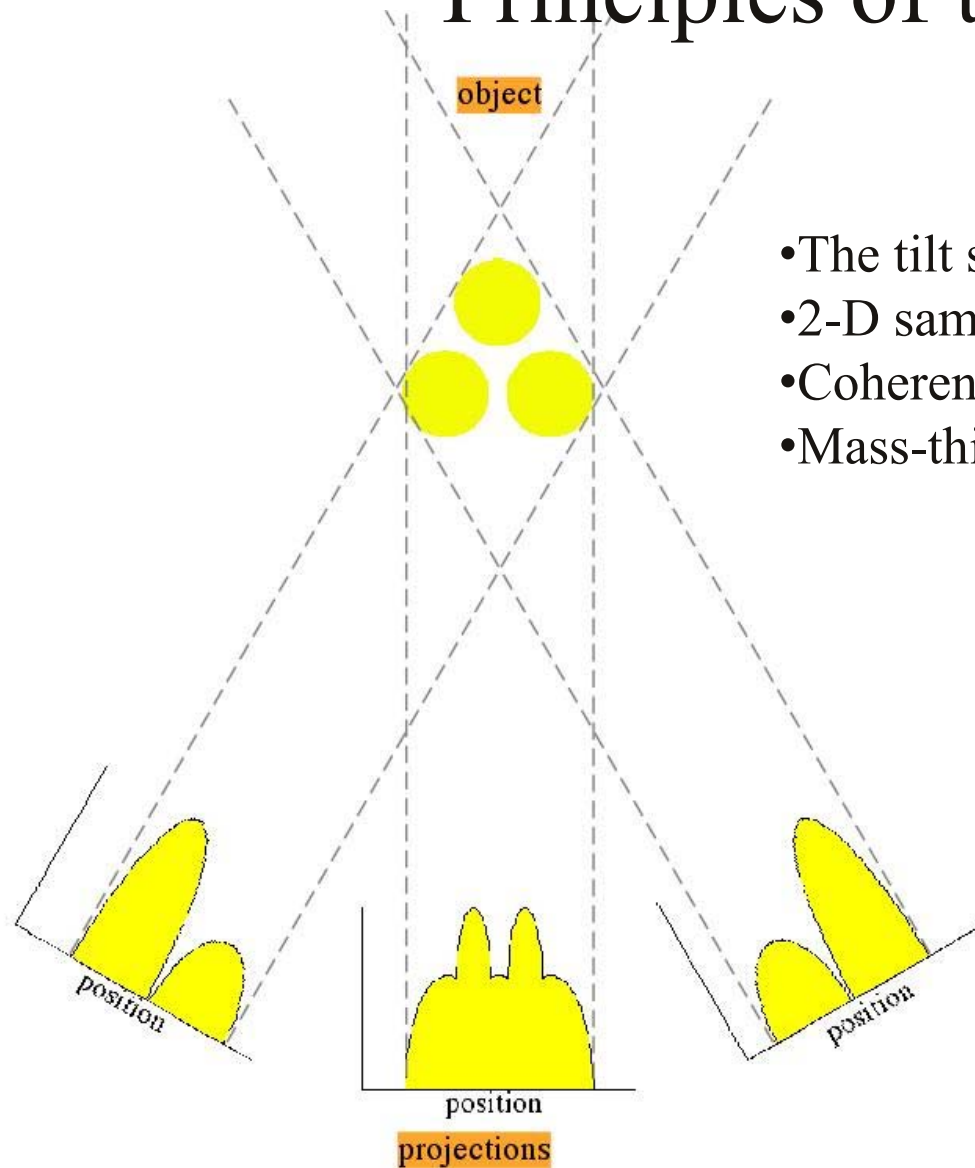
Allan M. Cormack



Godfrey N. Hounsfield

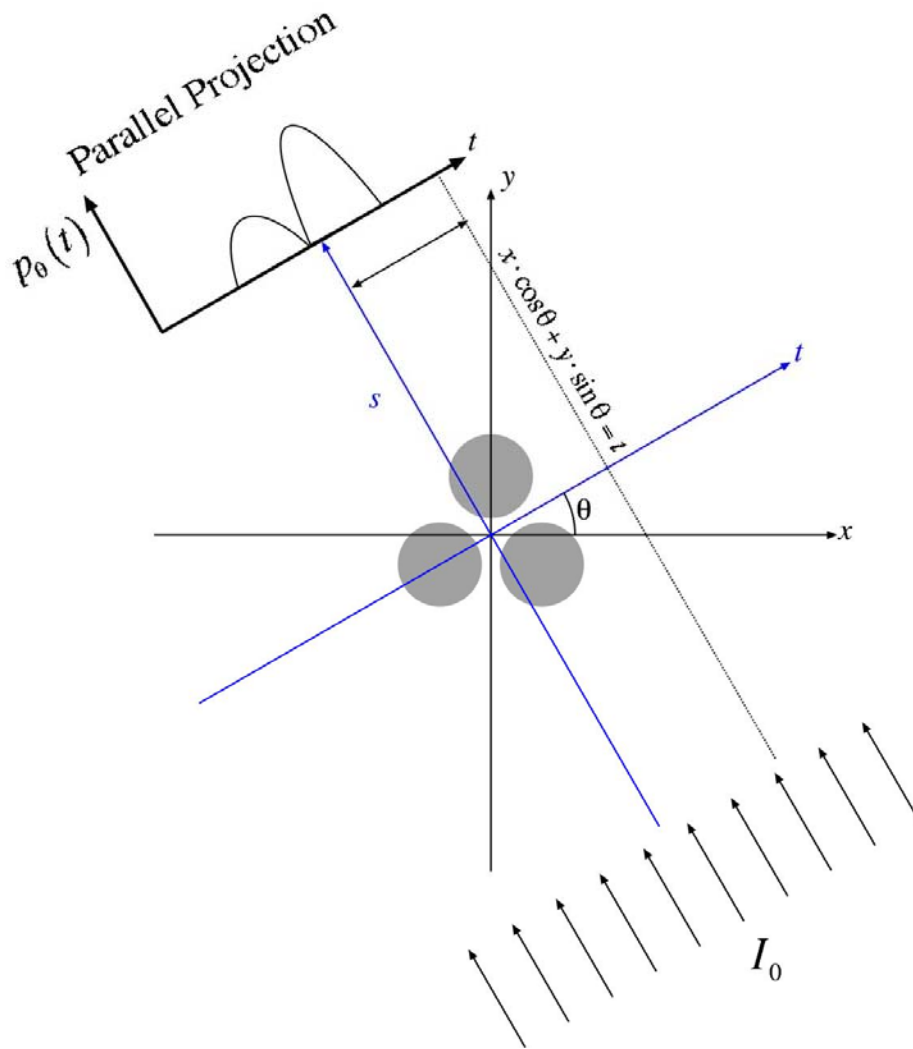
"for the development of computer assisted tomography"

Principles of tomography



- The tilt series comprise an image *stack*.
- 2-D sampling of the reconstruction is a *slice*.
- Coherent diffraction contrast is undesirable.
- Mass-thickness contrast is ideal.

Projection images



We are projecting some quantity:

$$p_{\theta}(t) = \int_s f(x, y) \cdot ds$$

In bright-field TEM, the projected quantity that can be related to the intensity is the absorption coef.:

$$f(x, y) = \mu(x, y)$$

The projection is then related to the intensity by:

$$p_{\theta}(t) = -\ln \left[\frac{I_{\theta}(t)}{I_0} \right] = \int_s \mu(x, y) \cdot ds$$

Fourier-slice theorem (I)

The 2-D Fourier Transform (FT) of each projection is equal to a 2-D slice of the FT of the complete 3-D object.

$$F(k_x, k_y) = \mathfrak{F}\{f(x, y)\} \quad \text{(2-D example)}$$

$$F(k_x, 0) = \int \int_{x \ y} f(x, y) e^{2\pi i[k_x x + (0)y]} \cdot dx \cdot dy \quad \text{(1-D slice)}$$

$$= \int_x \left[\int_y f(x, y) \cdot dy \right] e^{2\pi i k_x x} \cdot dx$$

$$F(k_x, 0) = \int_x P(x) e^{2\pi i k_x x} \cdot dx = \mathfrak{F}[p_{\theta=0}(t=x)]$$

We can Fourier transform each projection image:

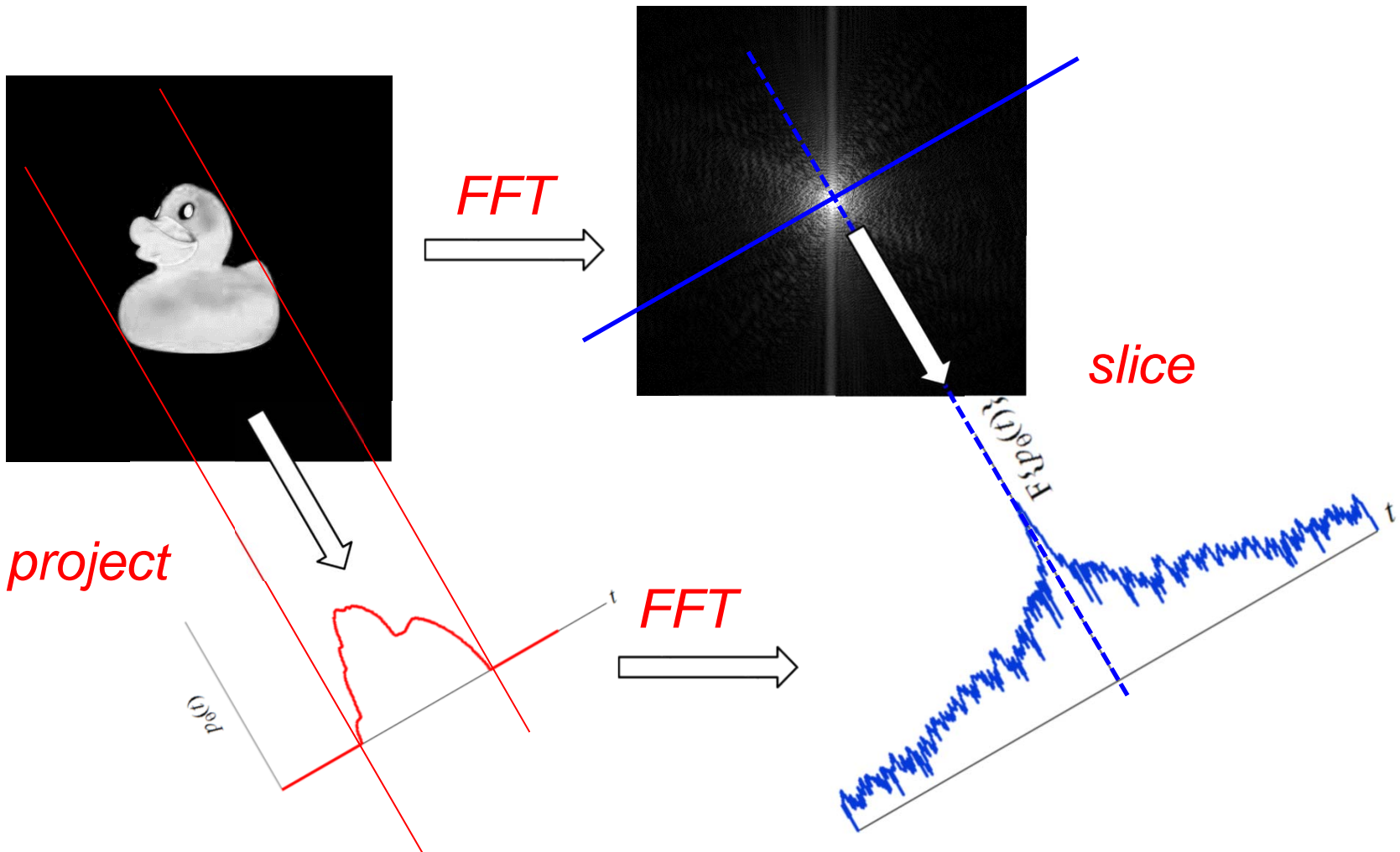
$$P_{\theta}(k) = \mathfrak{F}\{p_{\theta}(t)\}$$

Then build up the FT of the projected quantity:

$$\{p_{\theta}(t)\} \rightarrow \{P_{\theta}(k)\} \rightarrow F(k_x, k_y) \rightarrow f(x, y)$$

Fourier-slice theorem (II)

The Fourier Transform (FT) of a 1-D projection of a 2-D object is equal to a 1-D slice of the FT through the center of the complete 2-D object.

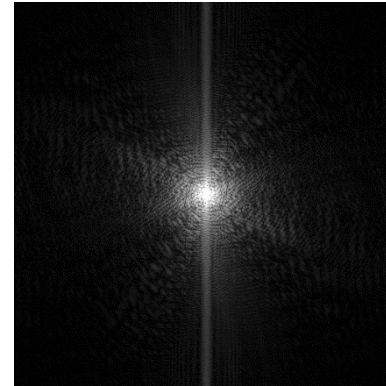


Tomogram artifacts

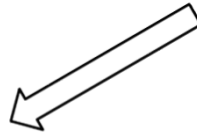
original



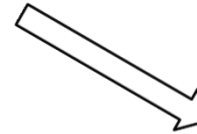
fft



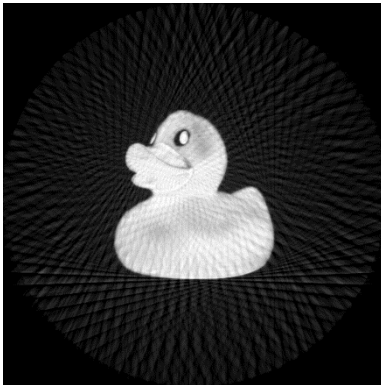
sparsely sliced



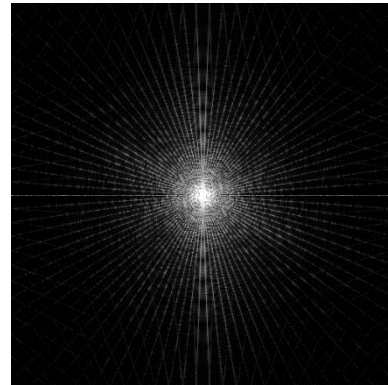
missing wedge



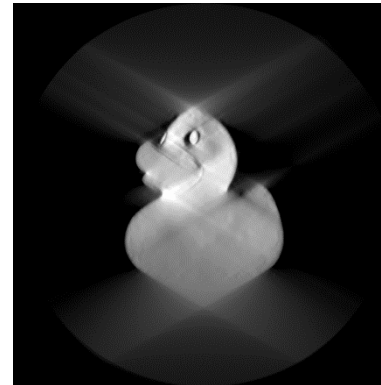
tomogram



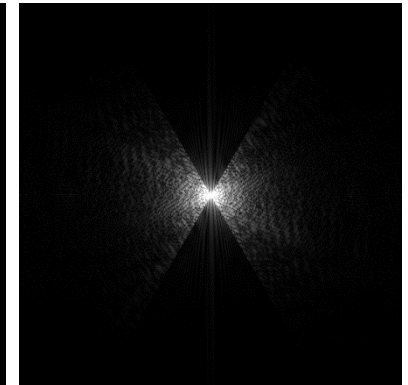
fft



tomogram



fft



Acquisition and reconstruction

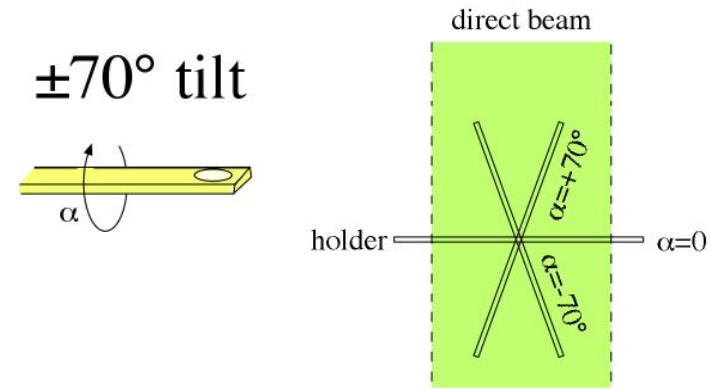
Data Acquisition

Prepare Sample

Drop solution on TEM grid
Add gold fiducials (optional)

Acquire

Calibrate TEM auto-focus, auto tracking
Scan tilt: $\pm 70^\circ$, $0.5\text{-}2^\circ$ increments



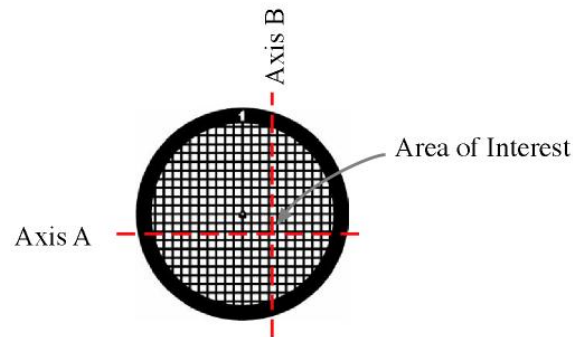
Reconstruction

Reconstruct

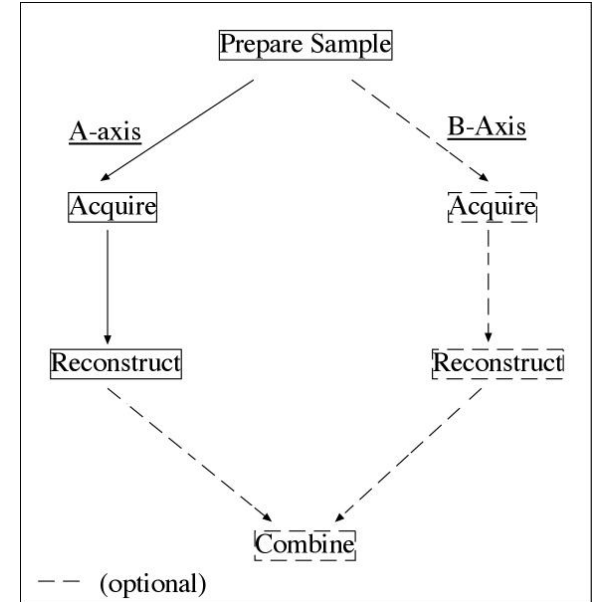
Coarse align by cross-correlation
Fiducial tracking refinement (optional)
Compute reconstruction

Combine

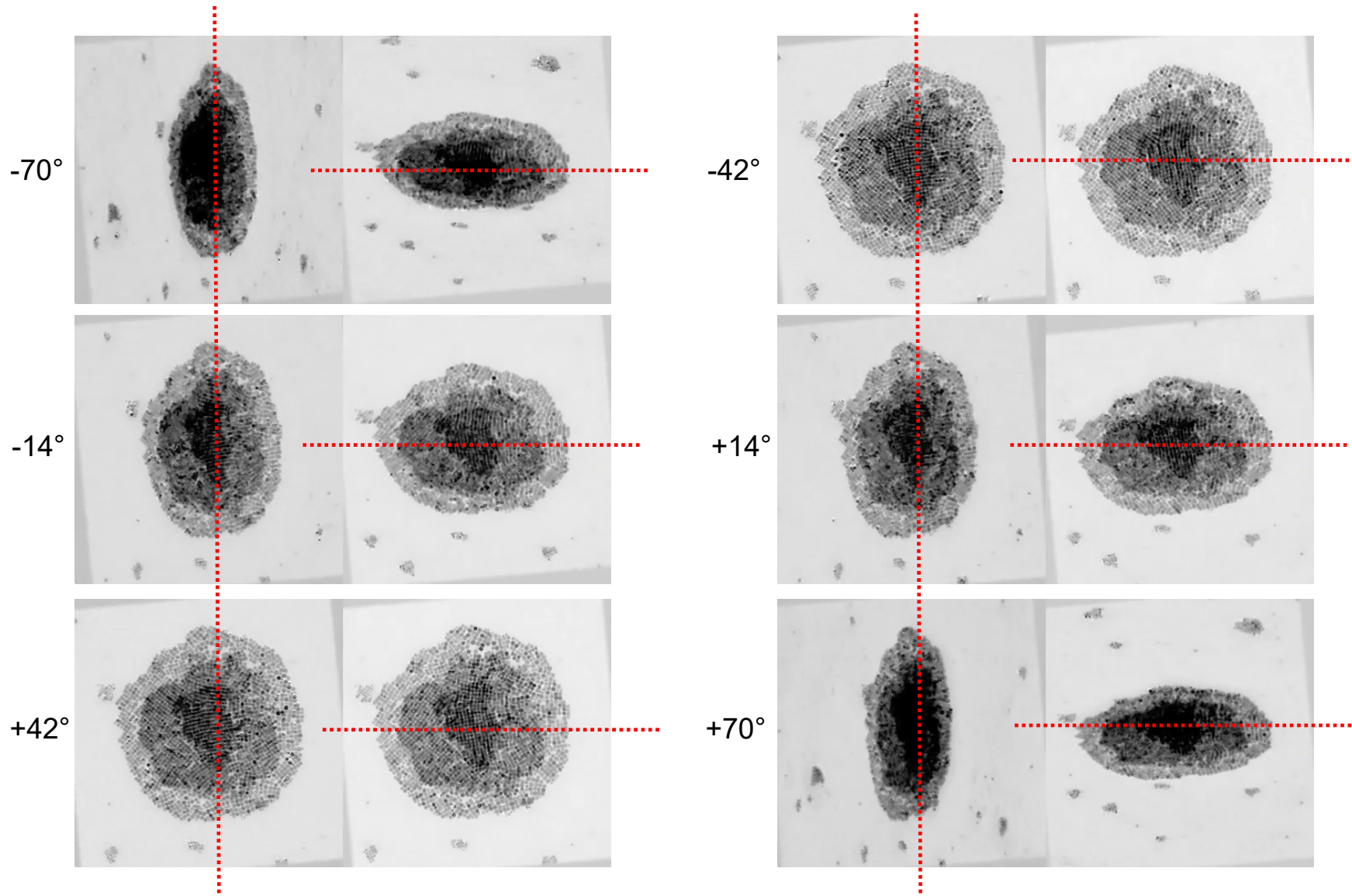
Match A&B-axis reconstructions
Generate dual-axis tomogram



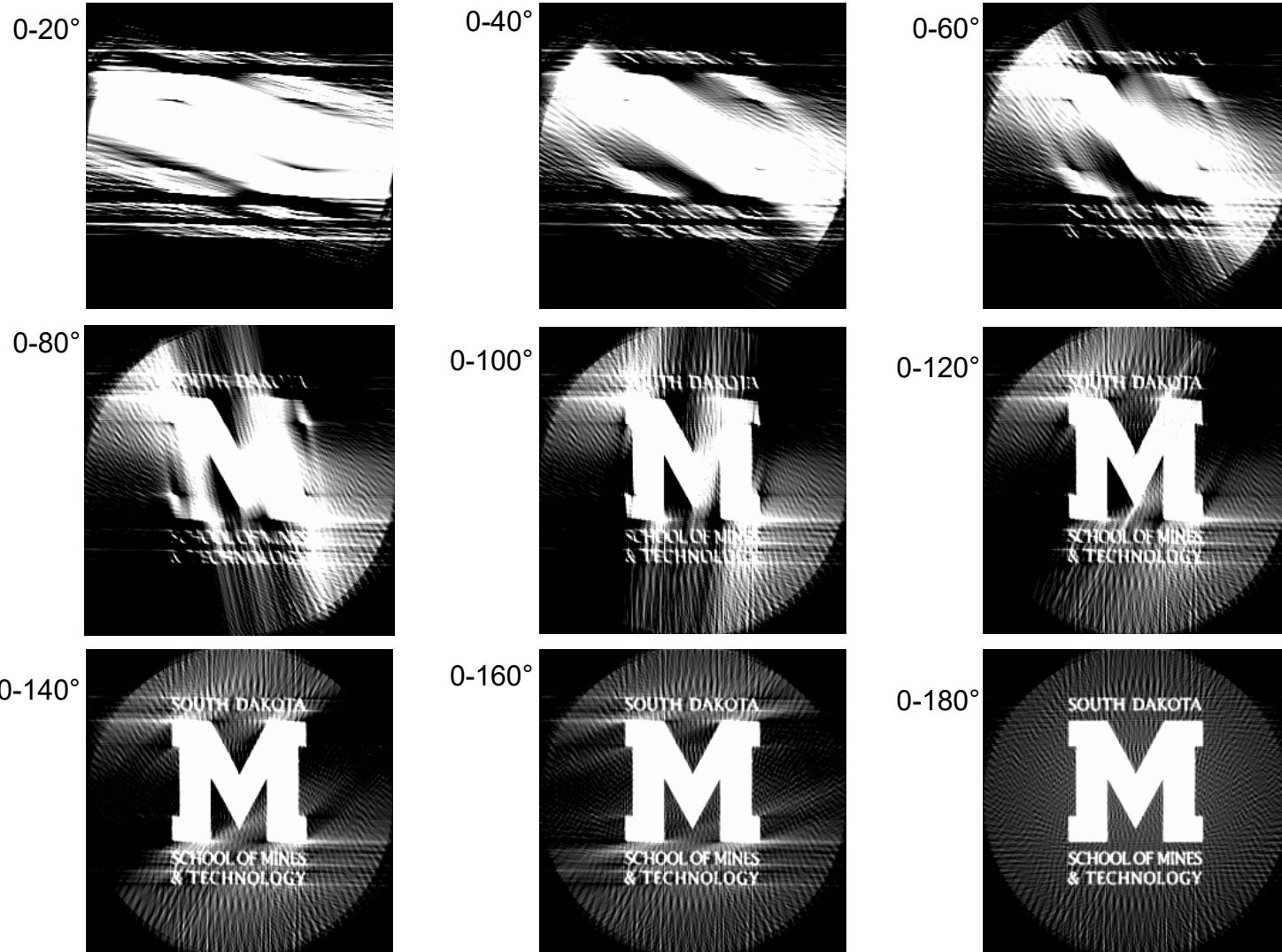
The grid is removed and rotated 90° to acquire a second tilt series.



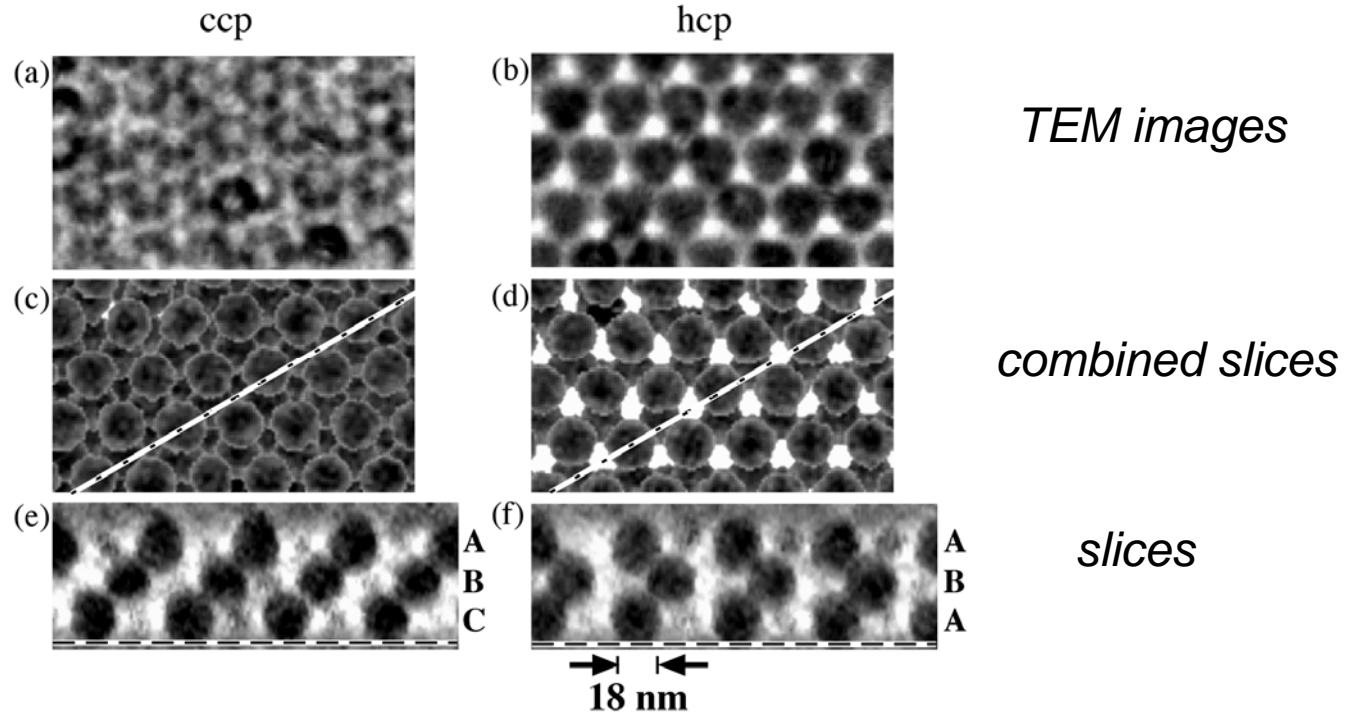
Dual-Axis Tilt Series



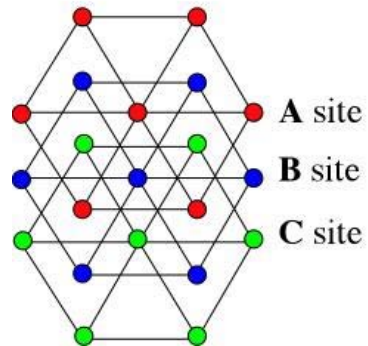
Back-projection example



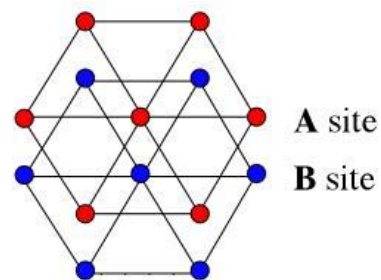
Stacking of In Spheres



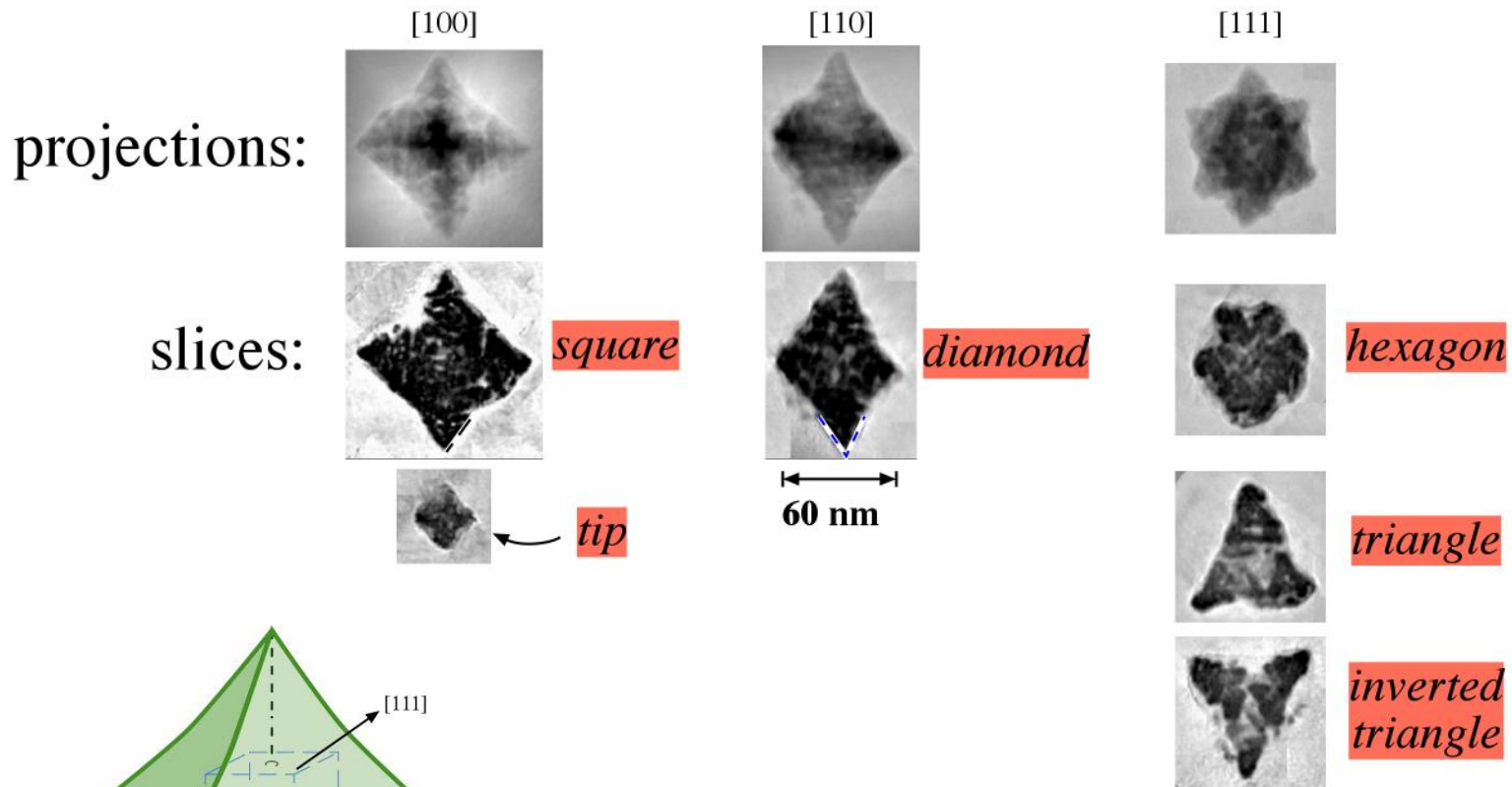
FCC stacking



HCP stacking



Analysis of PbSe octahedron



- Rocksalt (cubic) crystal structure
- Pointed tips parallel to $\langle 100 \rangle$

Stacking of PbSe cubes

