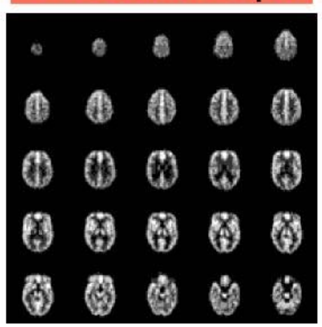
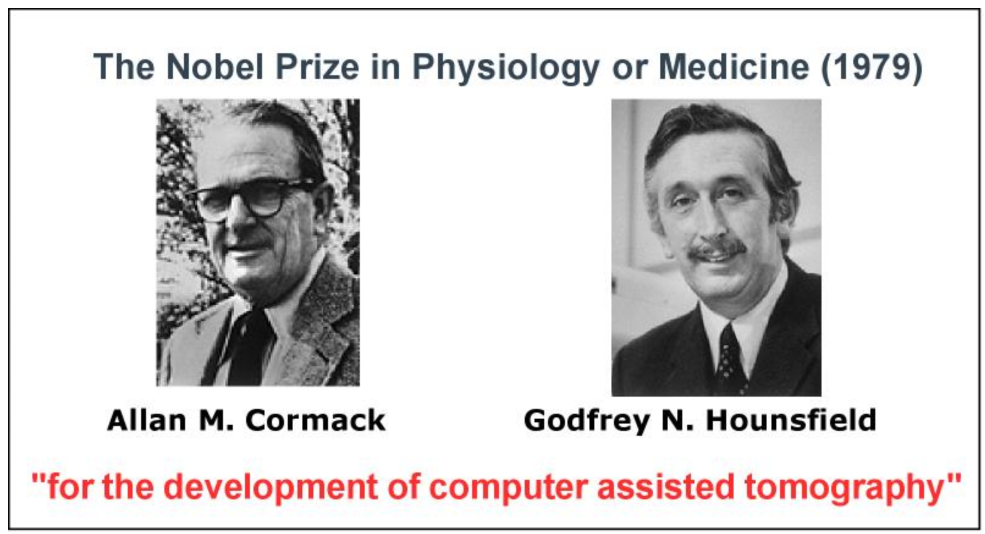
Tomography background

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

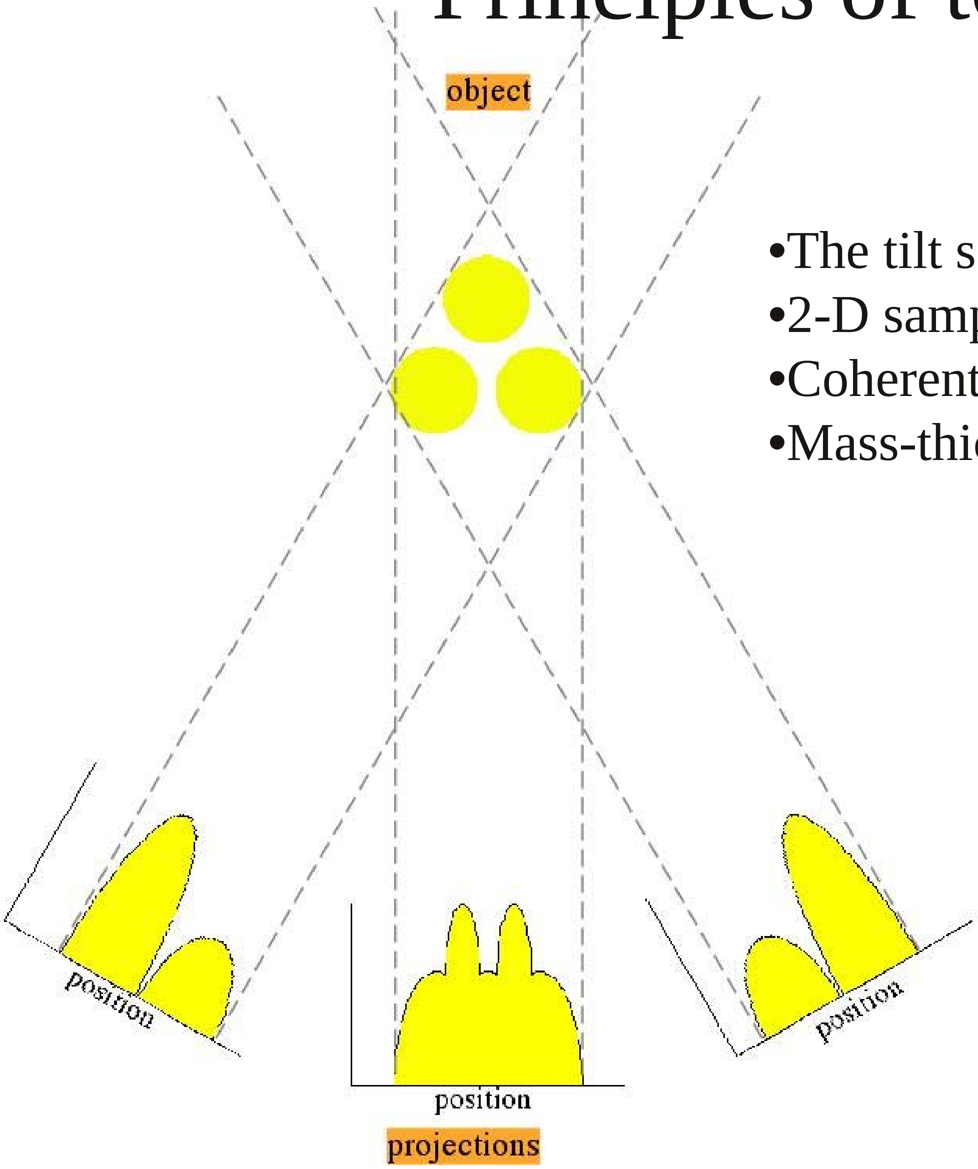
X-ray CT scanner

CT Scan Output



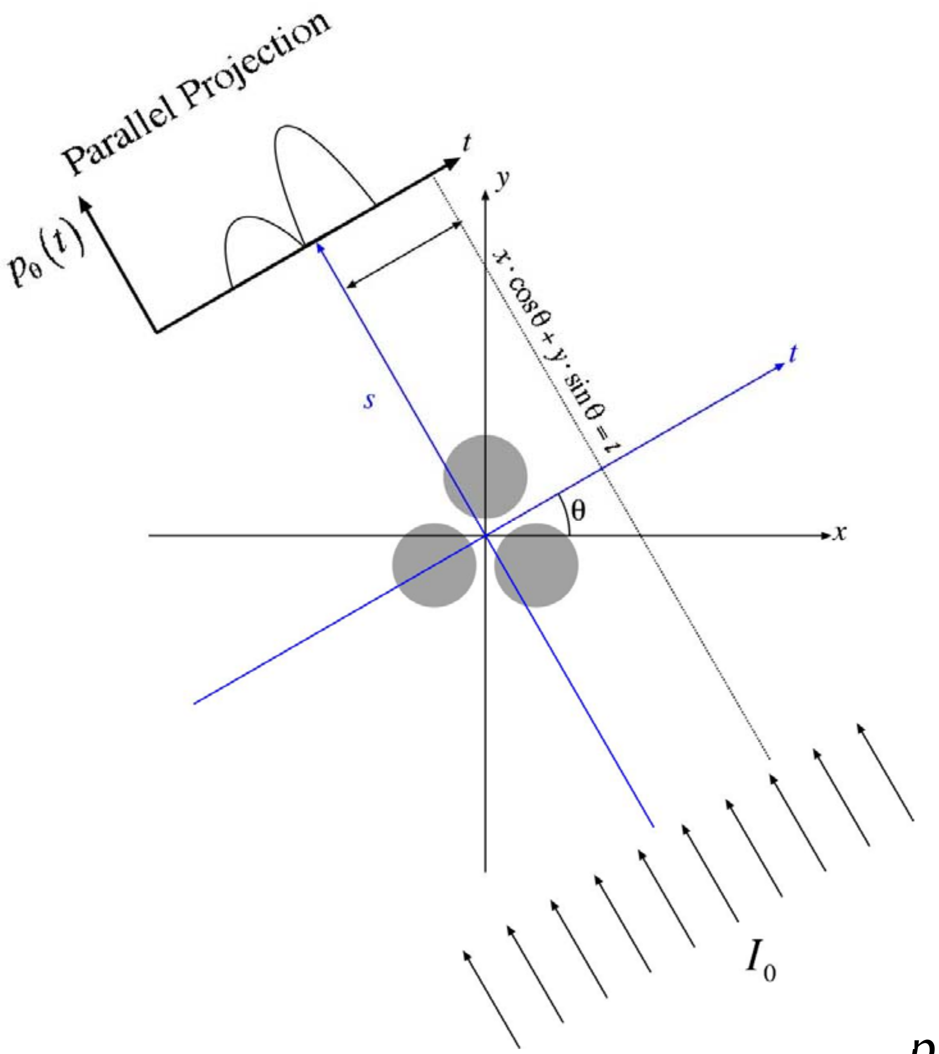


Principles of tomography



- 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.

$$F\left(k_x, k_y\right) = \Im\{ f(x,y)\}$$ (2-D example)

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

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

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

We can Fourier transform each projection image:

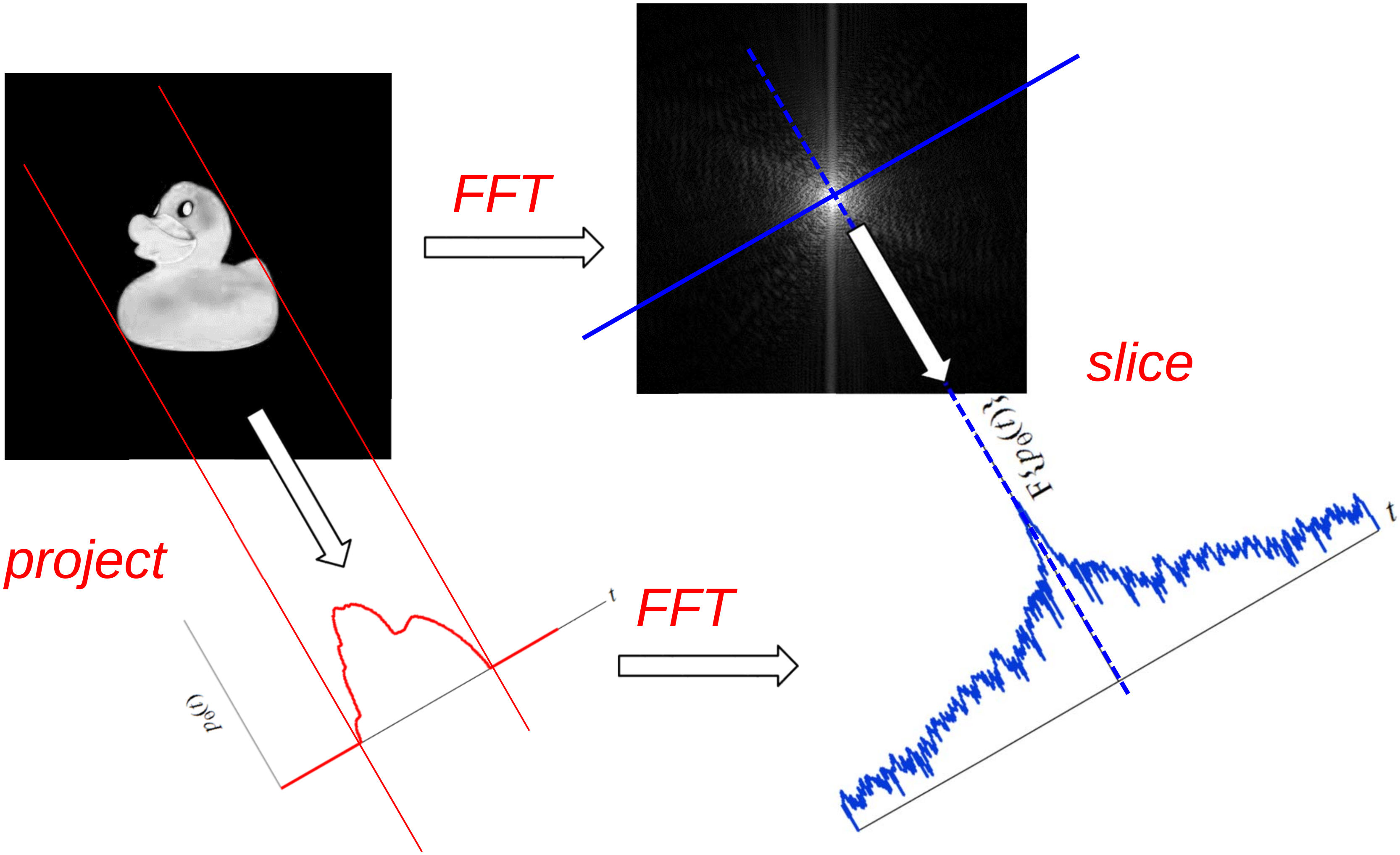
$$P_\theta(k) = \Im\{ p_\theta(t)\}$$

Then build up the FT of the projected quantity:

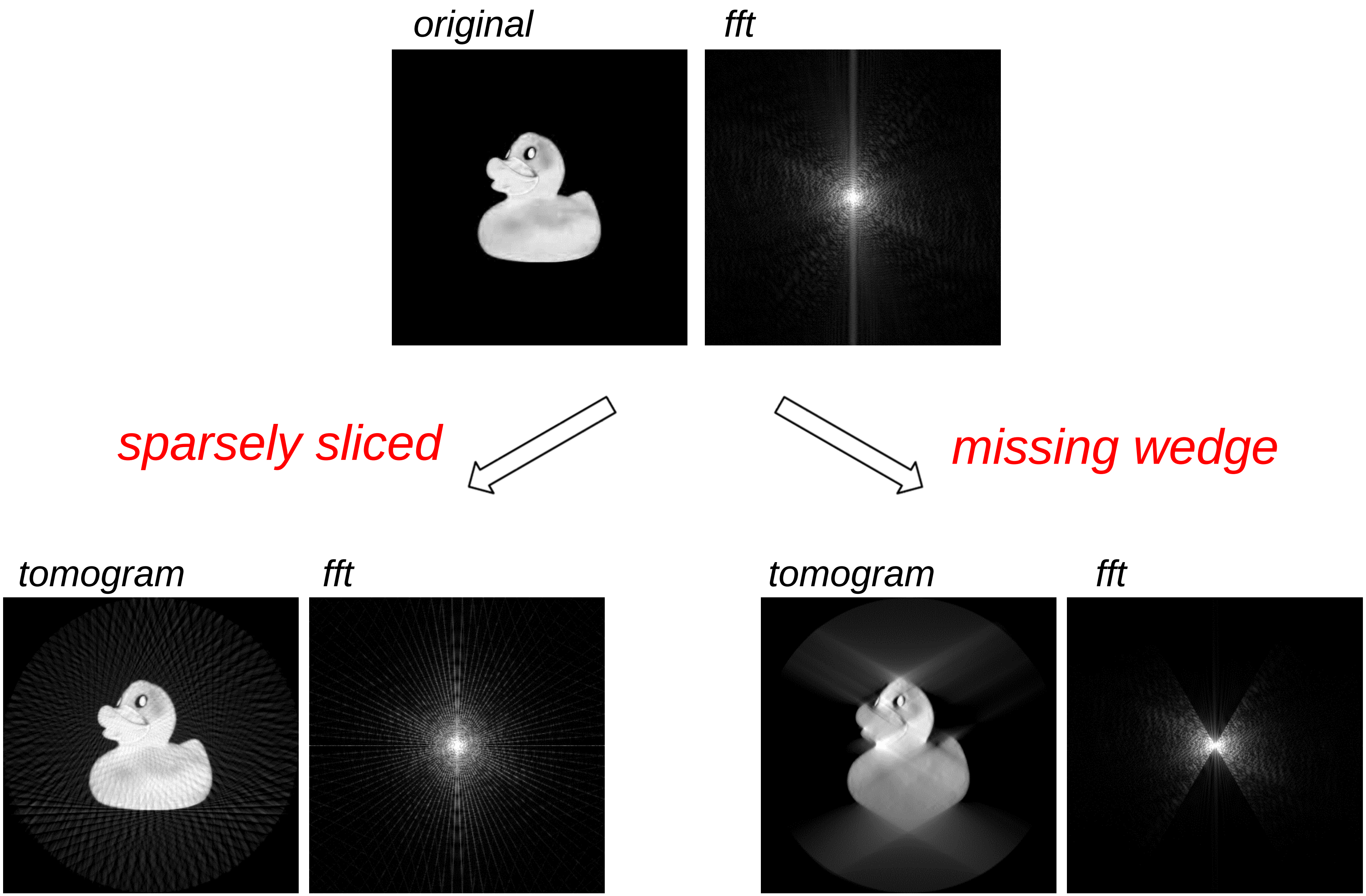
$$\{ p_\theta(t)\} \rightarrow \{P_\theta(k)\} \rightarrow F\left(k_x, k_y\right) \rightarrow f(x,y)$$

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

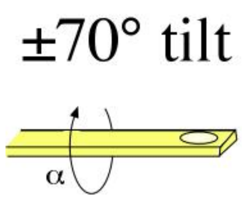


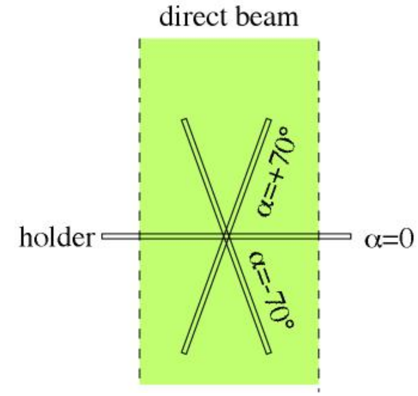
Acquisition and reconstruction

Data Acquisition

<u>Prepare Sample</u>
Drop solution on TEM grid
Add gold fiducials (optional)

<u>Acquire</u>
Calibrate TEM auto-focus, auto tracking
Scan tilt: ±70°, 0.5-2° increments

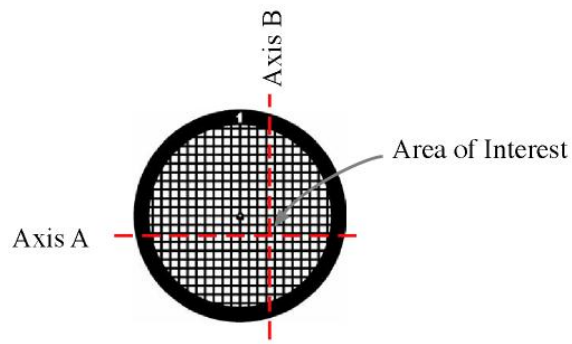




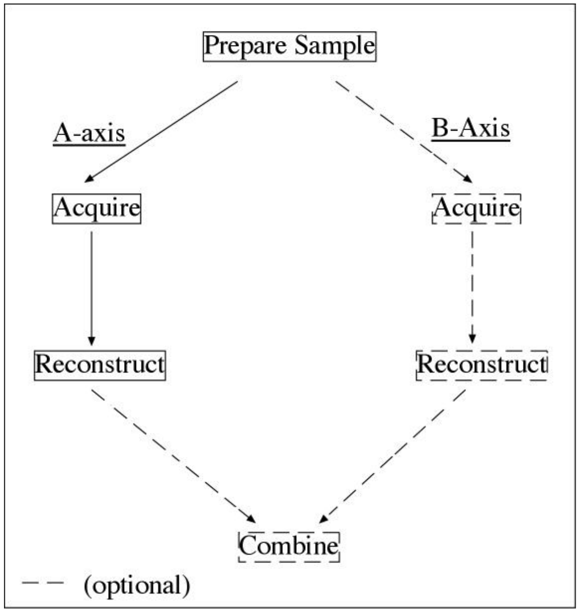
Reconstruction

<u>Reconstruct</u>
Coarse align by cross-correlation
Fiducial tracking refinement (optional)
Compute reconstruction

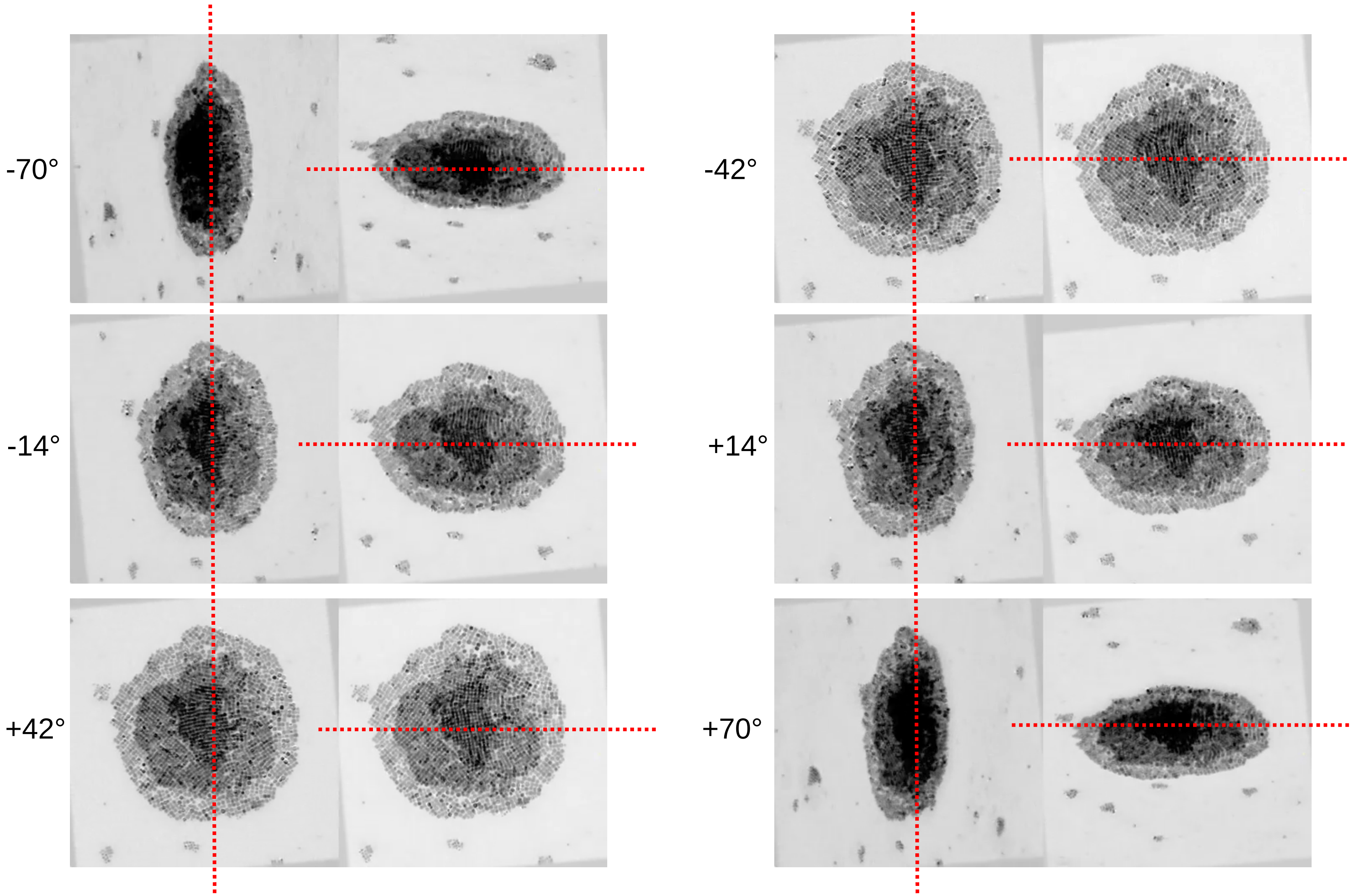
<u>Combine</u>
Match A&B-axis reconstructions
Generate dual-axis tomogram



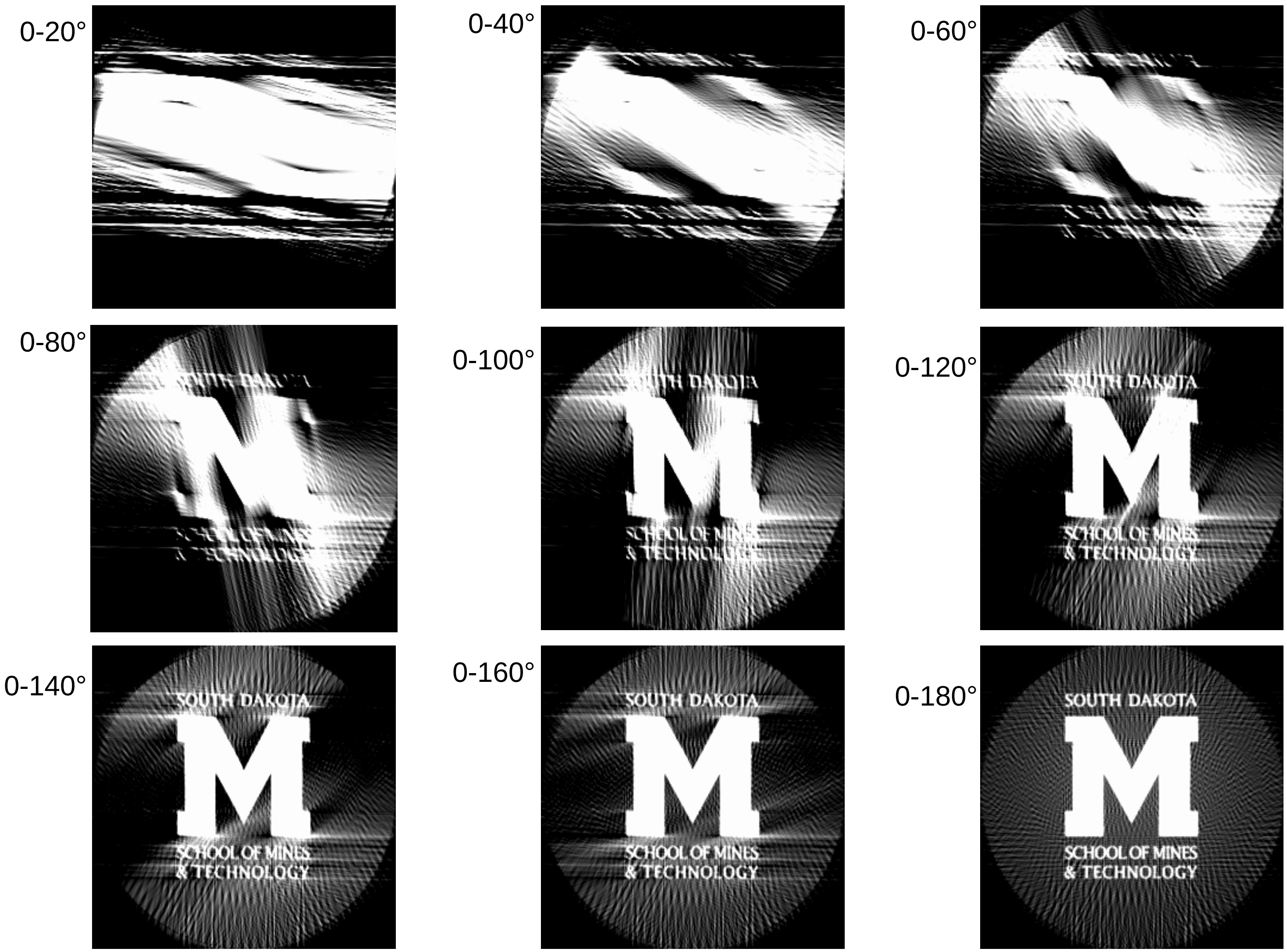
The grid is removed and rotated 90° to acquire a second tilt series.



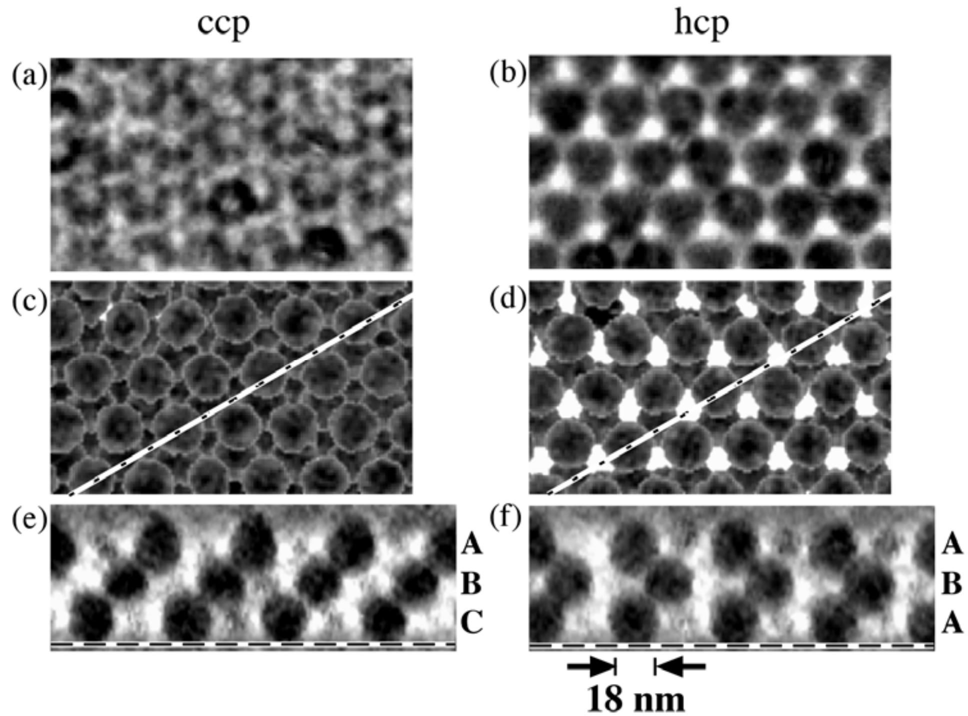
Dual-Axis Tilt Series



Back-projection example



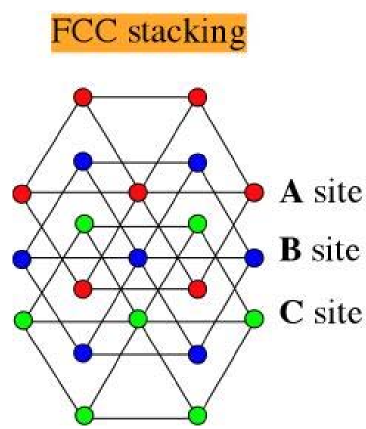
Stacking of In Spheres

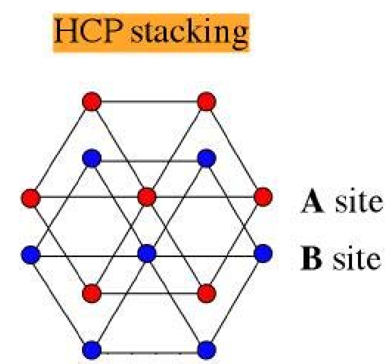


TEM images

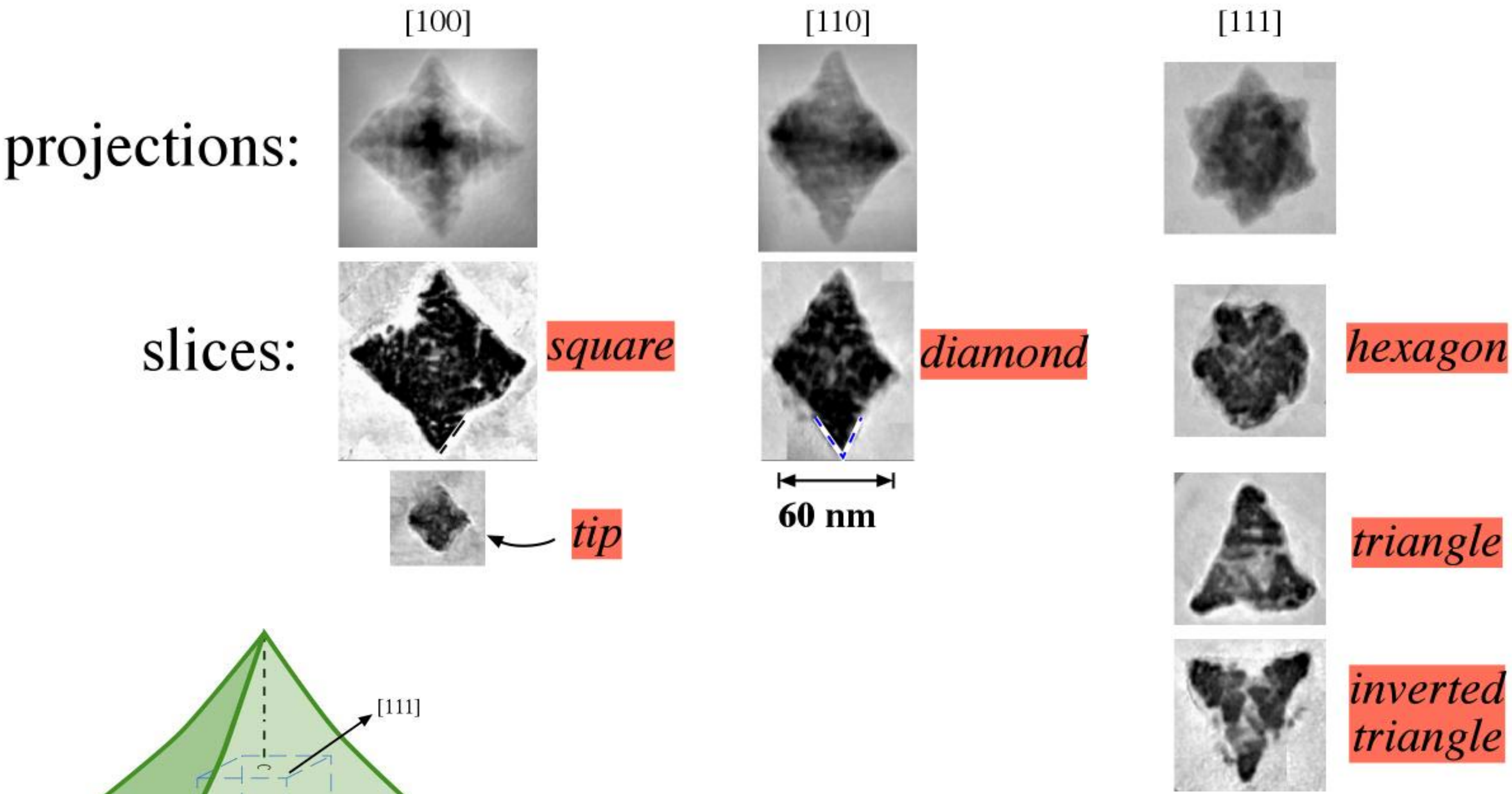
combined slices

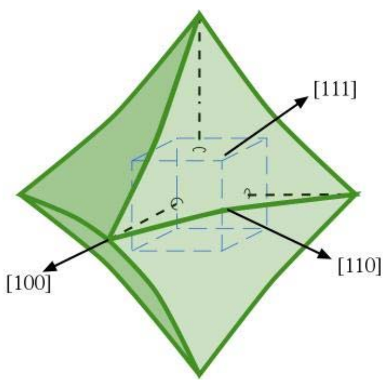
slices





Analysis of PbSe octahedron





- Rocksalt (cubic) crystal structure
- Pointed tips parallel to <100>

Stacking of PbSe cubes