Holographic Tomography

2.710 Project Presentation - Spring 2009

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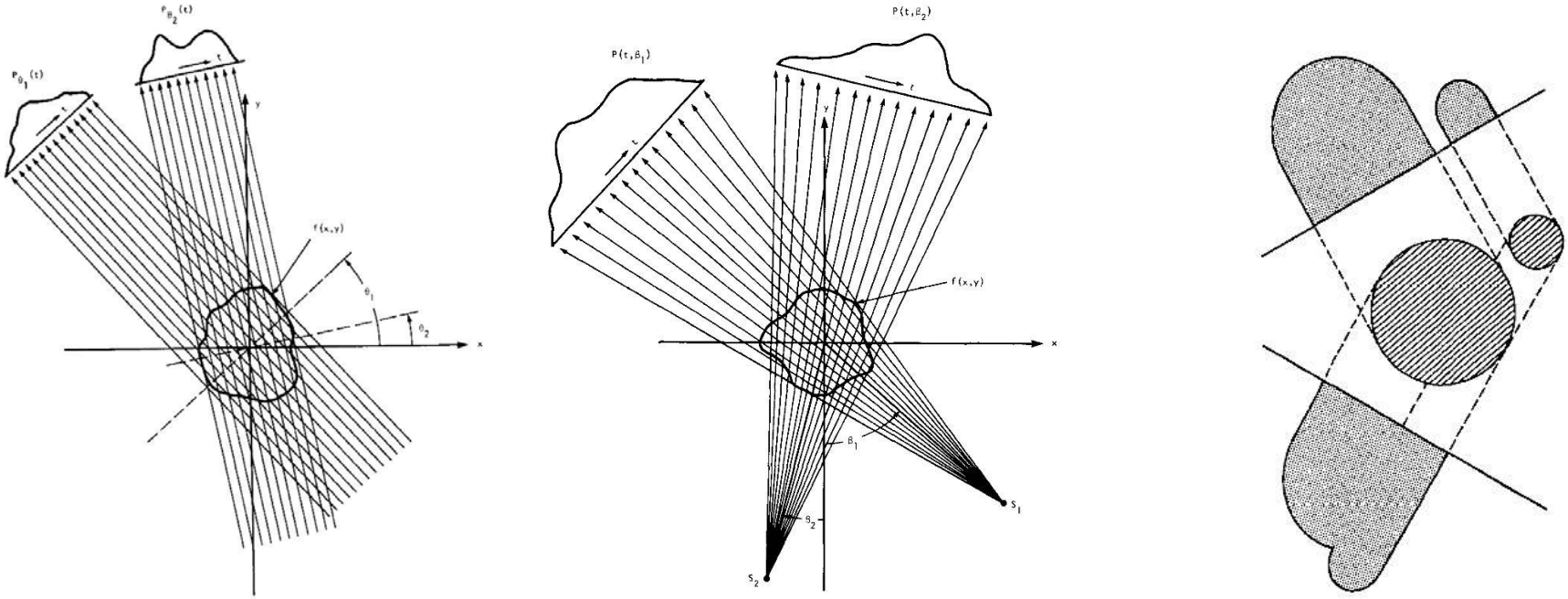
Outline

- Tomography overview
- Radon transforms
- Reconstruction
- Diffraction effects
- Experiments
- Applications

What is tomography?

Cross sectional imaging from transmission or reflection data

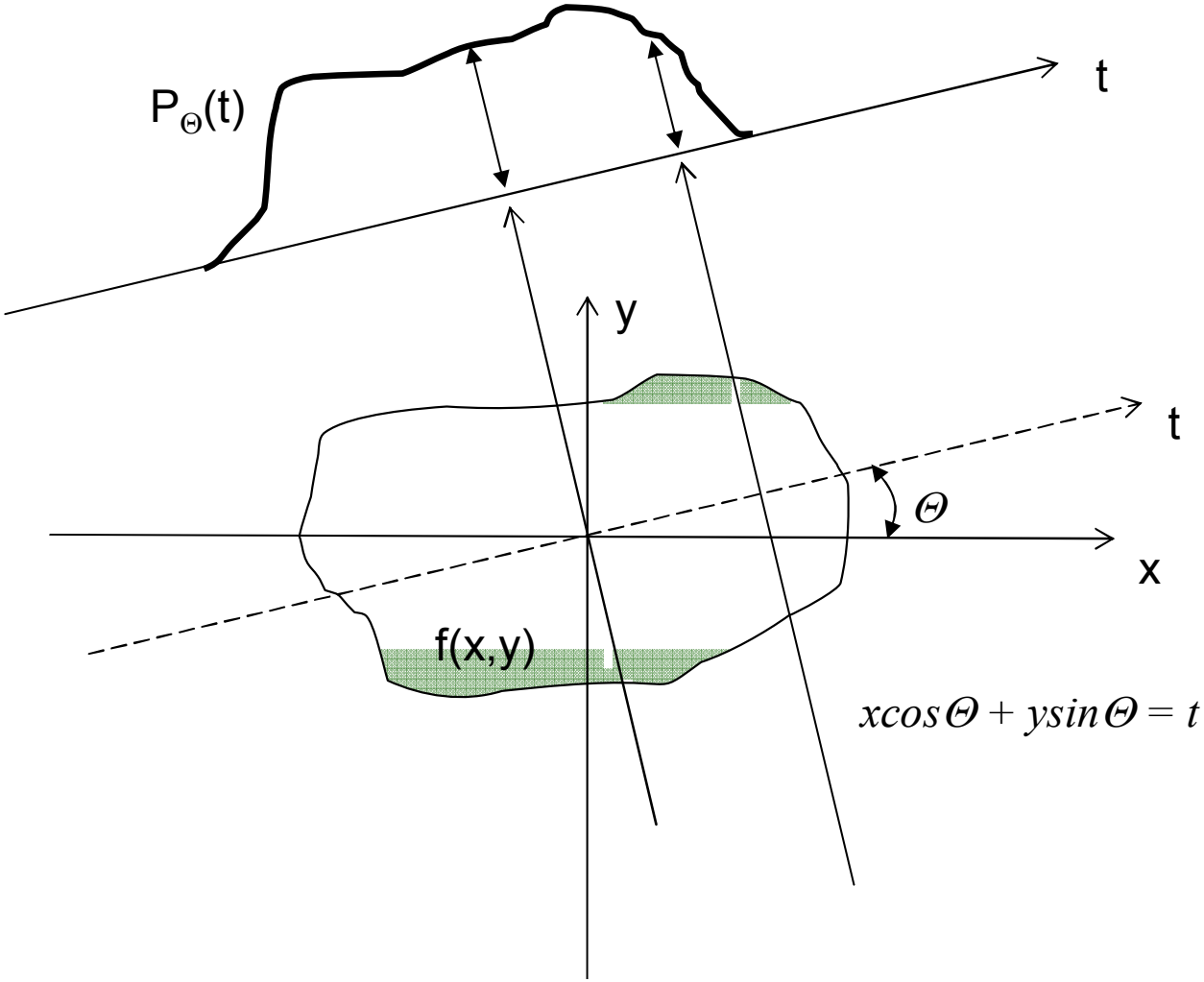
Reconstruction from projections



Courtesy of A. C. Kak and Malcolm Slaney. Used with permission.

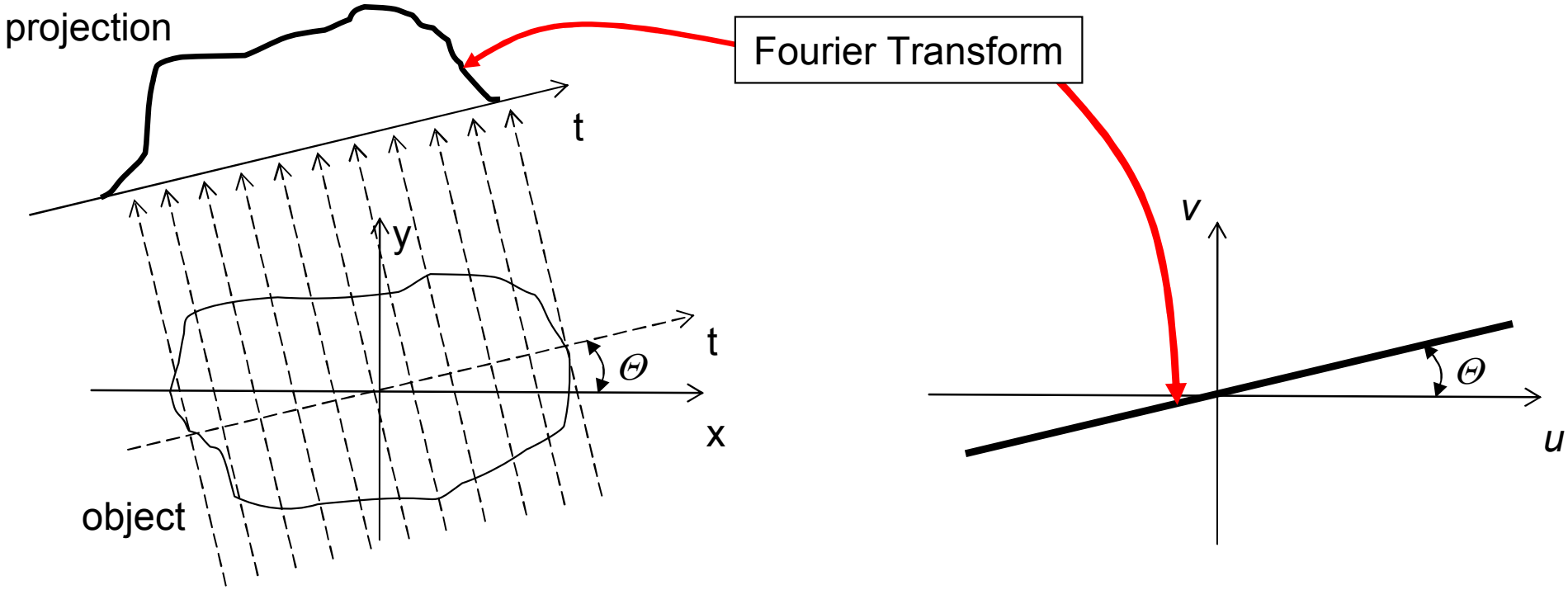
Kak and Slaney (2001)

Radon Transform



$$P_\theta(t) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(x, y)\delta(x \cos\theta + y \sin\theta - t)\, dx\, dy$$

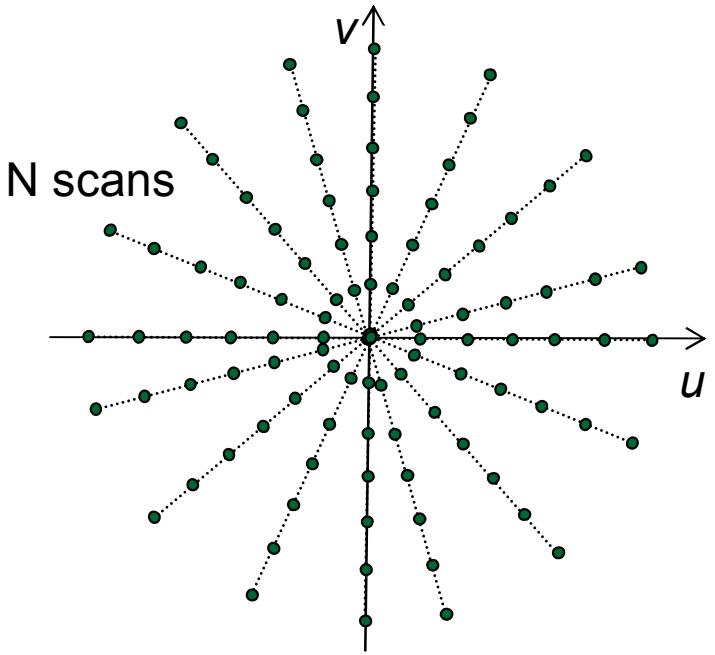
Fourier Slice Theorem



Spatial domain

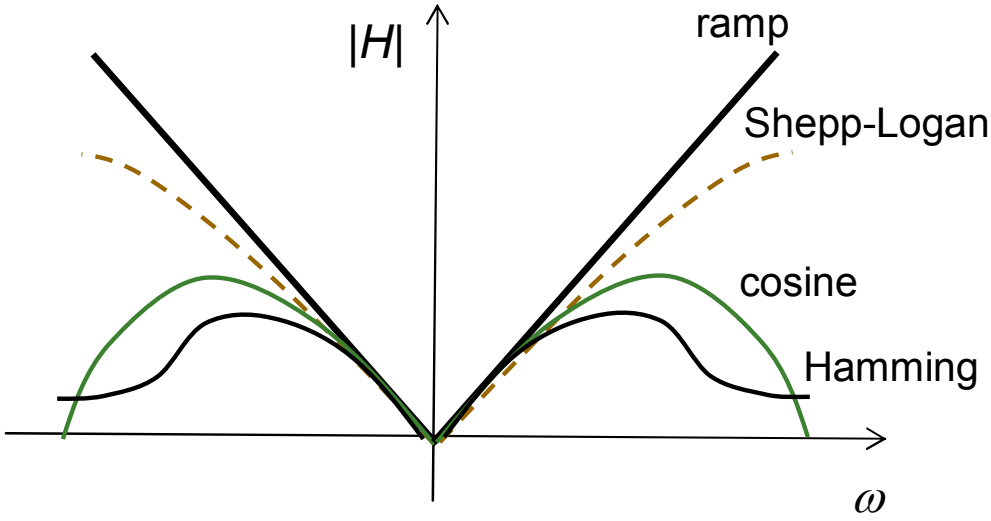
Frequency domain

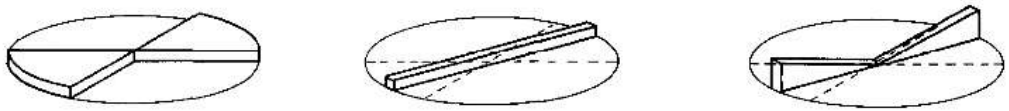
Backprojection Filters



Frequency domain

Filter types





Ideal *Collected* *Filtered*

Courtesy of A. C. Kak and Malcolm Slaney. Used with permission.

Kak and Slaney (2001)

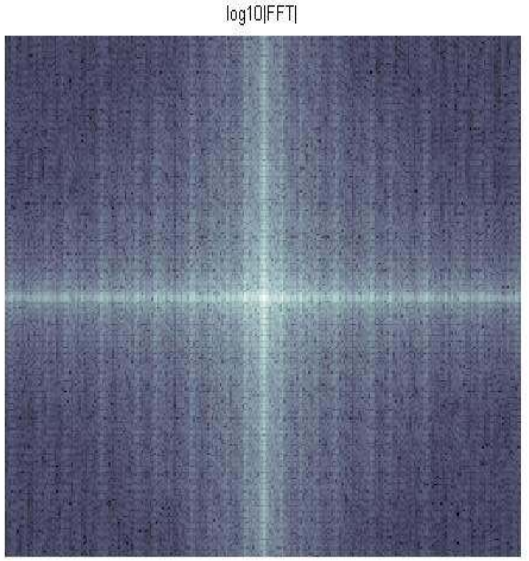
Example…

Image

Transmission Image

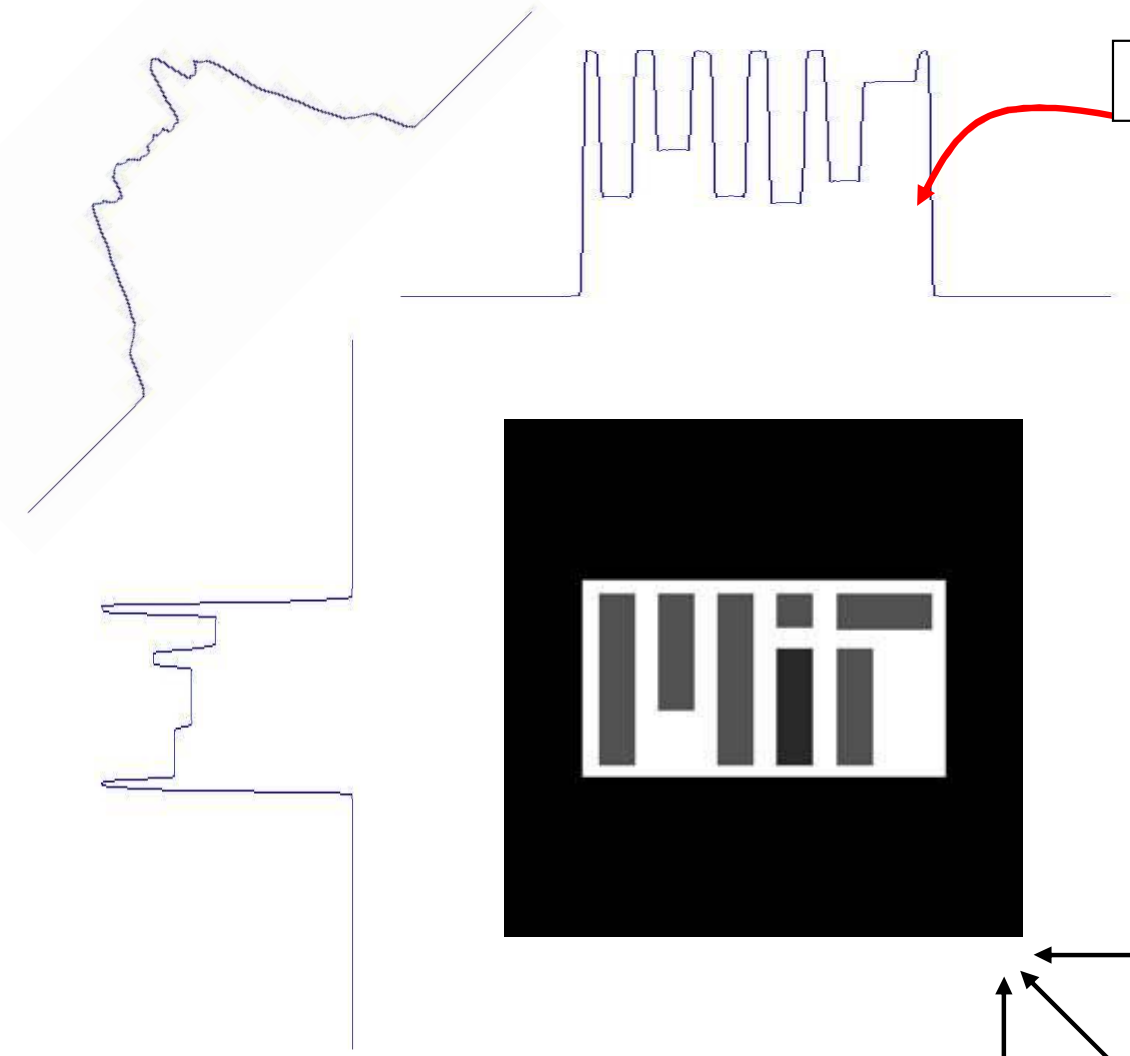
$\tau_{black} = 0$

$\tau_{white} = 1$

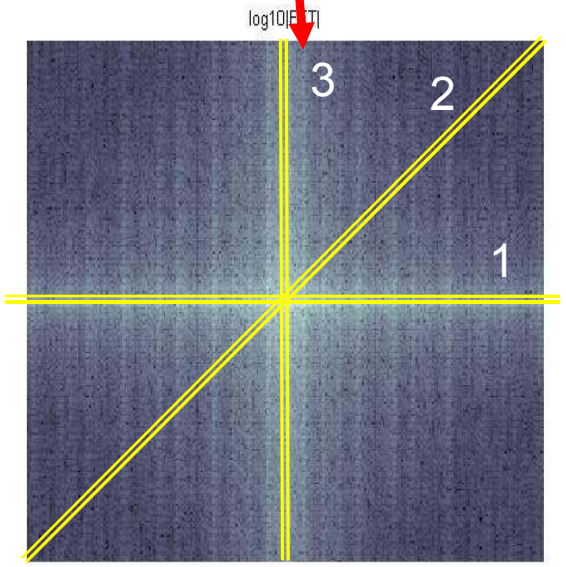


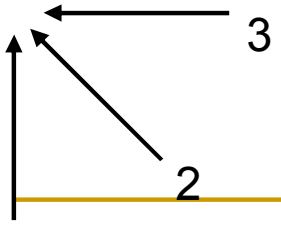
FFT

Projection Mapping



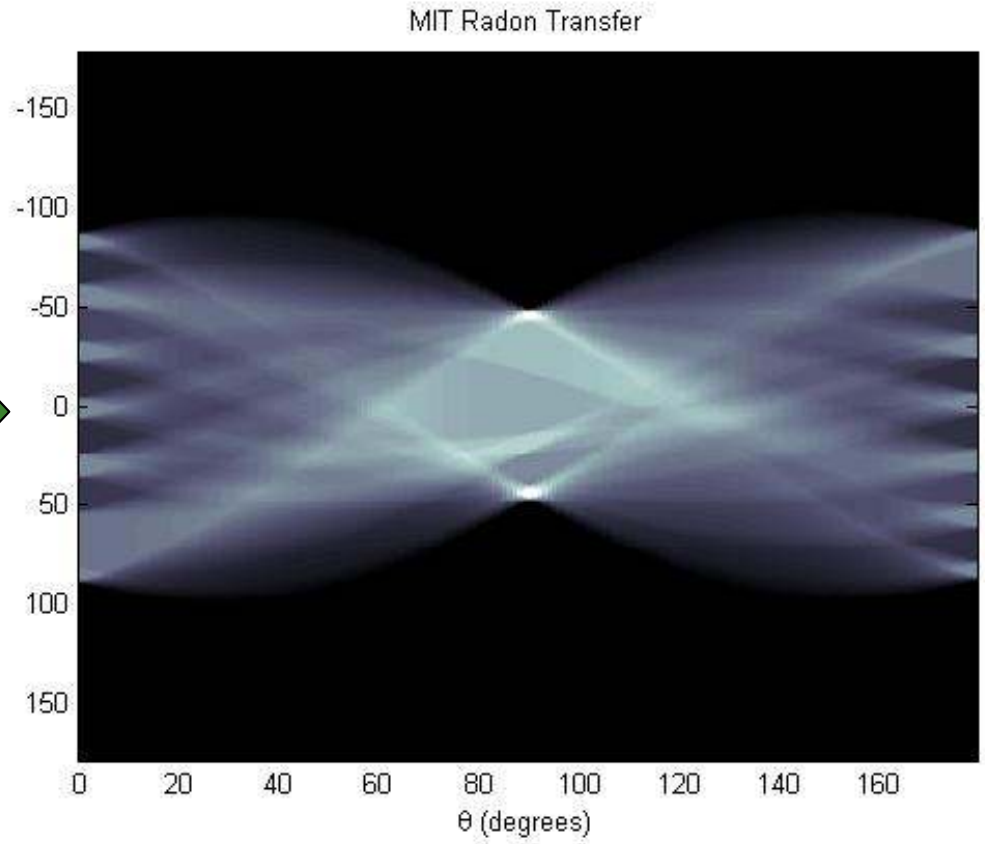
Fourier Transform



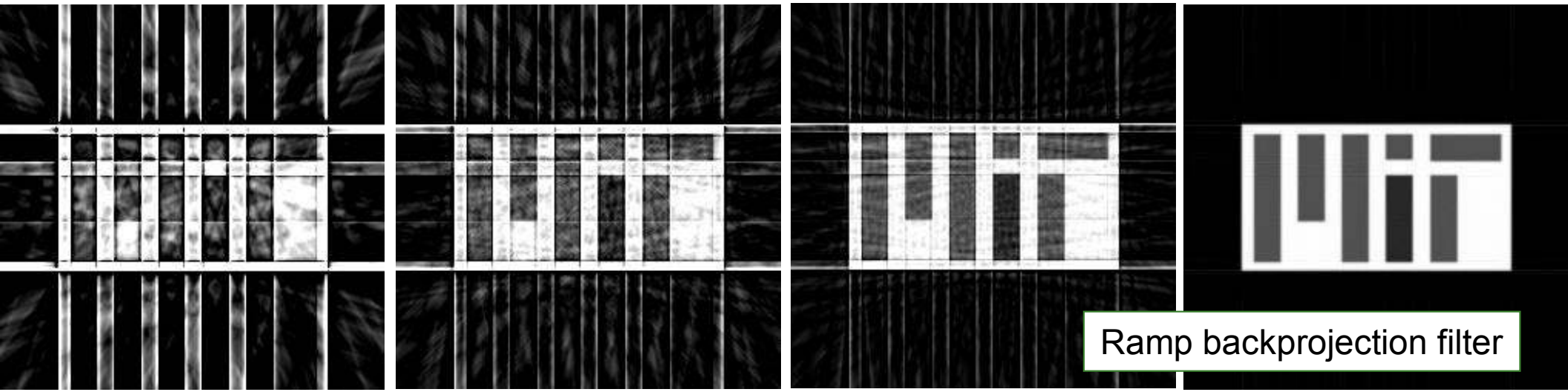


Frequency domain

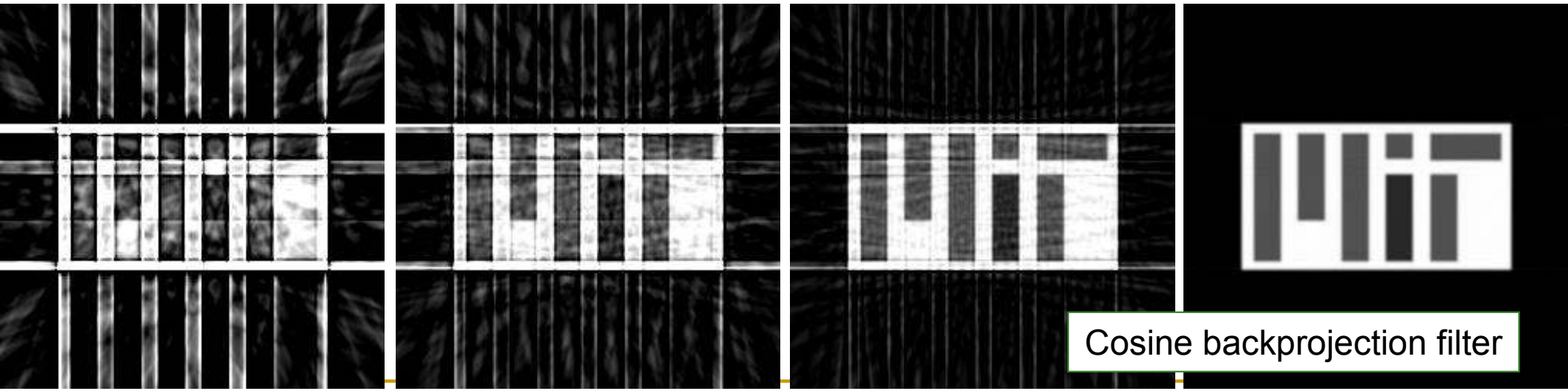
Projection Mapping



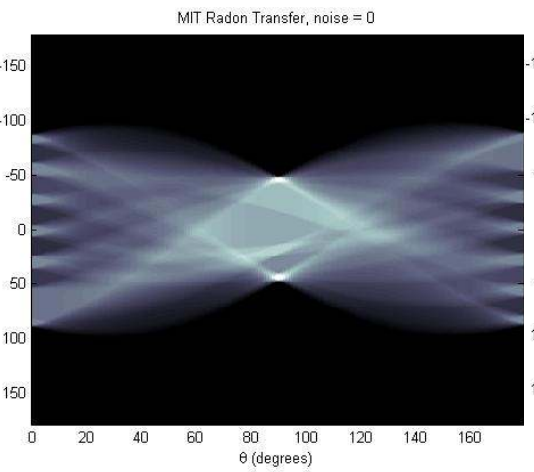
Number of Projections

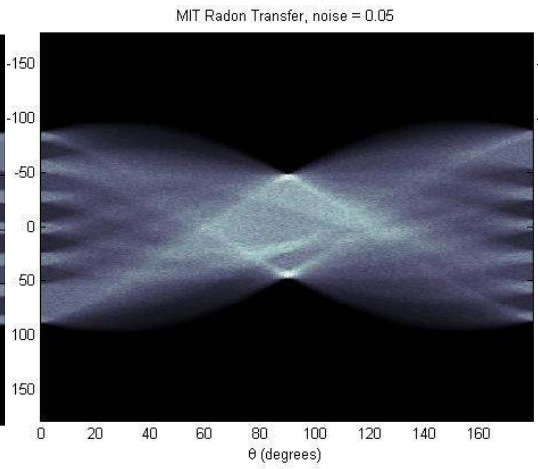


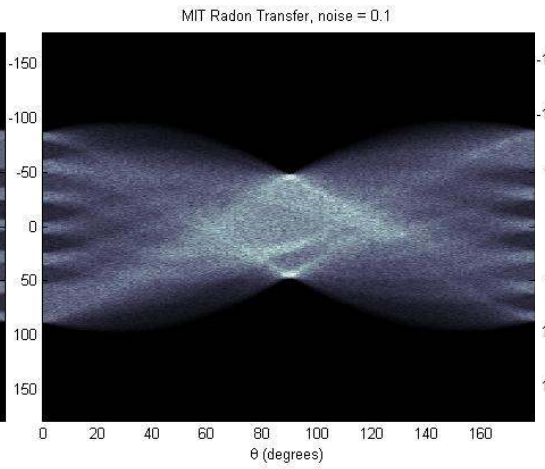
N = 10 *N = 20* *N = 36* *N = 180*

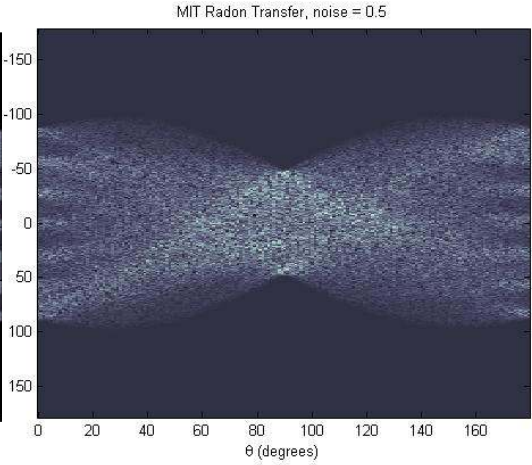


Noise in Projections

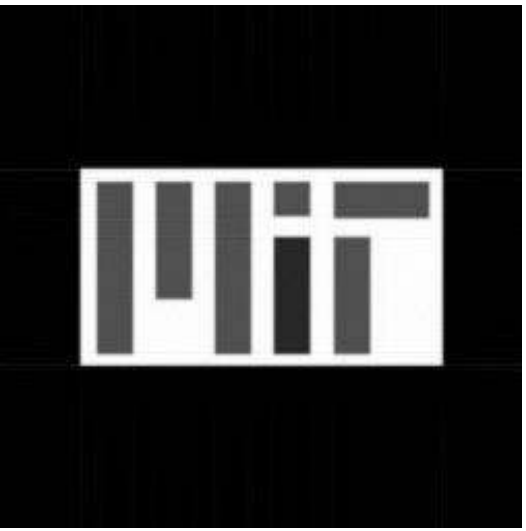


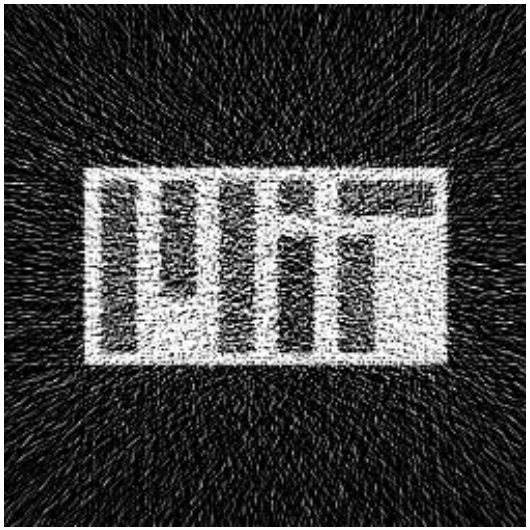


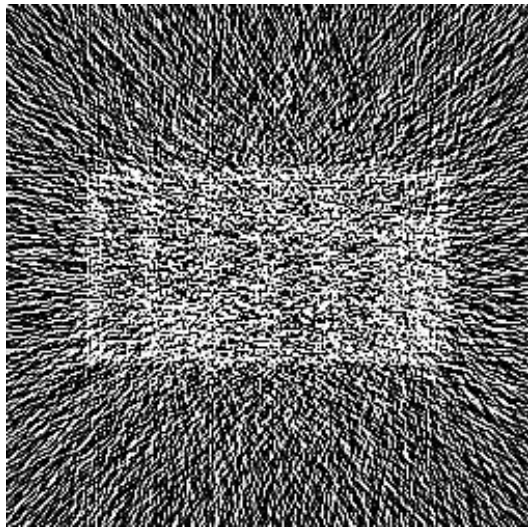




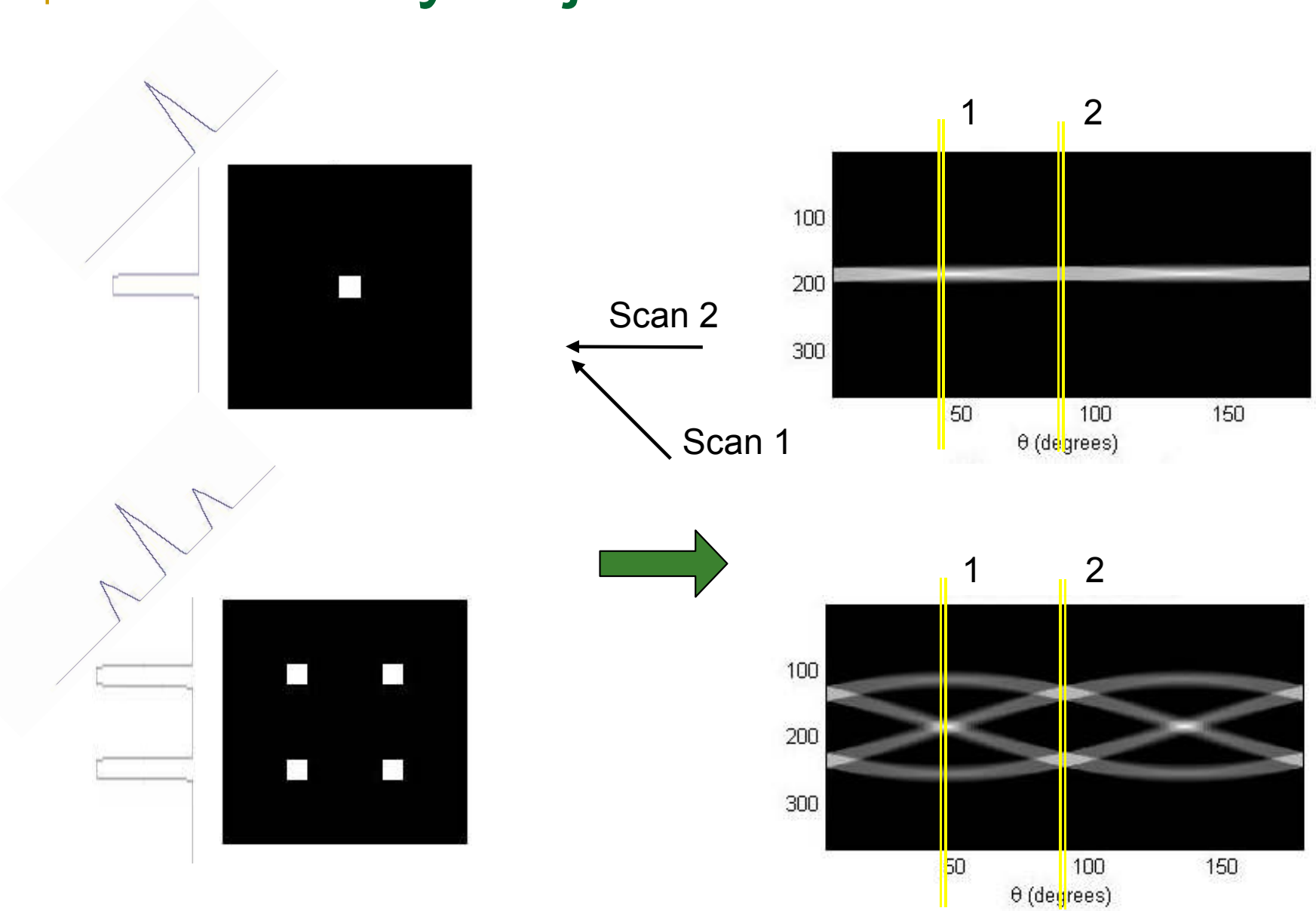
$\sigma = 0$ $\sigma = 0.05$ $\sigma = 0.10$ $\sigma = 0.50$







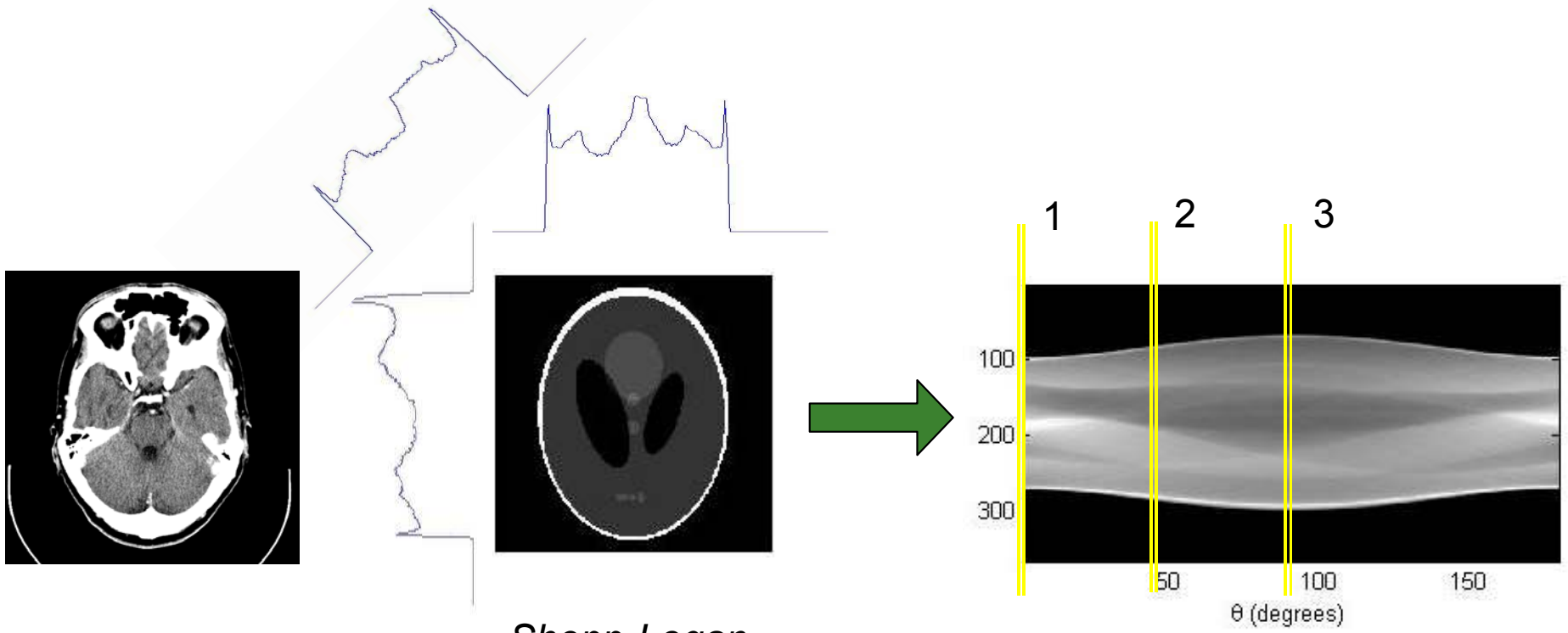
How many objects?



Object

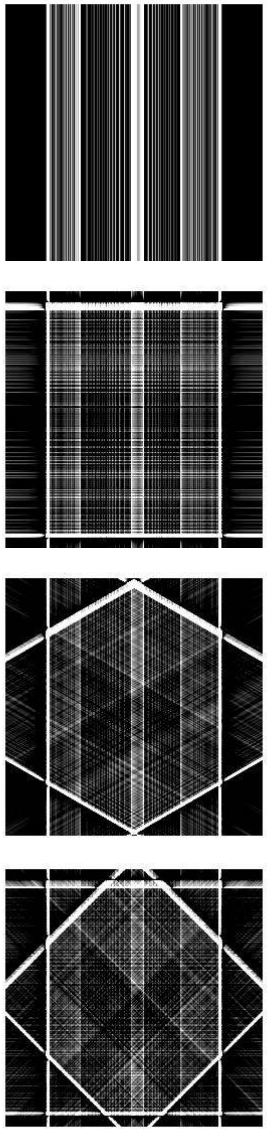
Radon Transform

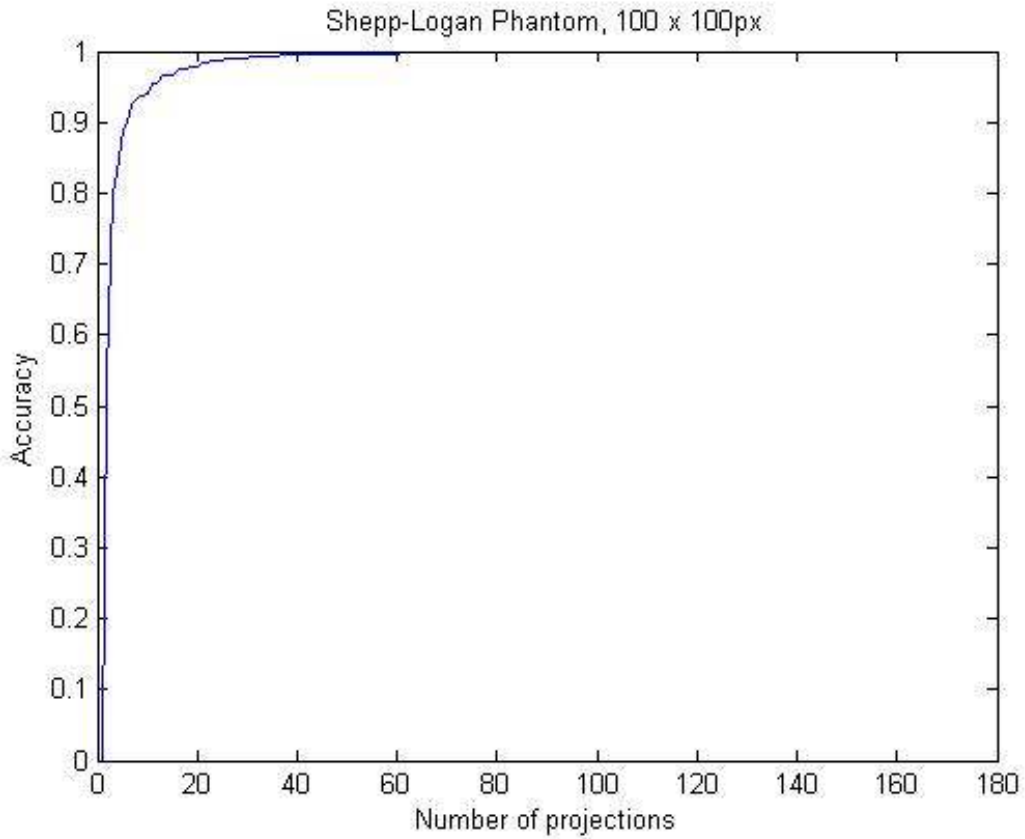
“Standard” Object



Shepp-Logan Head Phantom

Projections vs. Accuracy

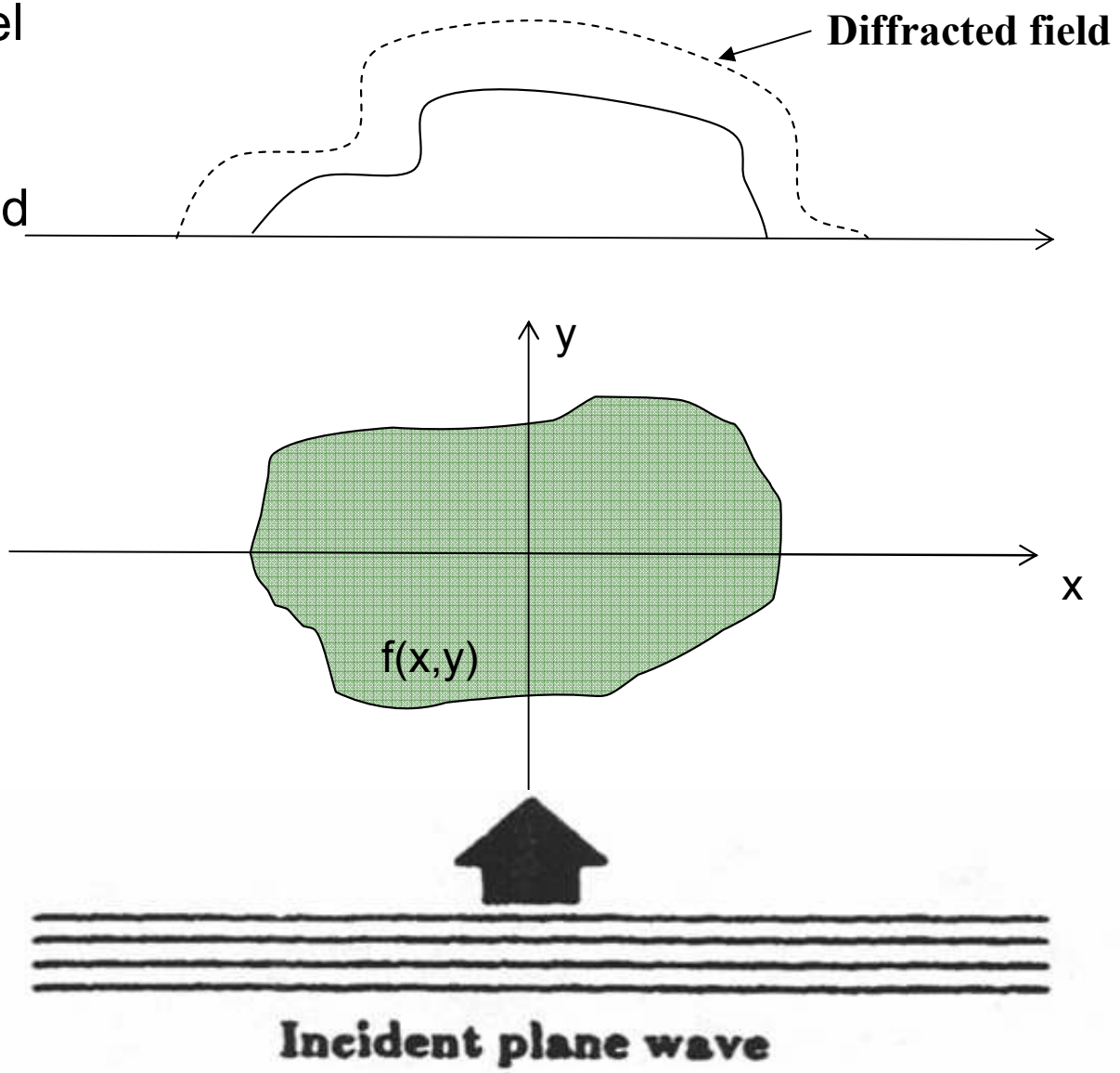




Shepp-Logan Phantom

Diffraction Tomography

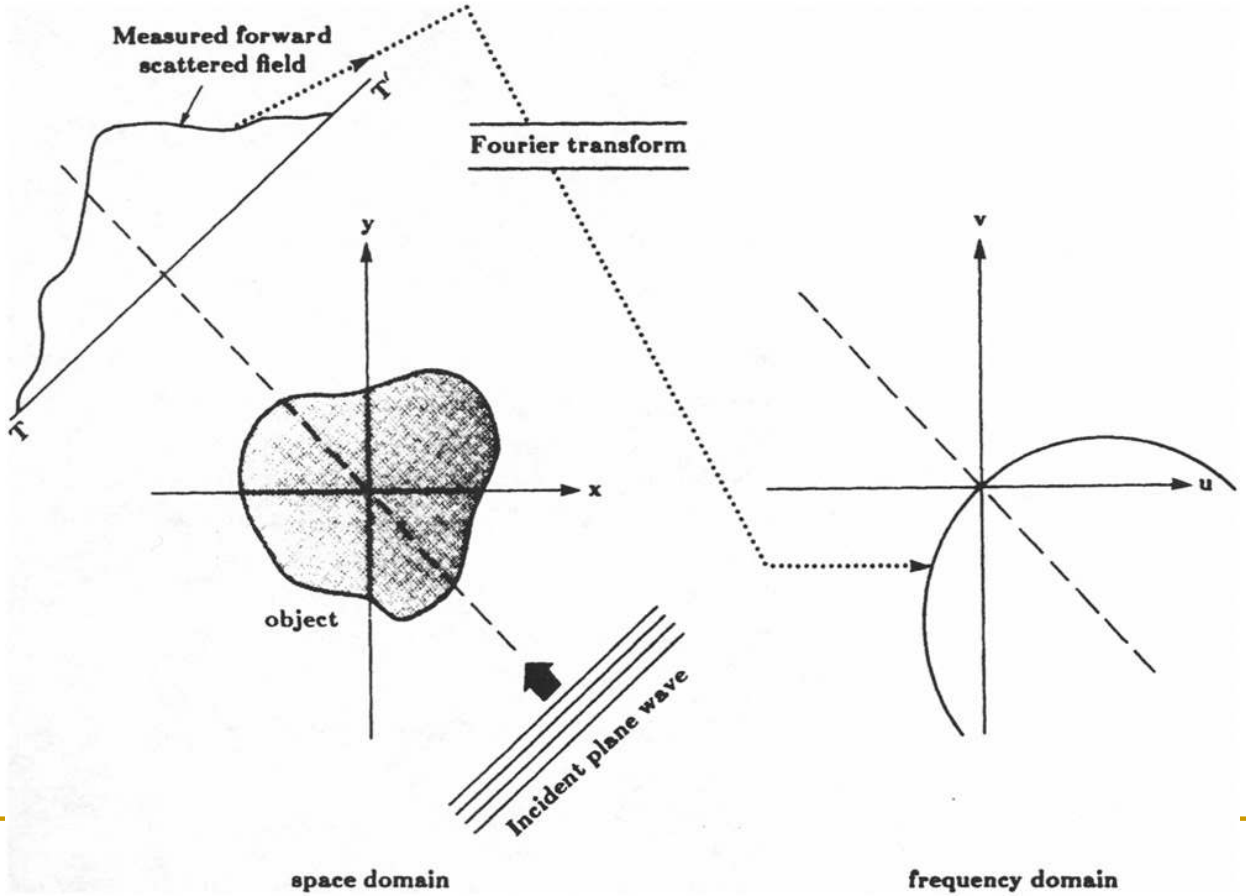
- Light does not travel along straight rays and a different approach is required to model the projections



Diffraction Tomography…

- Fourier Diffraction Theorem:

  An object *o(x,y)* when illuminated by a plane wave, the fourier transform of the projected field measured on the line (TT') gives the values of the 2D transform of the object along a *semicircular arc* in the frequency domain (instead of a straight line in non-diffracting case).

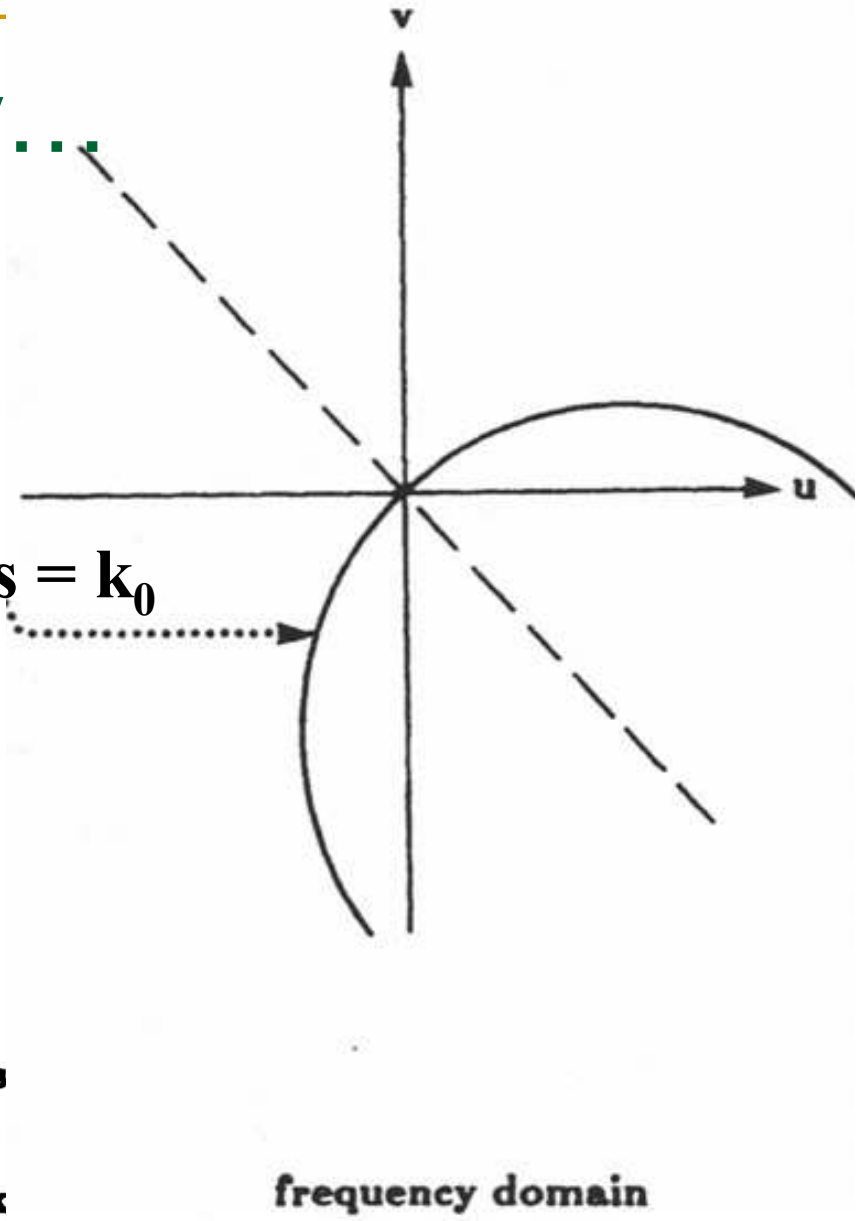


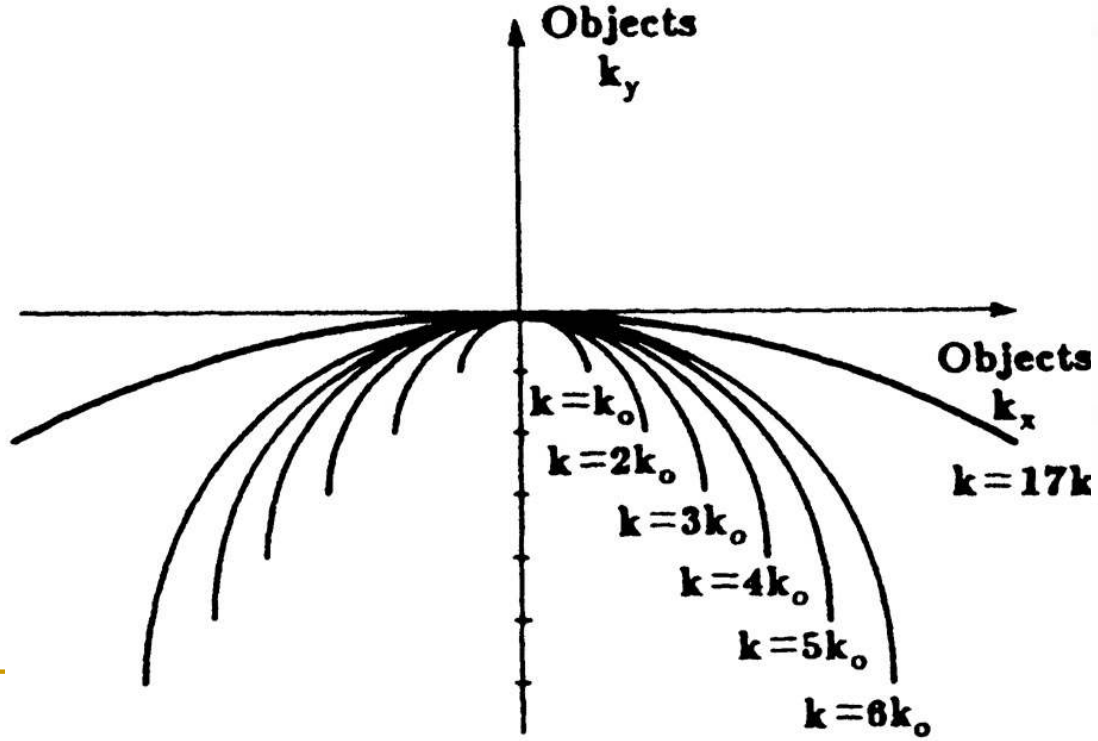
Courtesy of A. C. Kak and Malcolm Slaney. Used with permission.

Kak and Slaney (2001)

Diffraction Tomography…

- Short Wavelength limit:
  semicircular arc of radius k
  (the wave number)

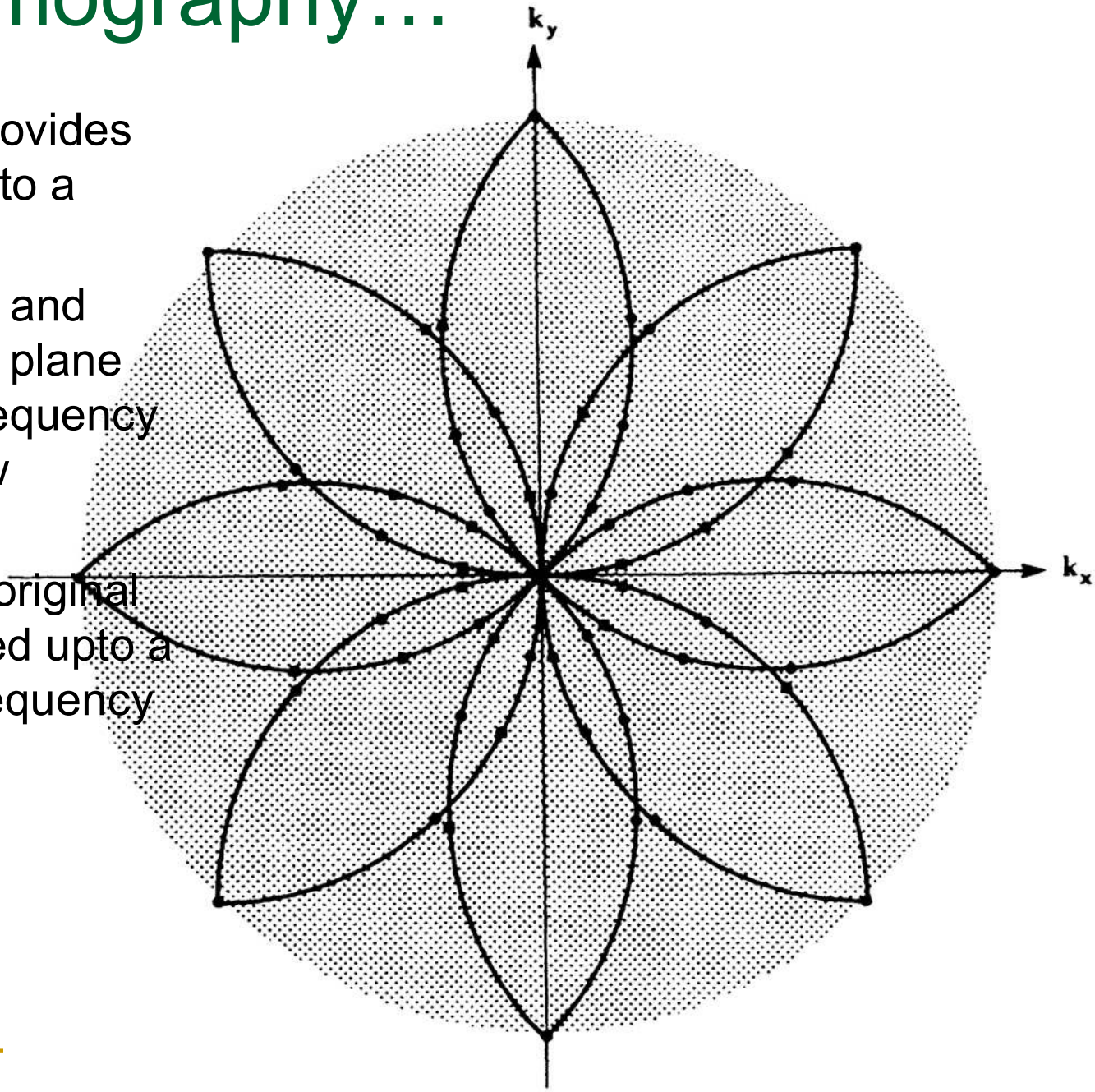




Kak and Slaney (2001)

Diffraction Tomography…

- Single plane wave provides exact information up to a frequency of ($\sqrt{2}\ k_0$)
- Changing orientation and frequency of incident plane waves change the frequency domain arcs to a new position.
- Low pass version of original object – object defined upto a maximum angular frequency of $\sqrt{2}\ k_0$

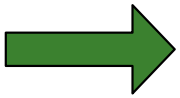


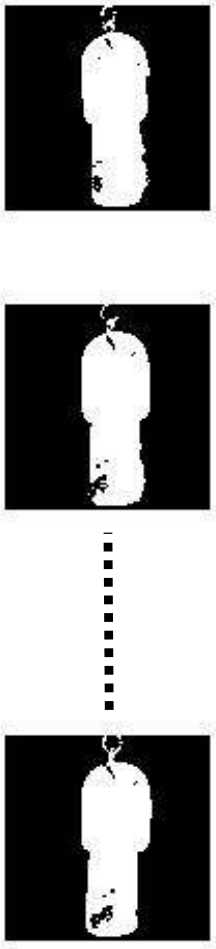
Courtesy of A. C. Kak and Malcolm Slaney. Used with permission.

3D Experiment

Shadow tomography

QuickTime™ and a
Motion JPEG OpenDML decompressor
are needed to see this picture.

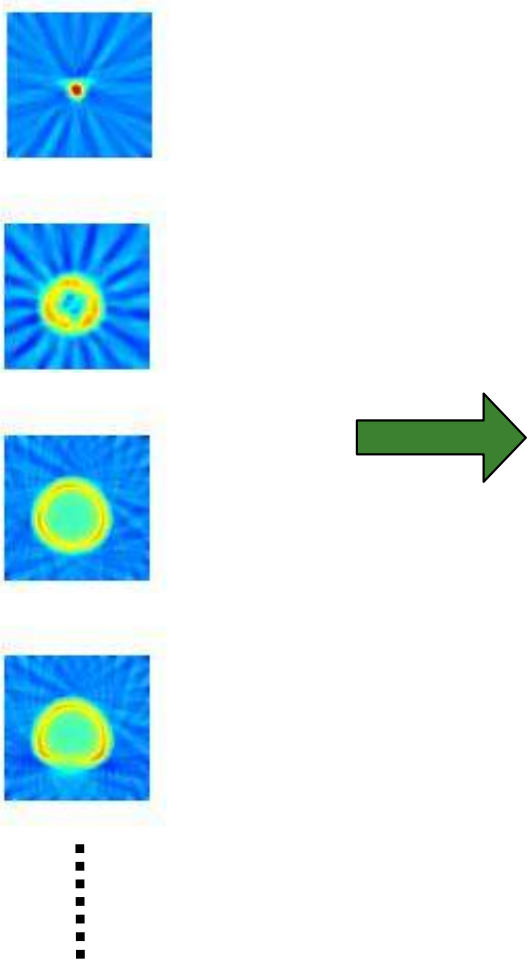




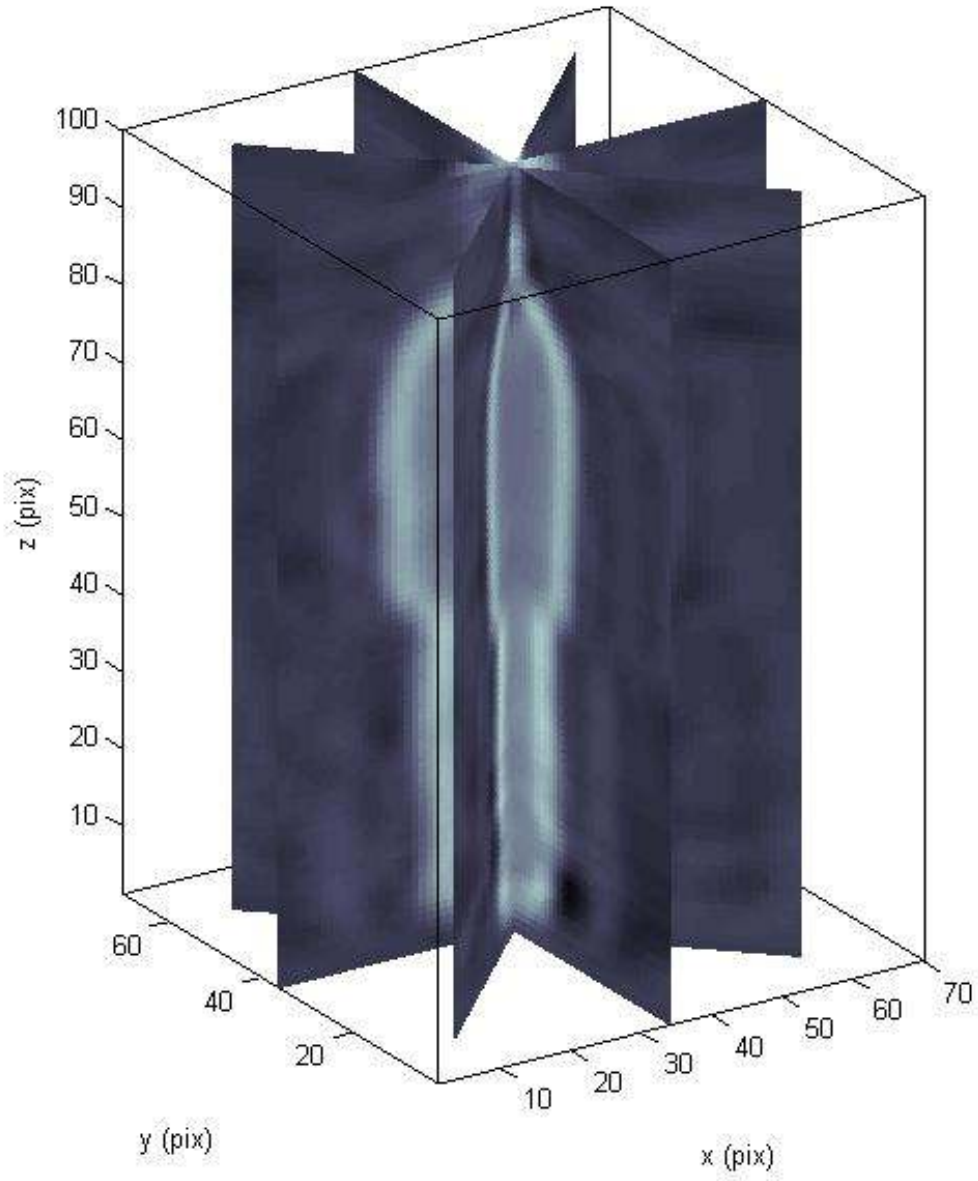
17 projections
(0 ≤ Θ < 360º)

3D Experiment

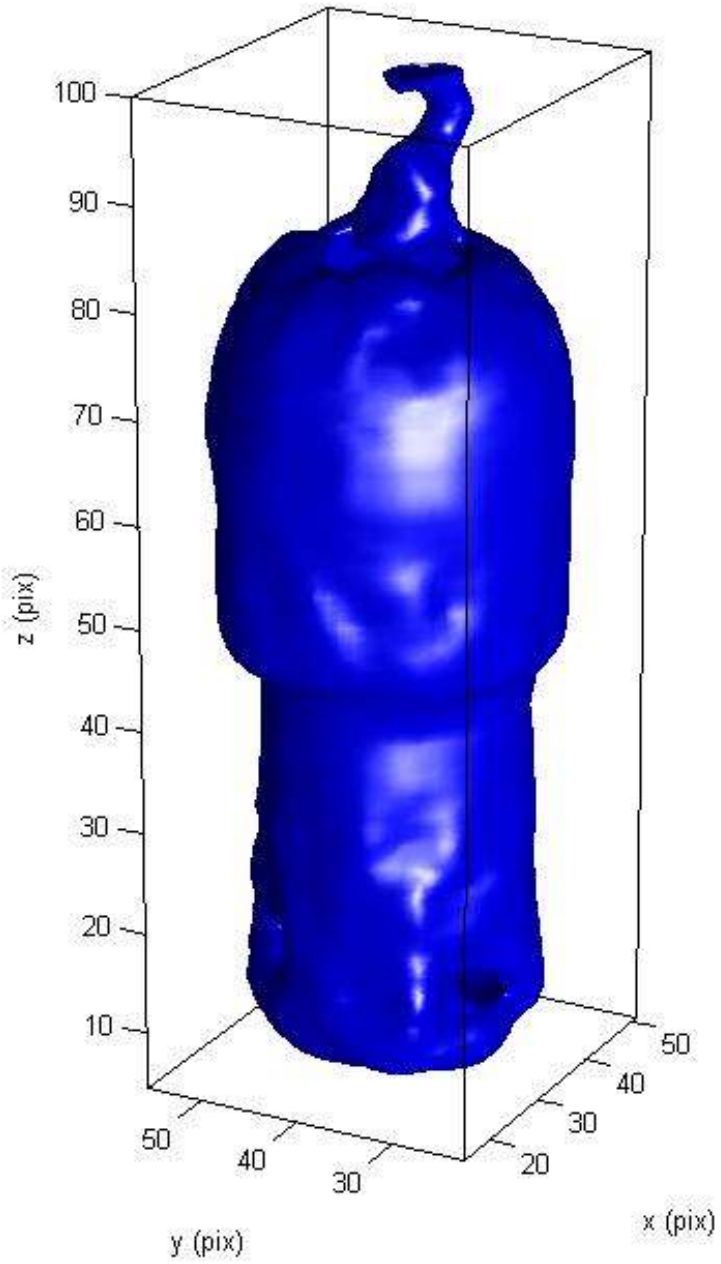
Shadow tomography

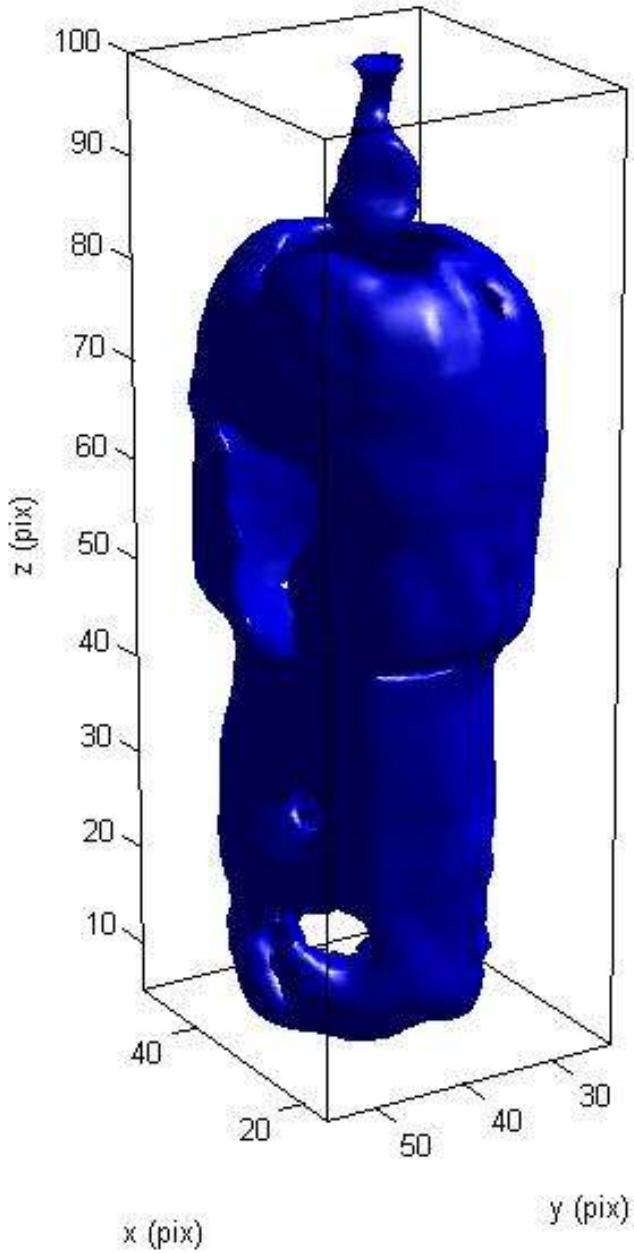


100 “slices”

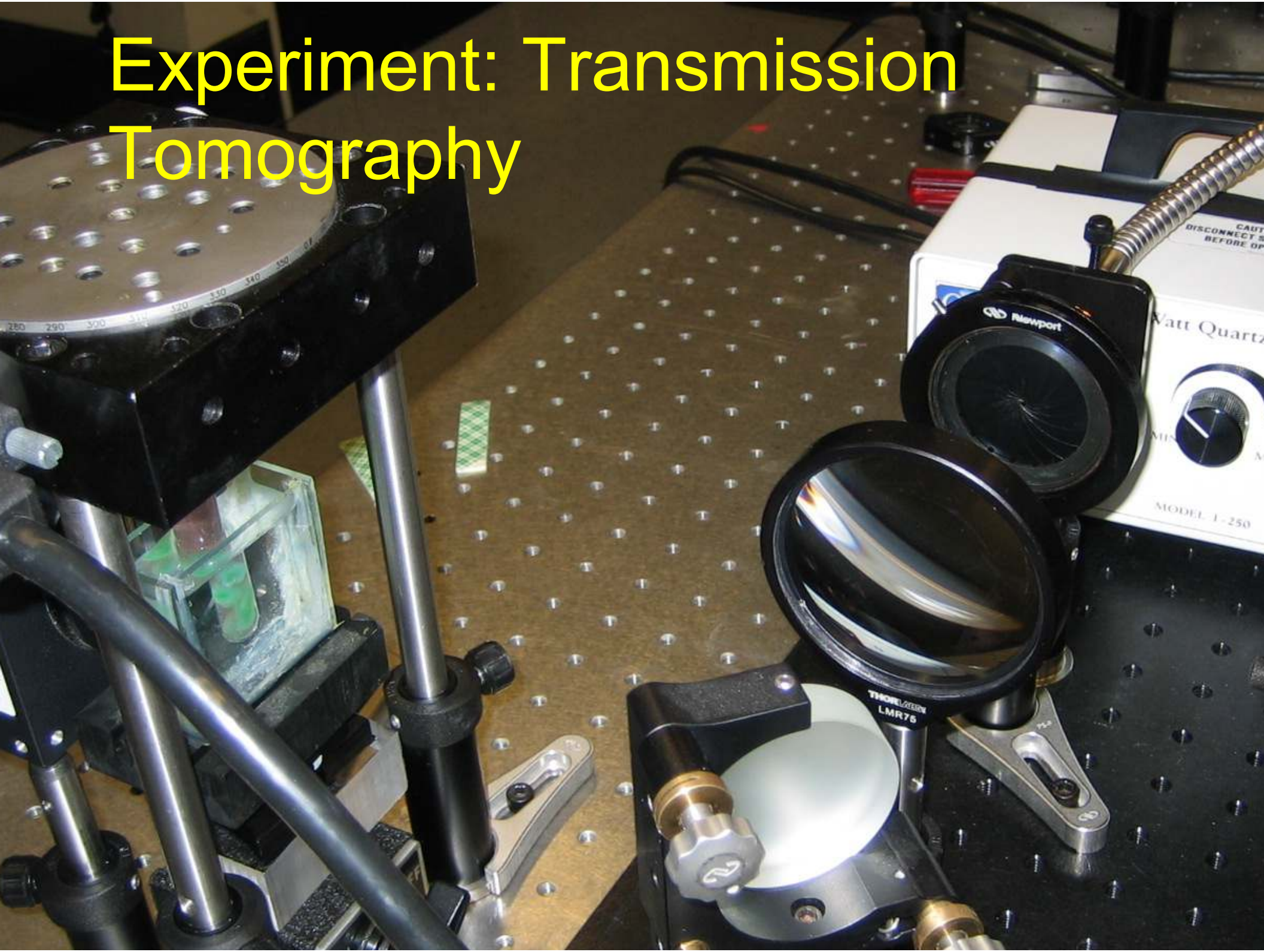


3D Experiment



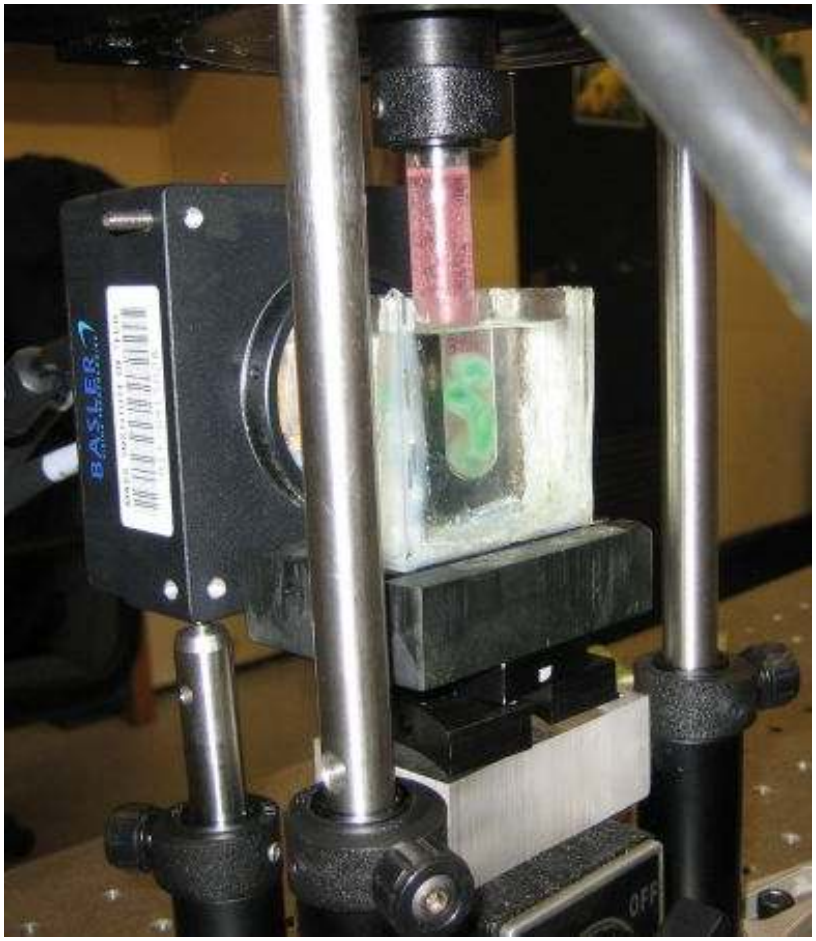


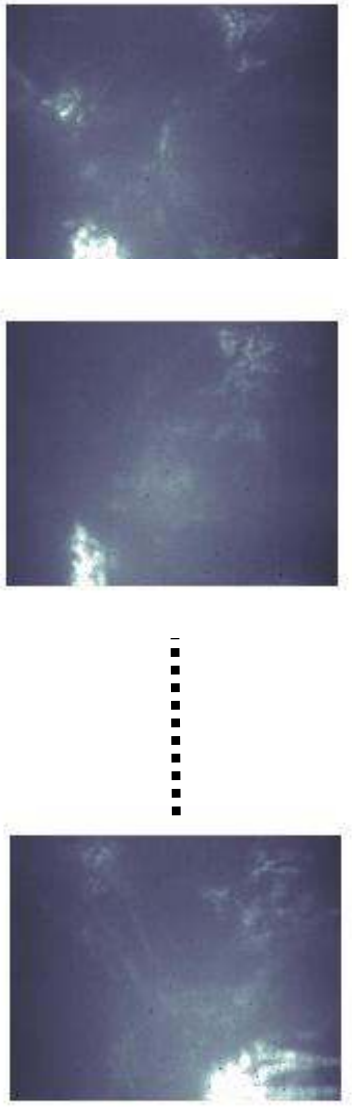
Experiment: Transmission Tomography



Reconstruction Experiment

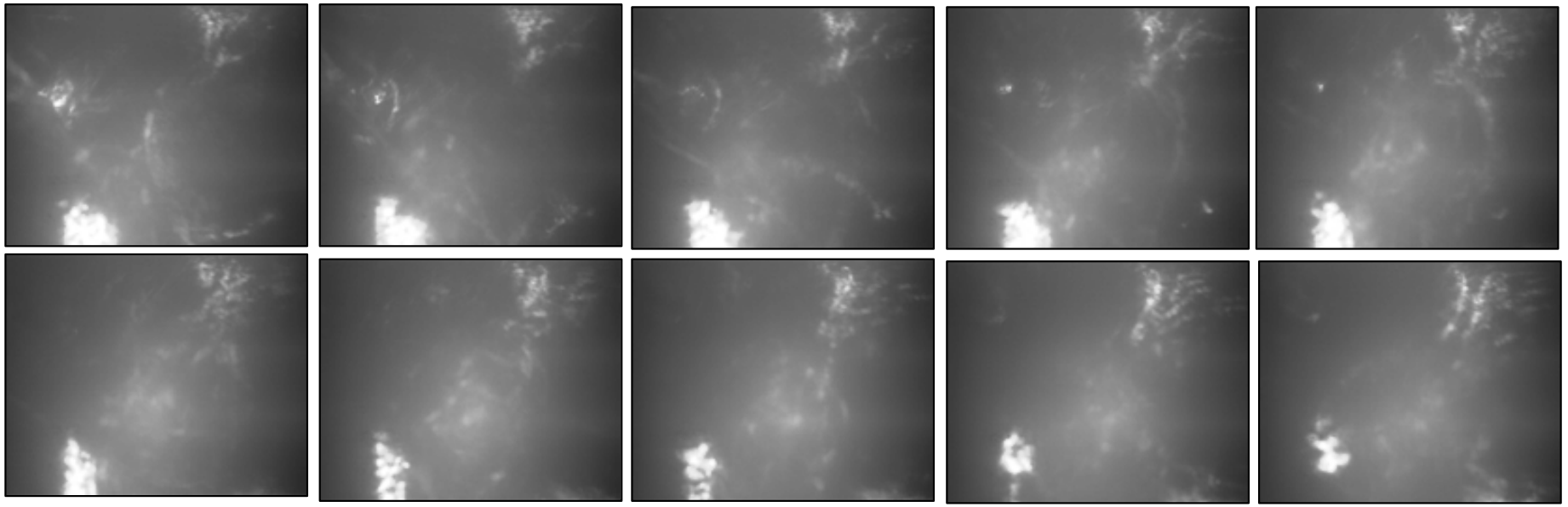
Transmission tomography





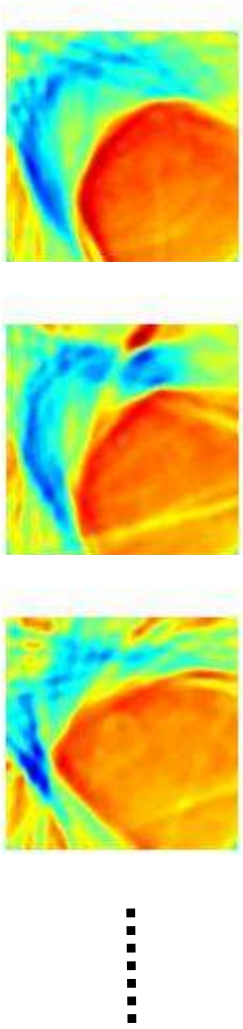
36 projections
(0 ≤ Θ < 180°)

Reconstruction Experiment

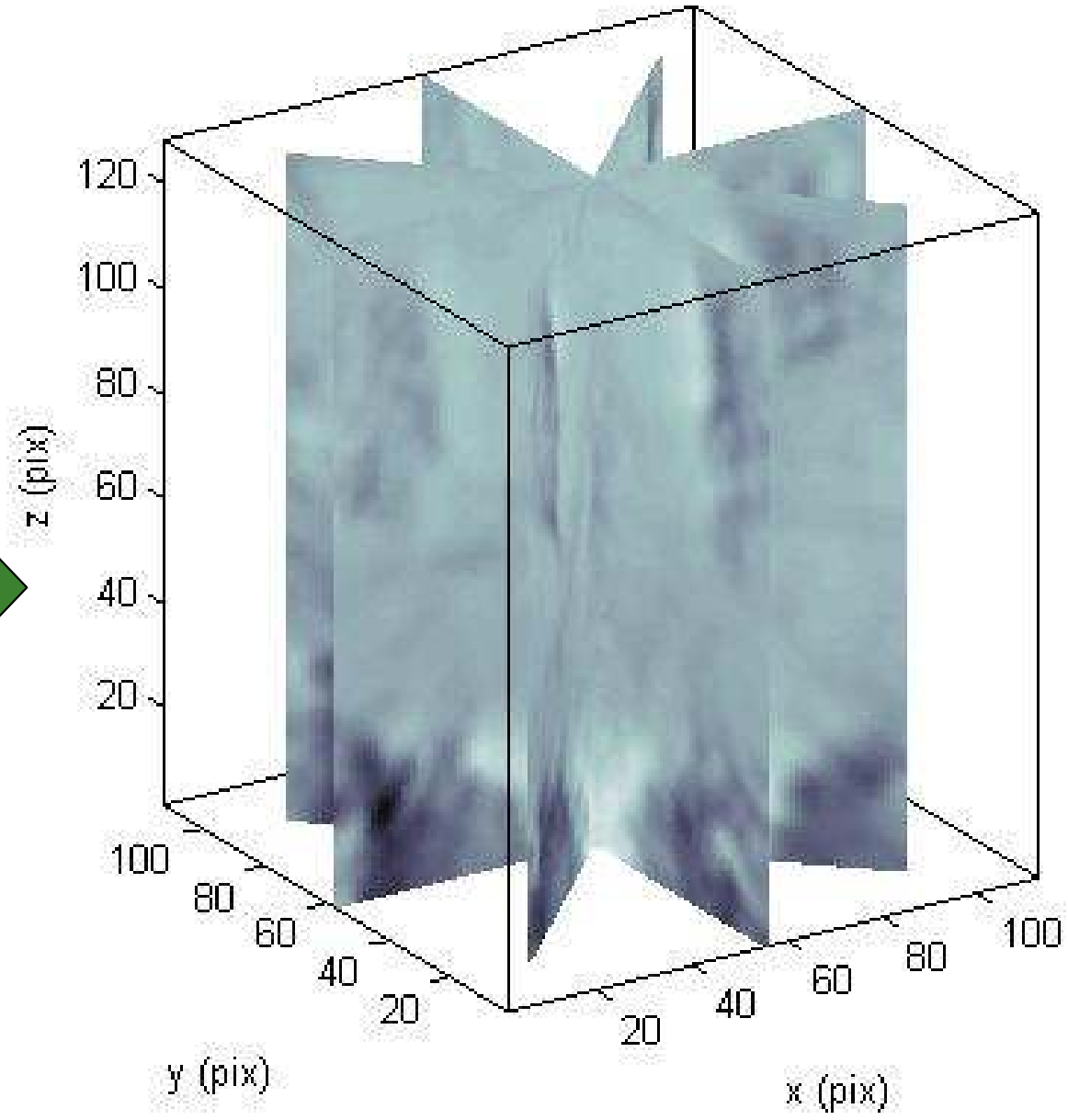


Images spaced over 5 deg

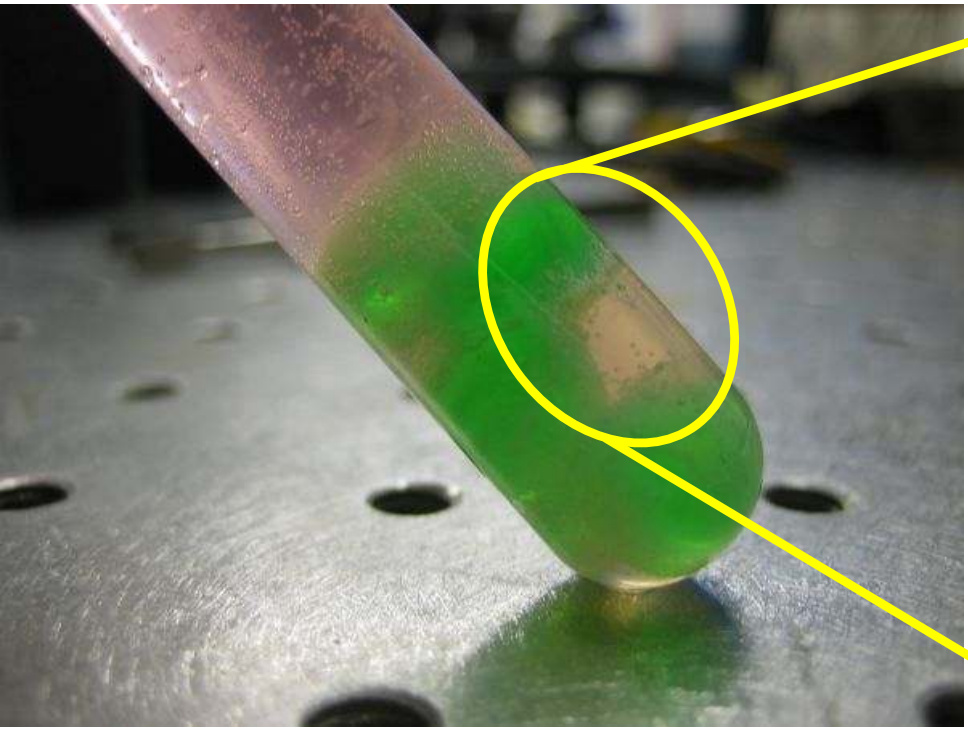
Holographic Reconstruction



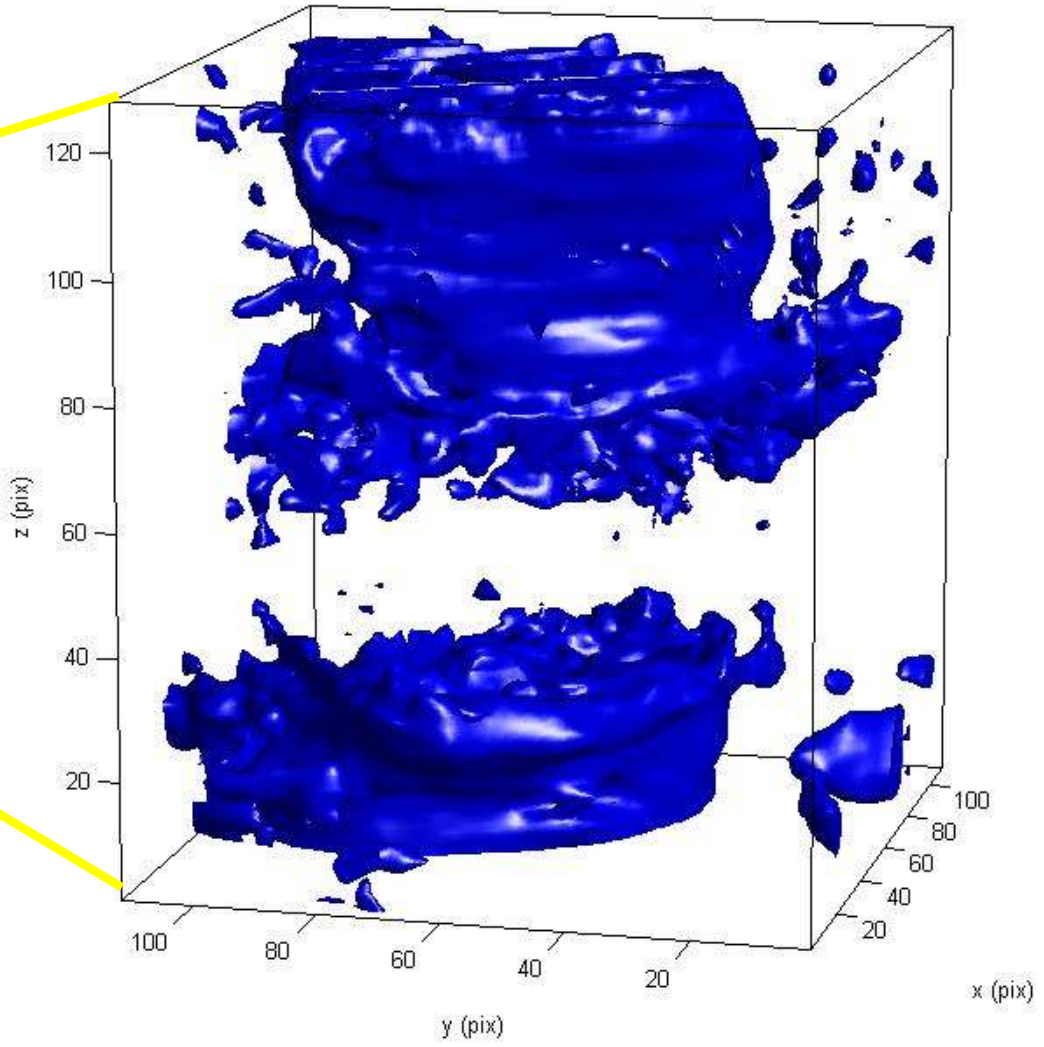
128 "slices"



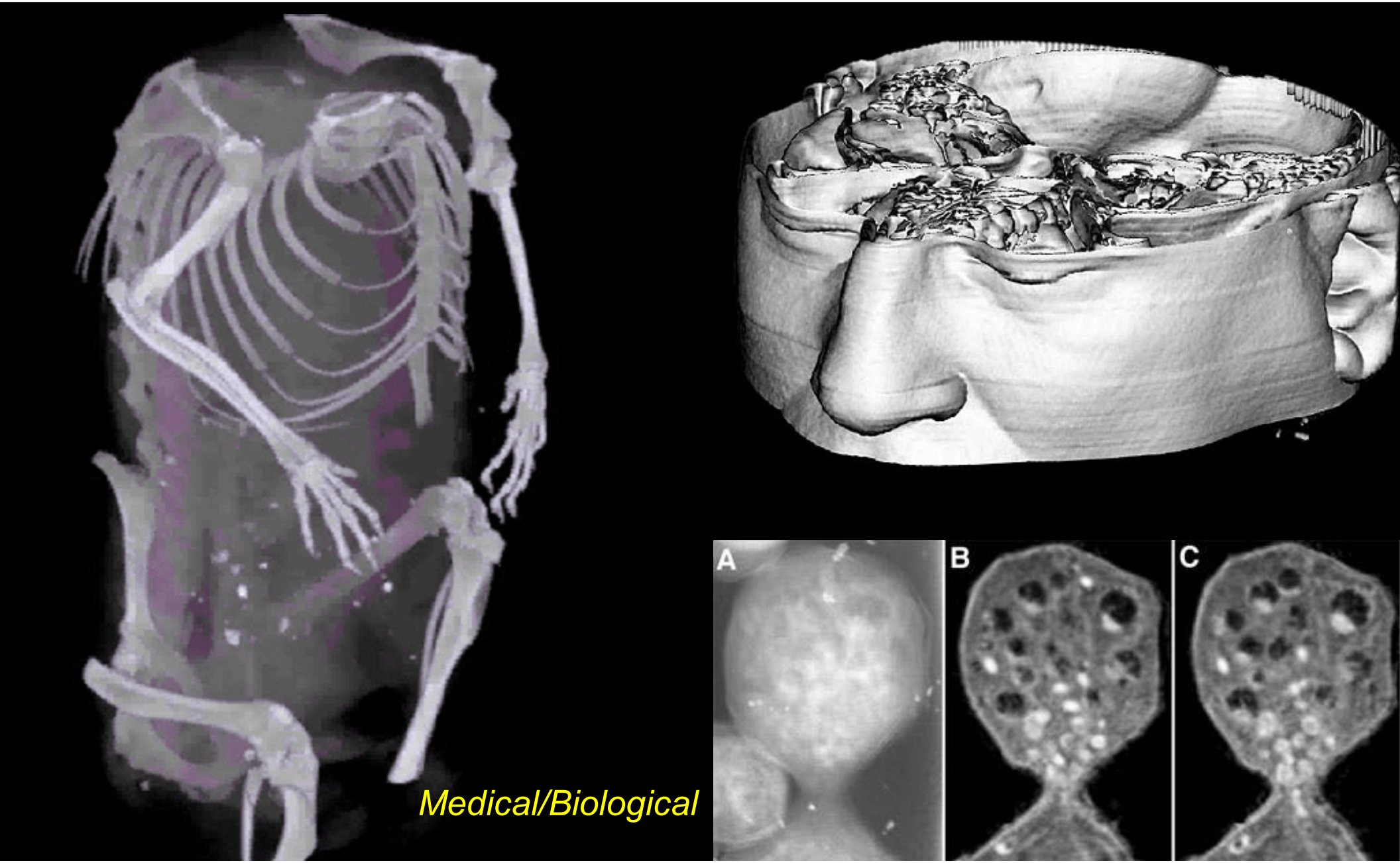
Holographic Reconstruction



“Gummi tomography”



Tomography Applications



Tomography Applications

Images removed due to copyright restrictions. Please see Fig. 4 and 8c,d in Midgley, Paul A., and Rafal E.Dunin-Borkowski. "Electron Tomography and Holography in Materials Science." *Nature Materials* 8 (April 2009): 271-280.

Also:

- Geology
- Oceanography
- Astrophysics
- Non-destructive testing
- Flow fields

Diffraction effects

Images removed due to copyright restrictions. Please see:

Fig. 12 and 13 in Jonas, P., and A. K. Louis. "Phase Contrast Tomography Using Holographic Measurements." *Inverse Problems* 20 (2004): 75-102.
Fig. 2 and 3 in Watanabe, Norio, and Sadao Aoki. "Three-dimensional Tomography Using a Soft X-ray Holographic Microscope and CCD Camera." *Journal of Synchrotron Radiation* 5 (1998): 1088-1089.

(Jonas & Louis, 2004)

(Watanabe & Aoki, 1998)

Have a good day!

2.71 / 2.710 Optics
Spring 2009