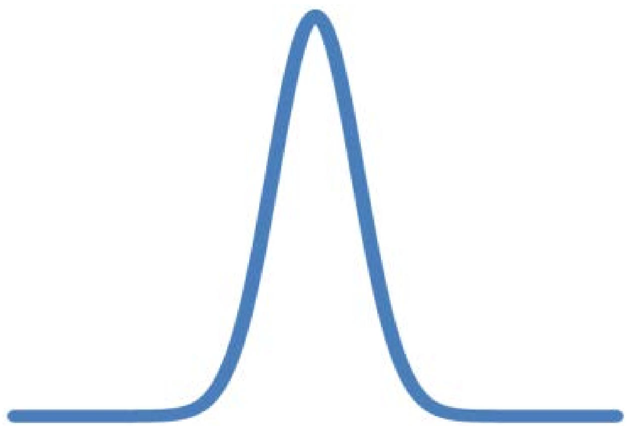
Image Quality Parameters and their Measurement



John M. Boone, Ph.D., FAAPM, FSBI, FACR
Professor and Vice Chair of Radiology
Professor of Biomedical Engineering
University of California, Davis

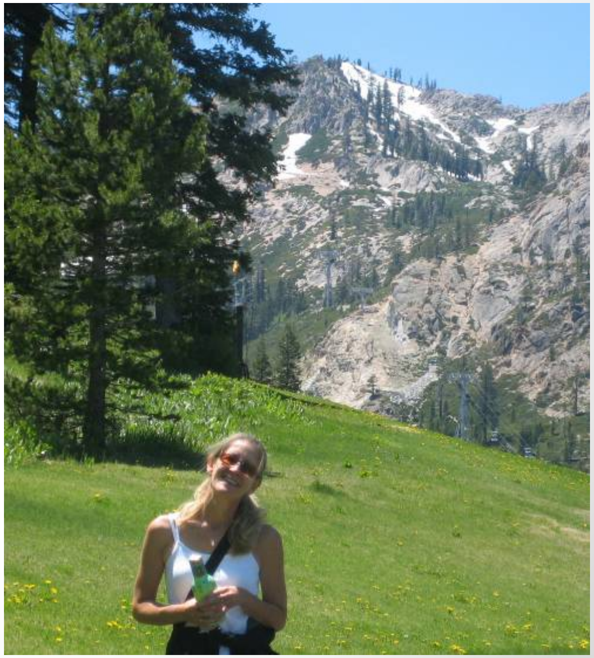


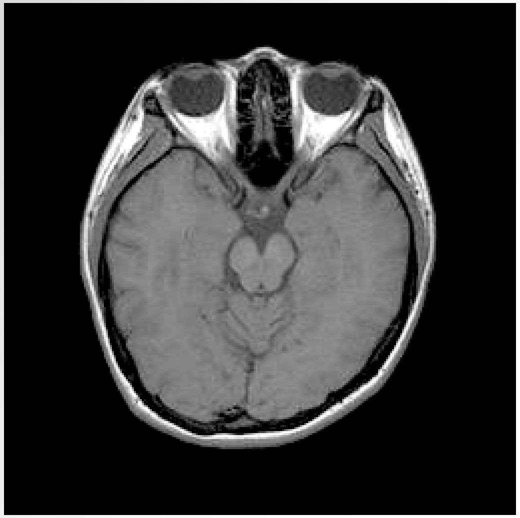


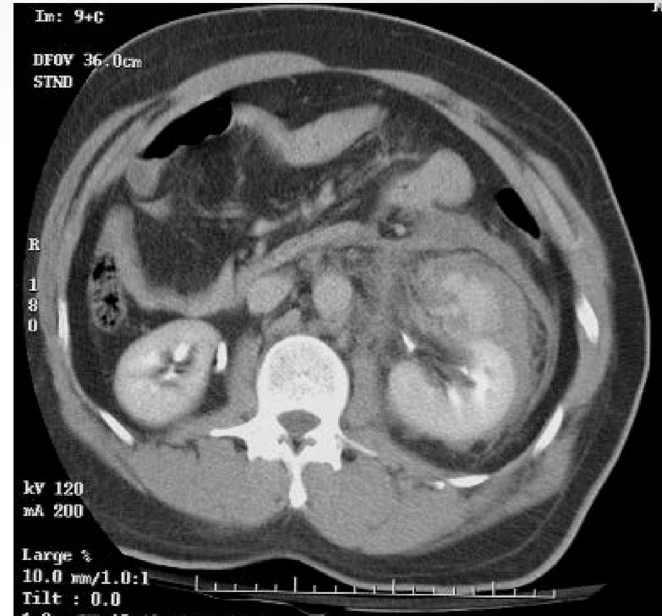


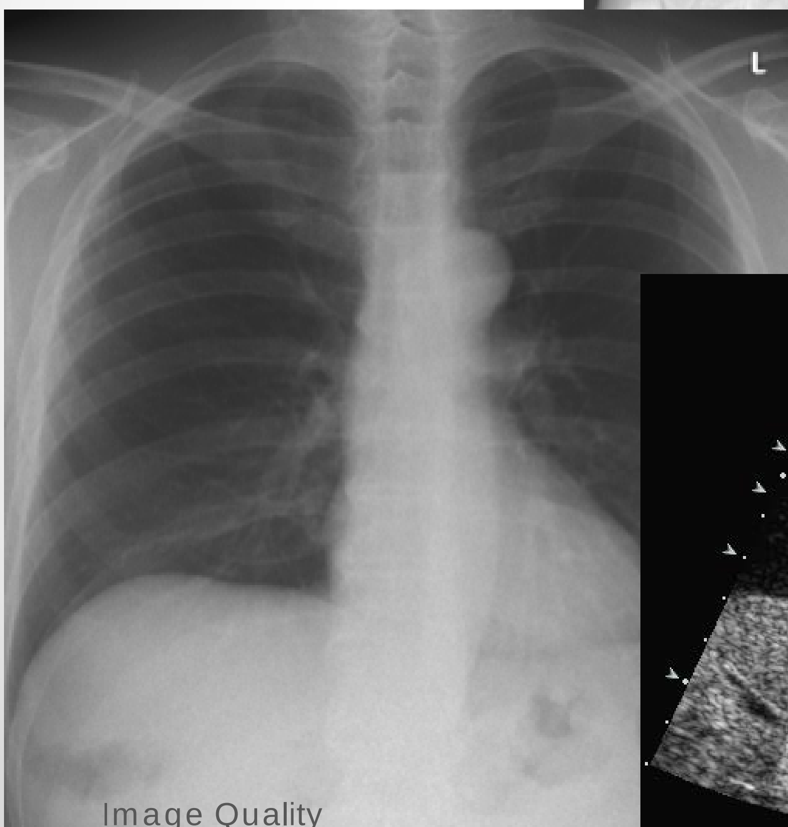












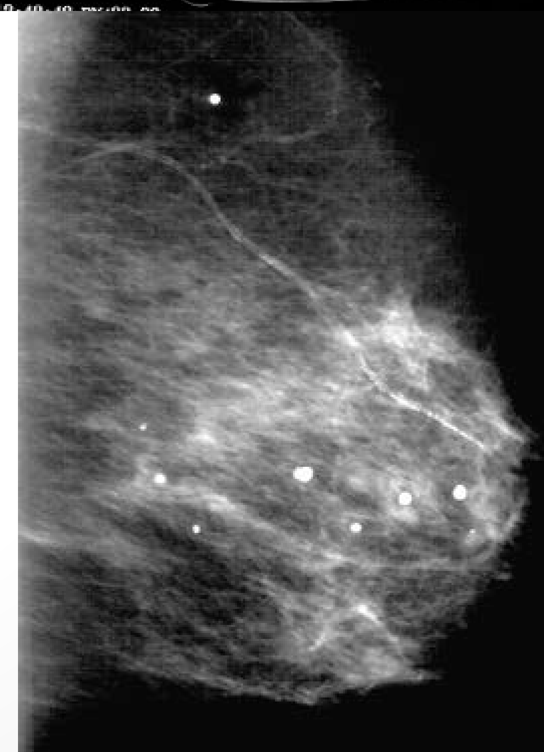


Image Quality

Image Quality Parameters and their Measurement

Linear Systems / Stationary Behavior

Spatial Resolution

field measurements

scientific characterization

Contrast Resolution (noise)

field measurements

scientific characterization

Signal to Noise Ratio

field measurements

scientific characterization

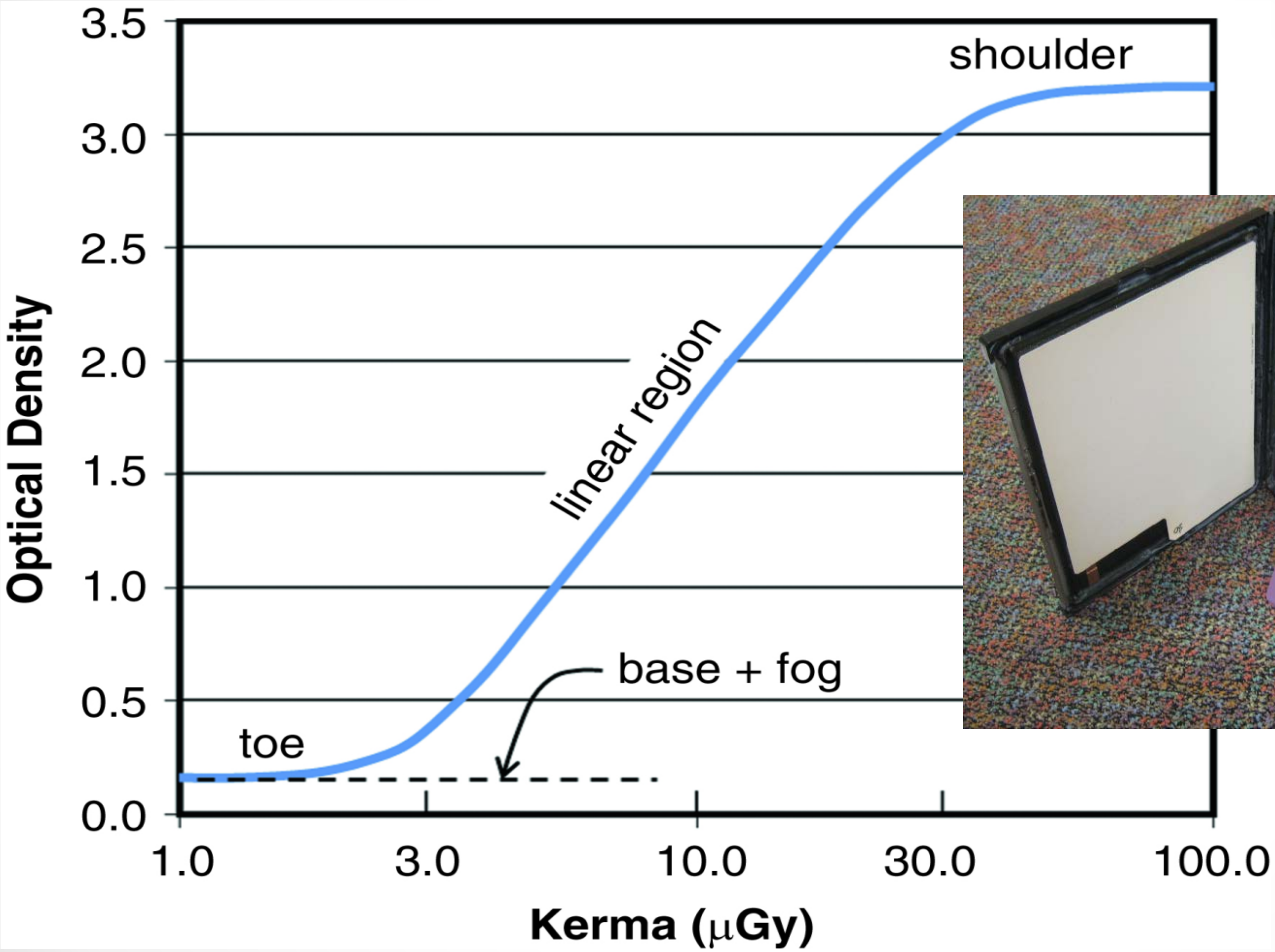
Summary

Linear Systems / Stationary Behavior
Spatial Resolution
Contrast Resolution (noise)
Signal to Noise Ratio
Summary

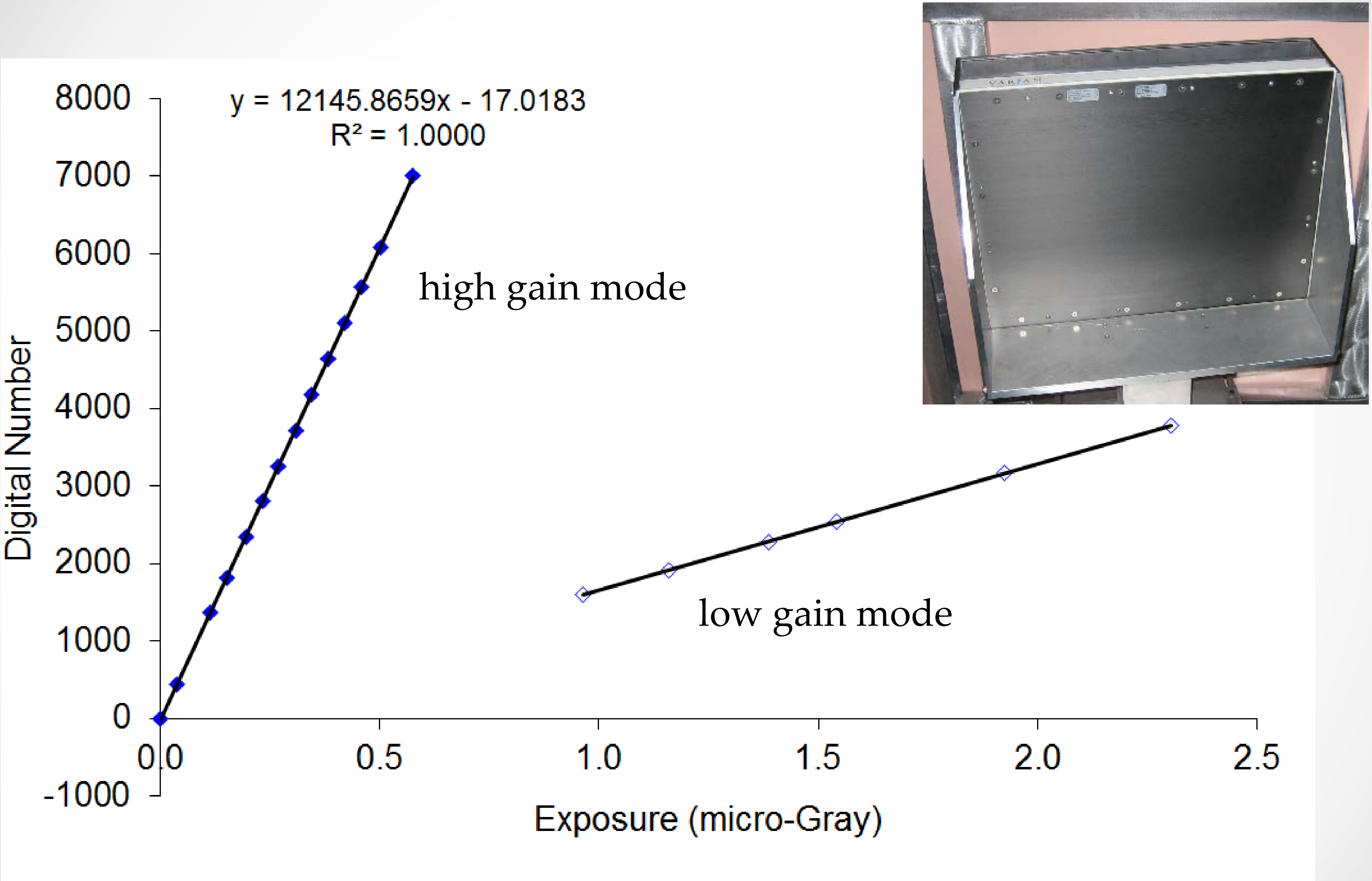
Image Quality Parameters and their Measurement

- Linear Systems / Stationary Behavior
- Spatial Resolution
- Contrast Resolution (noise)
- Signal to Noise Ratio
- Summary

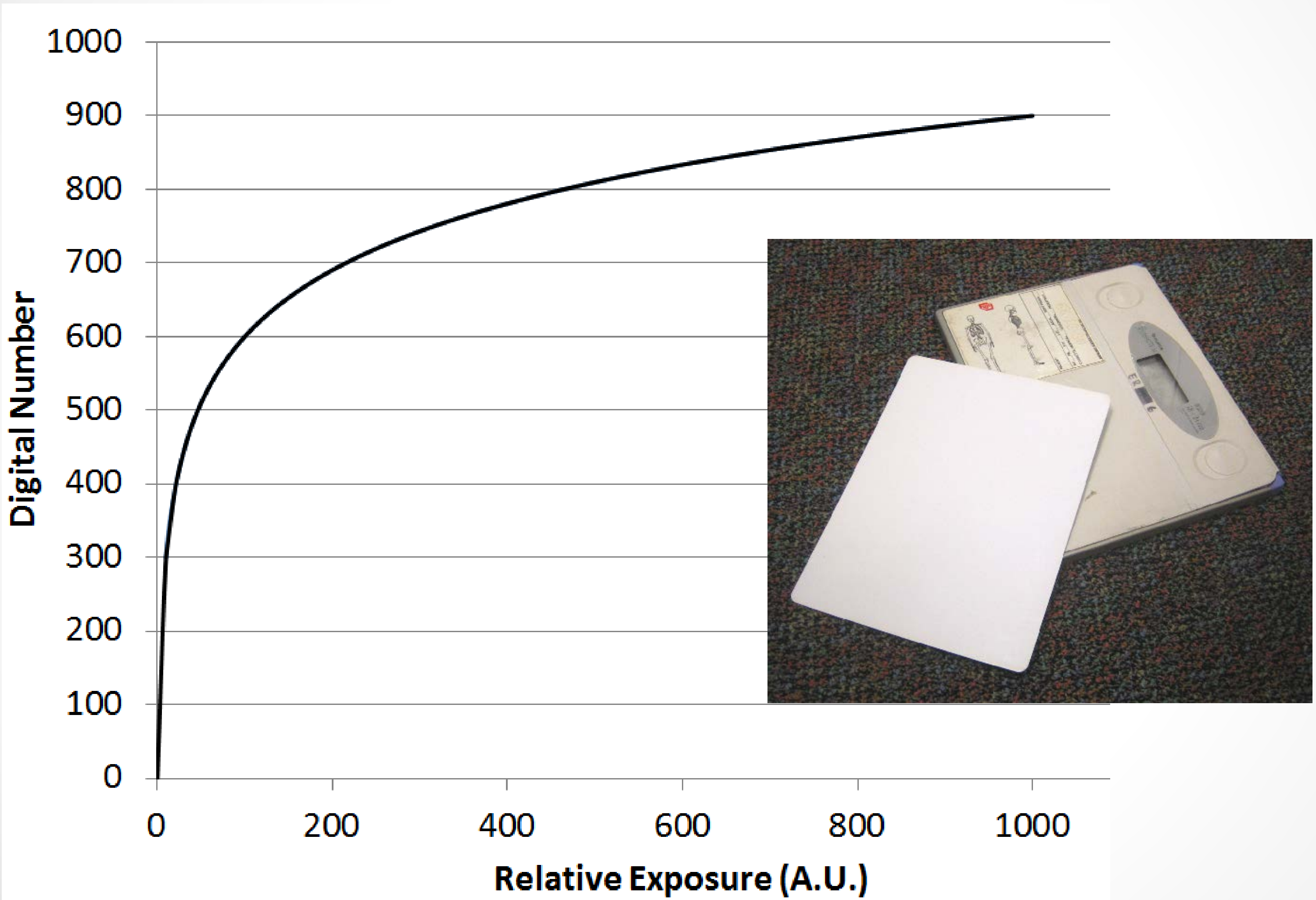
Response of a 400 speed screen-film system (Fuji)

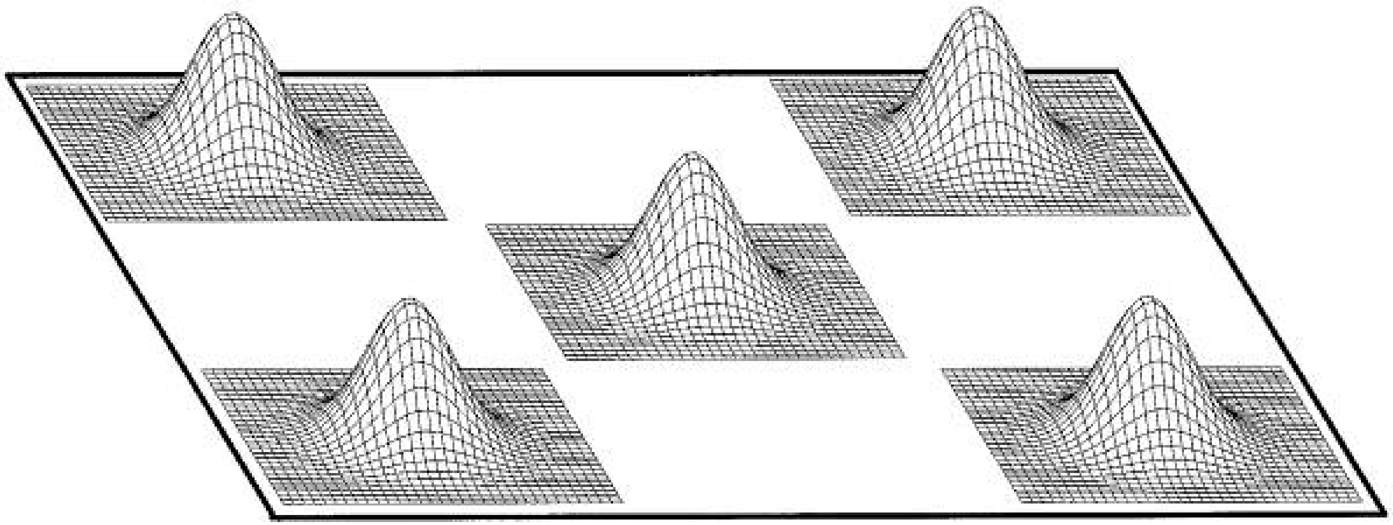


Response of a Varian 4030CB Flat Panel Detector



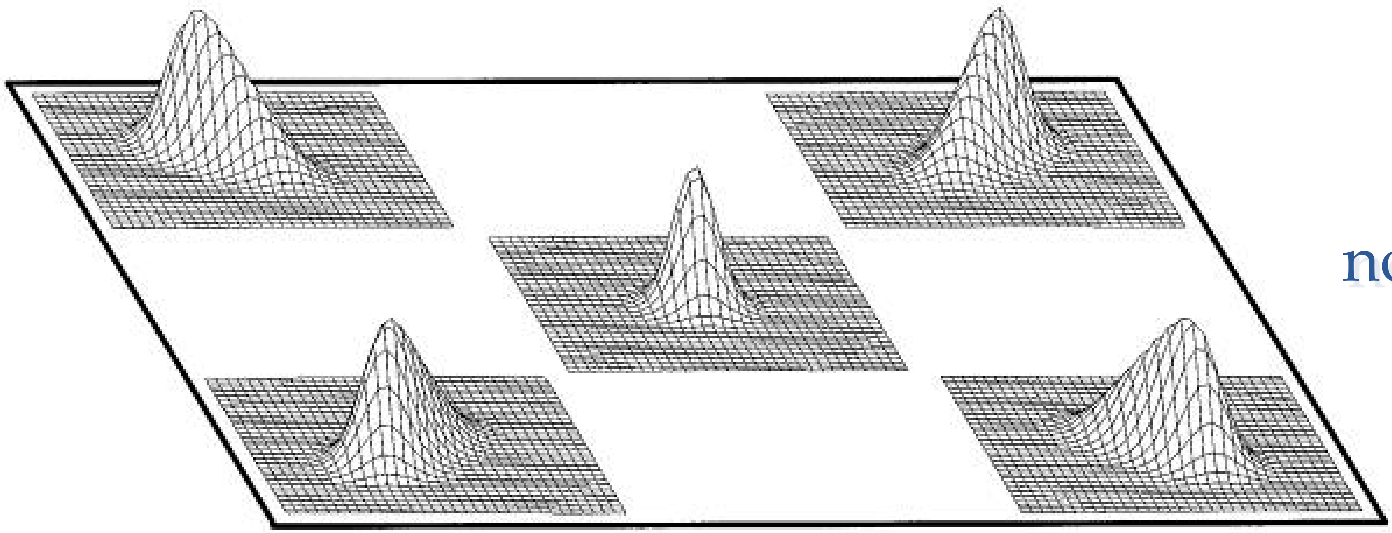
Response of a Fuji Computed Radiography (CR) System





stationary

point spread functions (PSFs)



non-stationary

Image Quality Parameters and their Measurement

- Linear Systems / Stationary Behavior
- Spatial Resolution
- Contrast Resolution (noise)
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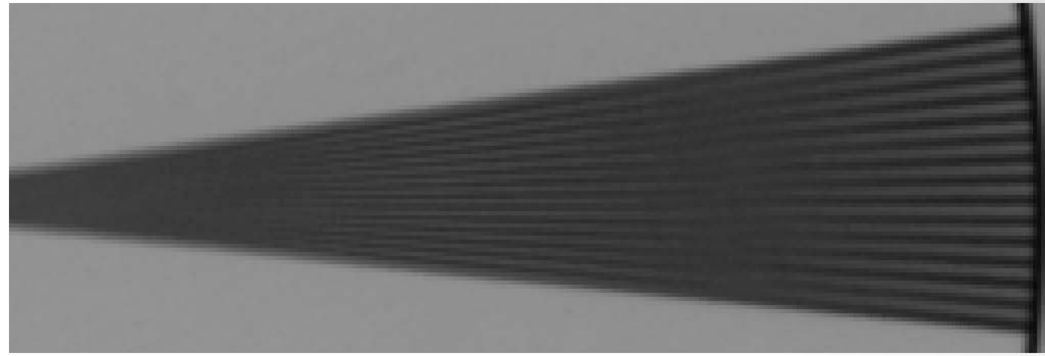
- Summary

Field Measurement

spatial resolution

resolution
test tools

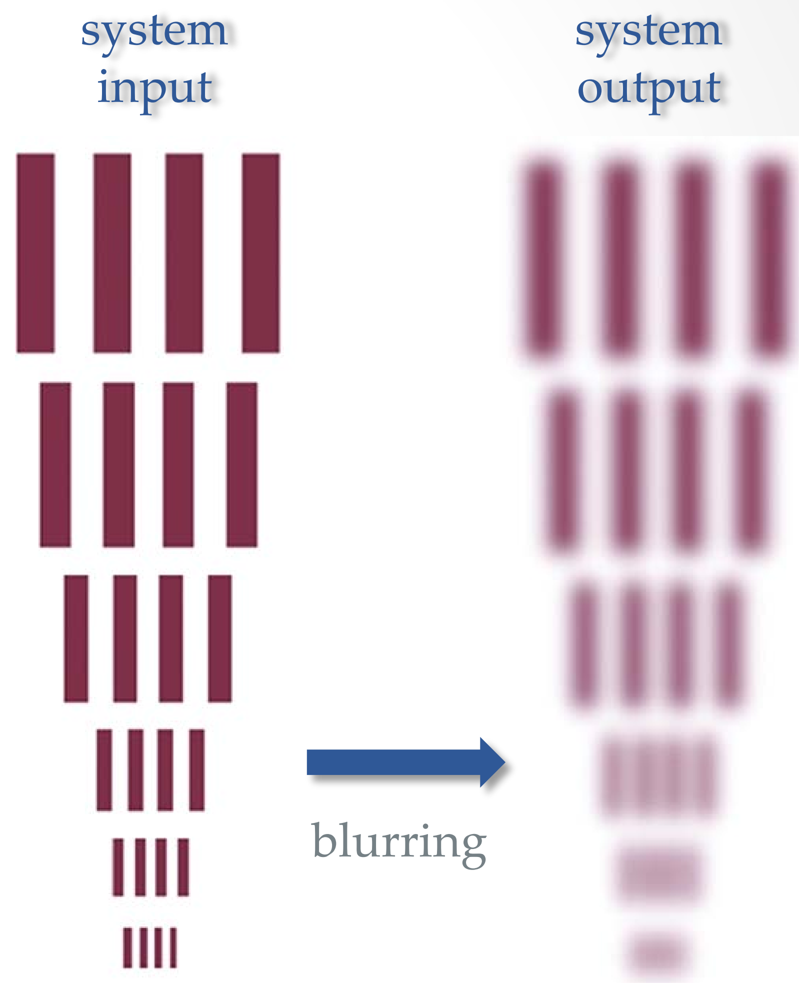


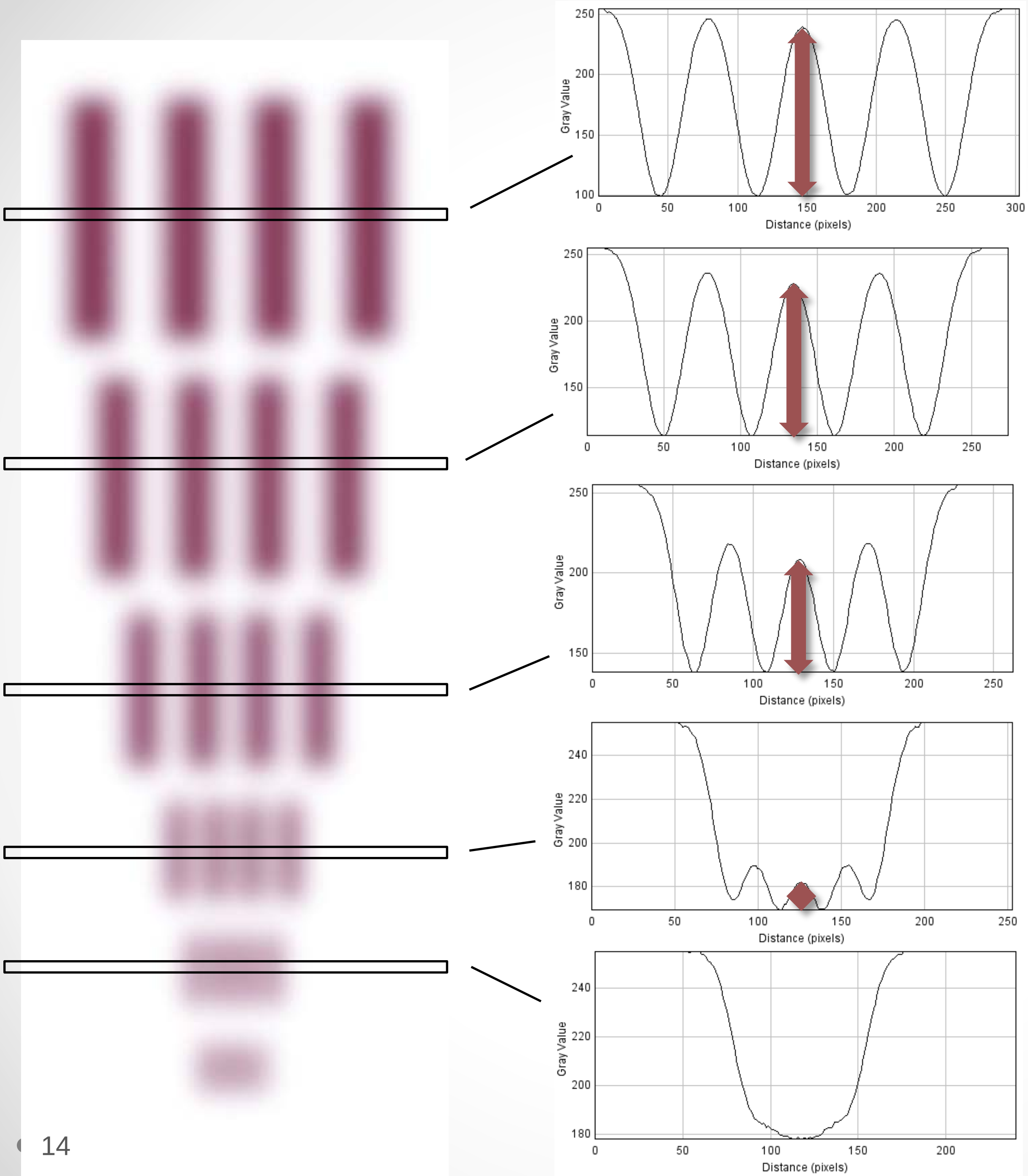
wedge

line pair phantom

star pattern phantom

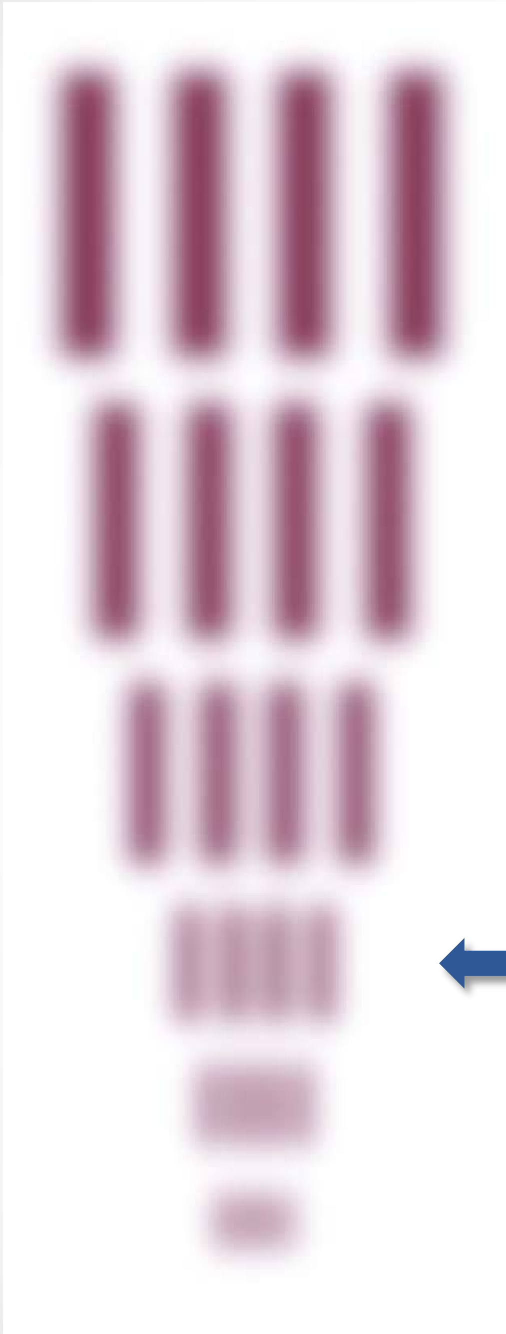
Spatial Resolution: Measurements in the Field




Gray Value
Distance (pixels)
250
200
150
100
0
50
100
150
200
250
300
240
220
180

modulation

can resolve 4 bars?



yes

yes

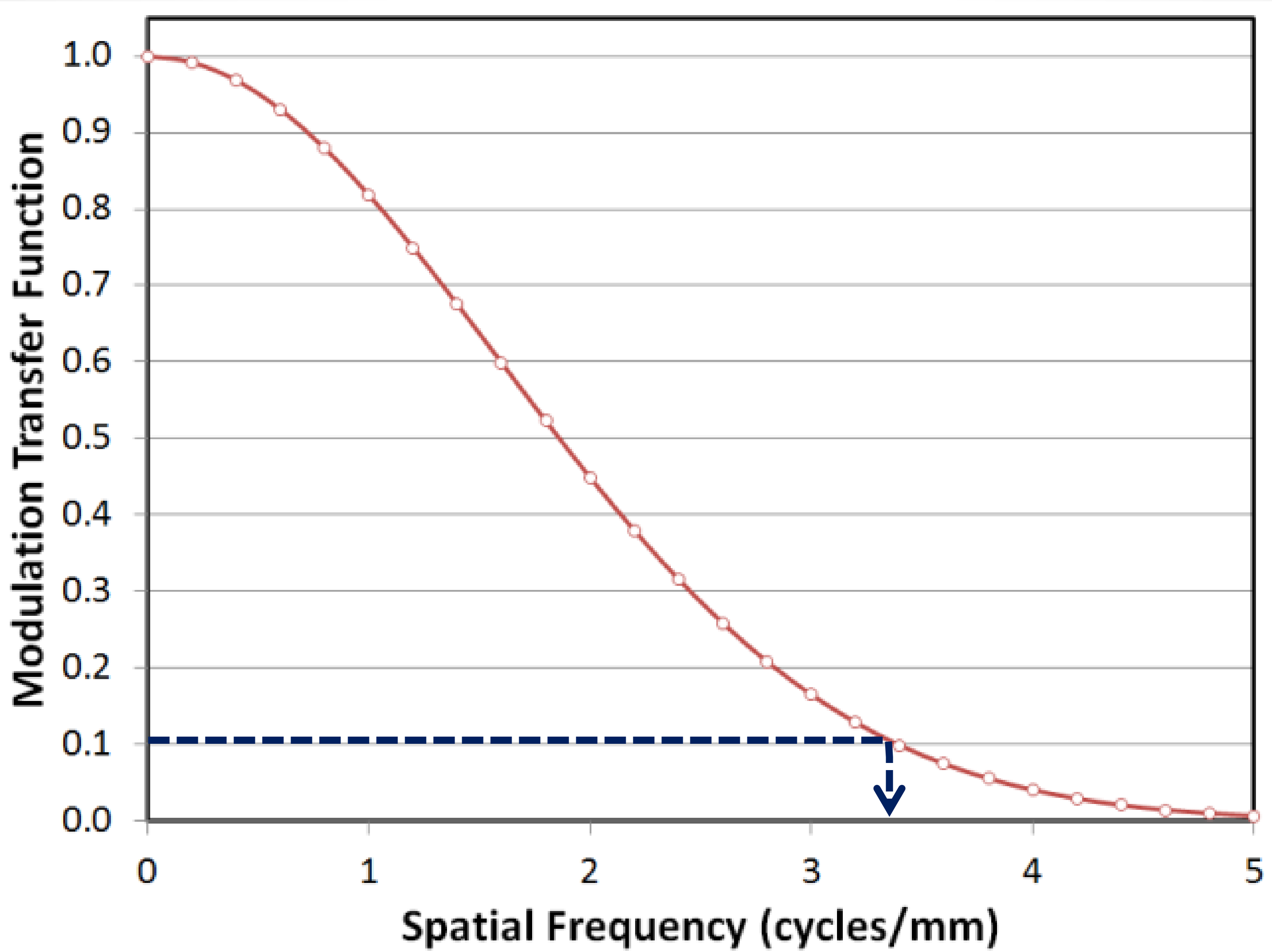
yes

yes limiting spatial resolution

no

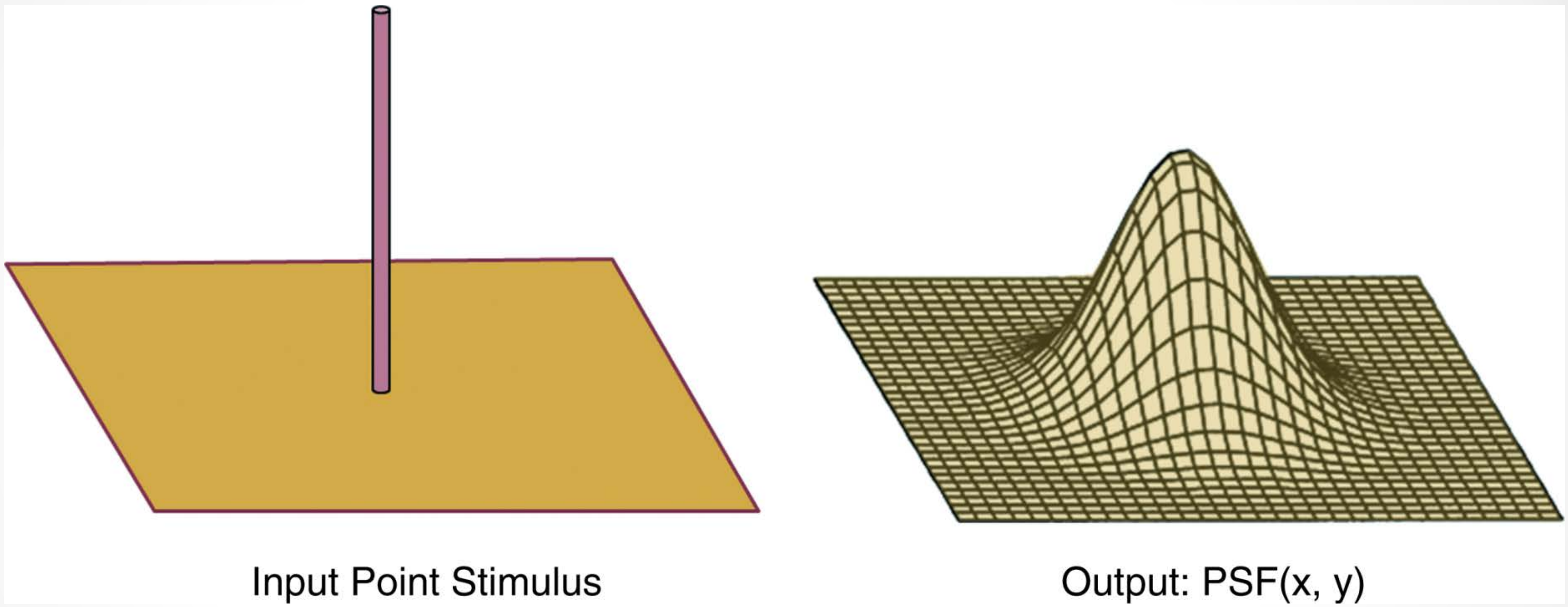
heck no

Limiting spatial resolution (~10% of MTF)

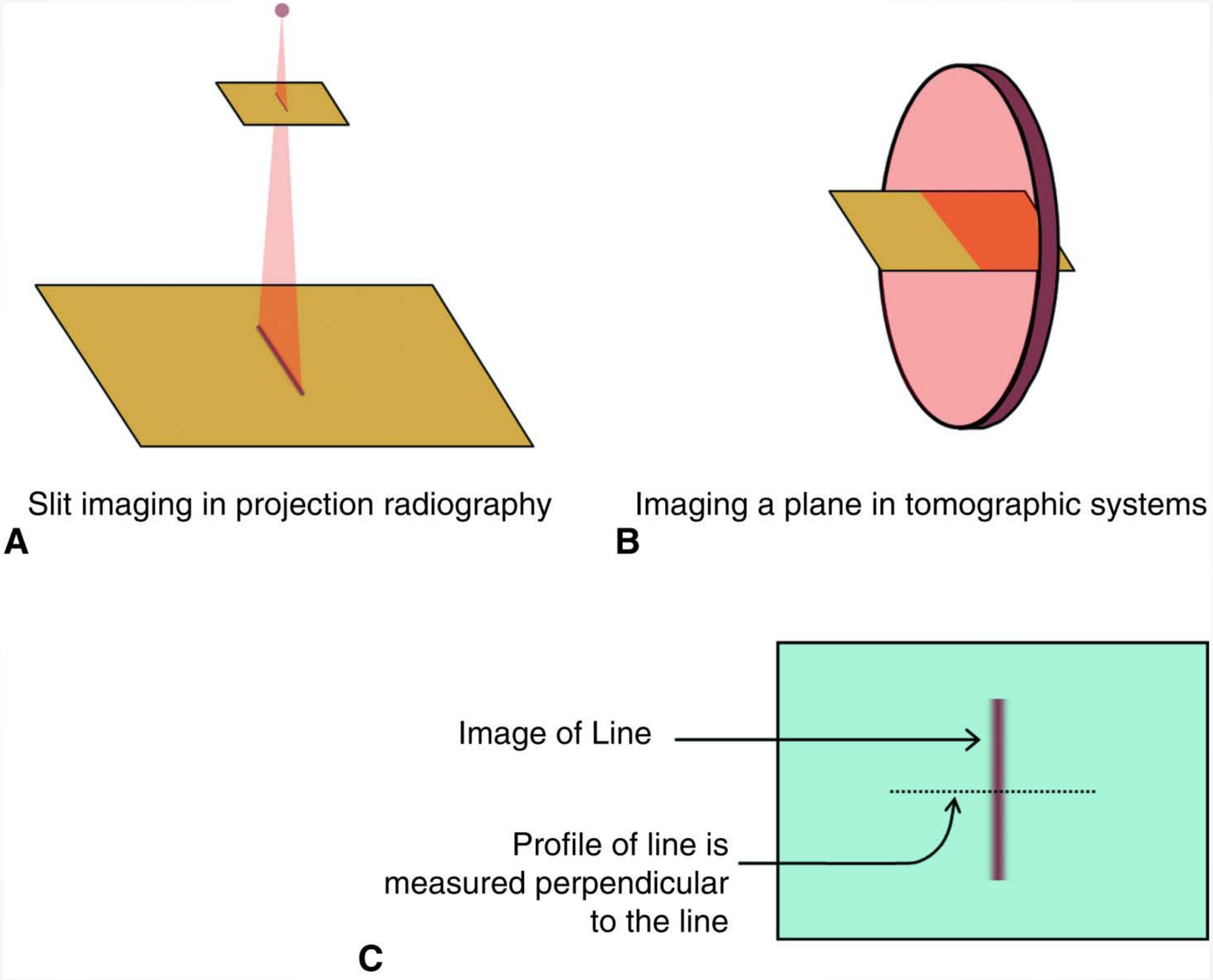


Scientific Characterization

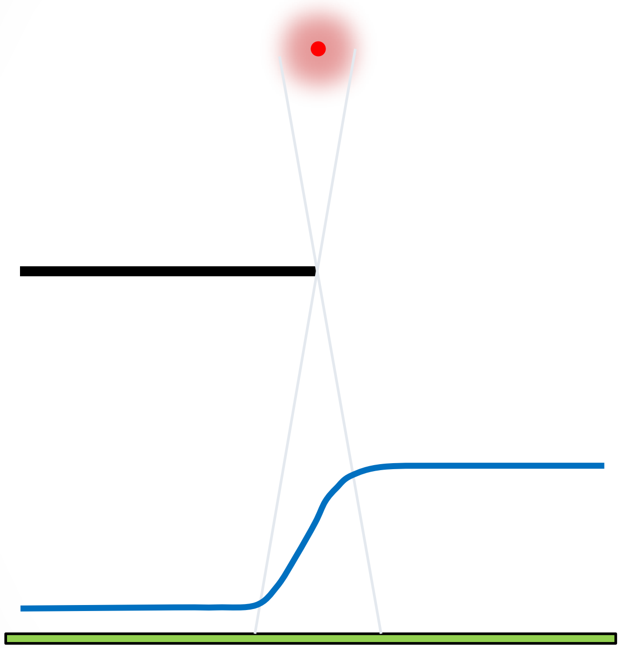
The Point Spread Function (PSF)

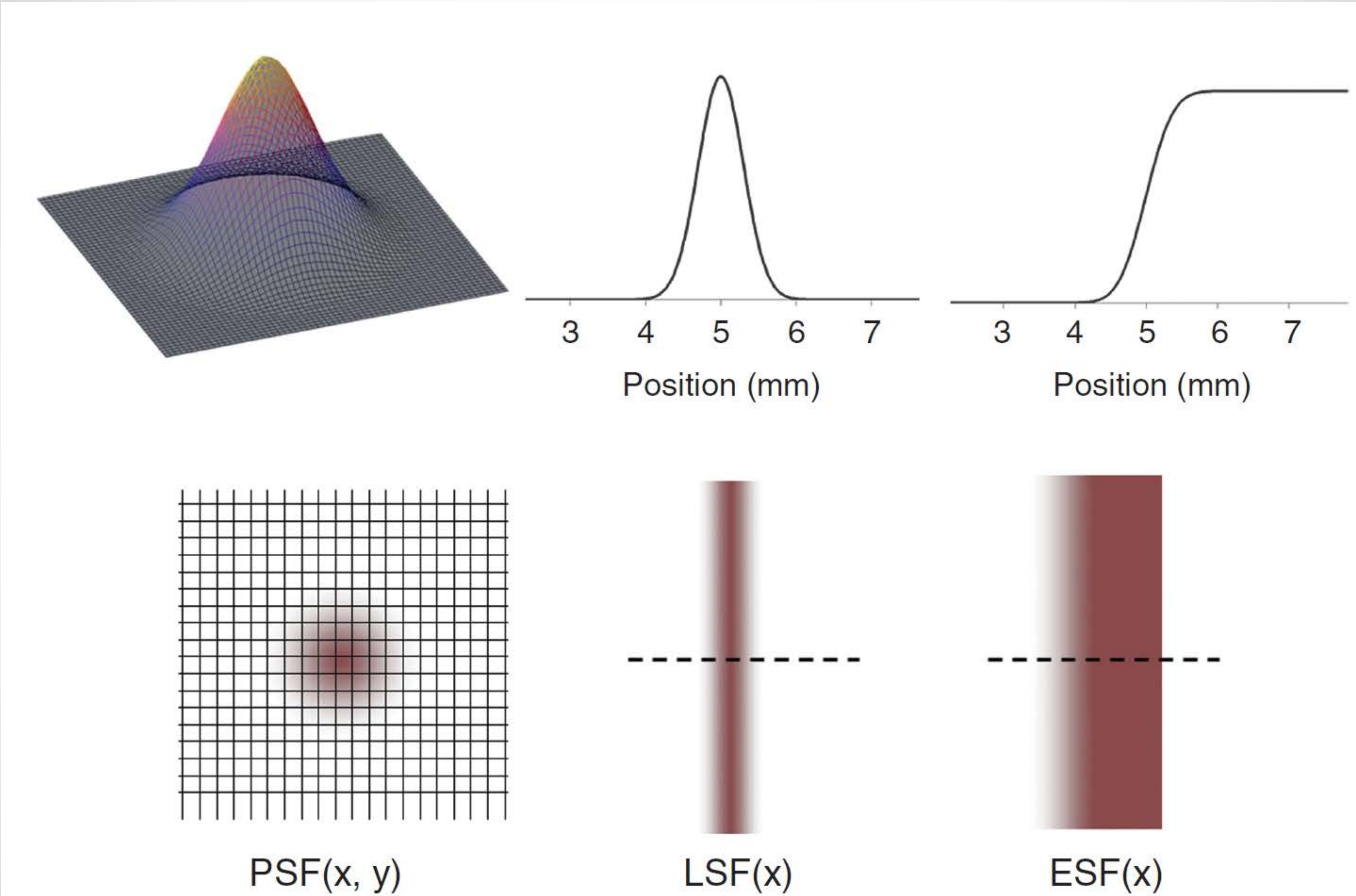


The Line Spread Function (LSF)

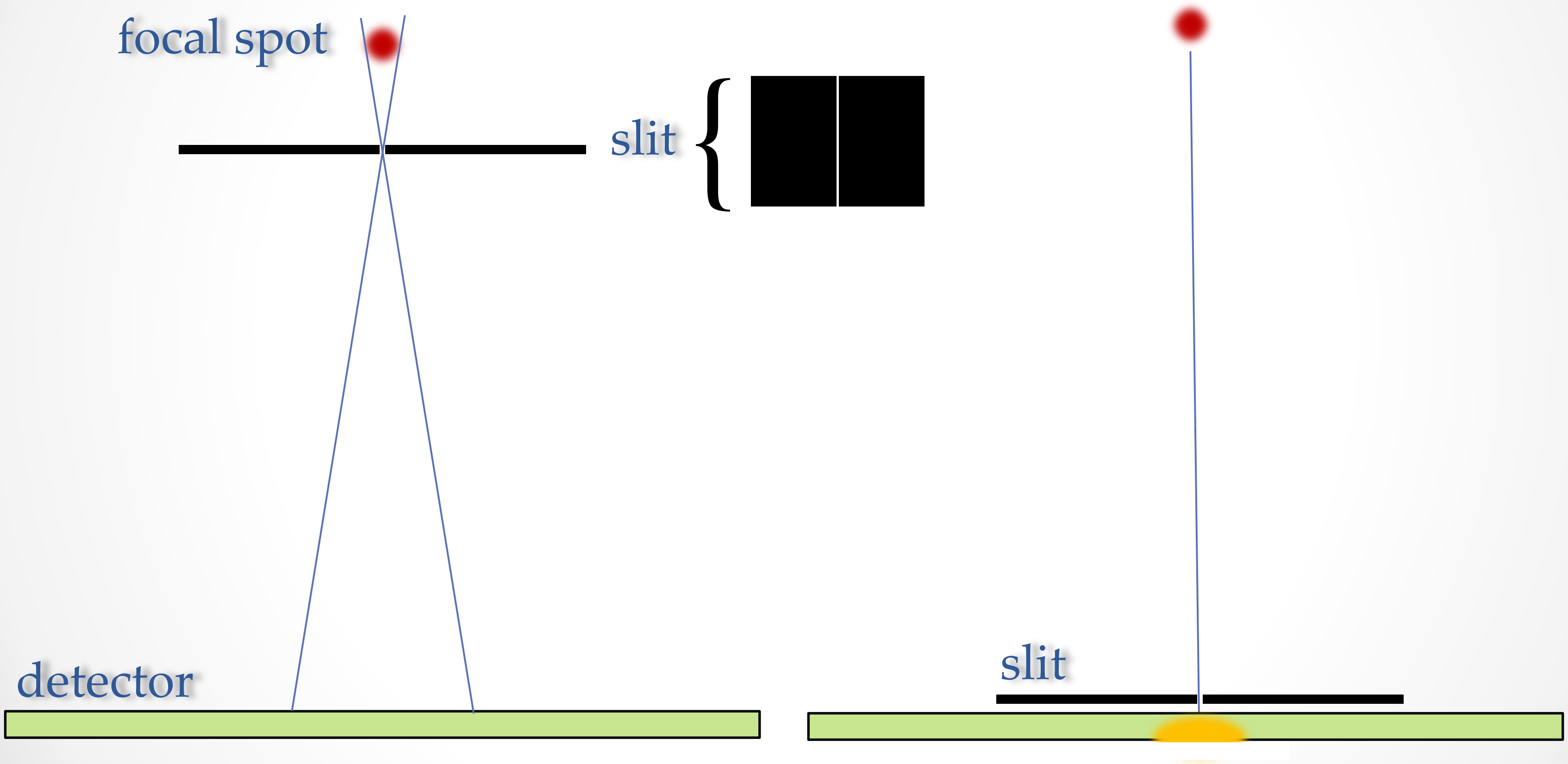


The Edge Spread Function (ESF)




3
4
5
6
7
Position (mm)
3
4
5
6
7
Position (mm)
PSF(x, y)
LSF(x)
ESF(x)

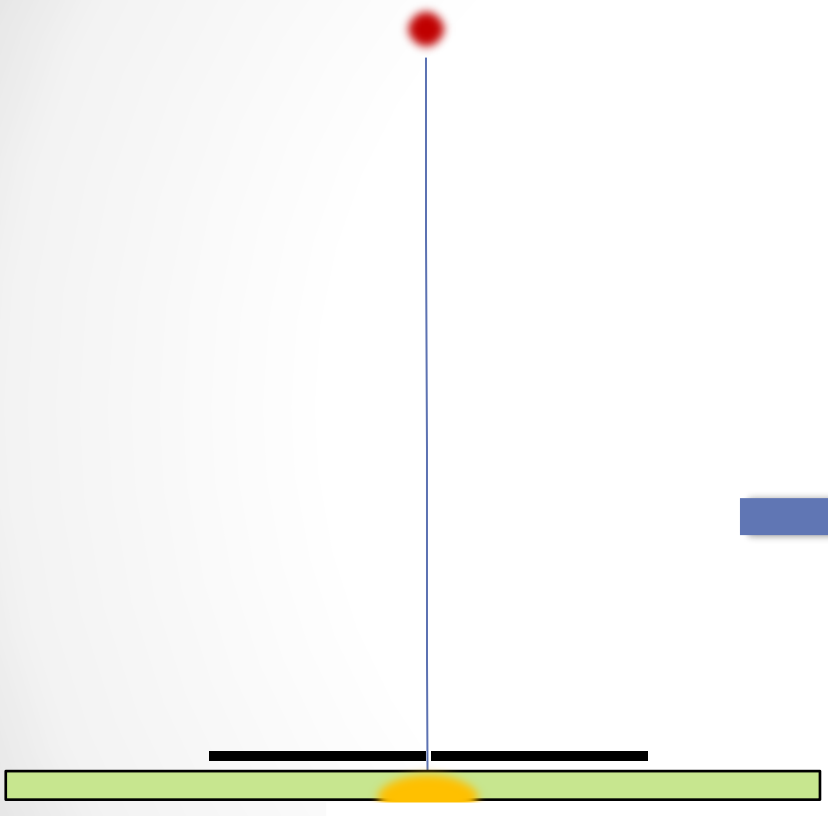
The Line Spread Function – *lsf*(x) – "slit image"



measures focal spot resolution

measures detector resolution

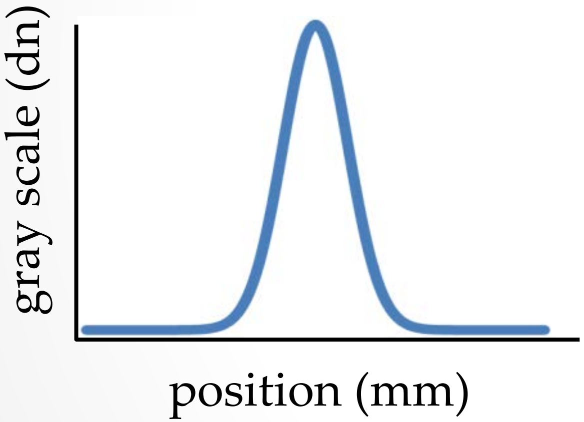
The Line Spread Function – *lsf*(x) – "slit image"



measurement geometry

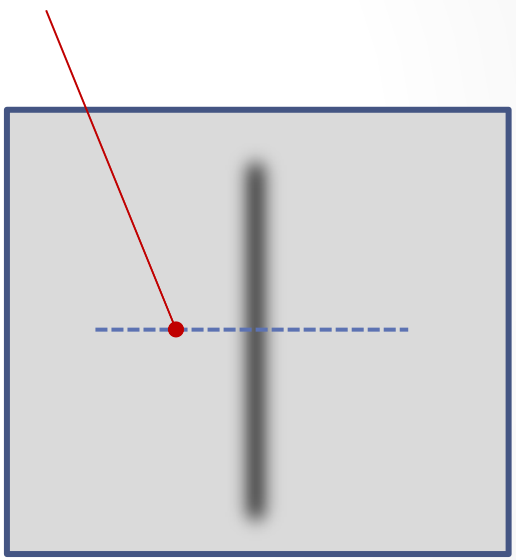
resulting image of slit

The Line Spread Function – *lsf*(*x*) – "slit image"



actual *lsf*(*x*)

orthogonal trace thru slit

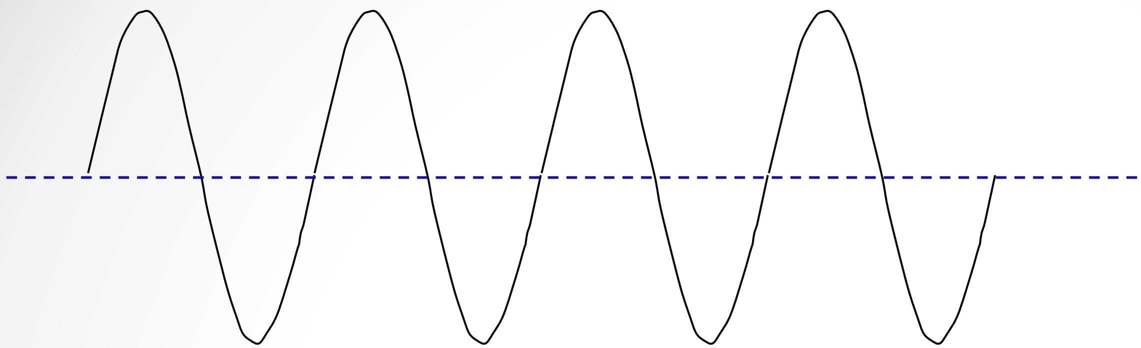


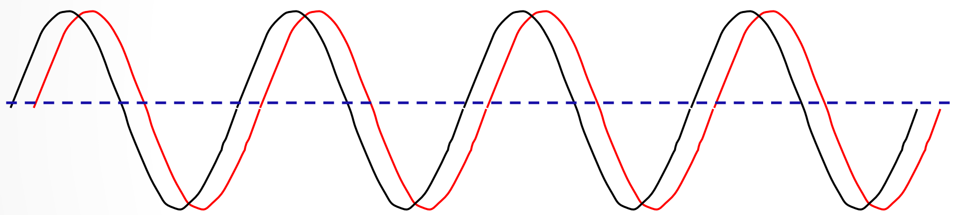
resulting image of slit

Fourier Representation

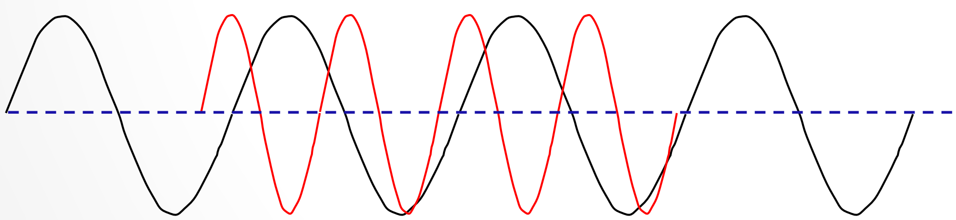
sine waves 101

$$g(x) = A \sin(2\pi f x + \phi)$$

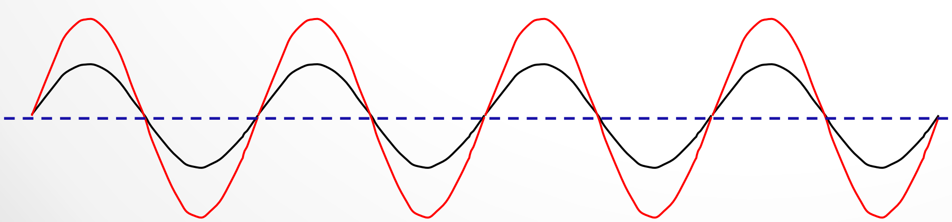




different phase



different frequency



different amplitude

complex

$$OTF(f) = \frac{\int_{-\infty}^{\infty} lsf(x) \quad e^{-2\pi i f x} \quad dx}{\int_{-\infty}^{\infty} lsf(x) \quad dx}$$

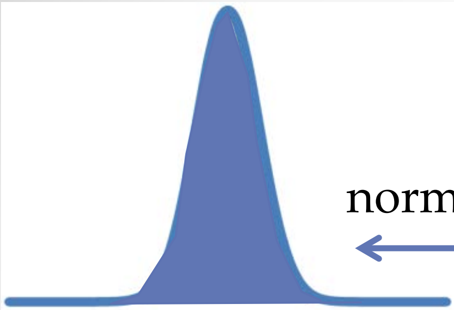
$$MTF(f) = \left\| OTF(f) \right\|$$

$$MTF(f) = \sqrt{\Re[OTF(f)]^2 + \Im[OTF(f)]^2}$$

real

real

imaginary

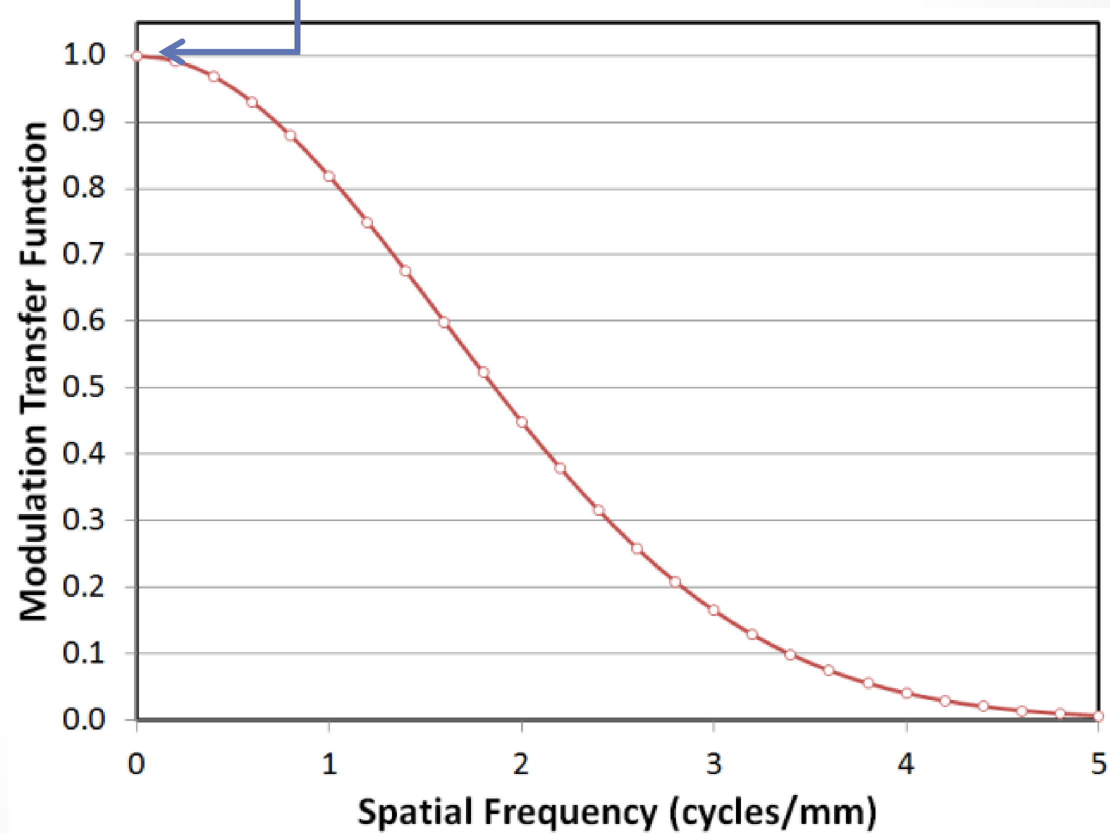


$lsf(x)$

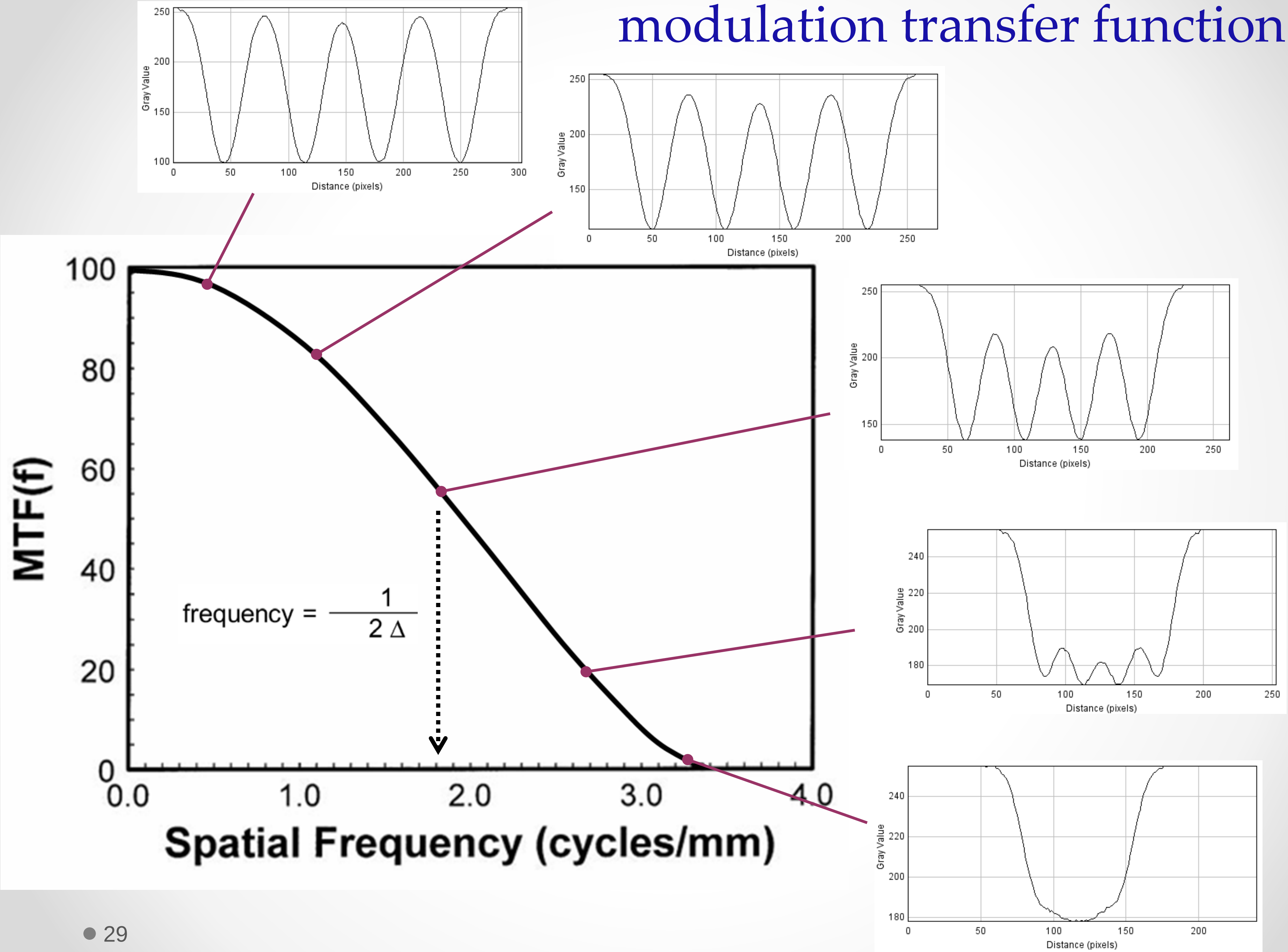
$$\frac{\int_{-\infty}^{\infty} lsf(x) \quad e^{-2\pi i f x} \quad dx}{\int_{-\infty}^{\infty} lsf(x) \quad dx}$$

normalizes area to 1.0

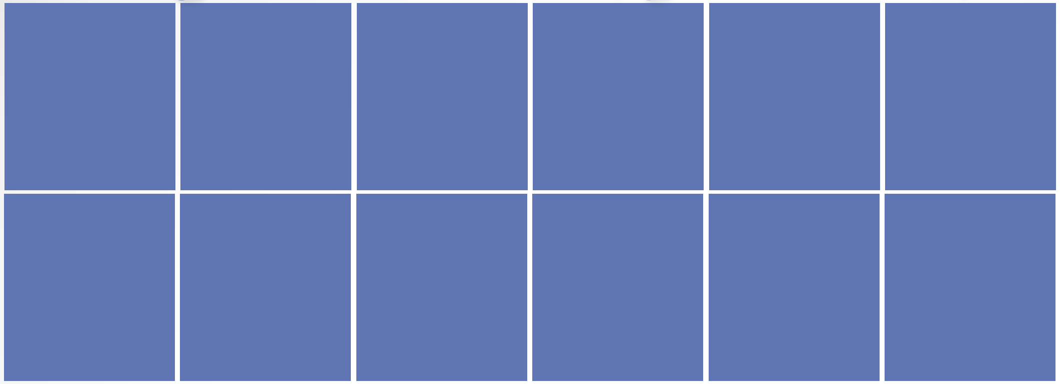
$MTF(f)$



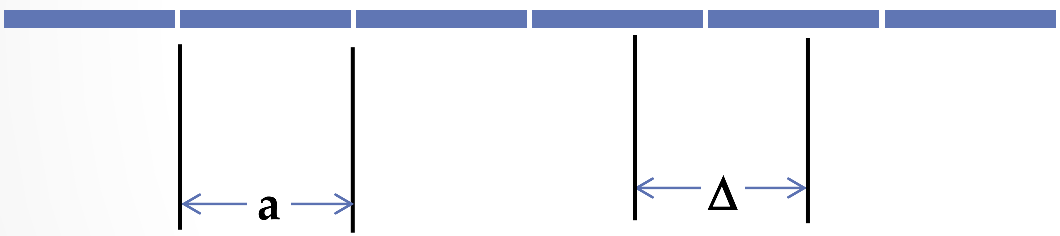
modulation transfer function



Direct Digital Detectors (*eg* Selenium)



top view of
detector array

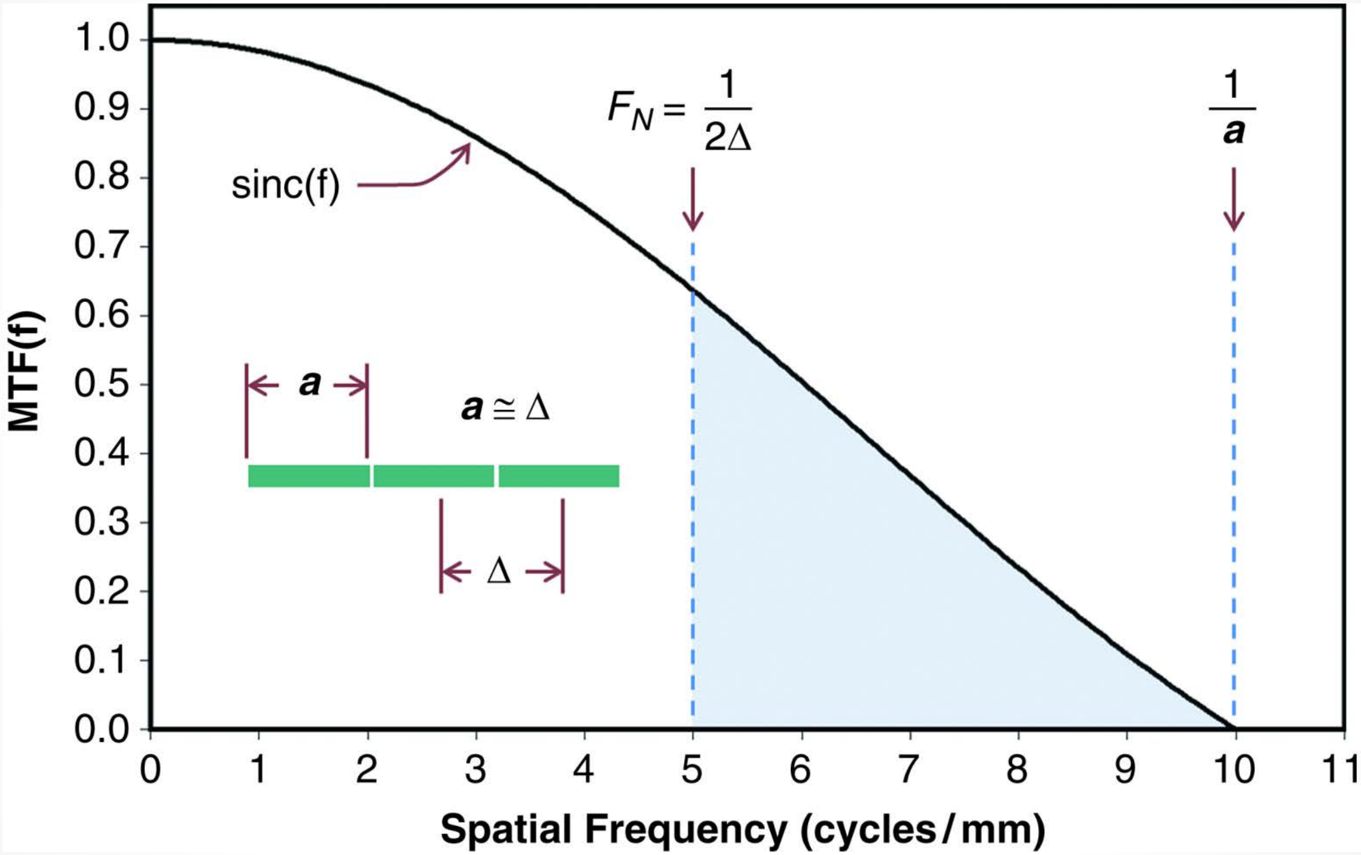


side view

aperture – *lsf*(*x*)   pitch – *Nyquist*

$$F_N = \frac{1}{2\,\Delta}$$

lsf(*x*) = RECT{x/a}



MTF(f)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
sinc(f)
$F_N = \frac{1}{2\Delta}$
$\frac{1}{a}$
a
$a \cong \Delta$
Δ
0
1
2
3
4
5
6
7
8
9
10
11
Spatial Frequency (cycles / mm)

other considerations

Pre-sampled LSF / ESF

Type of Image Processing

- flat fielding OK
- dead pixel correction OK
- "for presentation" not OK

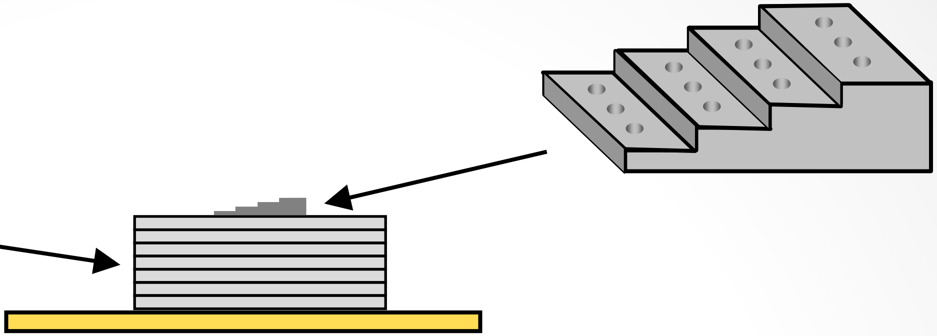
Paralax issues

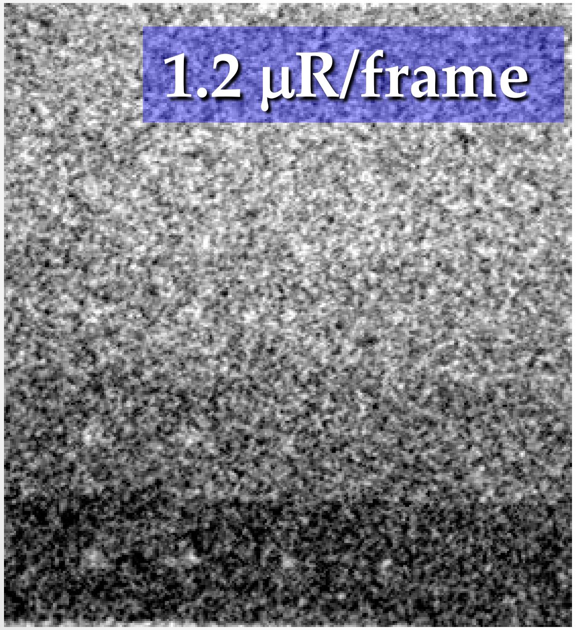
Image Quality Parameters and their Measurement

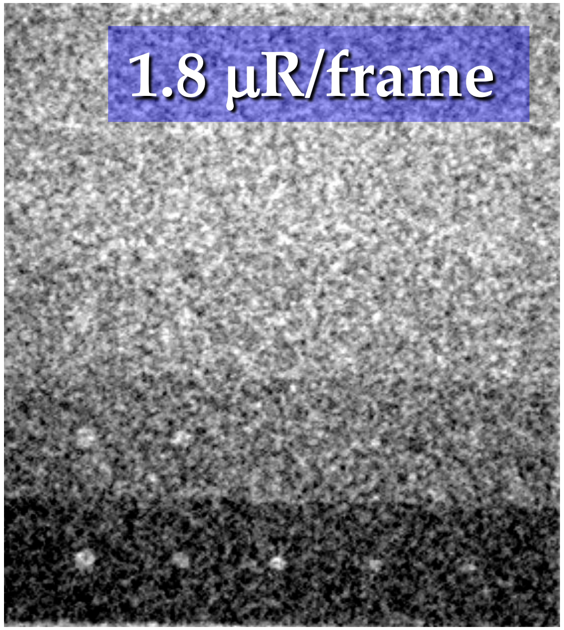
- Linear Systems / Stationary Behavior
- Spatial Resolution
- Contrast Resolution (noise)
- Signal to Noise Ratio
- Summary

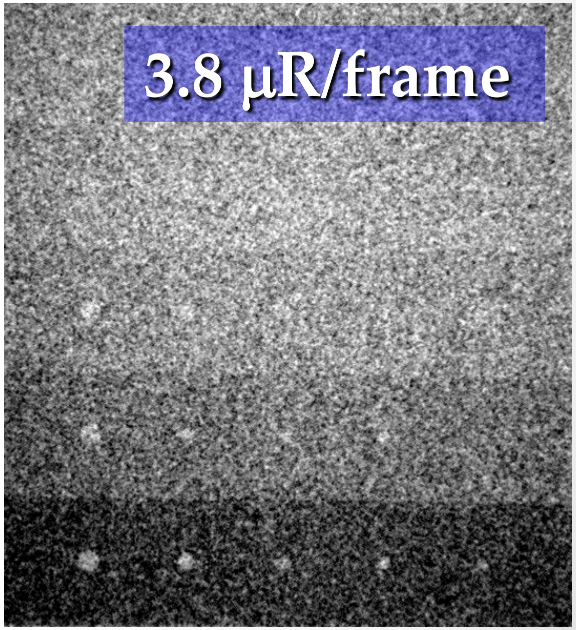
Field Measurement

contrast resolution



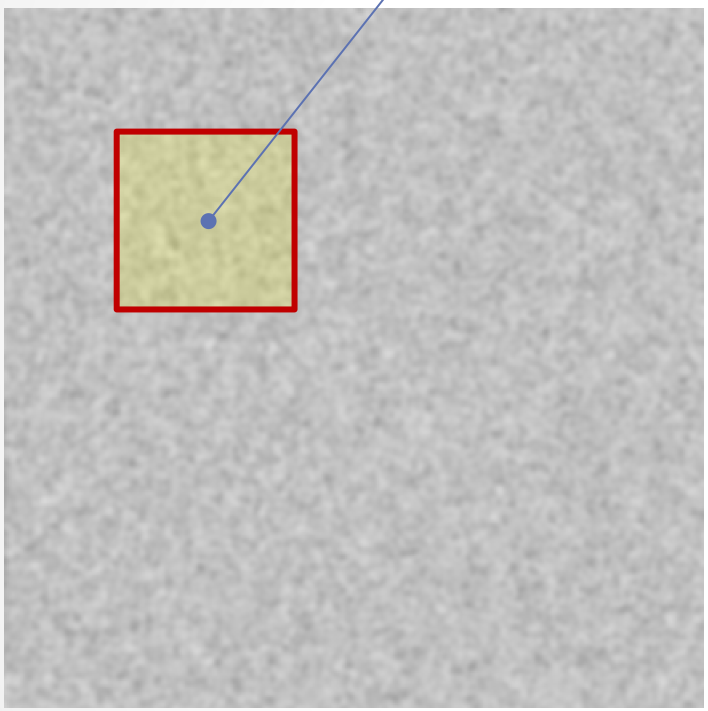






First Order Determination of Noise

region on interest (ROI)



digital image

N = number of pixels in ROI

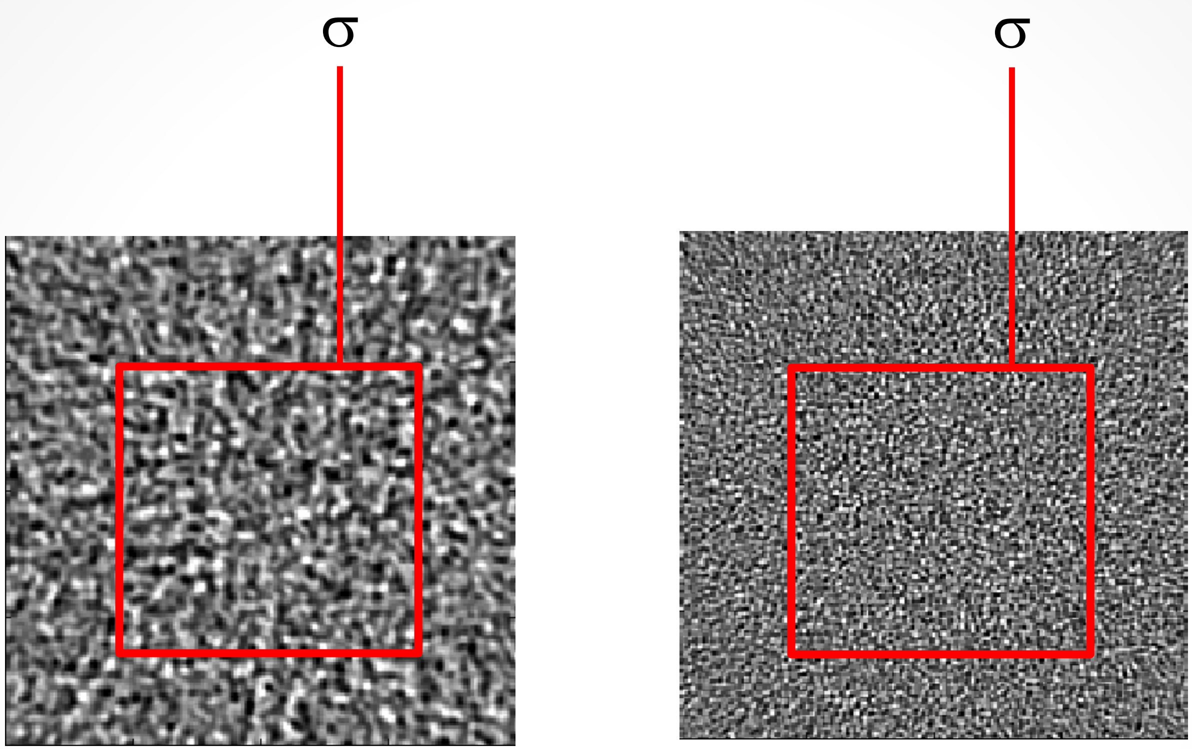
$h_i(x,y)$: the data in the ROI

$$\sigma^2 = \frac{1}{N-1} \sum_{i=1}^{N} \left(I_i(x,y) - \bar{I} \right)^2$$

$$\sigma = \sqrt{\sigma^2}$$

"noise"

Scientific Characterization



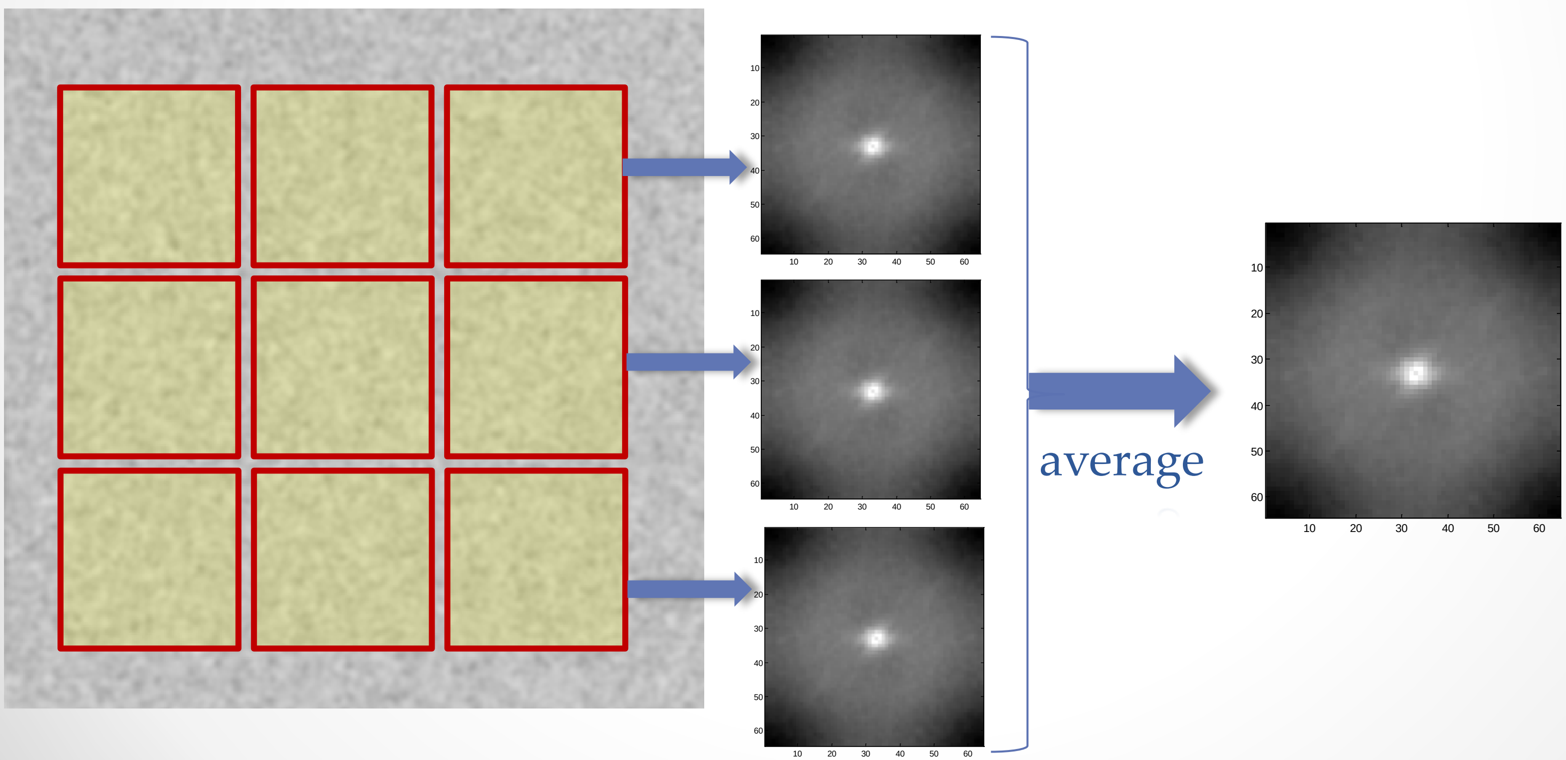
But "noise", or the standard deviation σ, does not tell the whole story

The Noise Power Spectrum (NPS) or Wiener Spectrum

$$NPS(f_x, f_y) = \frac{1}{N} \sum_{i=1}^{N} \left(\int_{x=-\infty}^{\infty} \int_{y=-\infty}^{\infty} \left(I_i(x,y) - \bar{I} \right)^2 e^{-2\pi i (f_x x + f_y y)} \, dxdy \right)$$

analytical equation

N regions on interest (ROIs)

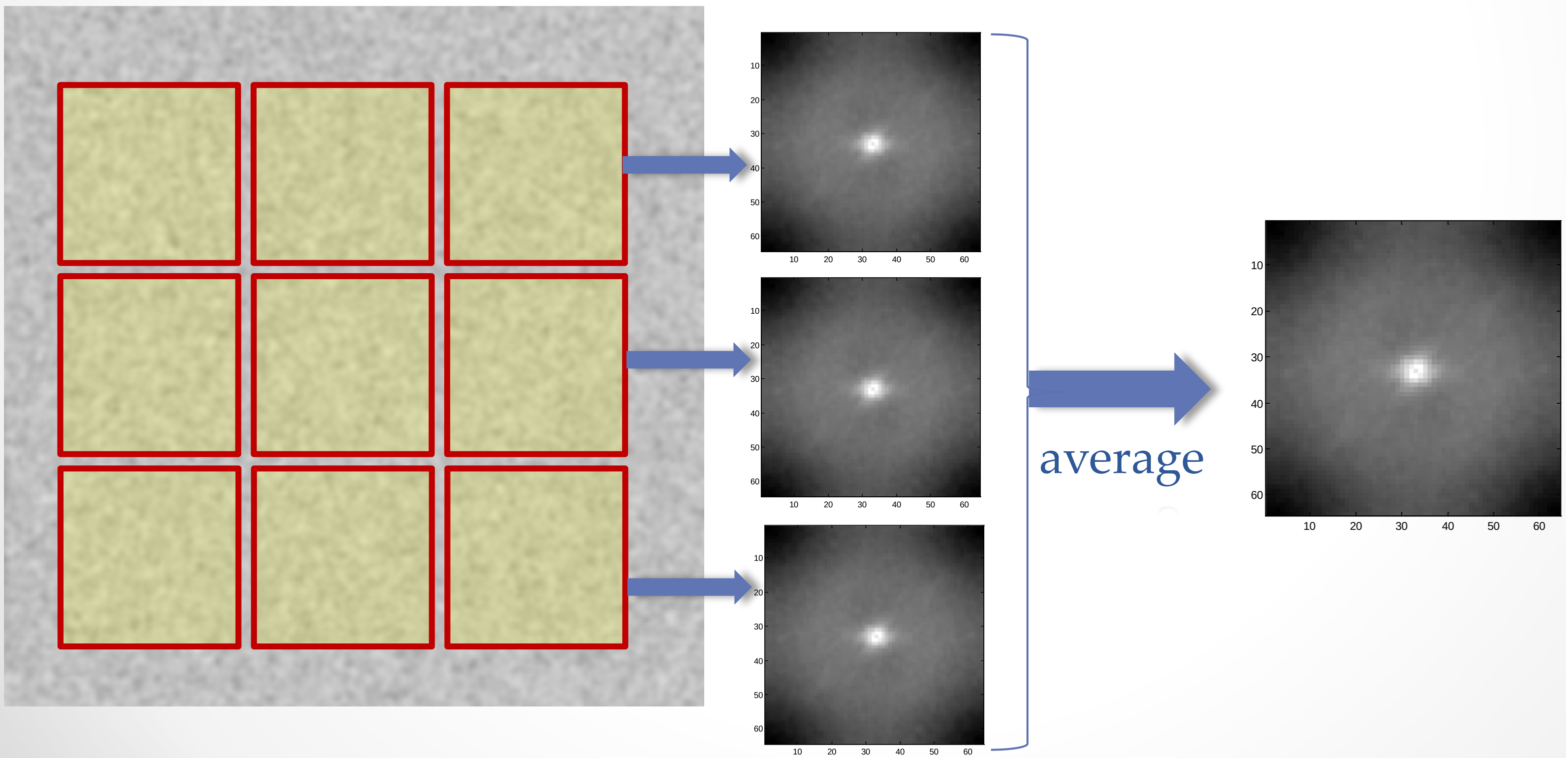


The Noise Power Spectrum (NPS) or Wiener Spectrum

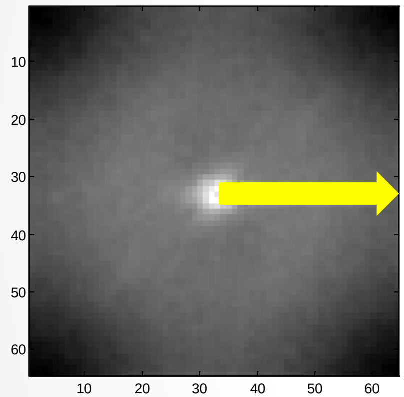
$$NPS(f_x, f_y) = \frac{1}{N} \sum_{i=1}^{N} \left| DFT_{2D}[I_i(x,y) - \bar{I}_i] \right|^2 \frac{\Delta_x \Delta_y}{N_x N_y}$$

discrete implementation

N regions on interest (ROIs)

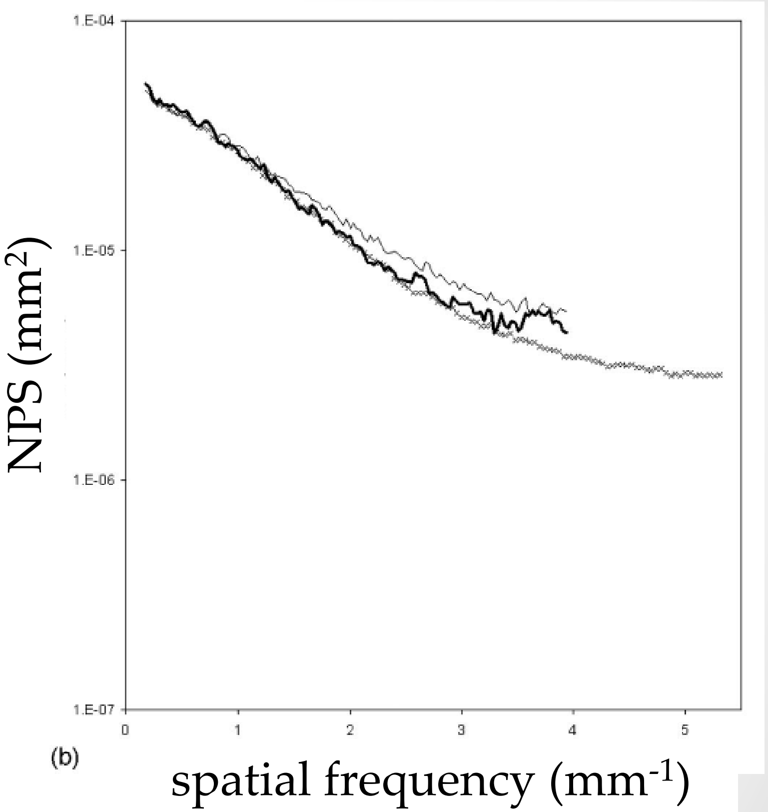


The Noise Power Spectrum (NPS) or Wiener Spectrum

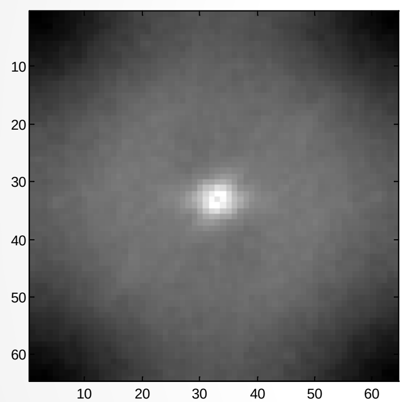


$$f_r = \sqrt{f_x^2 + f_y^2}$$

radial average

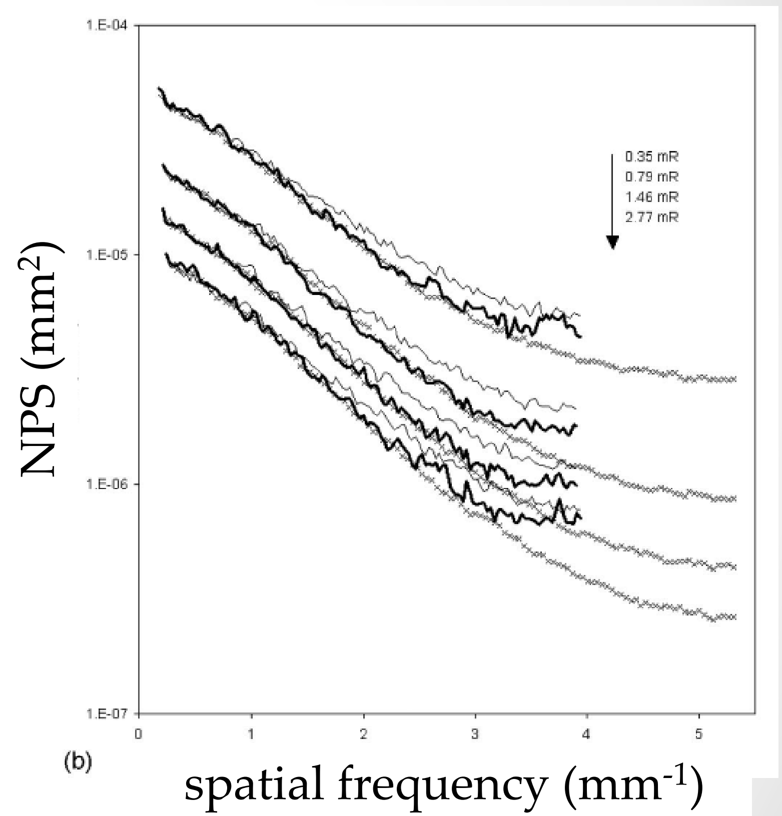


The Noise Power Spectrum (NPS) or Wiener Spectrum



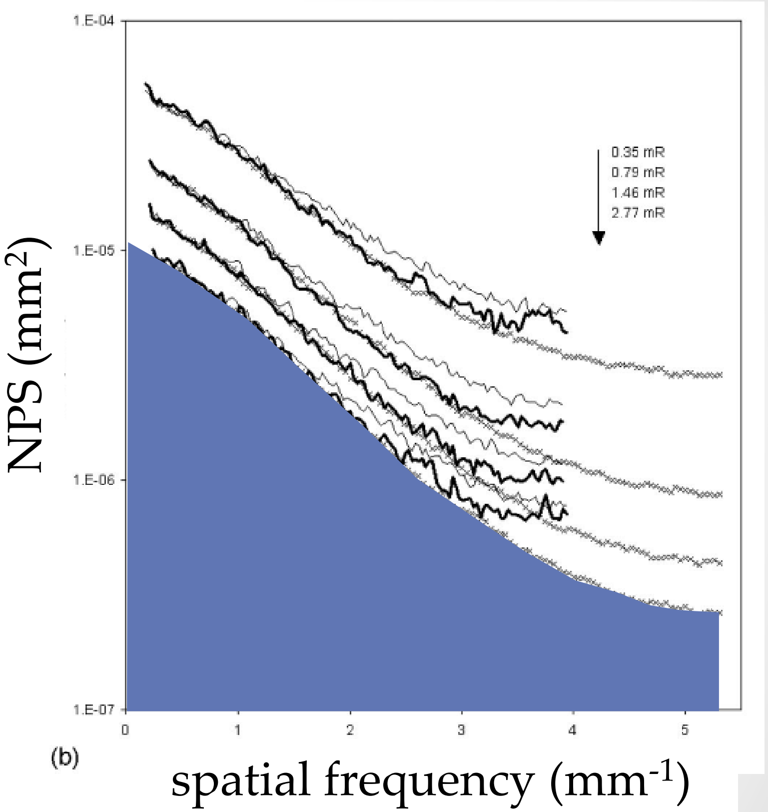
$$f_r = \sqrt{f_x^2 + f_y^2}$$

radial average

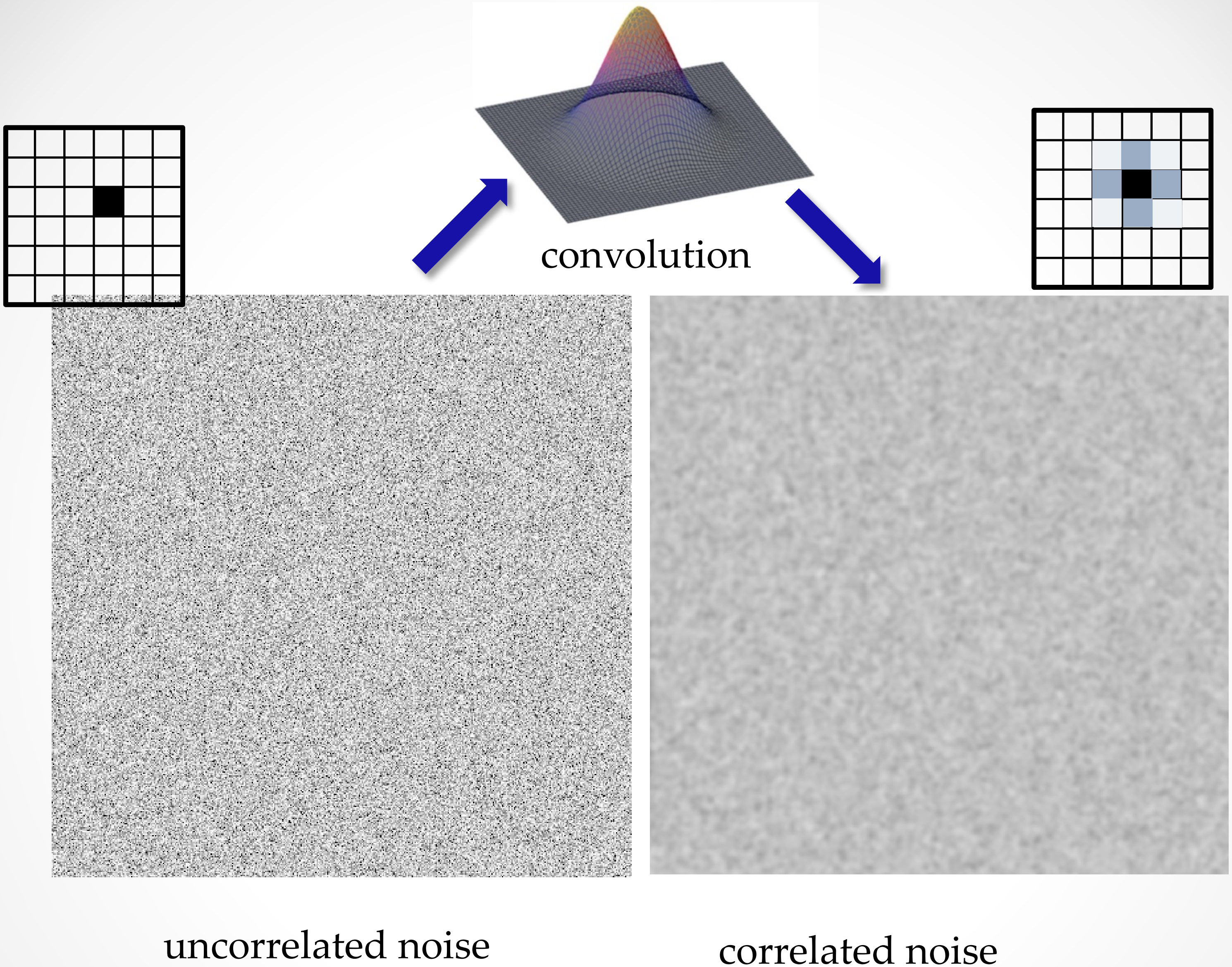


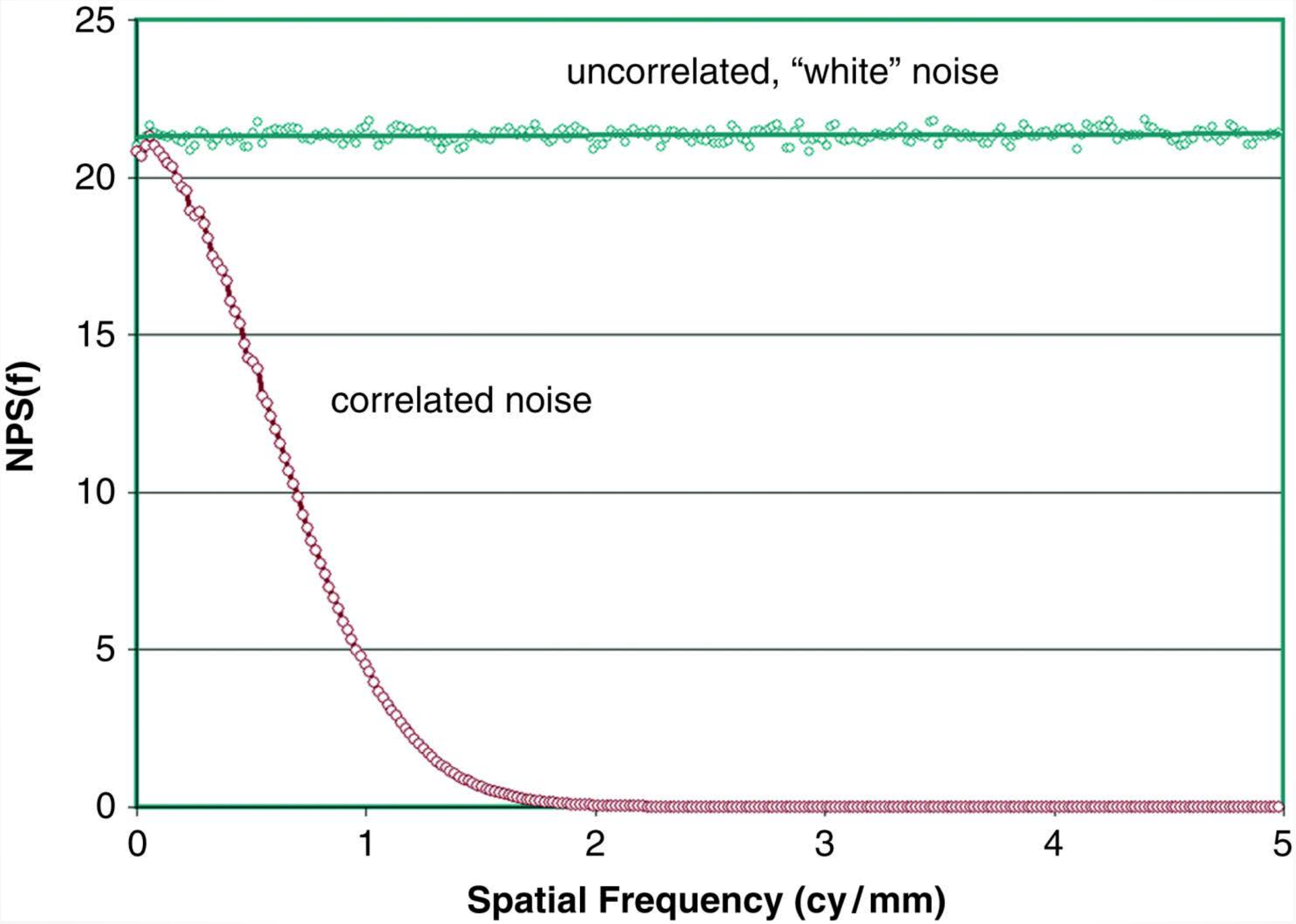
The Noise Power Spectrum (NPS) or Wiener Spectrum

$$\sigma^2$$



$$\sigma^2 = \int NPS(f) \quad df$$


convolution
uncorrelated noise
correlated noise



uncorrelated, “white” noise
correlated noise
NPS(f)
Spatial Frequency (cy / mm)
25
20
15
10
5
0
0
1
2
3
4
5

Image Quality Parameters and their Measurement

- Linear Systems / Stationary Behavior
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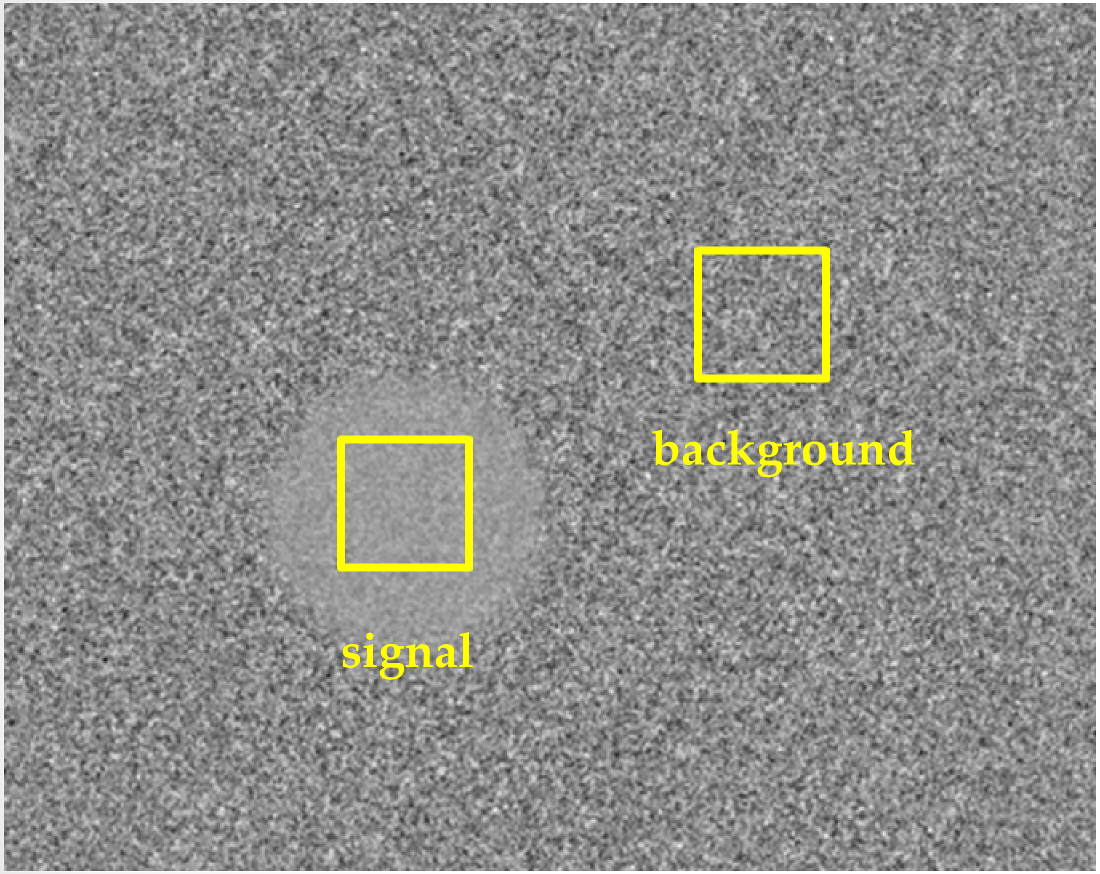
- Summary

Field Measurement

Signal difference to noise ratio (SDNR)

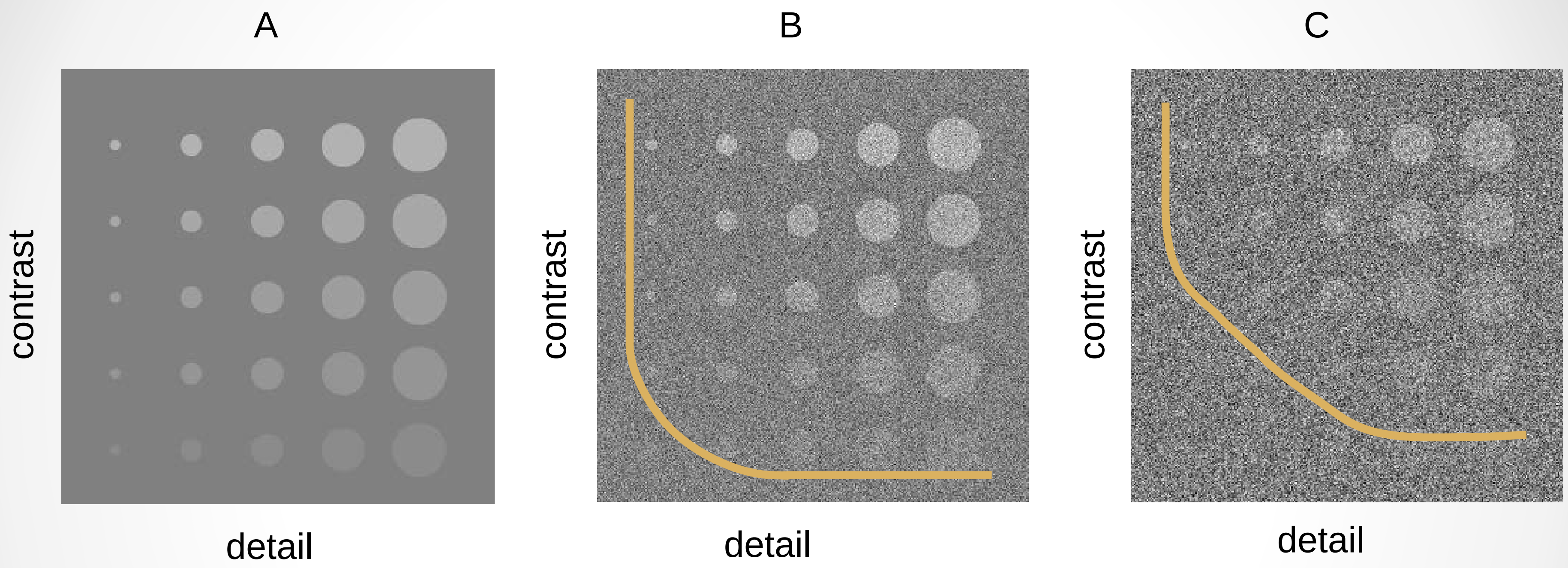
Contrast to Noise Ratio (CNR)



$$SDNR = \frac{\bar{x}_s - \bar{x}_{bg}}{\sigma_{bg}}$$

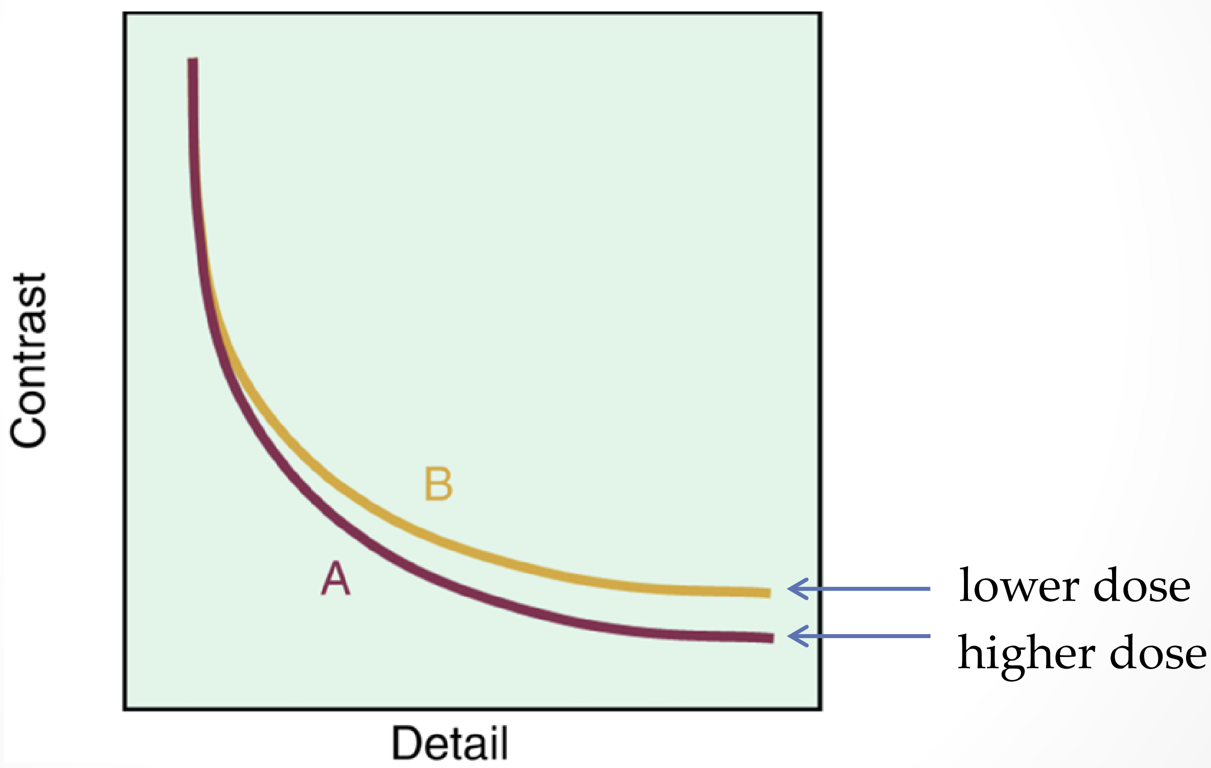
$$SDNR = \frac{\bar{x}_s - \bar{x}_{bg}}{\sqrt{\sigma_s^2 + \sigma_{bg}^2}}$$

the contrast detail curve



the contrast detail curve

interpretation



Scientific Characterization

$$SNR_{out}^{2}(f) = \frac{MTF^{2}(f)}{NPS(f)}$$

The *Noise Equivalent Quanta* (NEQ)

$$NEQ(f) = \frac{k^{2}\ MTF^{2}(f)}{NPS(f)}$$

$$DQE(f) = \frac{SNR_{out}^2(f)}{SNR_{in}^2(f)} \quad \Leftarrow \quad SNR_{in}^2(f) = q$$

$$DQE(f) = \frac{NEQ(f)}{q}$$

$$DQE(f) = \frac{k^2 \; MTF^2(f)}{q \; NPS(f)}$$

q = mean photons/mm^2 for this acquisition

k = mean GS value

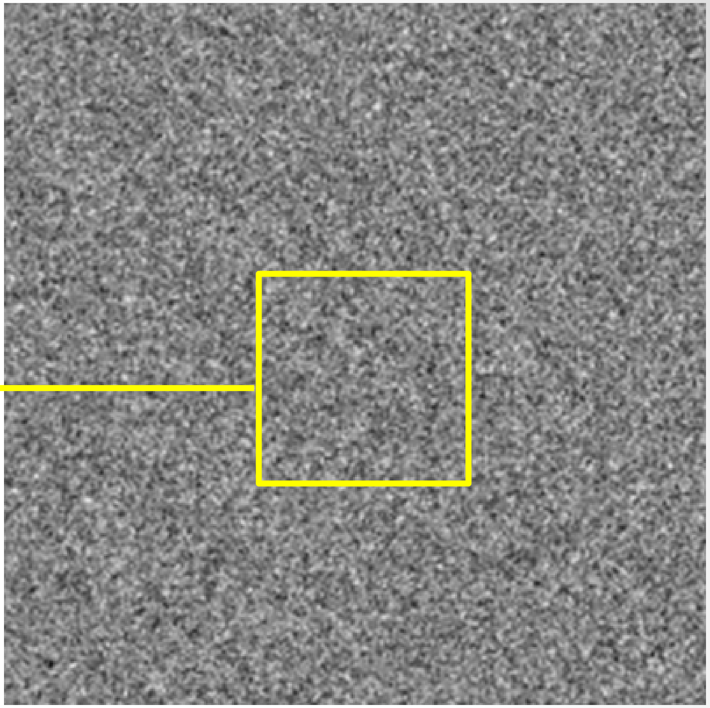
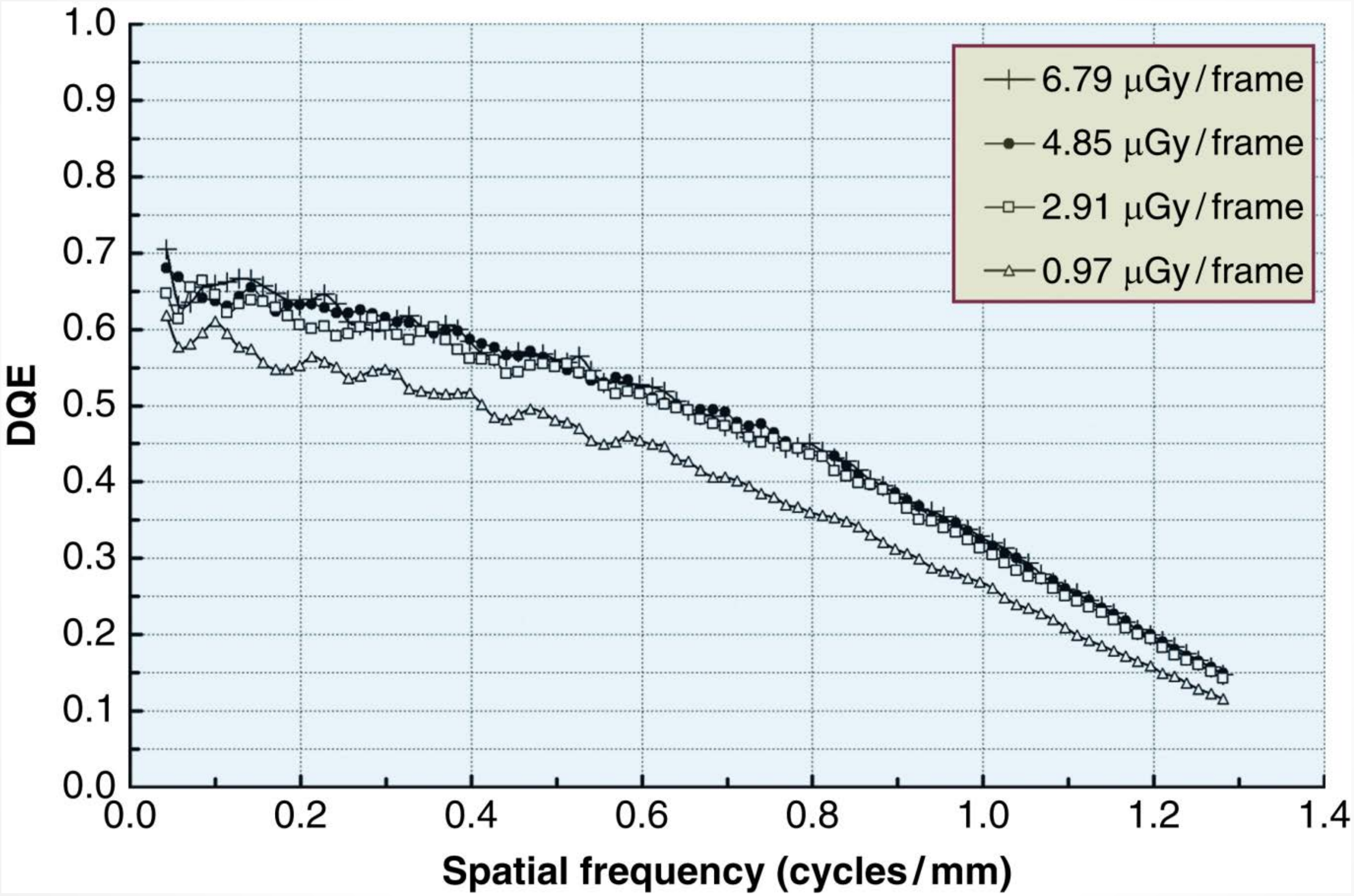


Image acquired to compute NPS(f)

$$DQE(f) = \frac{k^2 \; MTF^2(f)}{q \; NPS(f)}$$

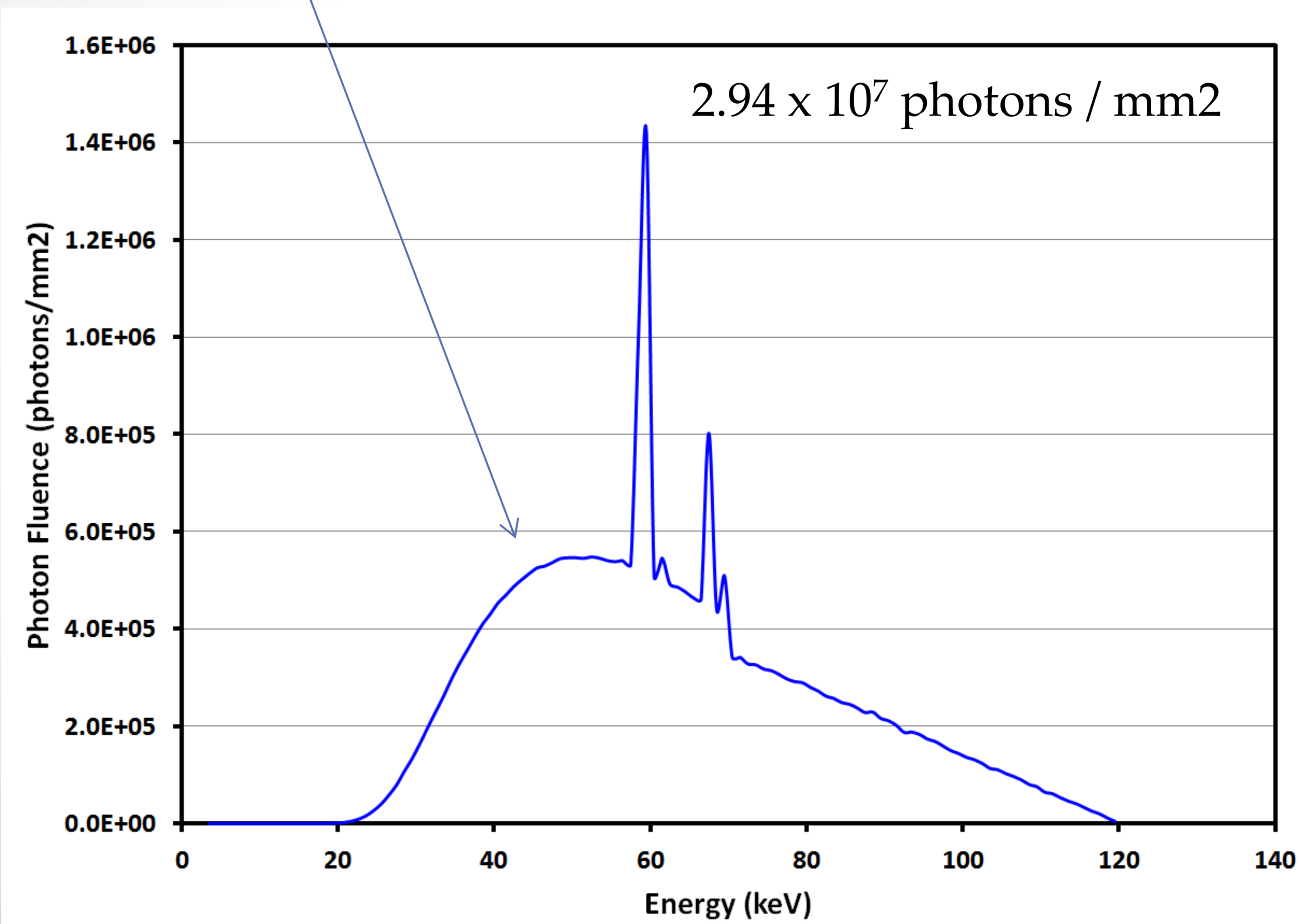
detective quantum efficiency (DQE)



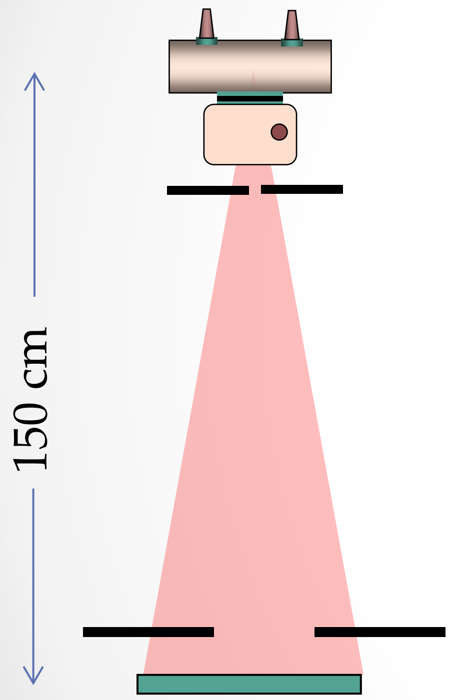
To determine *q*:

…some spectral modeling required

120 kV / 1.0 mGy air kerma incident



IEC: *International Electrotechnical Commission* (IEC 61267-1)



DQE measurement geometry

Radiation Quality Designation	Tube Voltage	~added Filtration (mm Al)	HVL (mm Al)
RQA3	50 kV	10	4.0
RQA5	70 kV	21	7.1
RQA7	90 kV	30	9.1
RQA9	120 kV	40	11.5

- *IEC values courtesy Nicole T. Ranger on line presentation*

Image Quality Parameters

and their Measurement

Linear Systems / Stationary Behavior

Spatial Resolution

Contrast Resolution (noise)

Signal to Noise Ratio

Summary

Summary

Field measurements of image quality are adequate

but are subjective and imprecise

Scientific measurements are useful in detector evaluation

but their quantitative nature is desirable

Digital radiography QC should convert to quantitative measures in time

Clinical Medical Physicists should understand MTF, NPS, NEQ, DQE

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