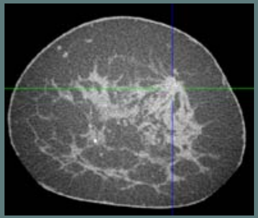
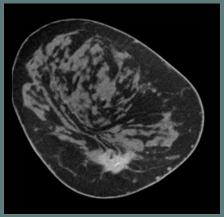

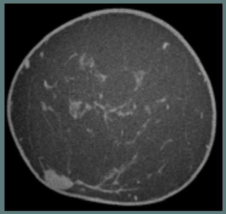
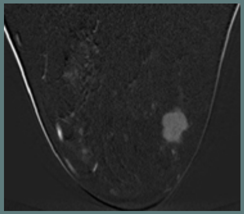
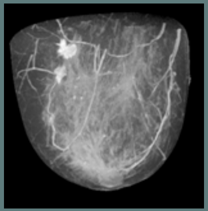
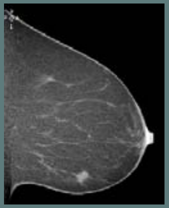
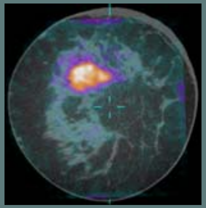

Breast CT (with PET) for Screening, Diagnosis, and Breast Cancer Treatment

The Breast Tomography Project

University of California, Davis

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

Corporate Disclosures (required by UC Davis):

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- Artemis, Consultant
- Varian Imaging Systems, Research Funding
- Hologic Corporation, Research Funding
- Fuji Medical Systems, Research Funding
- Stanford Research Institute, Research Funding (R21 subcontract)
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California BCRP 11I-0114
R21 CA89260
R01 EB002138-06 (BRP)
R01
R01
Susan G. Komen Foundation
University of Pittsburgh

Breast CT (with PET) for Screening, Diagnosis, and Breast Cancer Treatment

Breast Cancer: ➡ 1/8 U.S. Women will be diagnosed

~43,000 deaths per year in U.S.

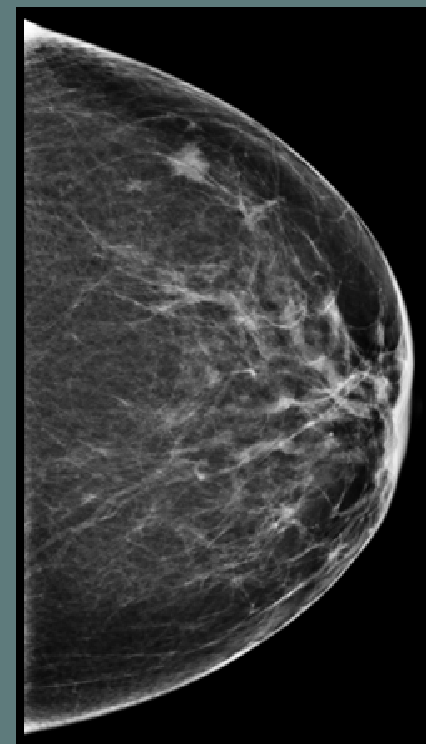
Second leading cause of cancer death in women

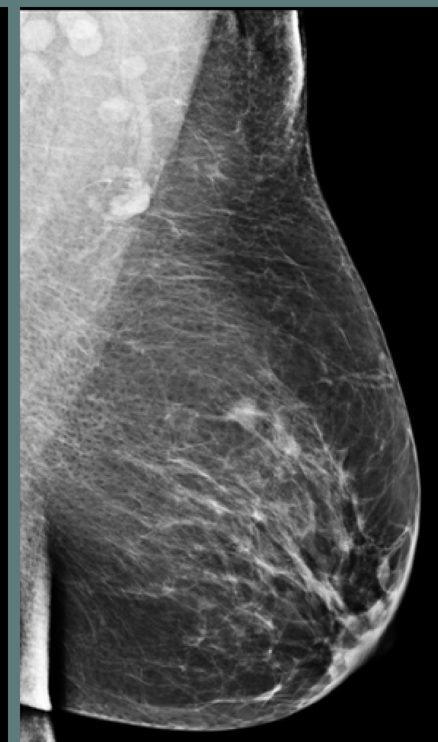
Early detection of breast cancer ➡ better prognosis

Mammography ➡ breast cancer screening

Women age 40 and up


Wendolyn Hill





Breast CT (with PET) for Screening, Diagnosis, and Breast Cancer Treatment

Motivation / System Design & Fabrication

Breast CT Imaging

Radiation Dosimetry

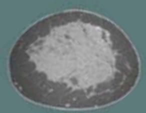
Image Quality Evaluation

Breast Image Analyses

Biopsy and Cancer Therapy

Summary

Breast CT (with PET) for Screening, Diagnosis, and Breast Cancer Treatment



Motivation / System Design & Fabrication

Breast CT Imaging

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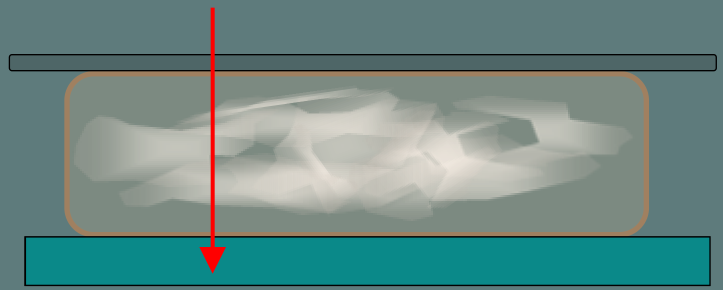
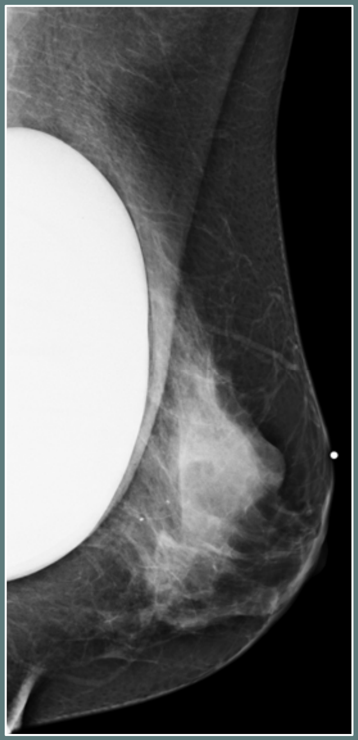
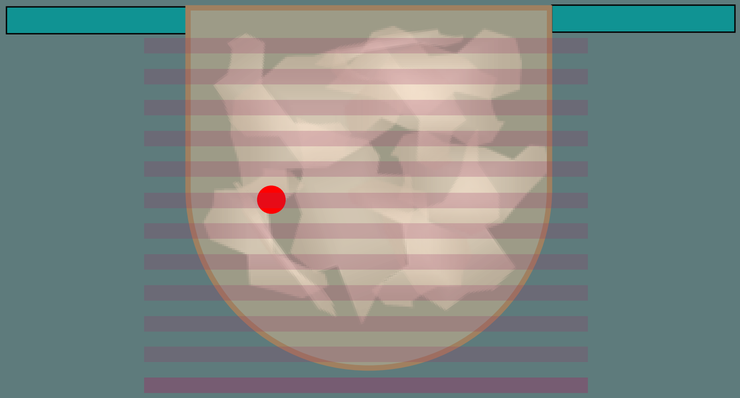
Summary

Mammography

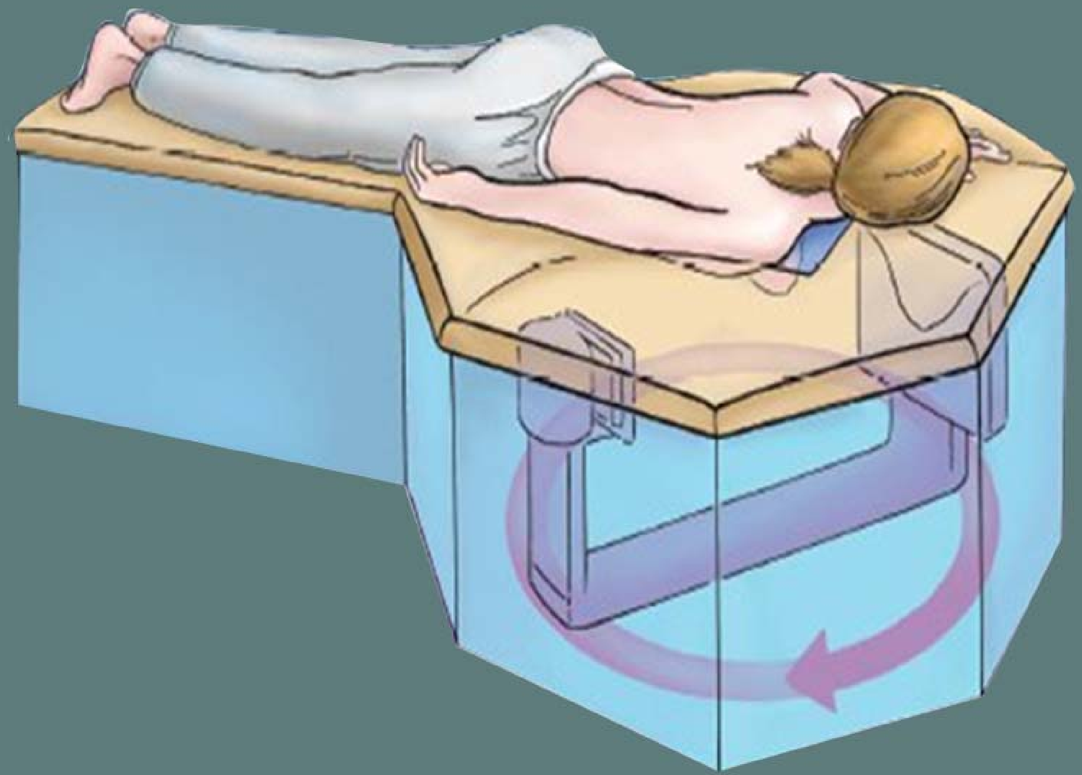




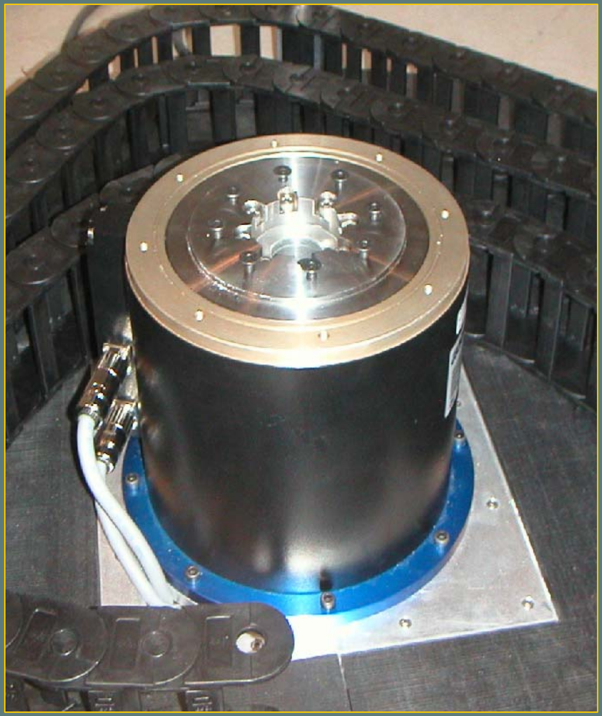
Breast CT



cone beam breast CT system



bodega



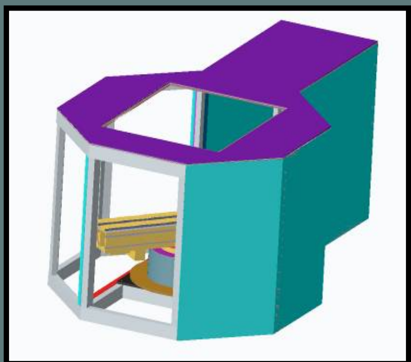
Varian 4030CB
194 mm pixels
2x2 → 388 mm
1024 x 768 x 30 FPS

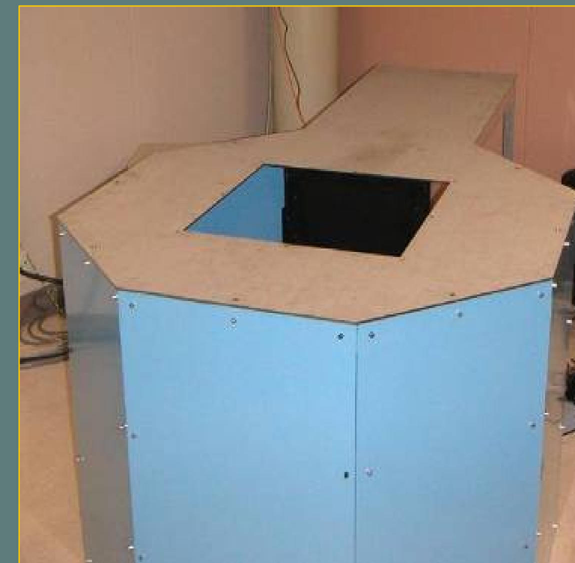
Kollmorgen Motor
- Propulsion
- Bearing
- Angle Encoder

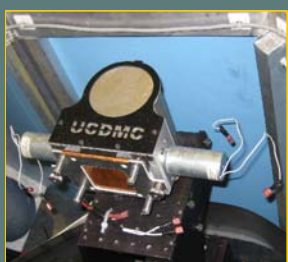
Comet 1 kW Tube
12.5 mA at 80 kVp

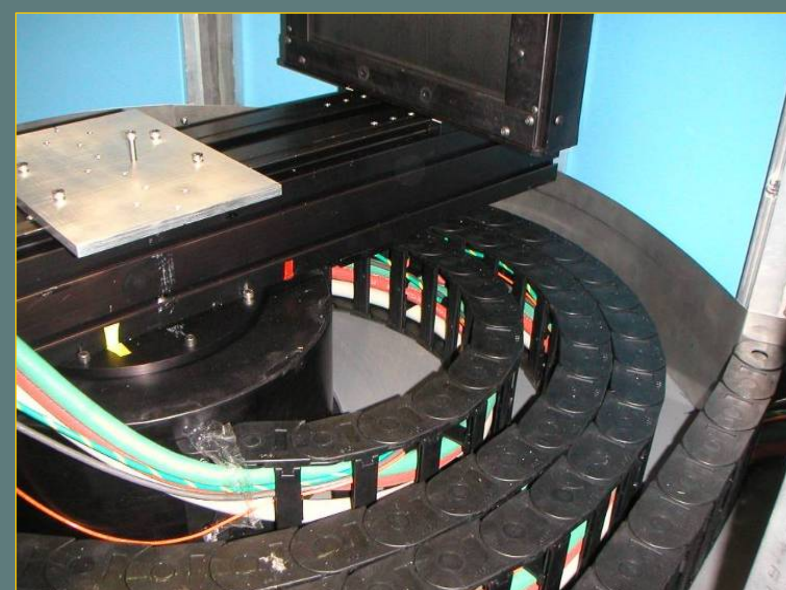
Fabrication ~2003

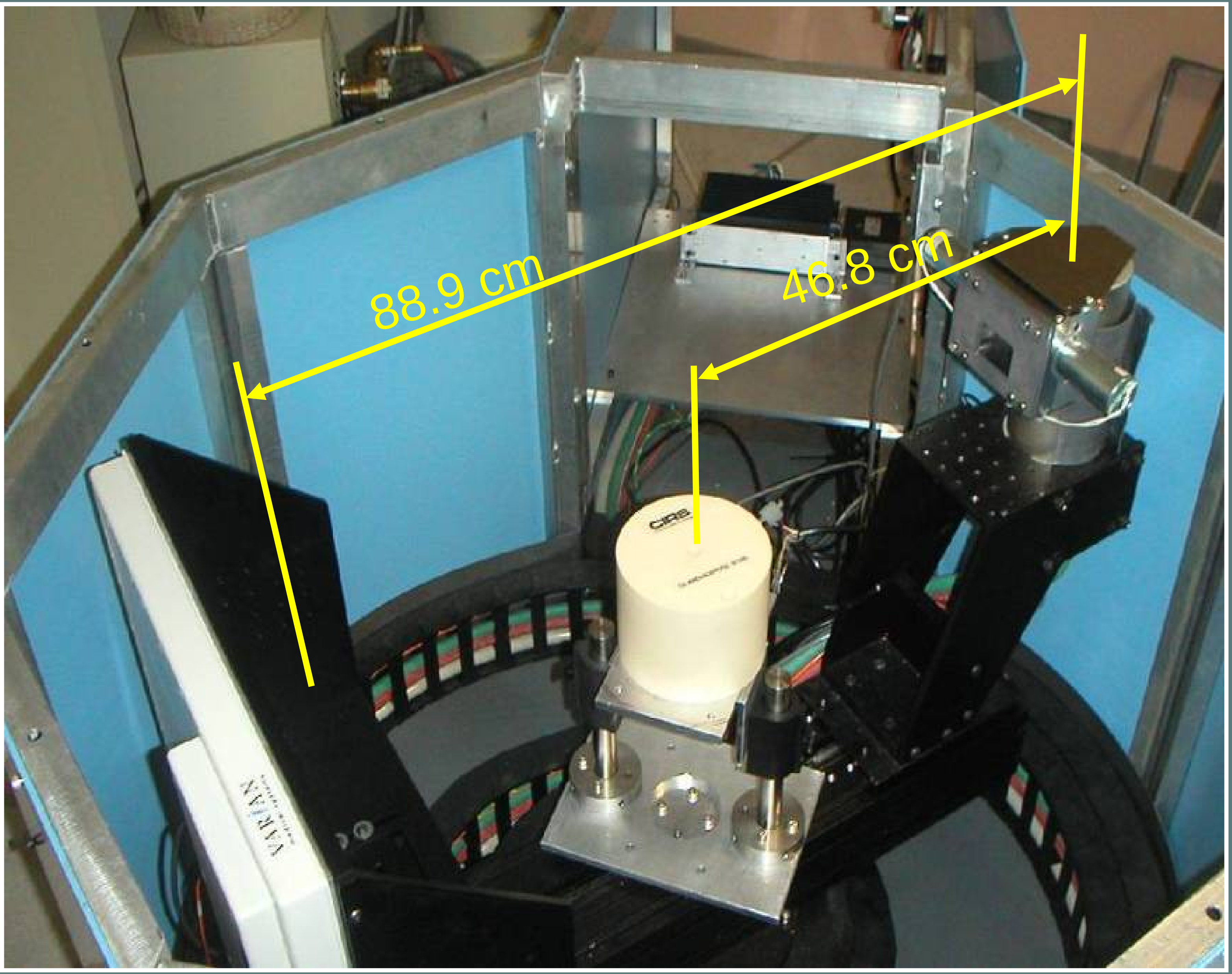
albion







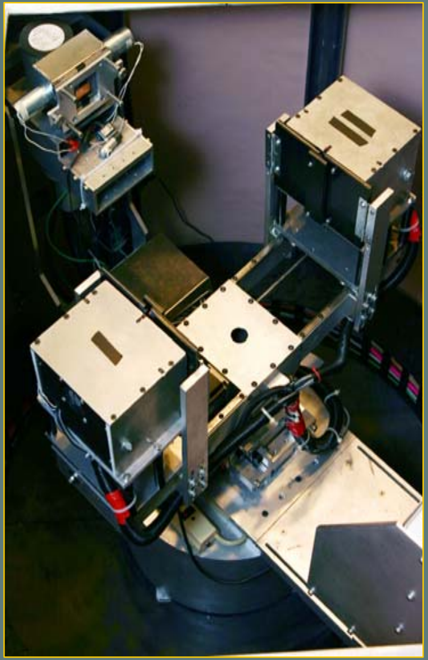
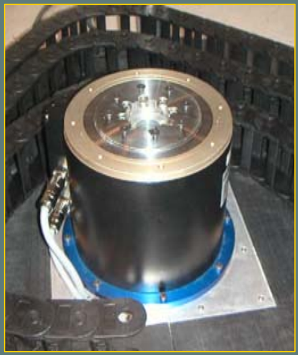



88.9 cm
46.8 cm
VARIAN

bodega

Fabrication
~2007

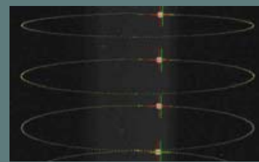


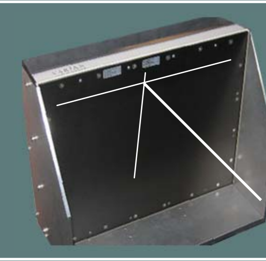



calibration, correction, and reconstruction

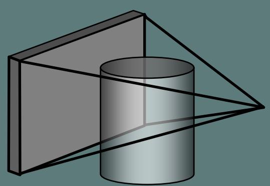
Geometric Calibration

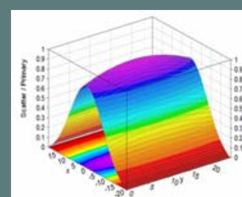


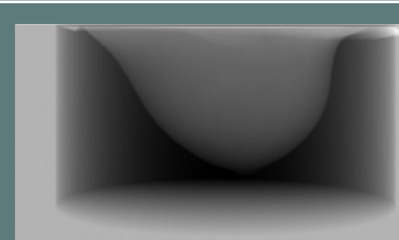
$$u_{wr} = y_{obj}\cdot\frac{D+u_{wr}\cdot\sin\phi}{C+x_{obj}}\cdot\frac{1}{\cos\phi},\quad v_{wr} = z_{obj}\cdot\frac{D+u_{wr}\cdot\sin\phi}{C+x_{obj}}.$$

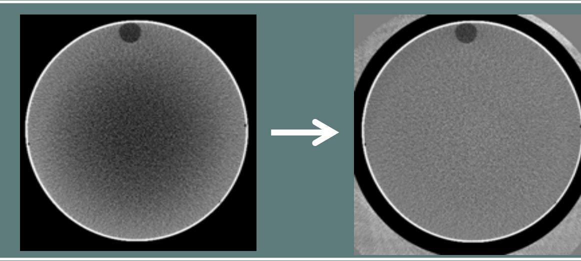


Hounsfield Unit Calibration









Flat Field Correction

$$I_{corr} = \bar{g}\,\frac{\lfloor I_{raw} - I_{r-offset}\rfloor}{\lfloor I_{grain} - I_{g-offset}\rfloor}$$

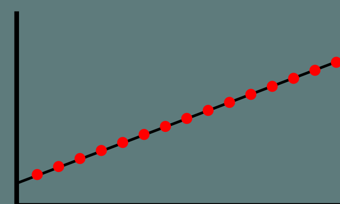
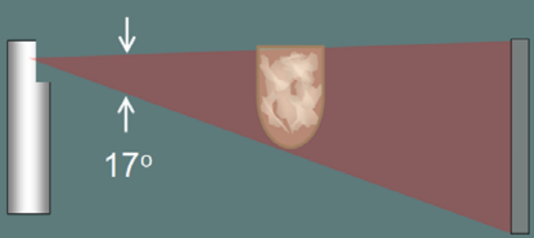
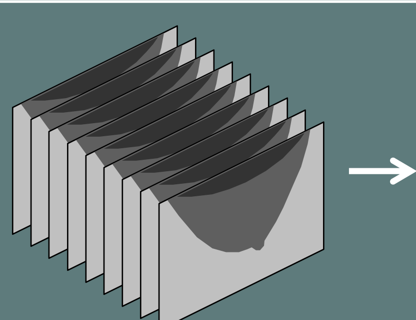
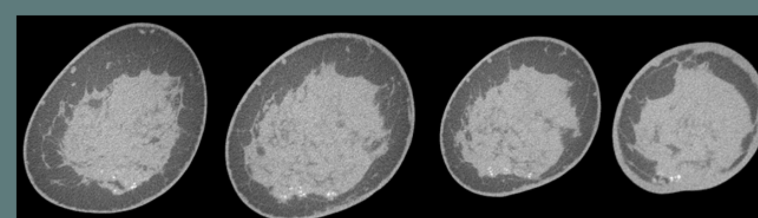
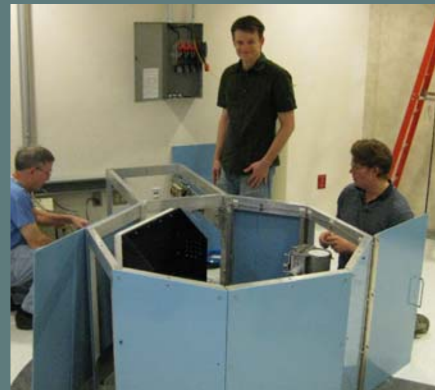


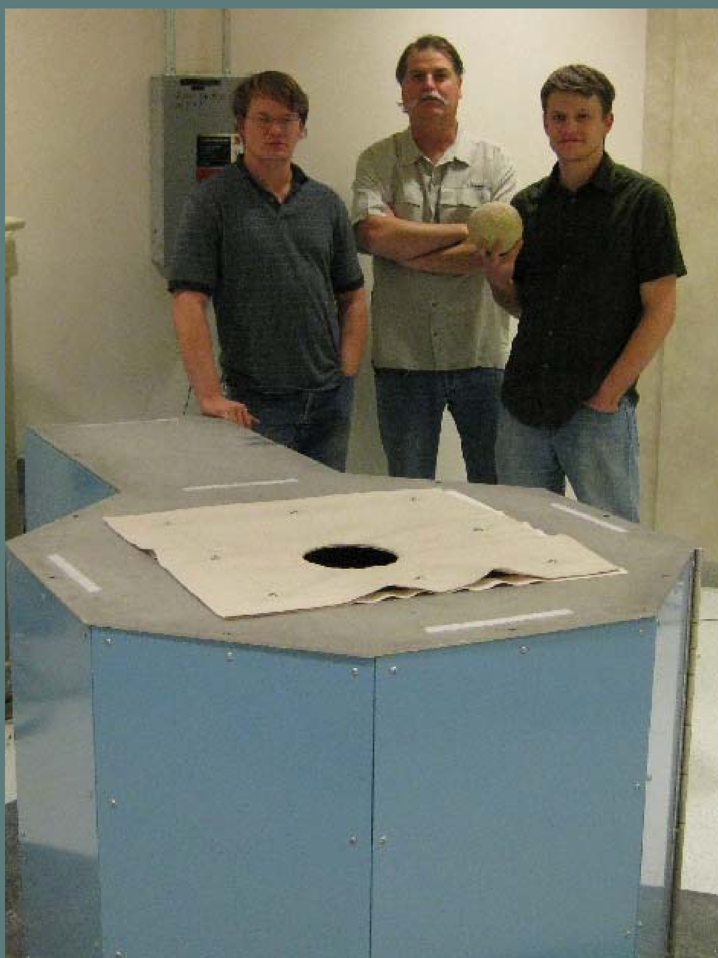
Image Reconstruction








Moved Dec 18, 2008


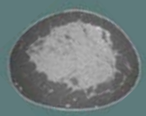




University of Pittsburgh

Breast CT (with PET) for Screening, Diagnosis, and Breast Cancer Treatment

Motivation / System Design & Fabrication



Breast CT Imaging

Radiation Dosimetry

Image Quality Evaluation

Breast Image Analyses

Biopsy and Cancer Therapy

Summary

pendant geometry breast CT scanner

Breast CT Imaging:

~Same radiation dose as two view mammography

~360 patients imaged on two UC Davis bCT

~60 patients imaged with pre/post iodine contrast

(100 ml visopaque 320 @ 4 4ml/sec, ~100 sec delay)

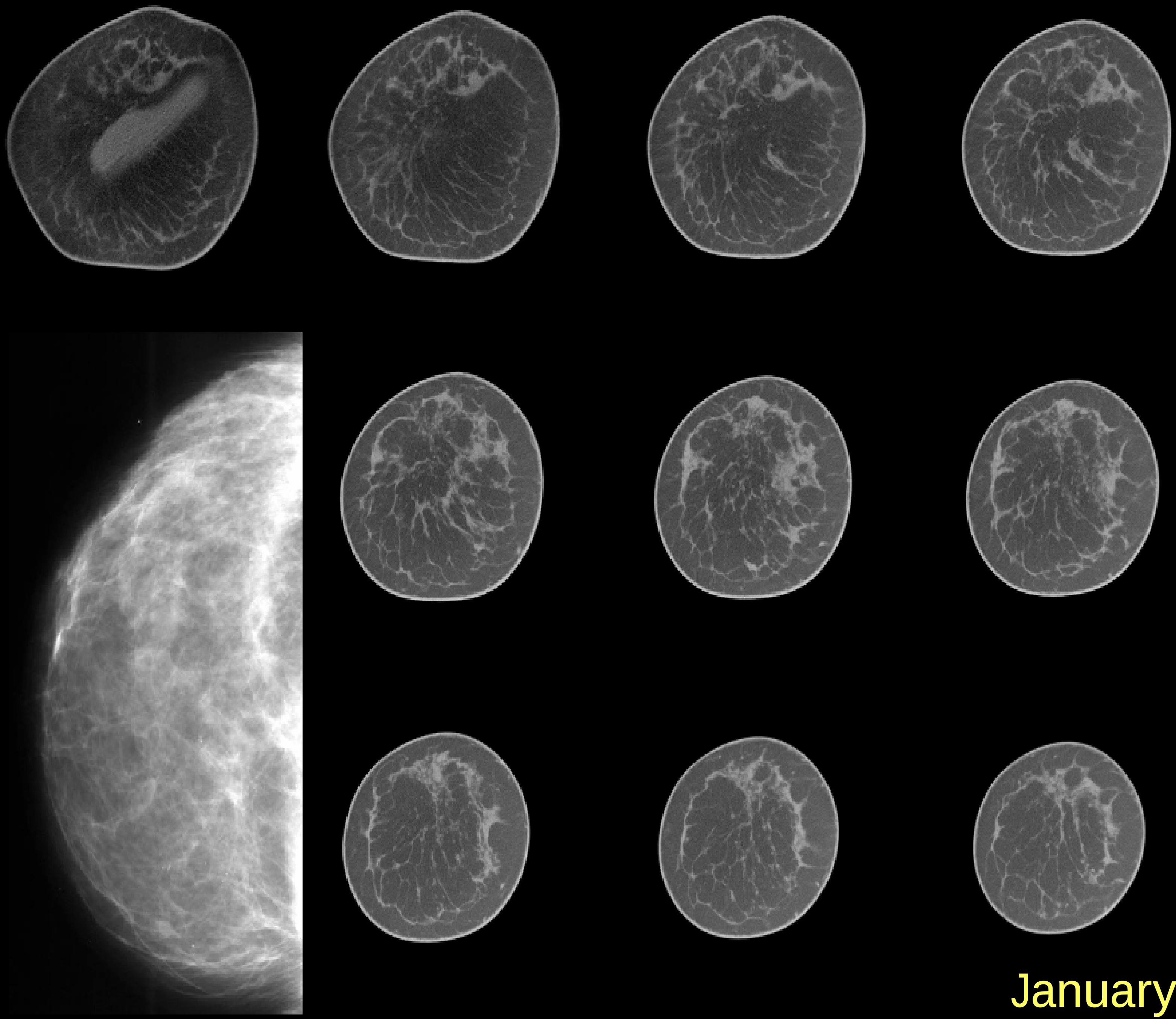
~7 patients imaged with PET/CT

(5 mCi ^{18}FDG)

~4 patient hands imaged PET/CT for rheumatoid arthritis

(10 mCi ^{18}FDG)

First in human (cone beam bCT) – Nov 22, 2004



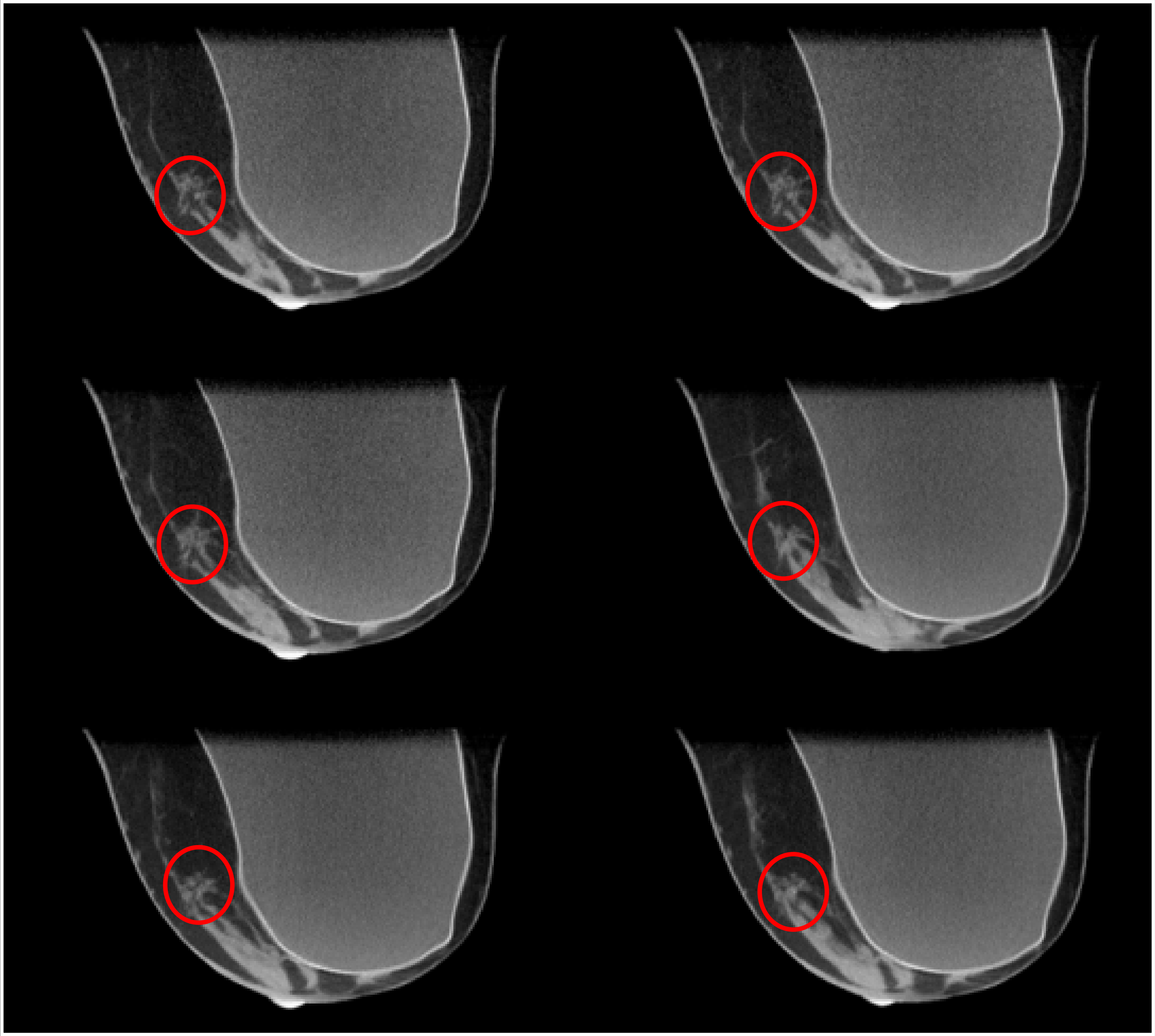
January 2005

Pre-pectoral Saline Implants

Diagnosis:

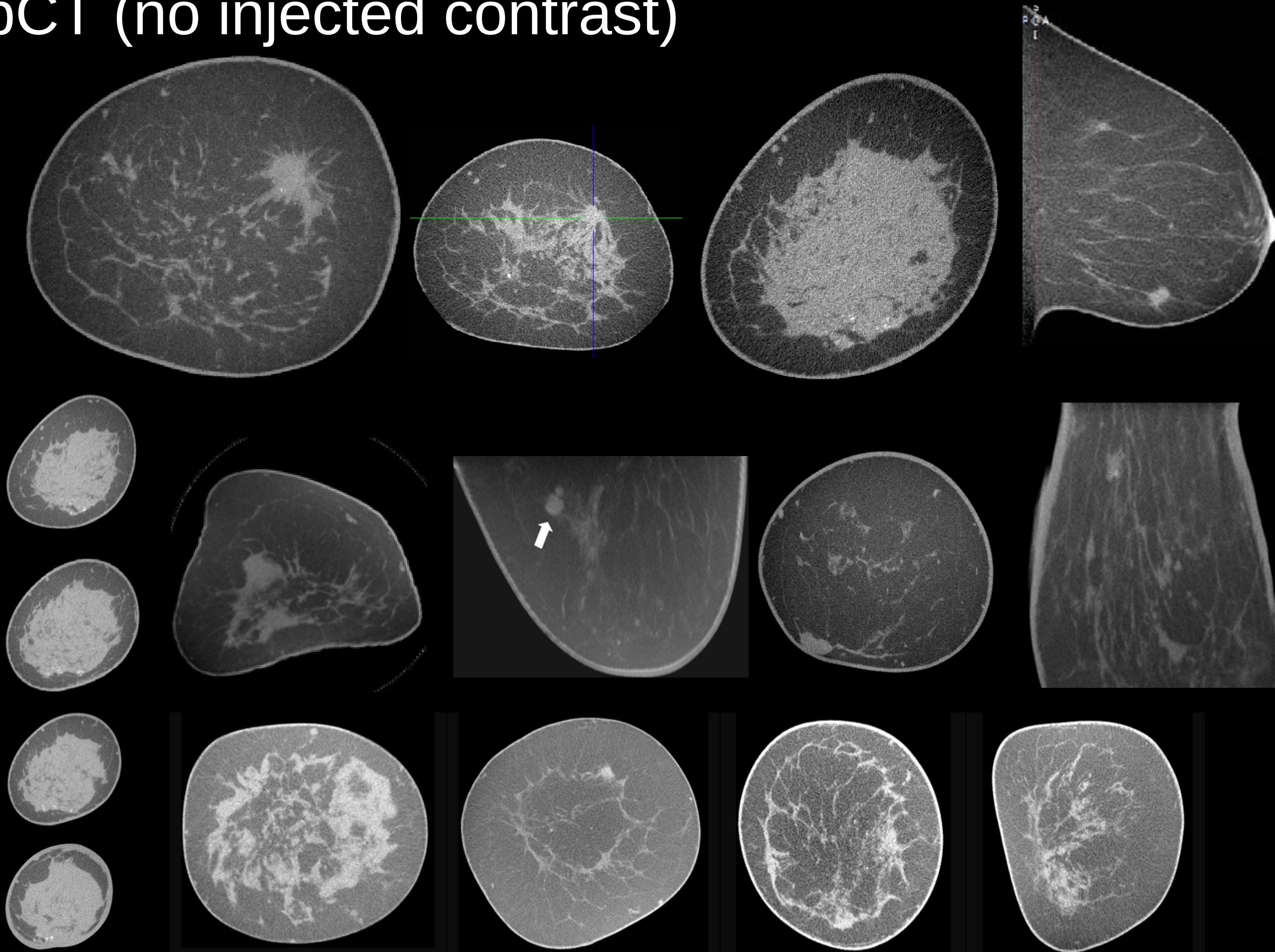
IDC/ILC

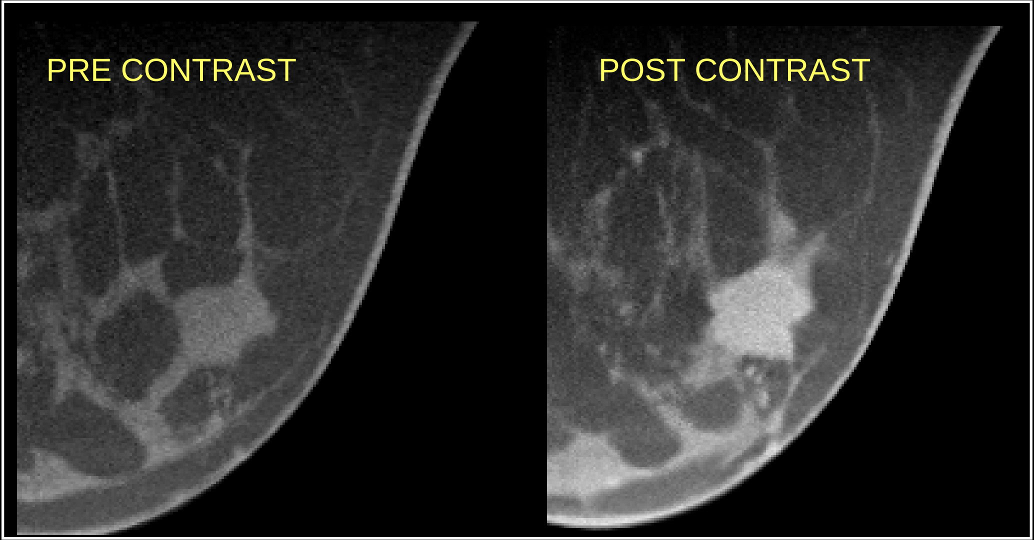
January 2005

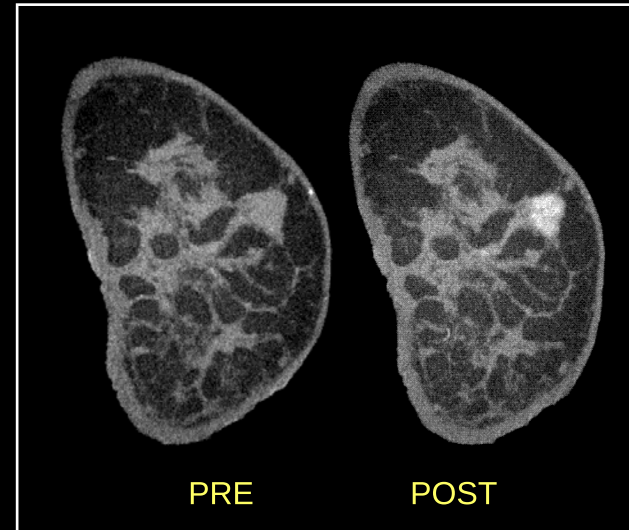


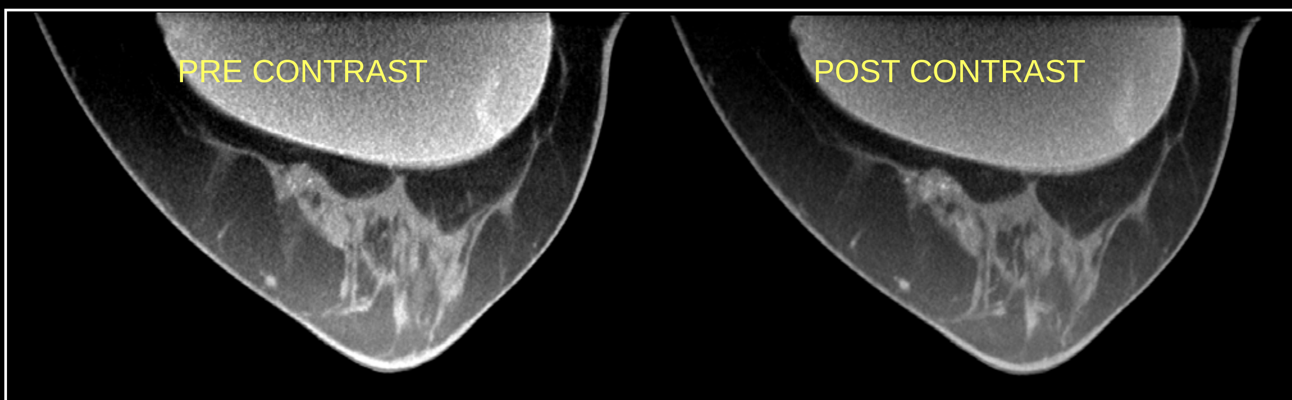
Tumor is seen on many images

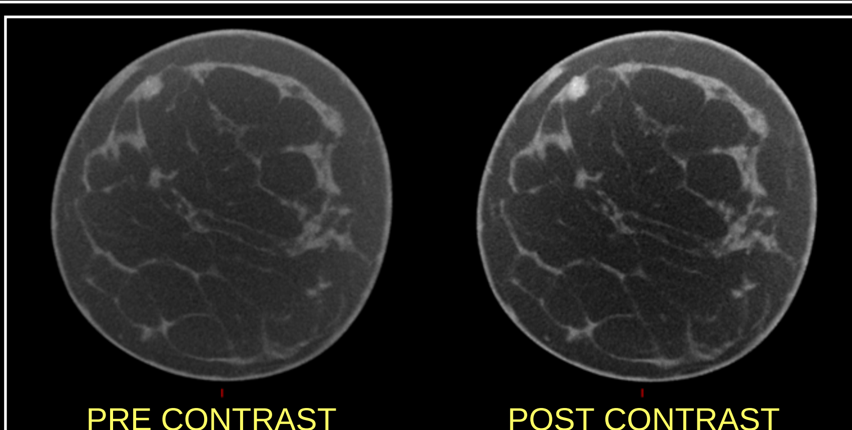
bCT (no injected contrast)





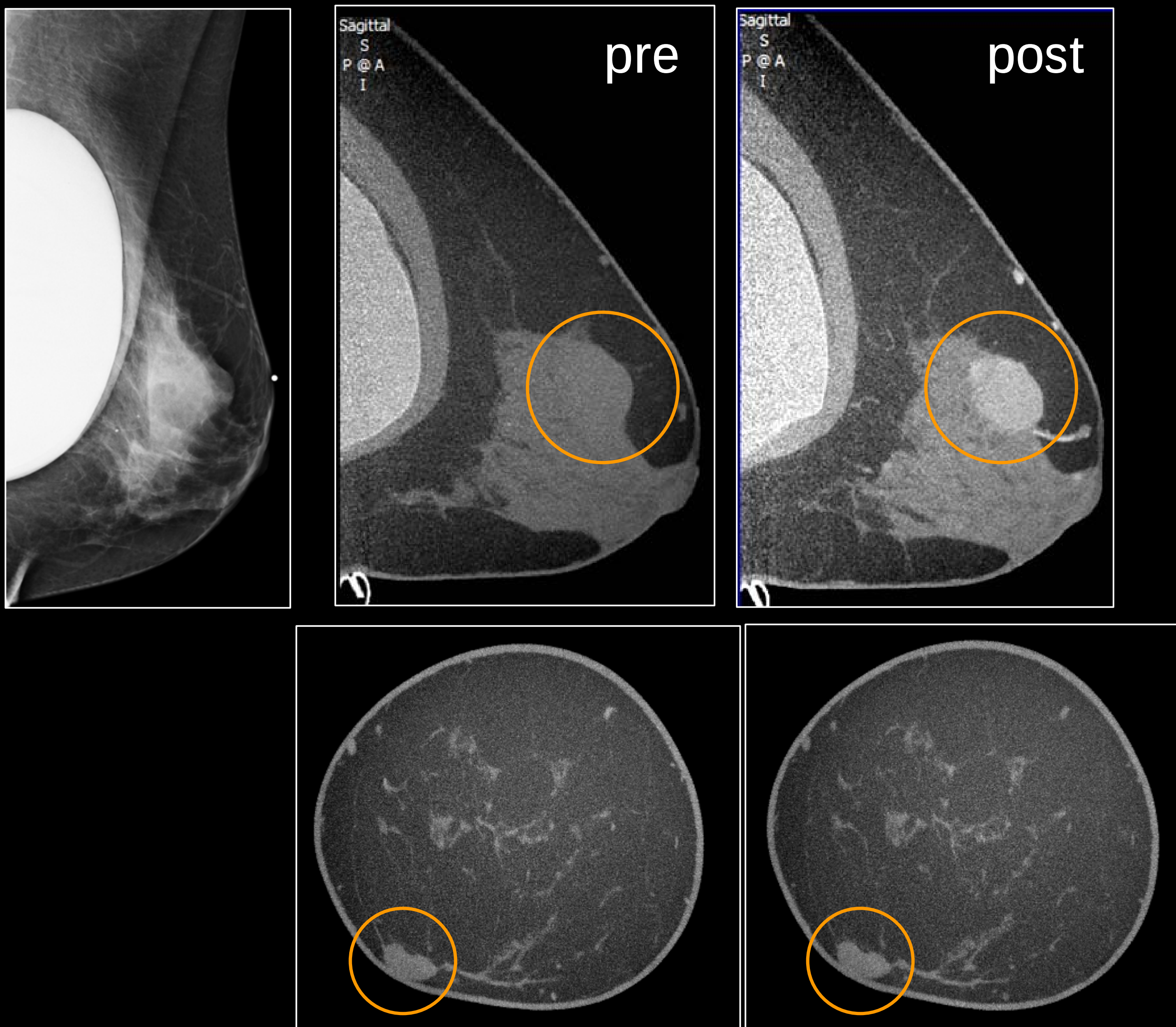






bCT (with contrast)

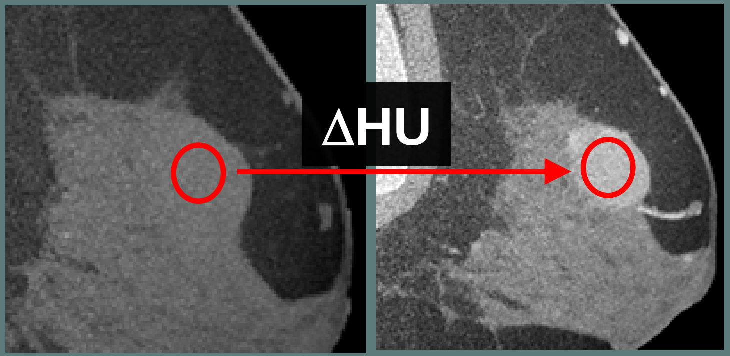
Contrasted Enhanced breast CT

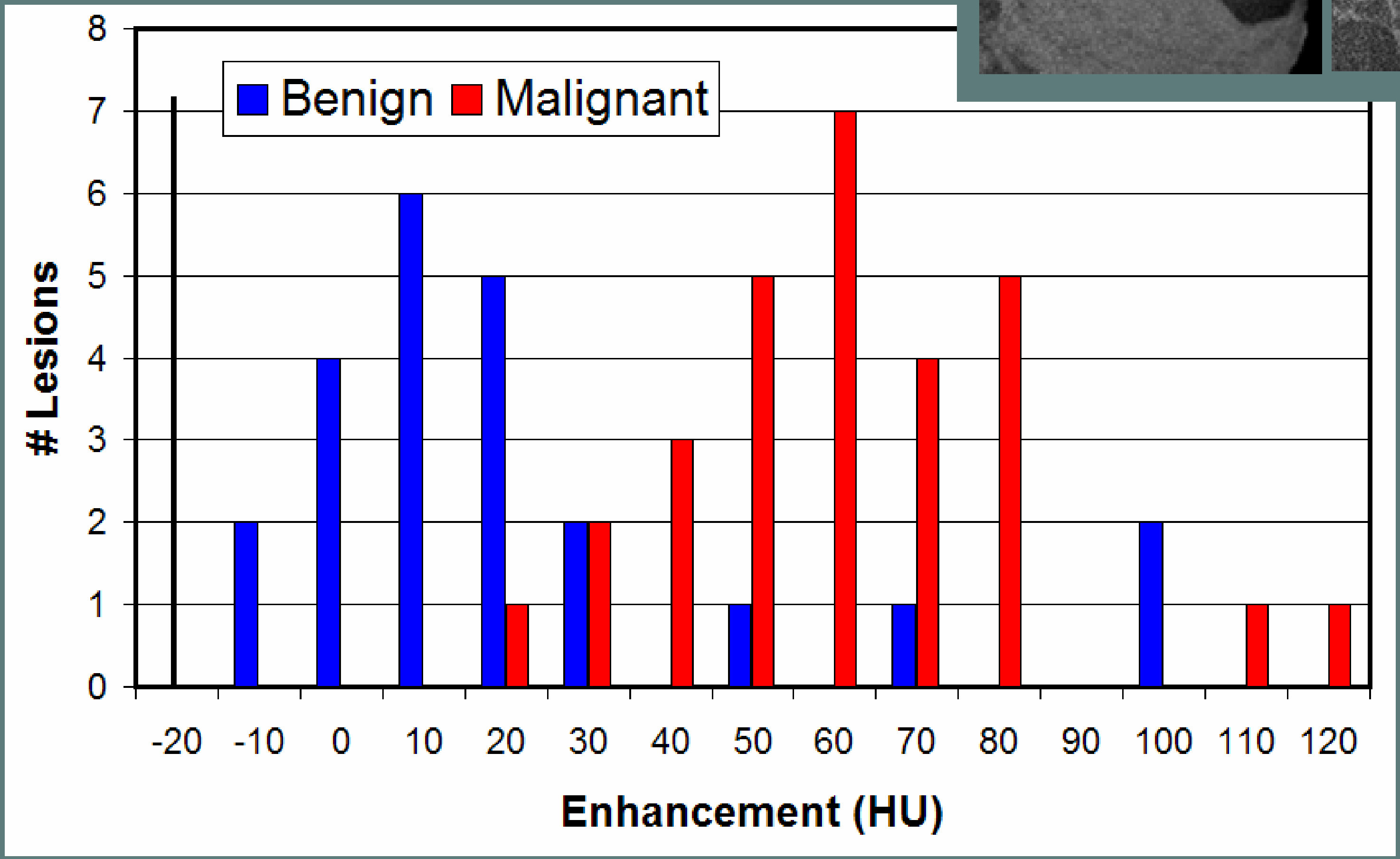


Malignant

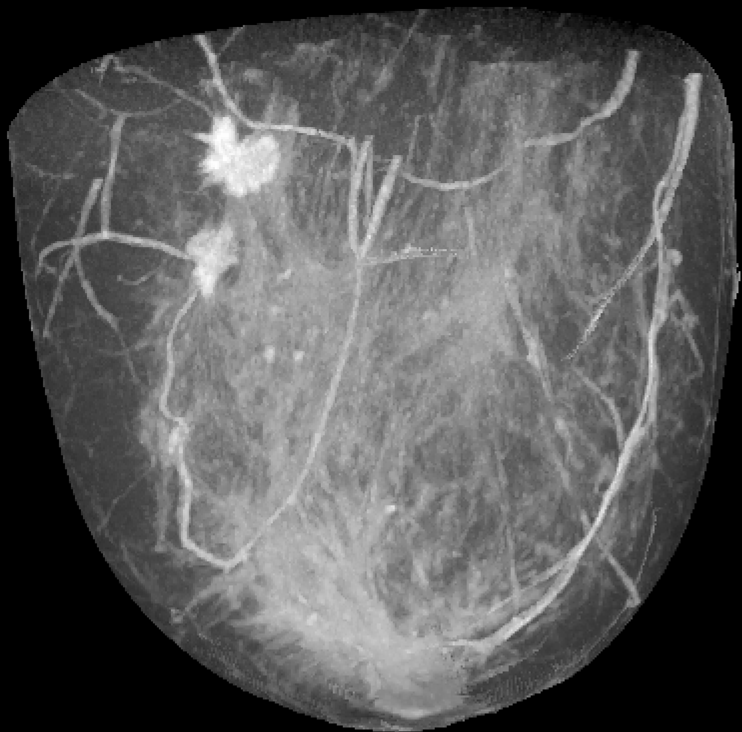
benign

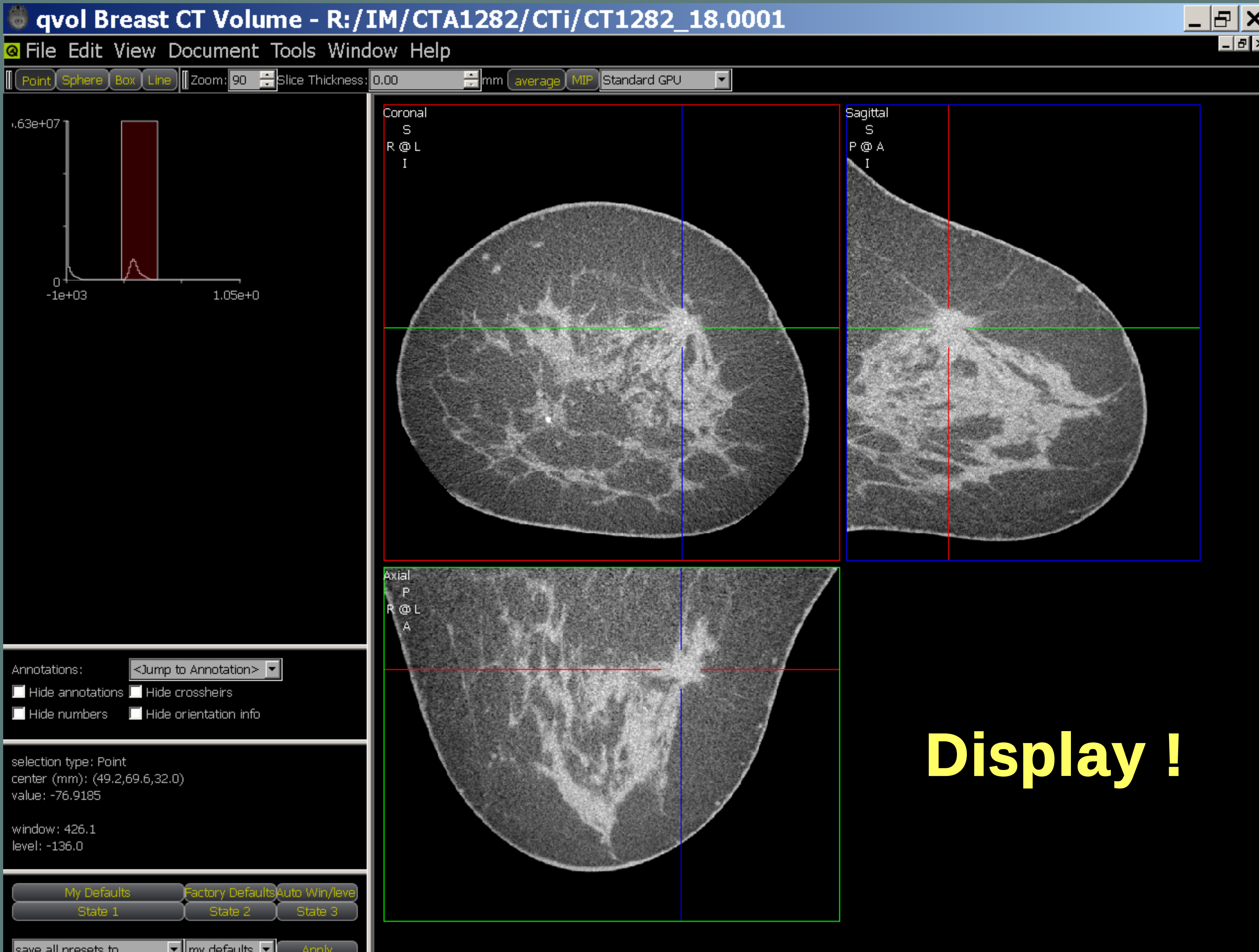
AUC = 0.87





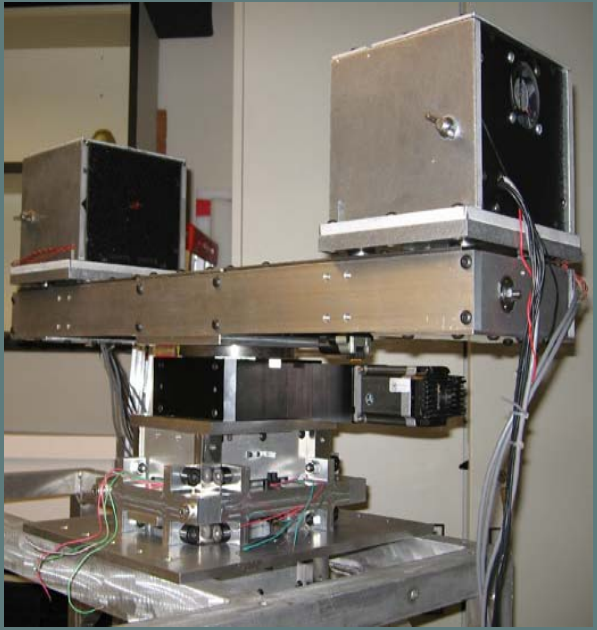
Malignant tumors tend to enhance more than benign lesions

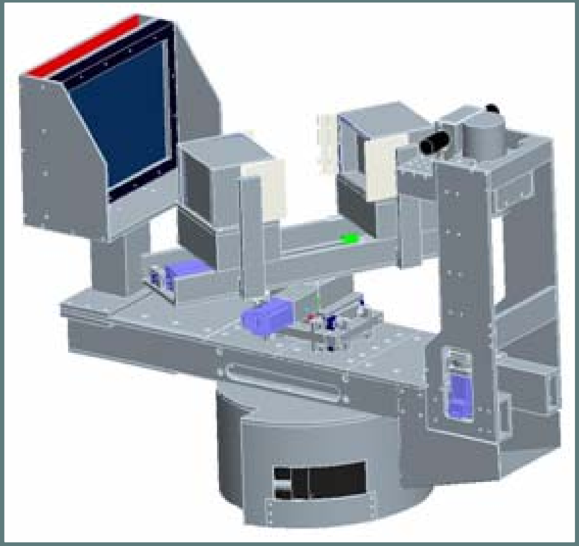



qvol Breast CT Volume - R:/IM/CTA1282/CTi/CT1282_18.0001
File Edit View Document Tools Window Help
Point Sphere Box Line Zoom: 90 Slice Thickness: 0.00 mm average MIP Standard GPU
.63e+07
0
-1e+03
1.05e+0
Coronal
S
R @ L
I
Sagittal
S
P @ A
I
Axial
P
R @ L
A
Annotations: <Jump to Annotation>
Hide annotations
Hide crossheirs
Hide numbers
Hide orientation info
selection type: Point
center (mm): (49.2,69.6,32.0)
value: -76.9185
window: 426.1
level: -136.0
My Defaults
Factory Defaults
Auto Win/leve
State 1
State 2
State 3
save all presets to
my defaults
Apply

Display !

PET / CT for dedicated breast imaging

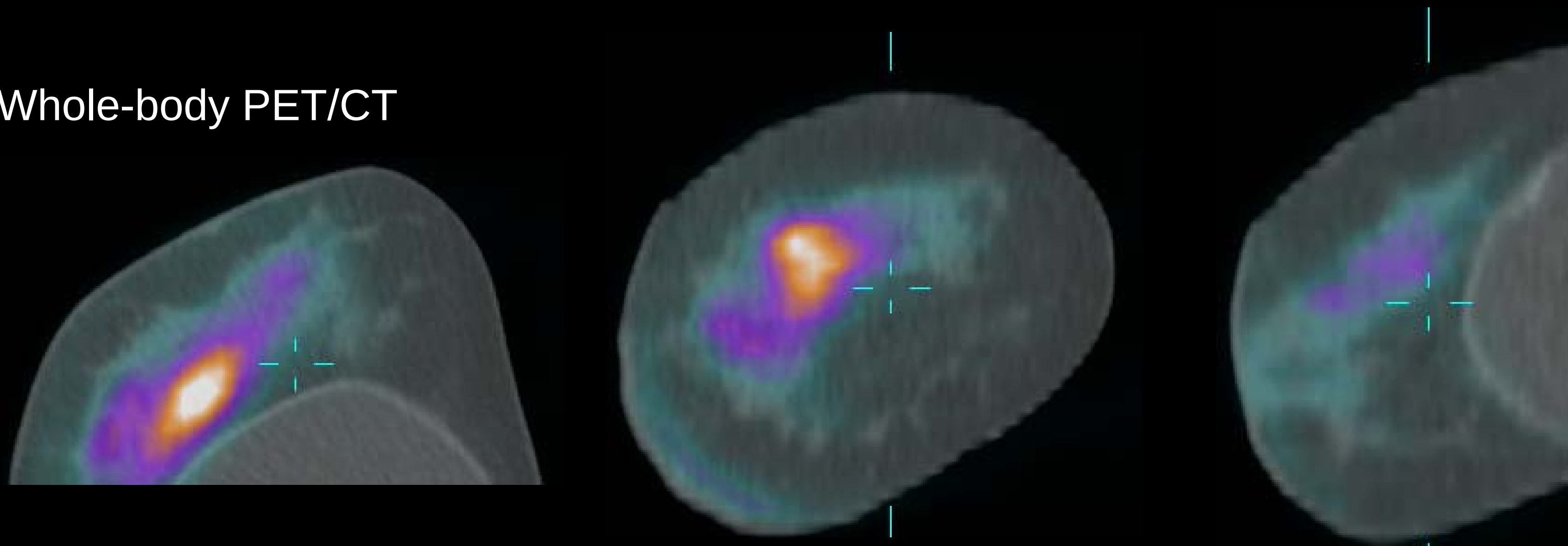




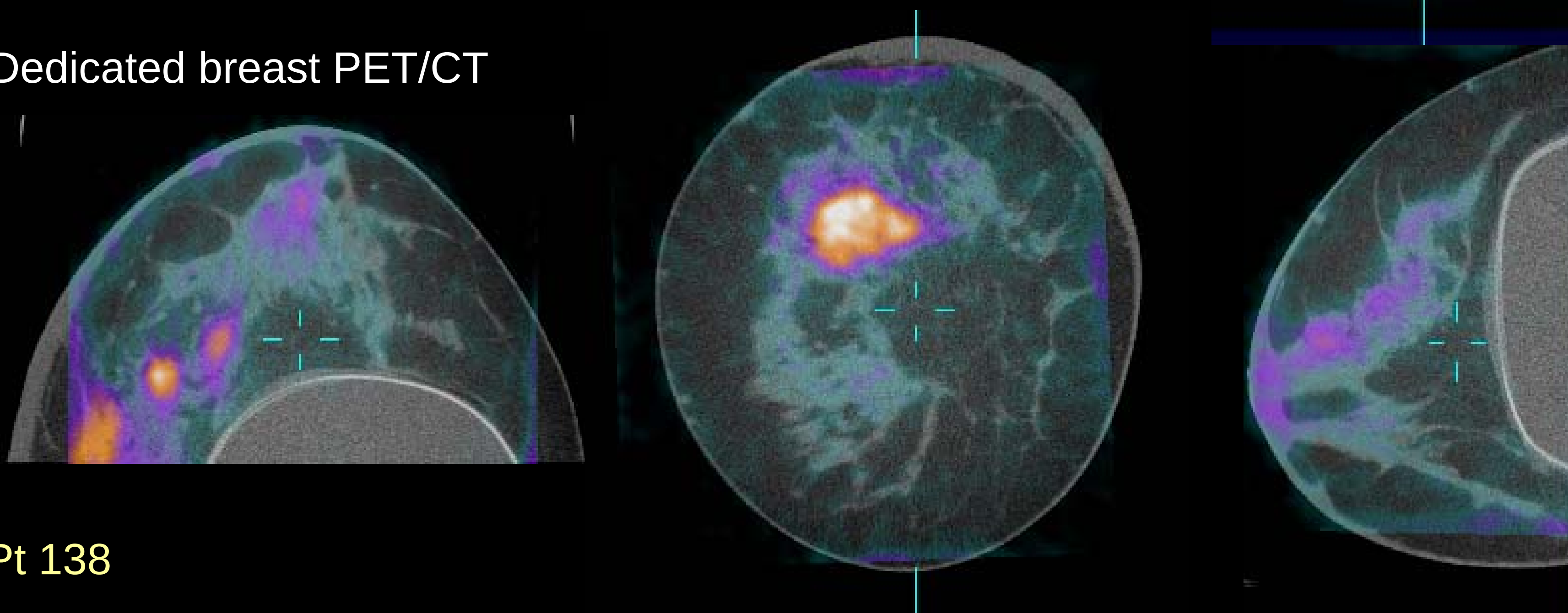
ramsey badawi
simon cherry
abhijit chaudhari
spencer bowen

Invasive Mammary Carcinoma

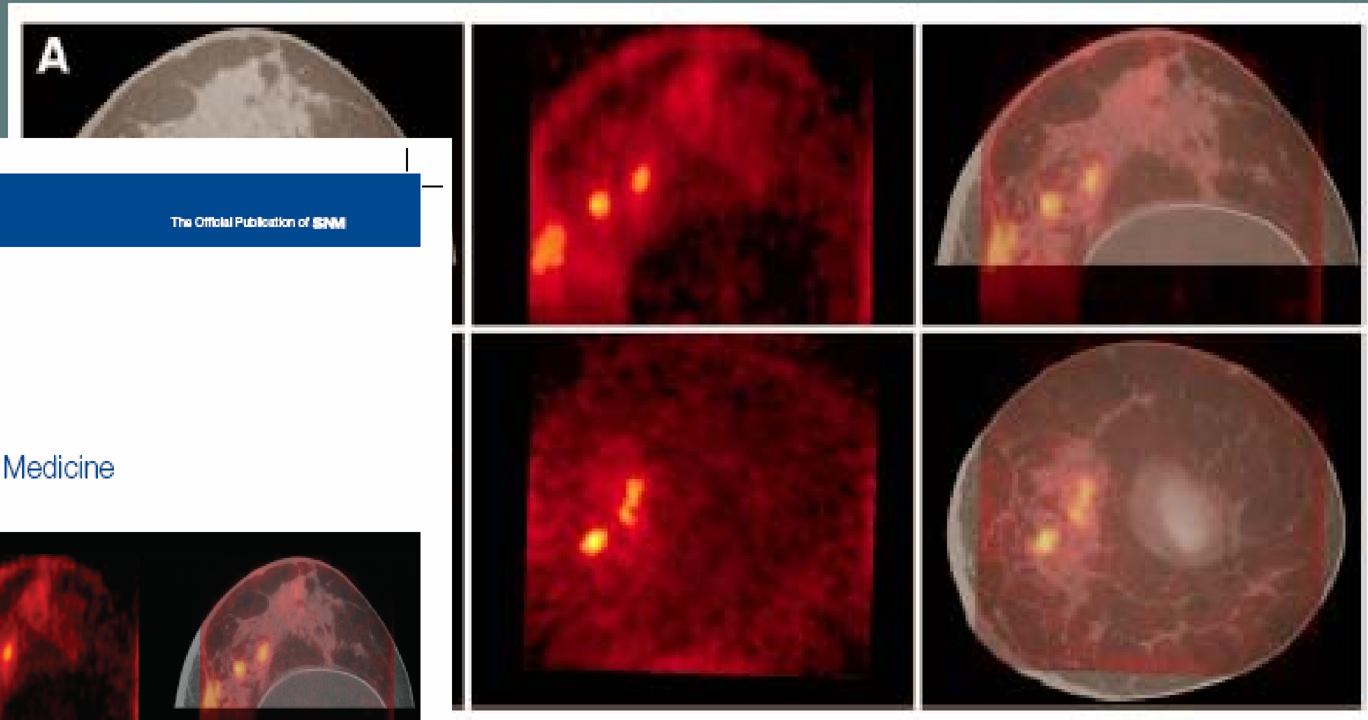
Whole-body PET/CT



Dedicated breast PET/CT



Pt 138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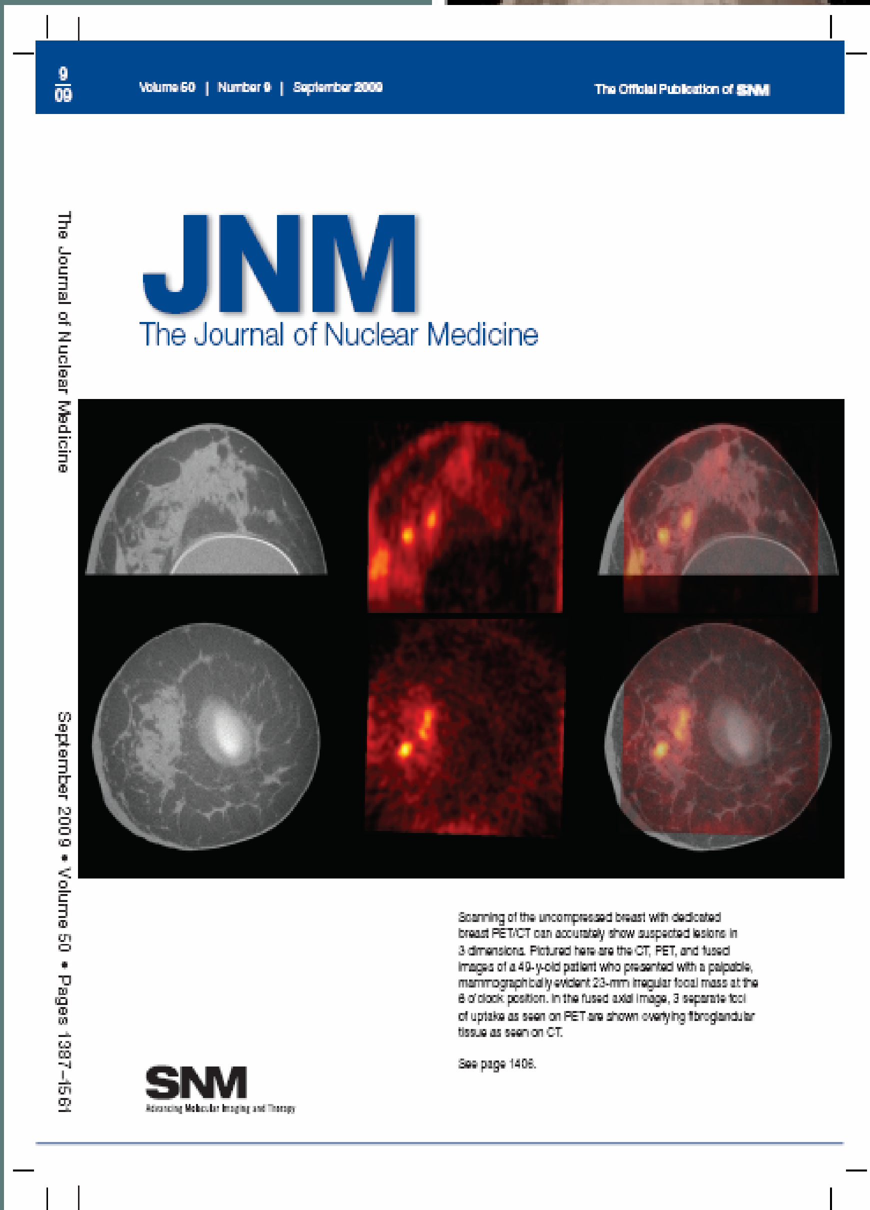
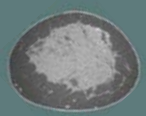

9
09
Volume 50 | Number 9 | September 2009
The Official Publication of SNM
The Journal of Nuclear Medicine
JNM
The Journal of Nuclear Medicine
Scanning of the uncompressed breast with dedicated breast PET/CT can accurately show suspected lesions in 3 dimensions. Pictured here are the CT, PET, and fused images of a 49-y-old patient who presented with a palpable, mammographically evident 23-mm irregular focal mass at the 8 o'clock position. In the fused axial image, 3 separate foci of uptake as seen on PET are shown overlying fibroglandular tissue as seen on CT.
See page 1406.
SNM
Advancing Molecular Imaging and Therapy
September 2009 • Volume 50 • Pages 1387–1561

Breast CT (with PET) for Screening, Diagnosis, and Breast Cancer Treatment

Motivation / System Design & Fabrication

Breast CT Imaging



Radiation Dosimetry

Image Quality Evaluation

Breast Image Analyses

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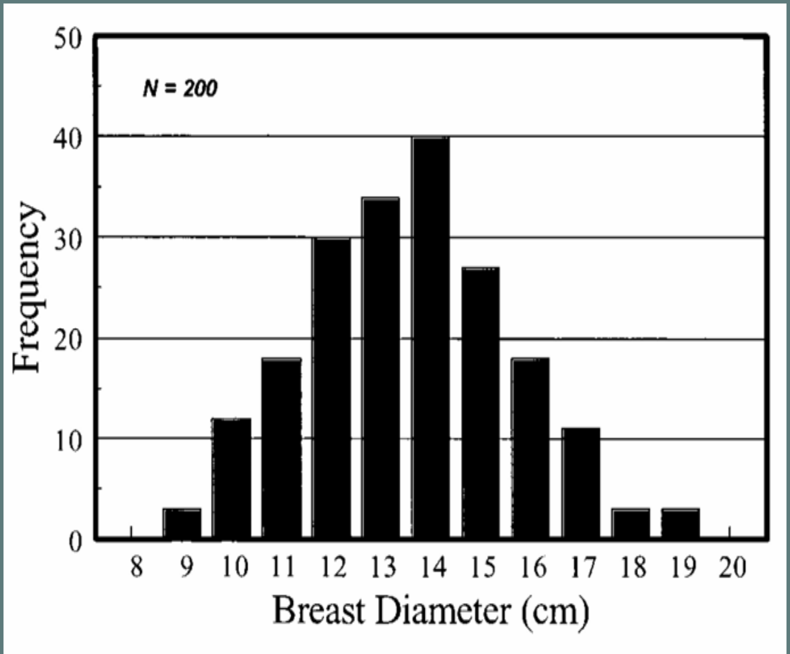
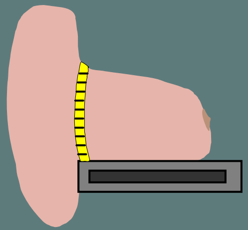
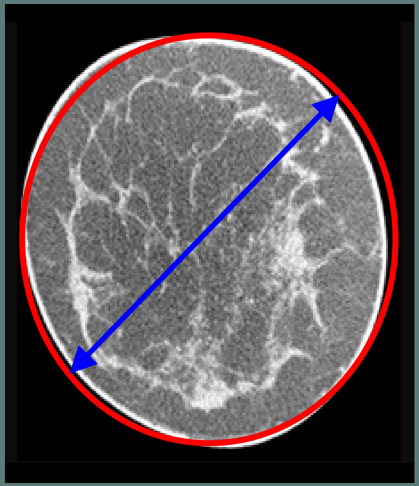
Summary

Dose is size dependent !



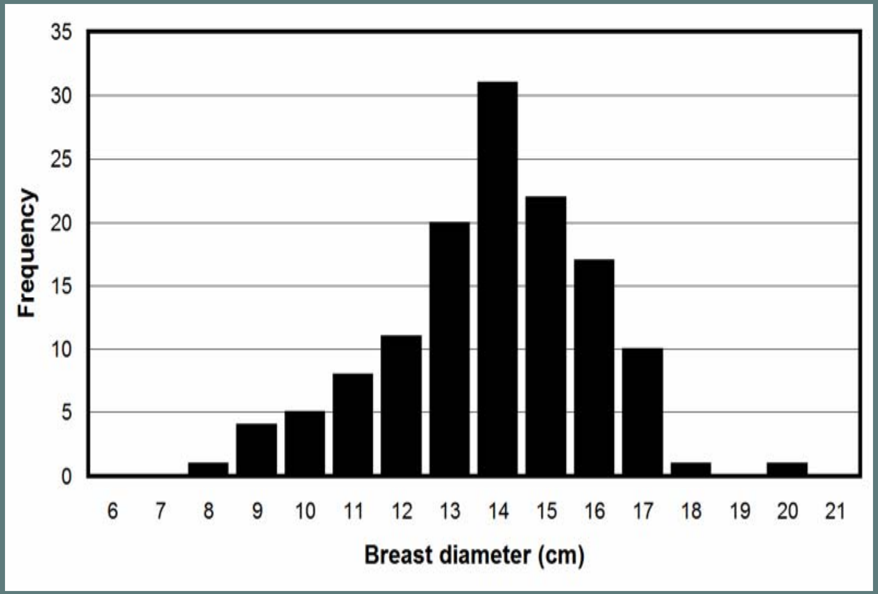
2001 tape measure results (N = 200)



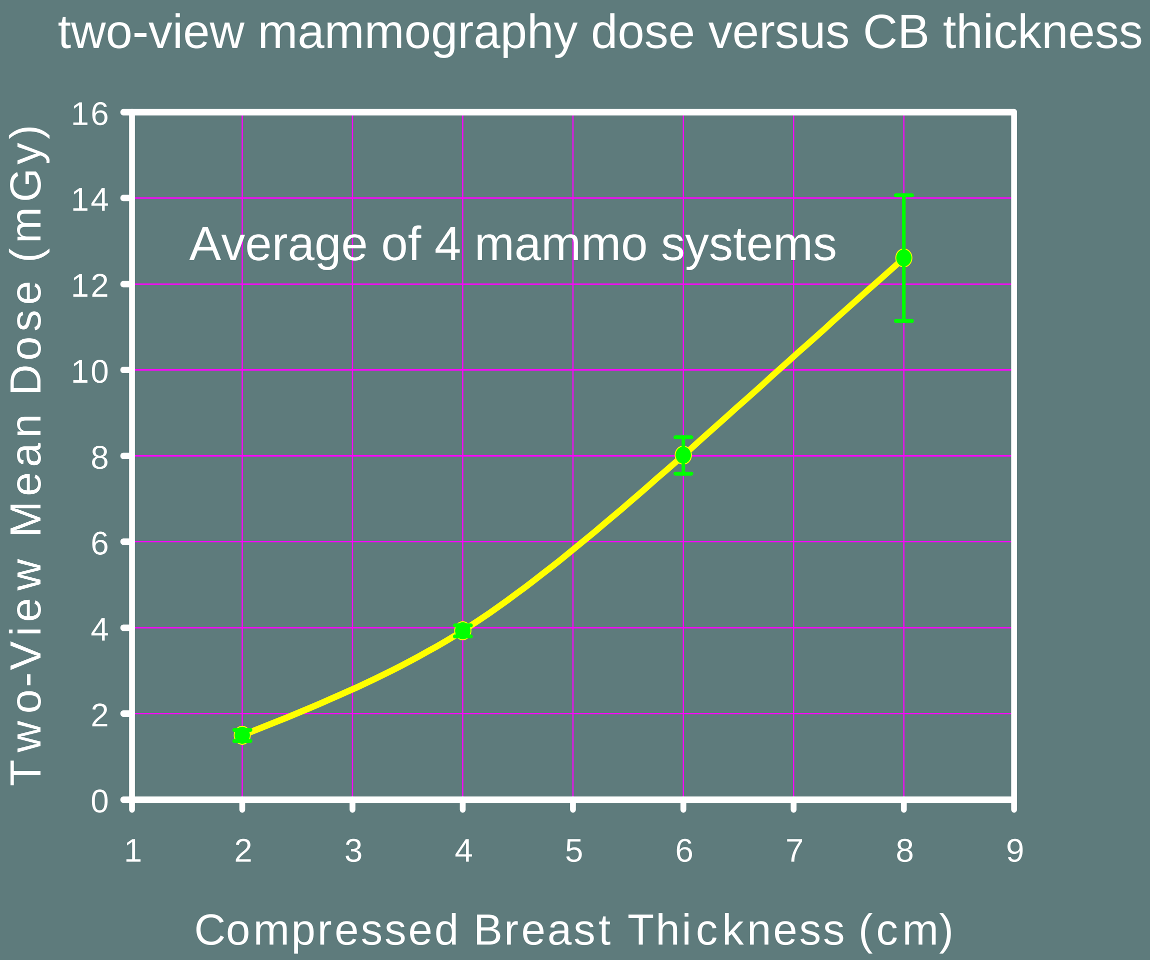


X = 13.4 cm
σ= 2.0 cm
Median = 13.6 cm

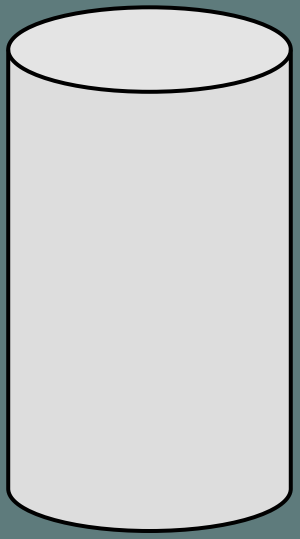
2008 assessment on bCT images (N = 137)



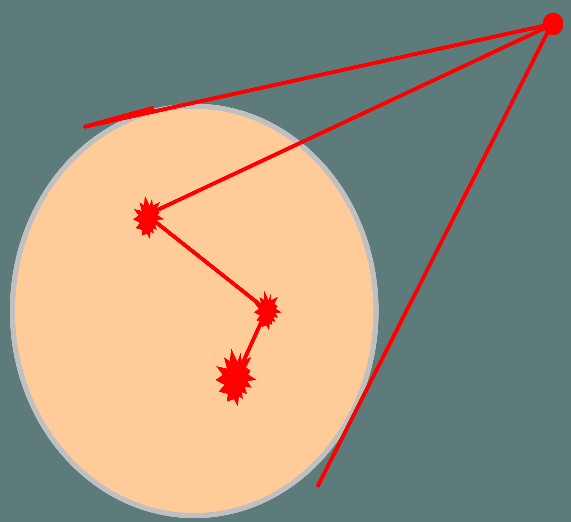
Mean Glandular Dose in Mammography



Monte Carlo Assessment of Dose Deposition

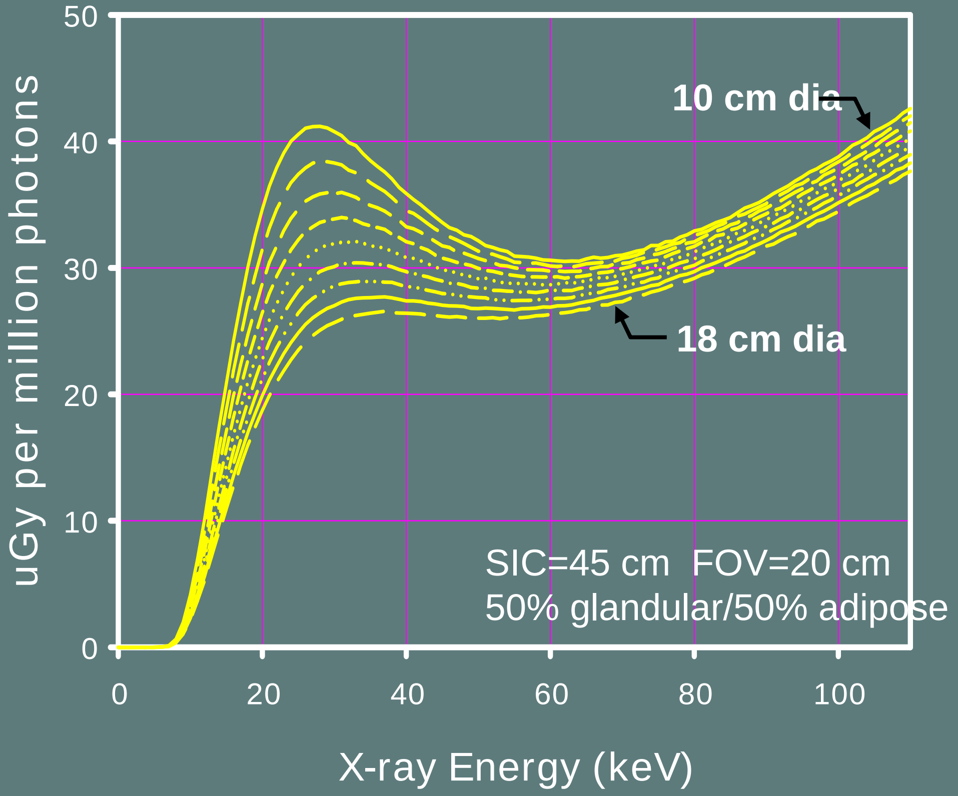


breast modeled as cylinder



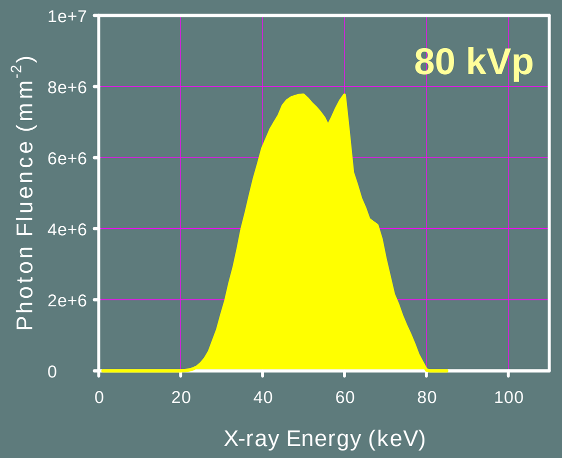
SIERRA MC code used

monoenergetic functions



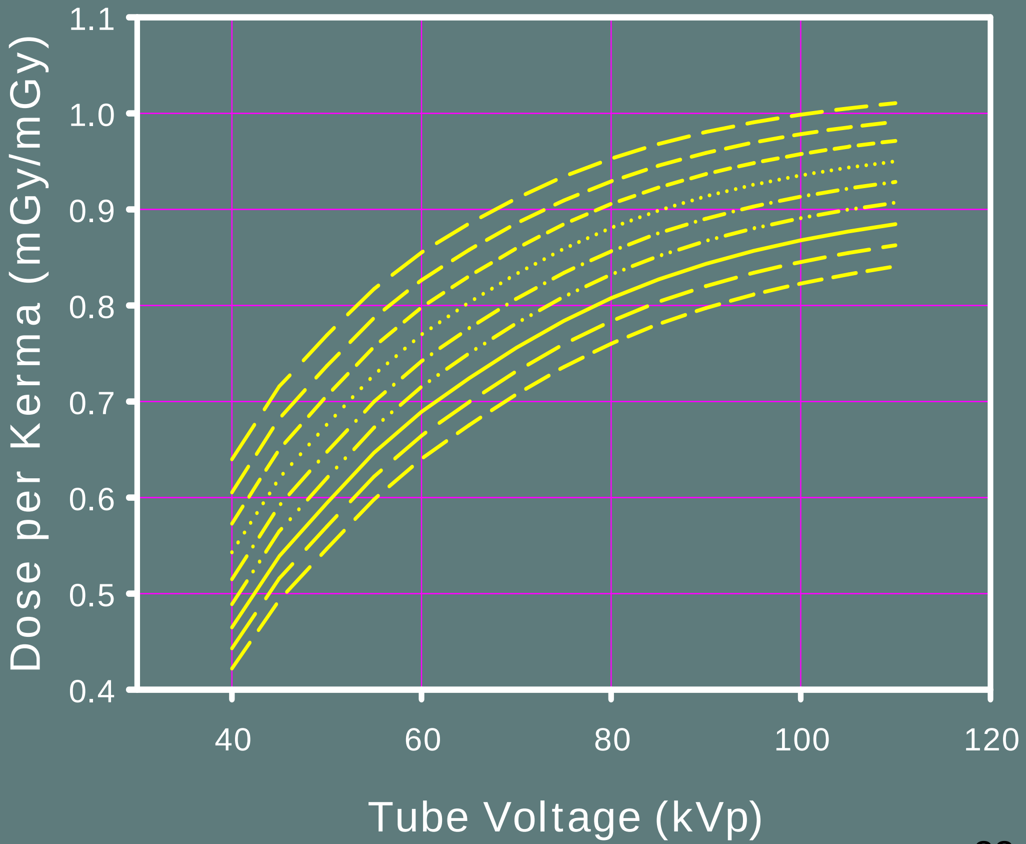
Mean Glandular Dose in Breast CT

spectral model*



*JM Boone and JA Seibert, *An accurate method for computer-generating tungsten anode x-ray spectra from 30 kV to 140 kV*, Medical Physics 24;1661-670, 1997.

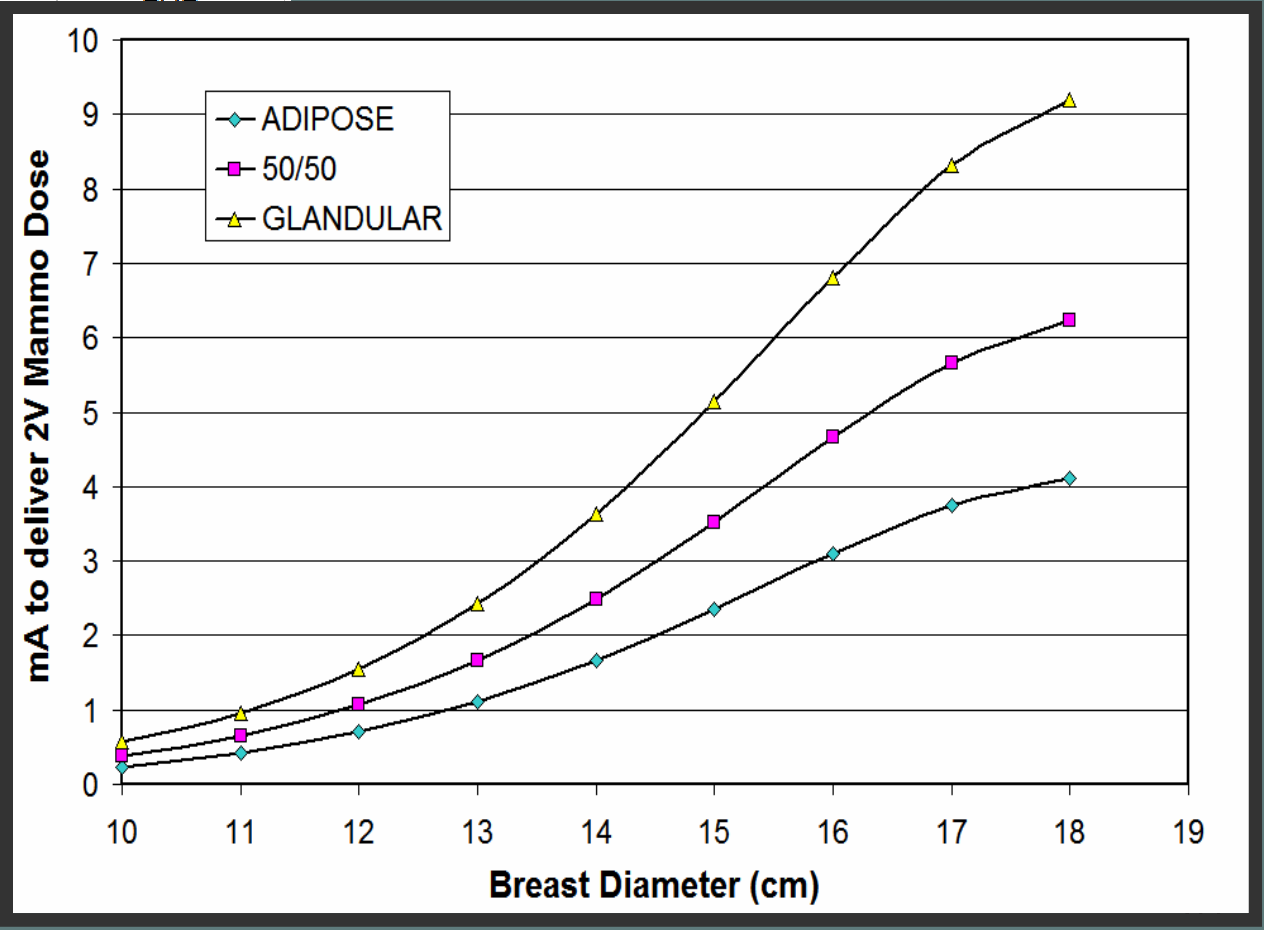
polyenergetic functions



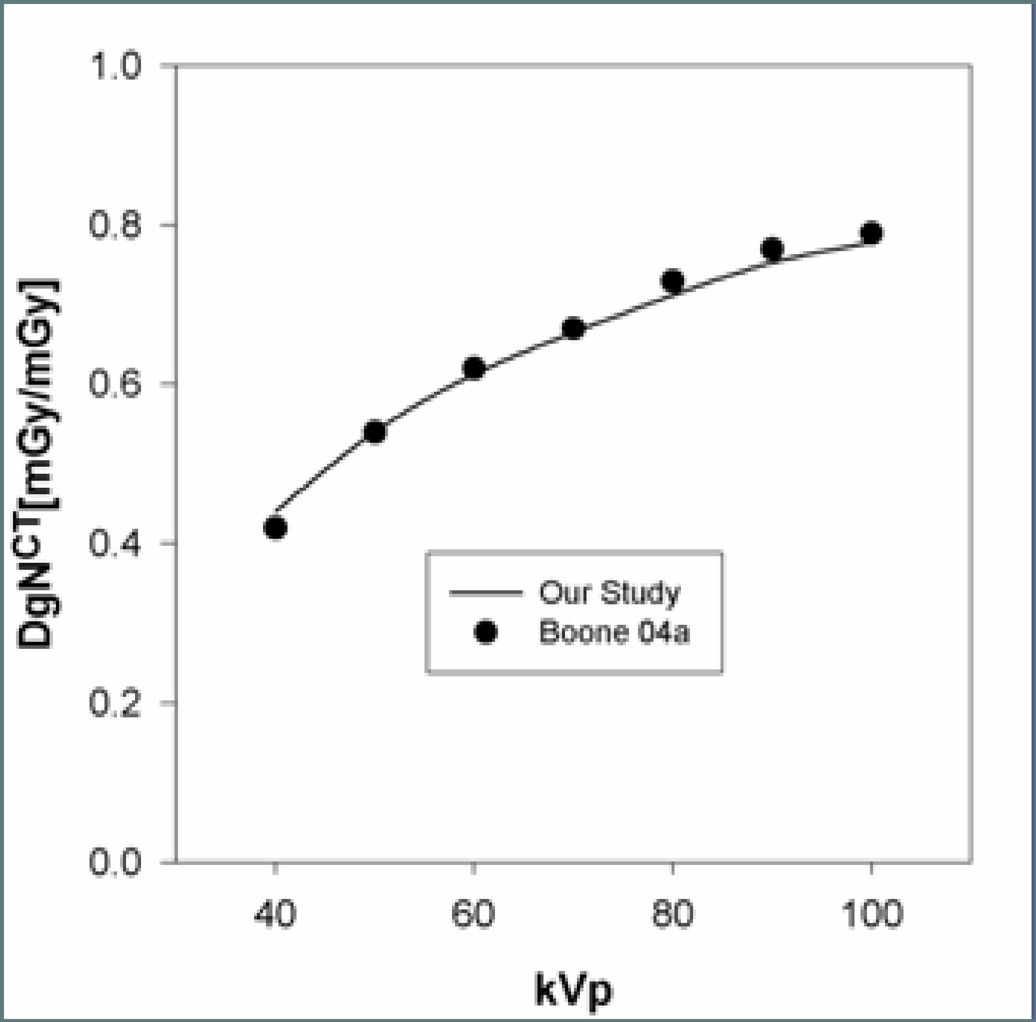
80 kVp 0.20 mm Copper			
mA on Bodega to deliver 2V mammography			
Dia (cm)	**ADIPOSE**	**50/50**	**GLANDULAR**
10	0.23	0.38	0.57
11	0.42	0.65	0.96
12	0.70	1.07	1.55
13	1.11	1.67	2.42
14	1.66	2.49	
15	2.35	3.52	
16	3.10	4.66	
17	3.74	5.66	
18	4.11	6.24	

Dose in breast CT is set to be EQUAL to the dose of two-view mammography for that women.

bCT technique chart



Dose assessment repeated by Karellas and by Glick



Breast CT (with PET) for Screening, Diagnosis, and Breast Cancer Treatment

Motivation / System Design & Fabrication

Breast CT Imaging

Radiation Dosimetry

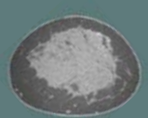


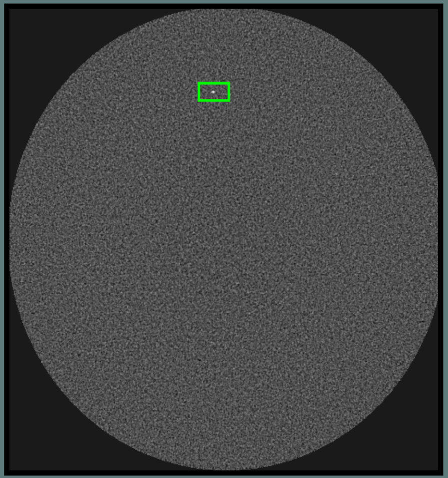
Image Quality Evaluation

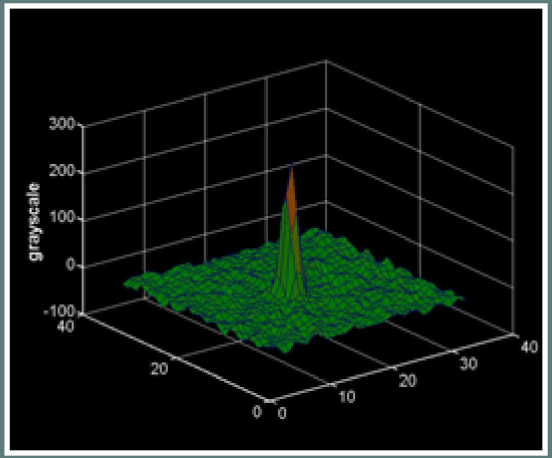
Breast Image Analyses

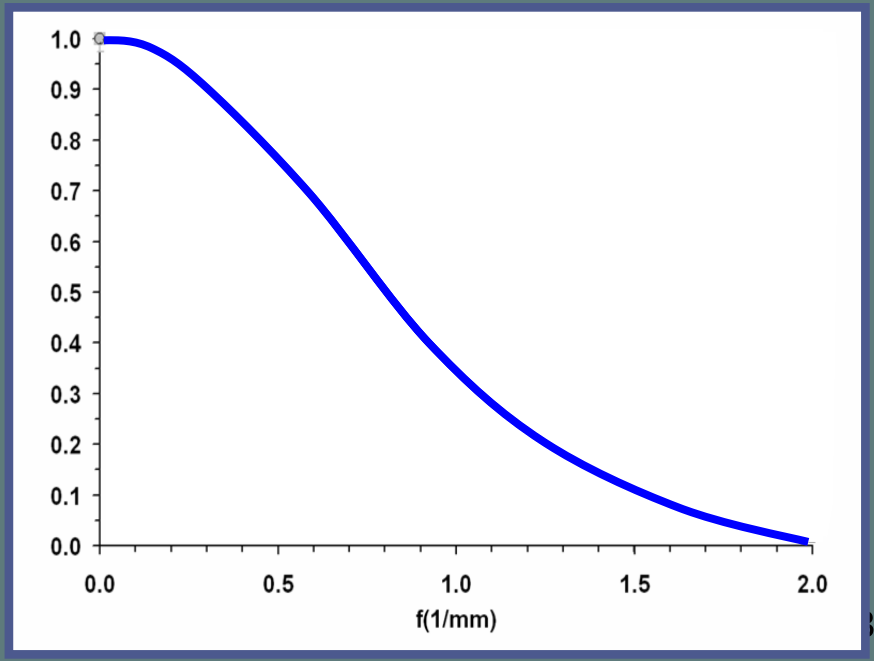
Biopsy and Cancer Therapy

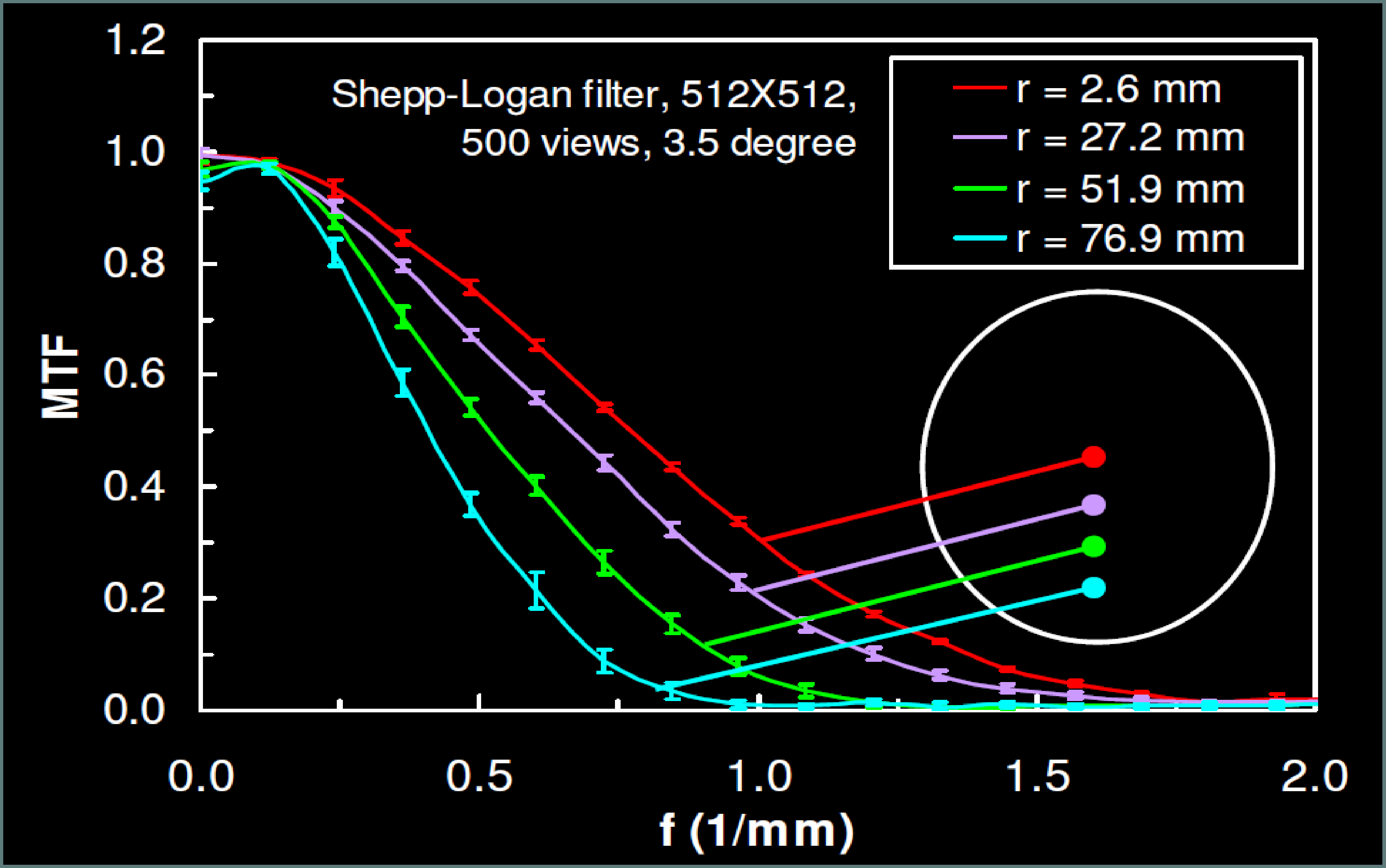
Summary

Spatial Resolution: MTF measurements

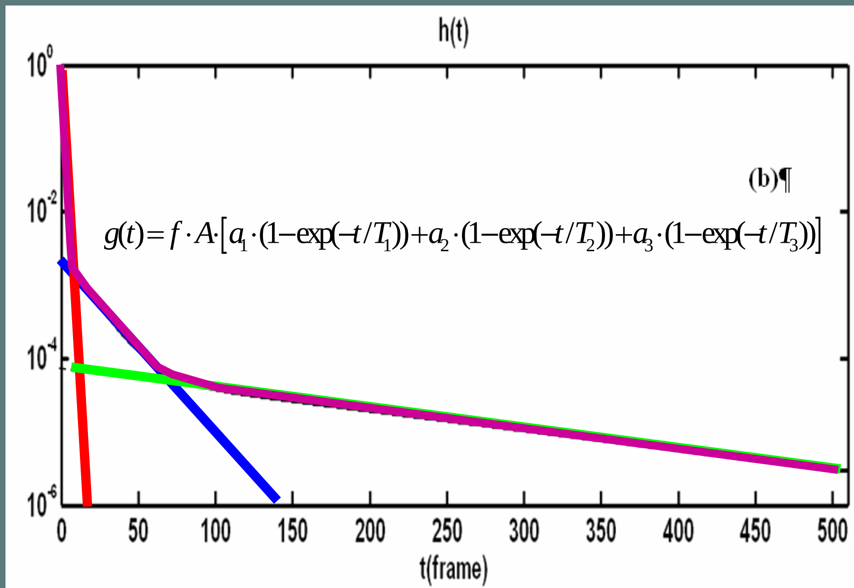




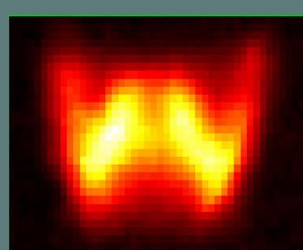



Shepp-Logan filter, 512X512,
500 views, 3.5 degree
r = 2.6 mm
r = 27.2 mm
r = 51.9 mm
r = 76.9 mm
MTF
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.5
1.0
1.5
2.0
f (1/mm)

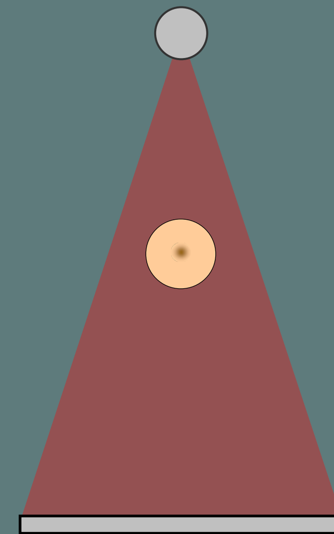
MTF: computer simulation



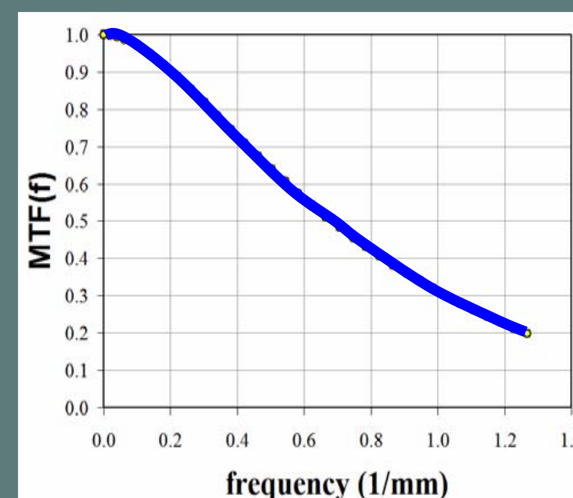
temporal lag of detector



focal spot measurement

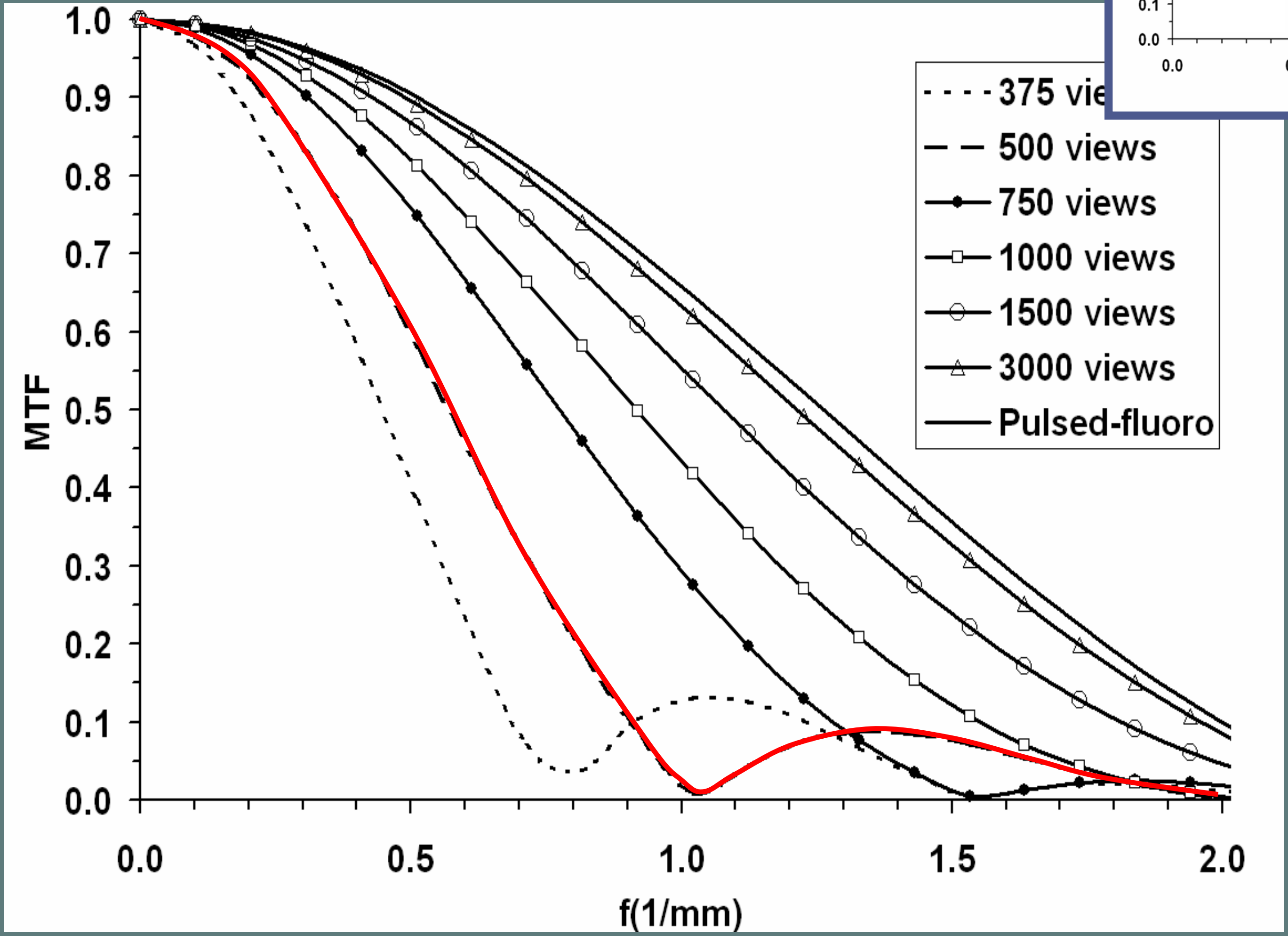


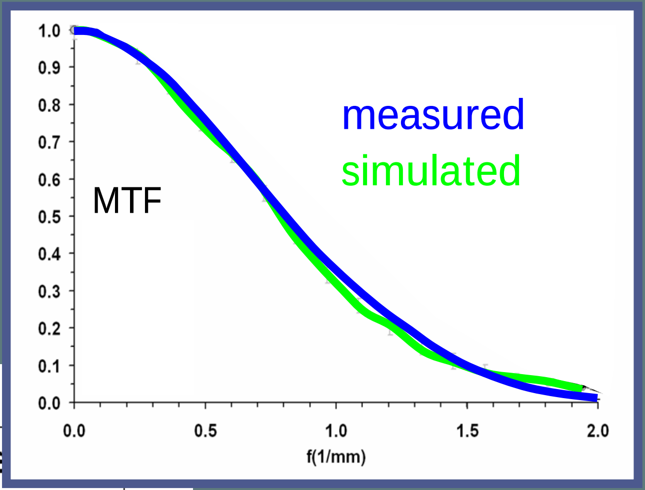
scanner motion



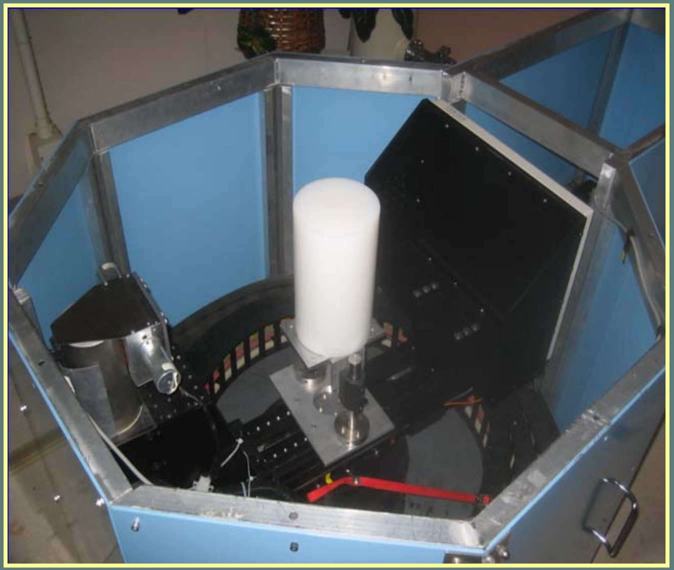
measured detector MTF

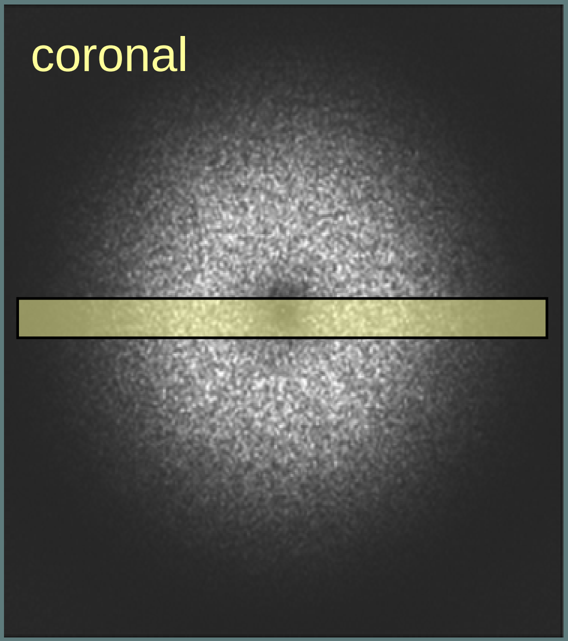
MTF simulations
(worst case at periphery)

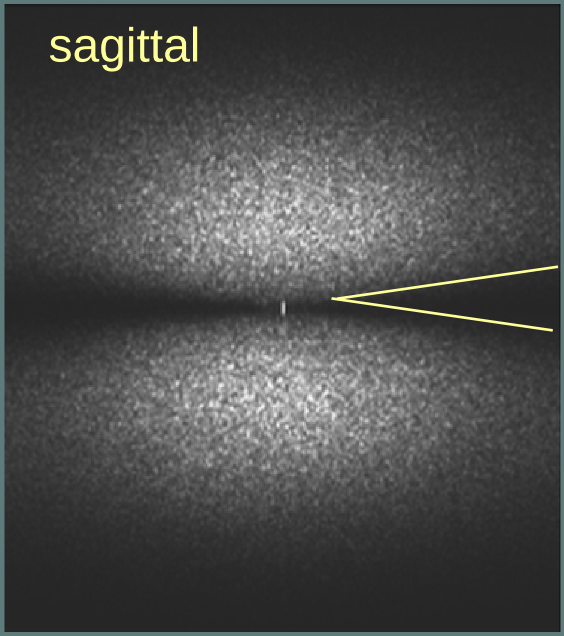


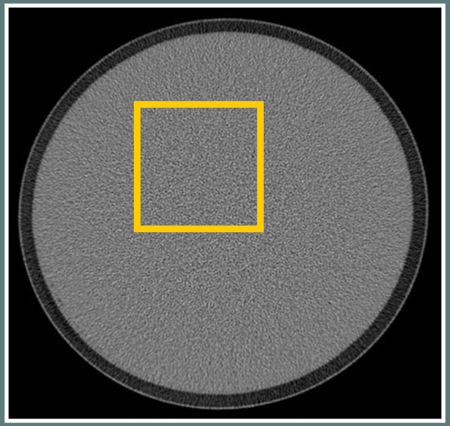


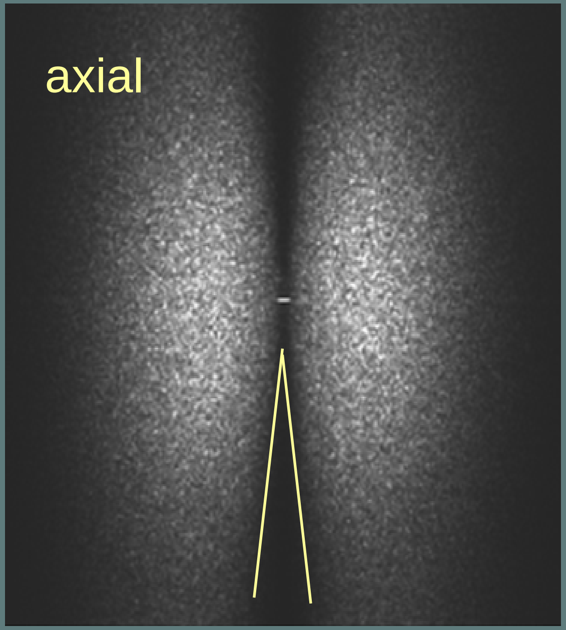
Contrast Resolution: NPS measurements

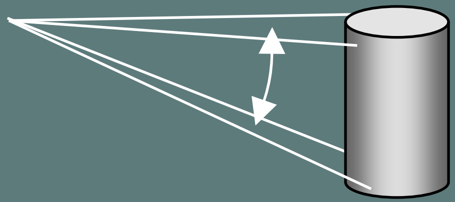








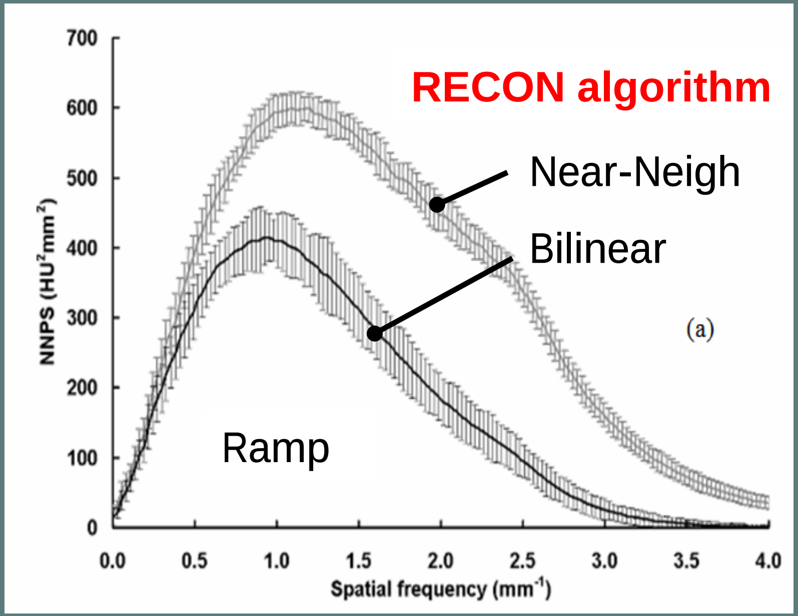


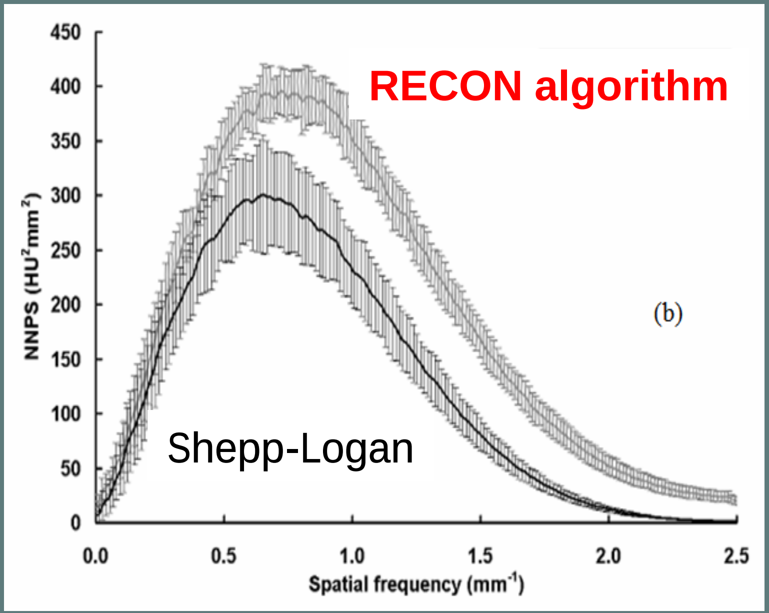


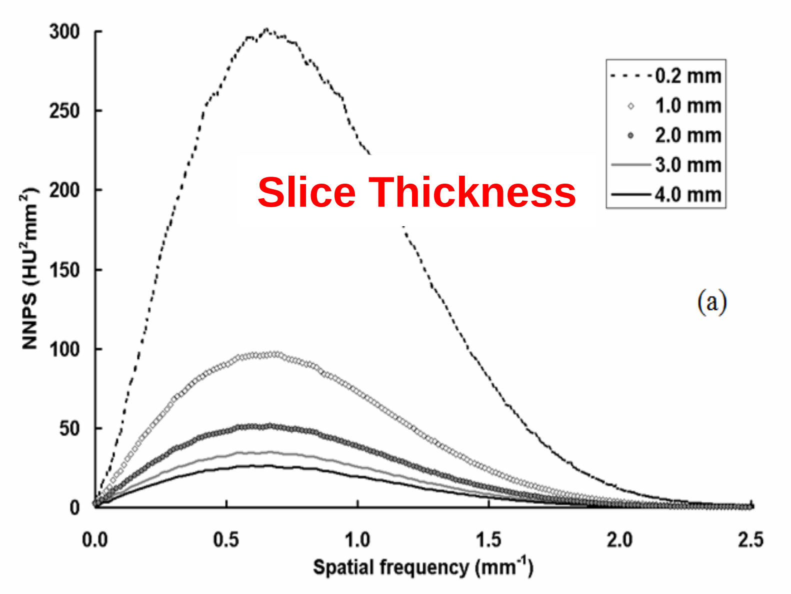
$$NPS(u,v) = \frac{\left|F(u,v)\right|^2}{N_X N_Y} \Delta_X \Delta_Y$$

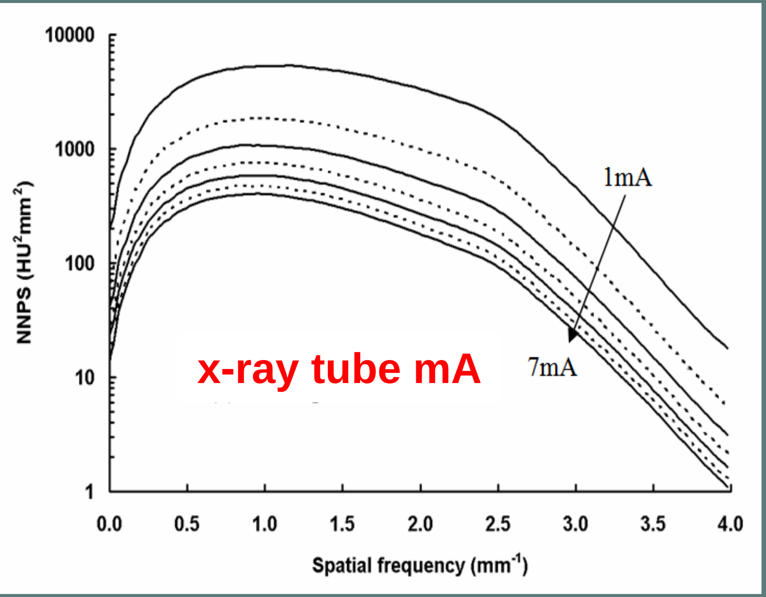
cone angle

Contrast Resolution: NPS measurements









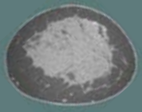
Breast CT (with PET) for Screening, Diagnosis, and Breast Cancer Treatment

Motivation / System Design & Fabrication

Breast CT Imaging

Radiation Dosimetry

Image Quality Evaluation



Breast Image Analyses

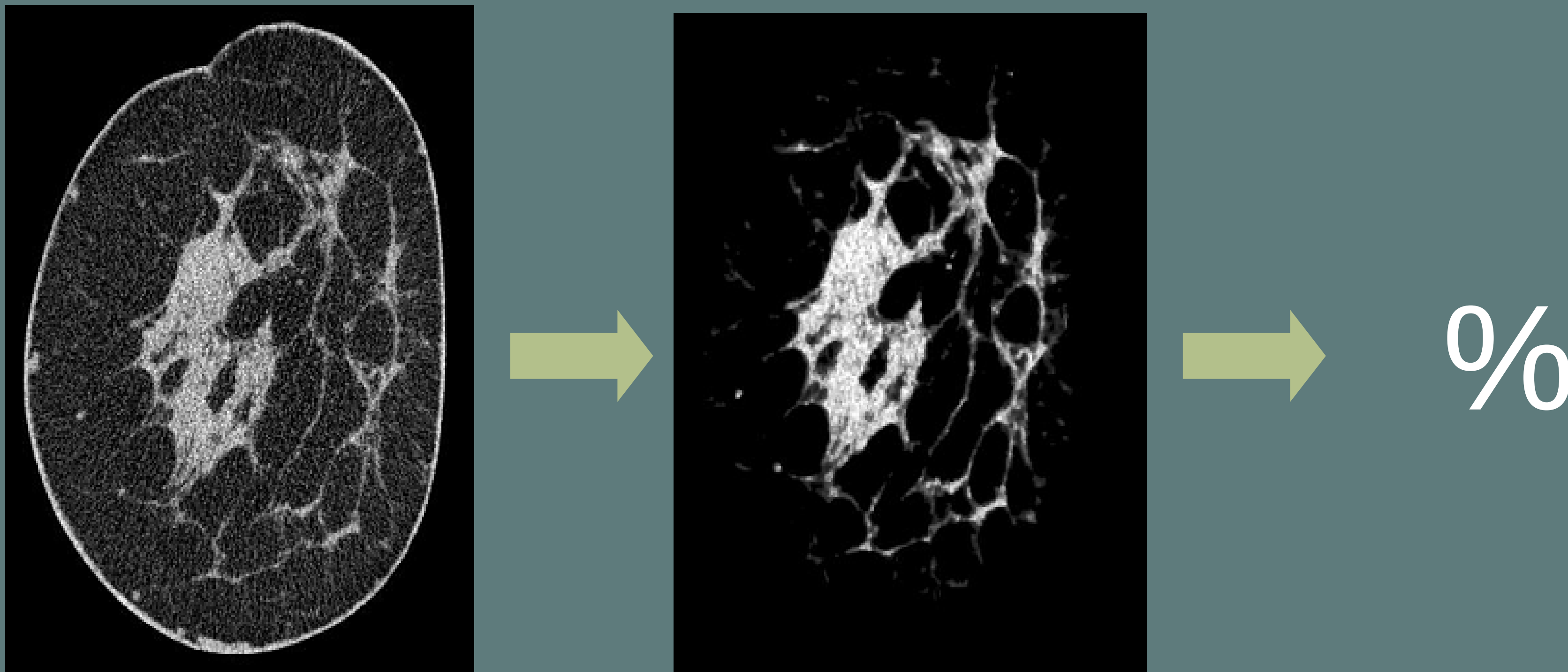
Biopsy and Cancer Therapy

Summary

Nathan Packard   Clare Huang

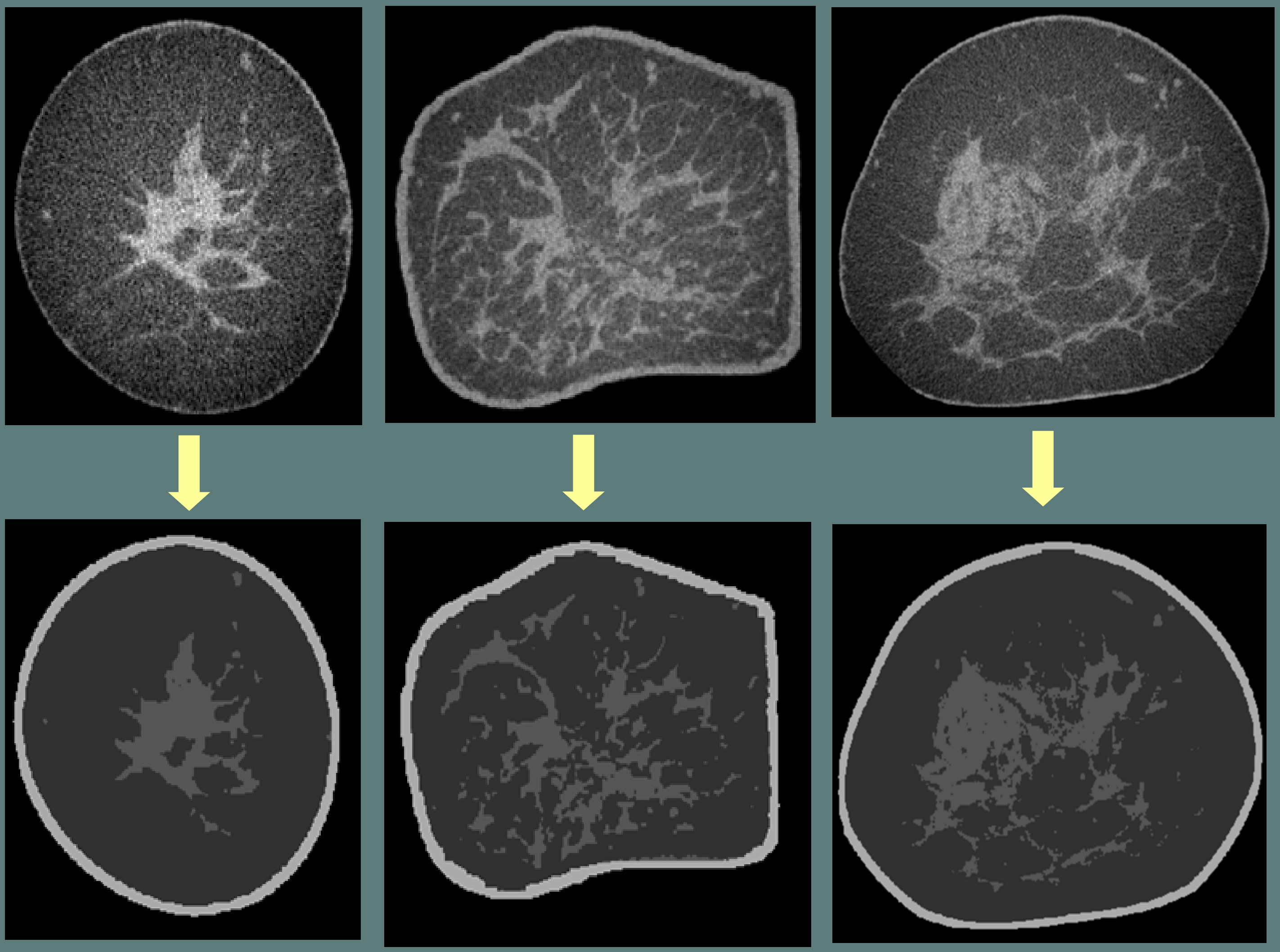
Breast Glandular Fraction

Glandular Tissue Segmentation: Glandular Fraction



- Risk assessment & Dosimetry
- Validation of 2D approaches (M. Yaffe)

Glandular Tissue Segmentation: Glandular Fraction



The myth of the 50-50 breast

M. J. Yaffe[a)]
Sunnybrook Health Sciences Centre, University of Toronto, Toronto, Ontario M4N 3M5, Canada

J. M. Boone and N. Packard
UC Davis Medical Center, University of California-Davis, Sacramento, California 95817

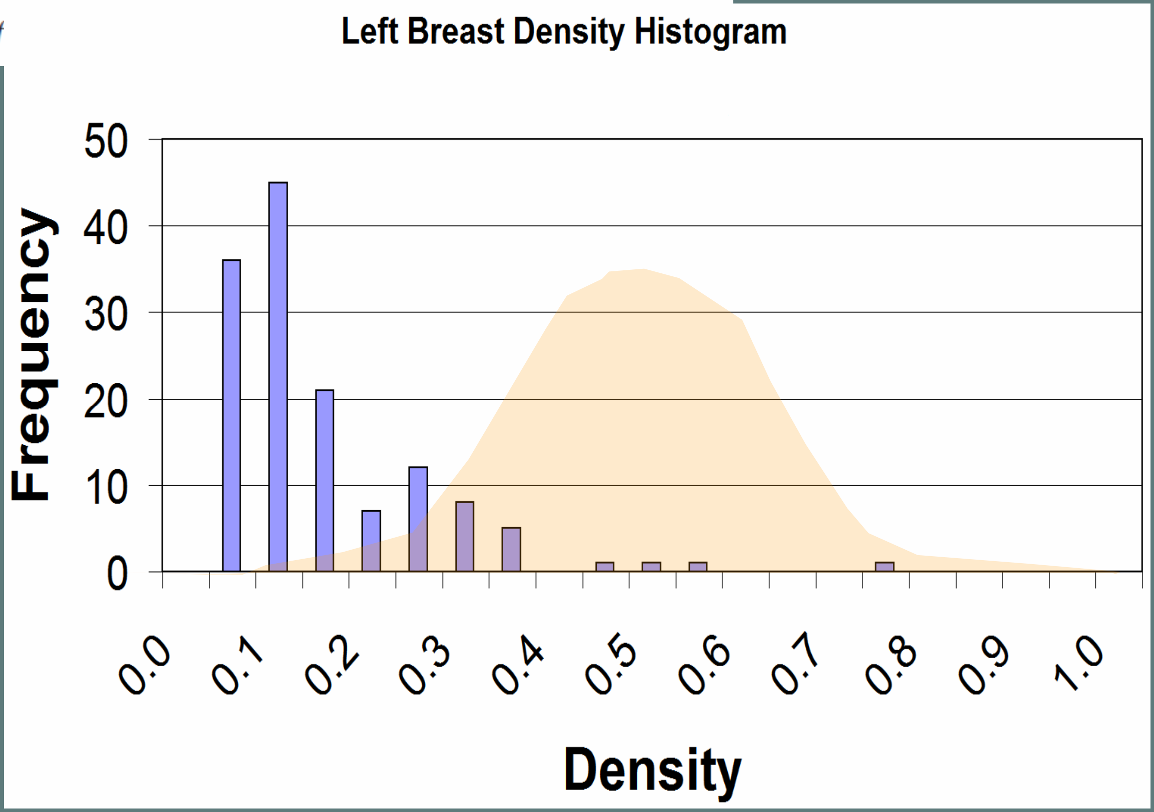
O. Alonzo-Proulx
Sunnybrook Health Sciences Centre, University of Toronto, Toronto, Ontario M4N 3M5, Canada

S.-Y. Huang
UC Davis Medical Center, University of California-Davis, Sacramento, California 95817

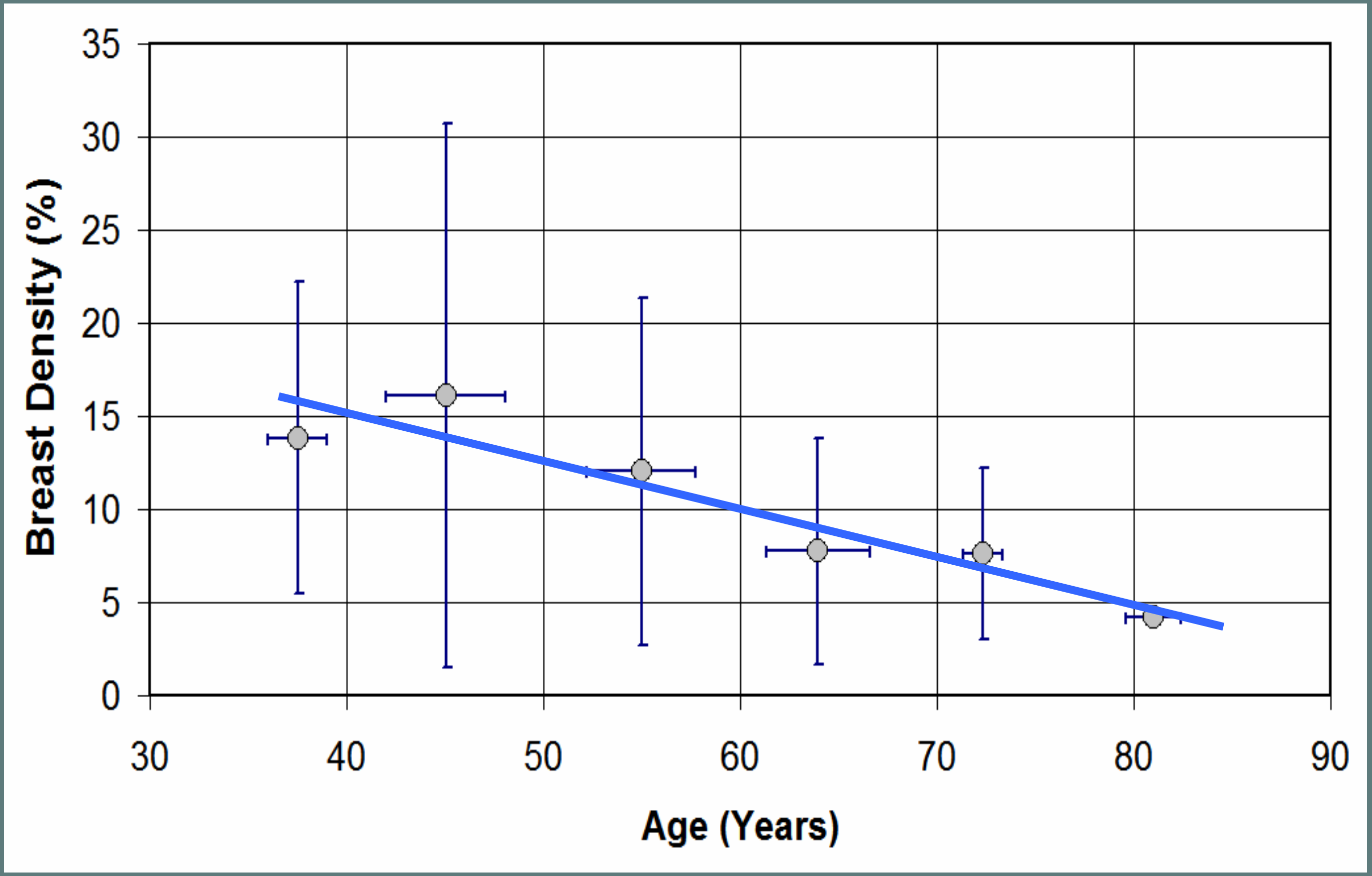
C. L. Peressotti
Sunnybrook Health Sciences Centre, University of Toronto, Toronto, Ontario M4N 3M5, Canada

A. Al-Mayah and K. Brock
University Health Network, University of

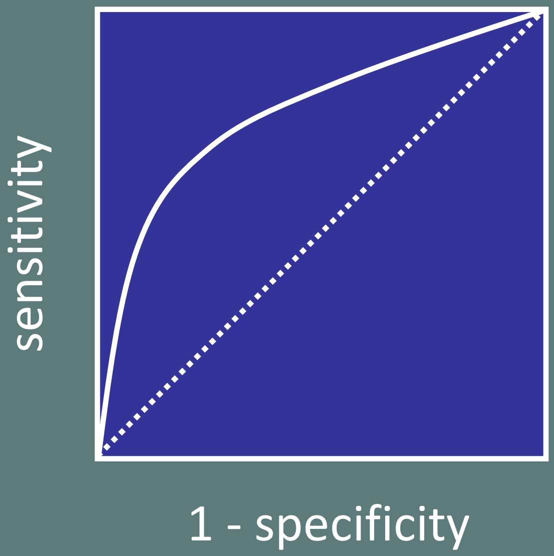
N = 138
x = 12.3%
σ = 8.5%



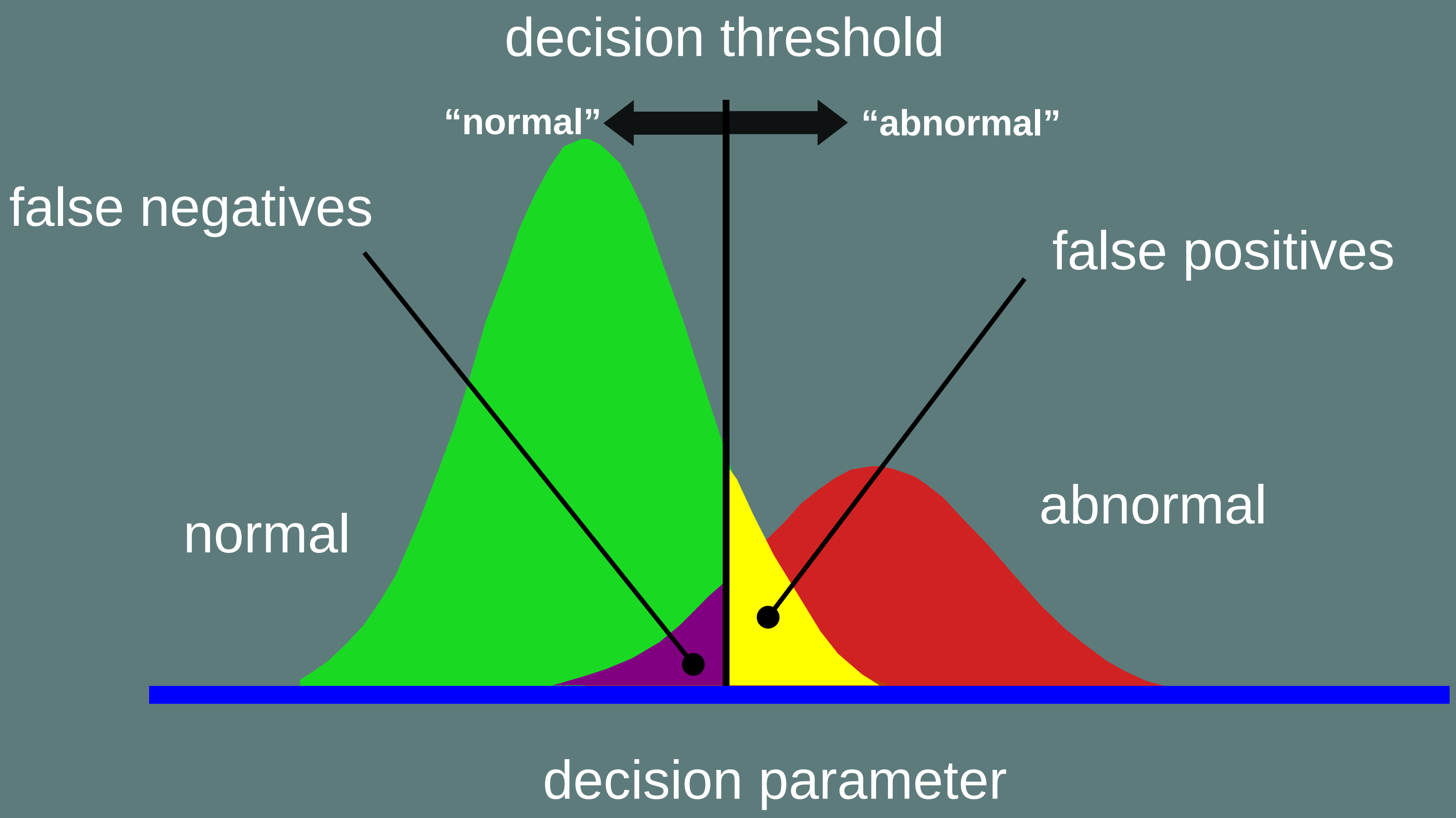
2.5% loss in breast density every decade



Receiver Operating Characteristic (ROC) Curve Basics

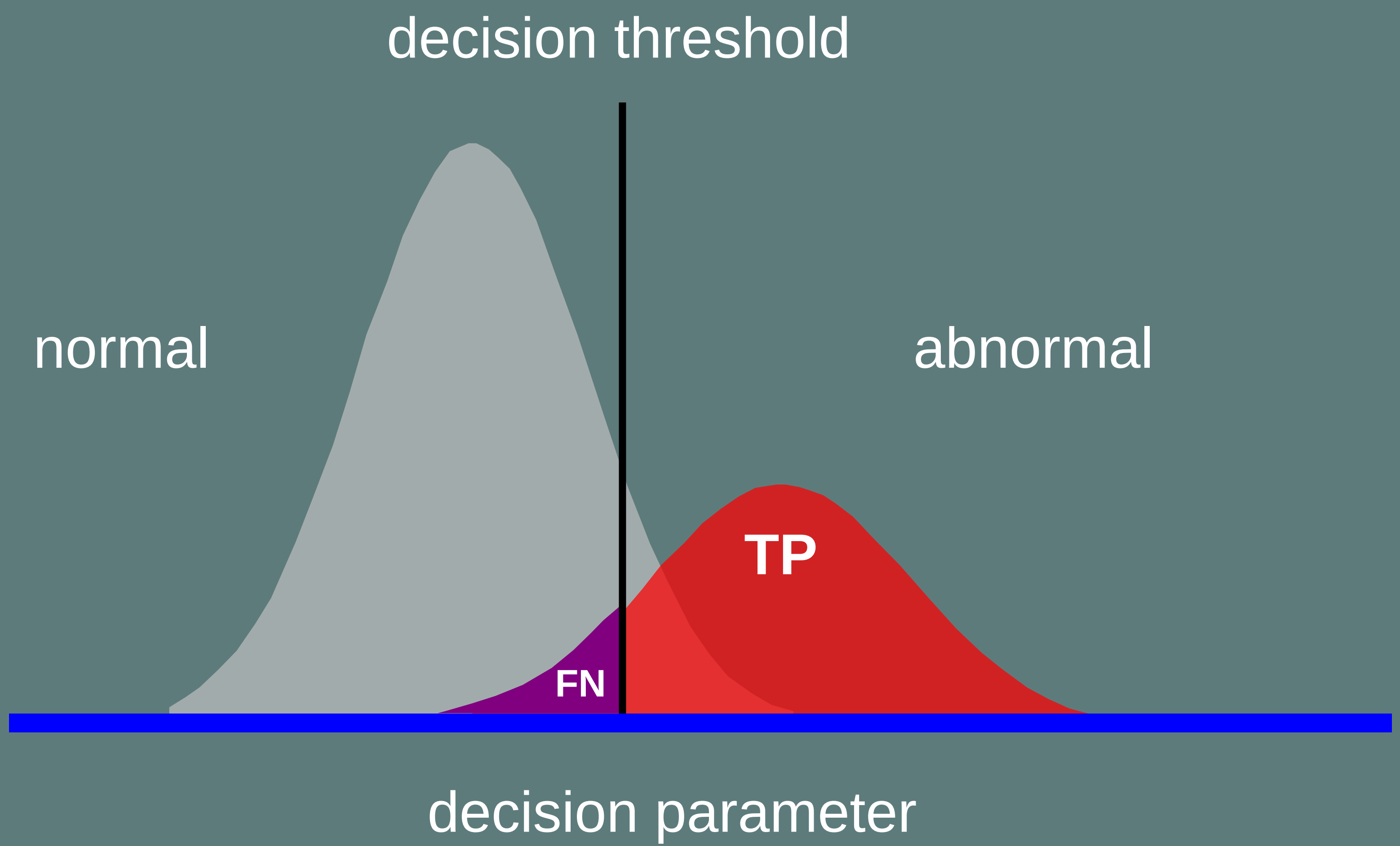


Any medical test produces data which can be considered the decision parameter. Both normal and abnormal patients will undergo that test, and the trained physician applies a decision threshold to “call” normals from abnormals.



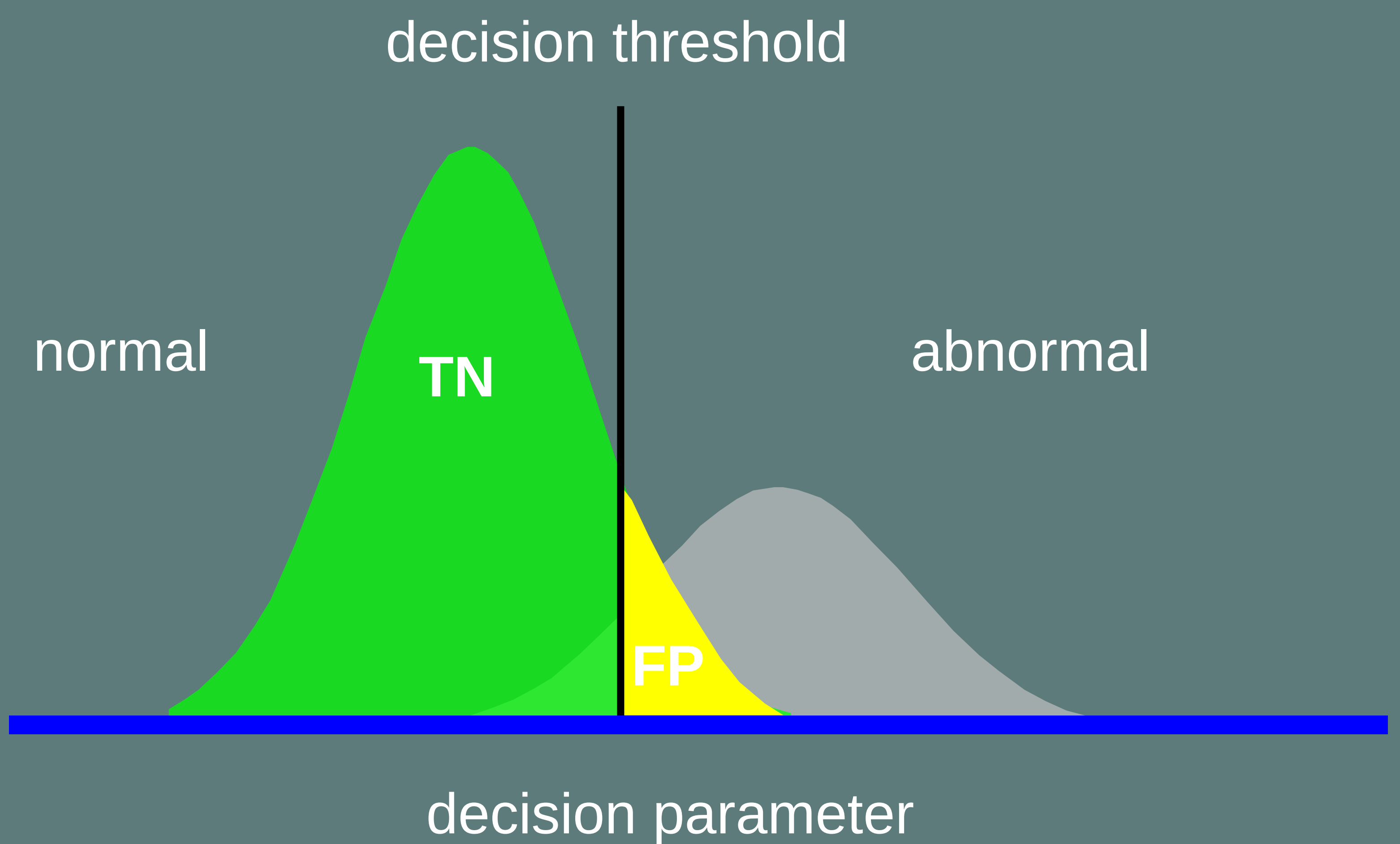
Sensitivity is the accuracy of diagnosis in all patients who are abnormal.

$$\text{sensitivity} = \frac{TP}{TP + FN}$$

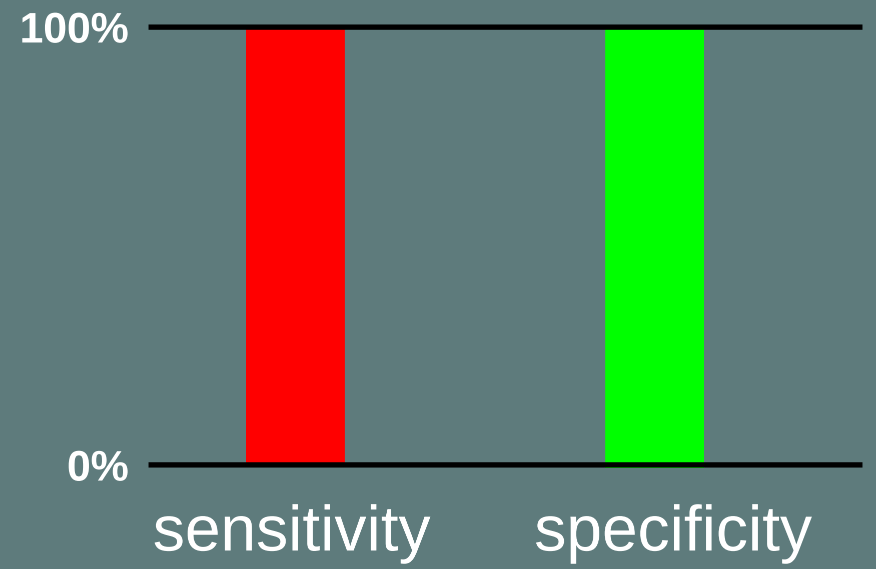


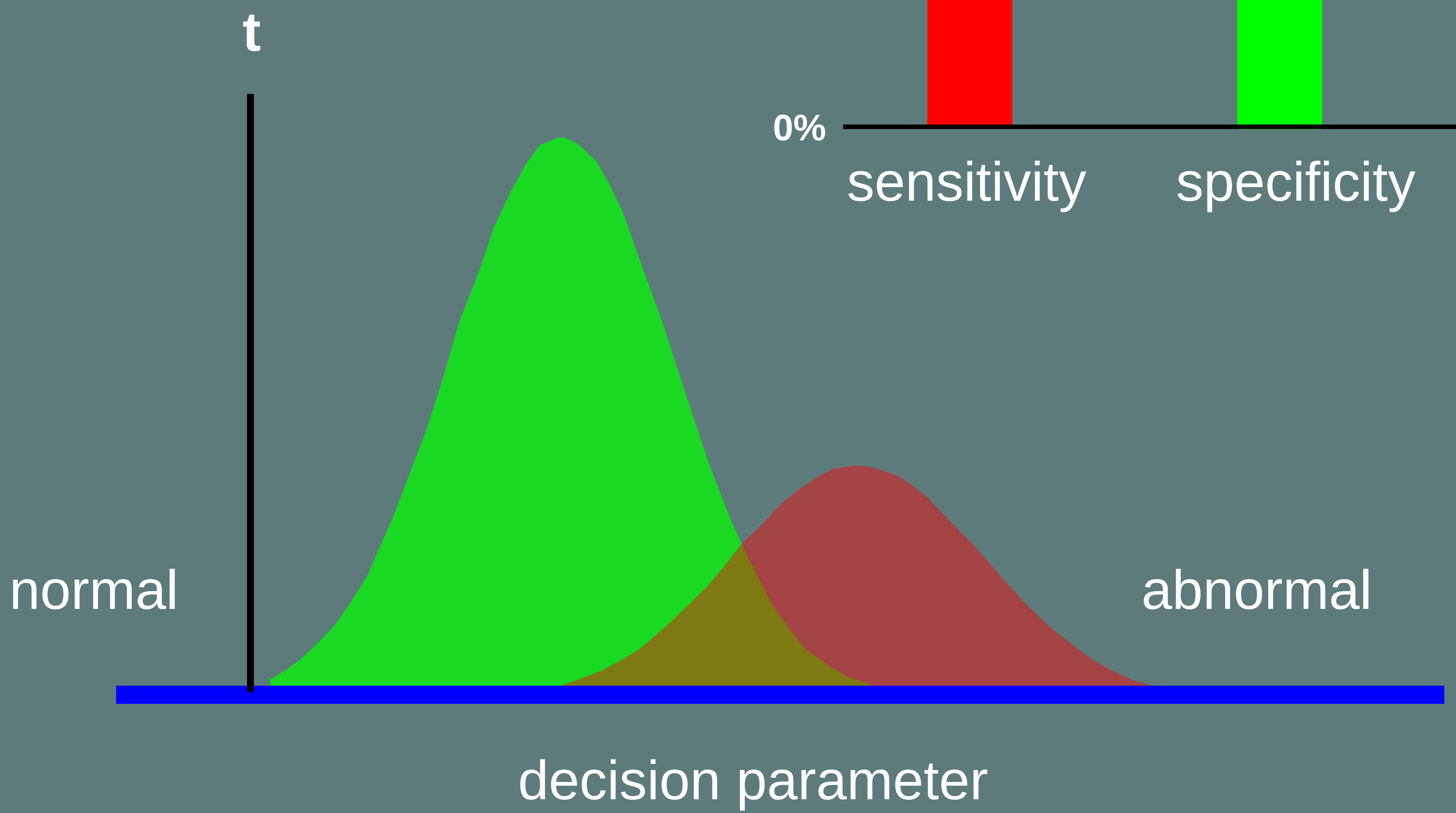
$$\text{specificity} = \frac{TN}{TN + FP}$$

Specificity is the accuracy of diagnosis in all patients who are normal.

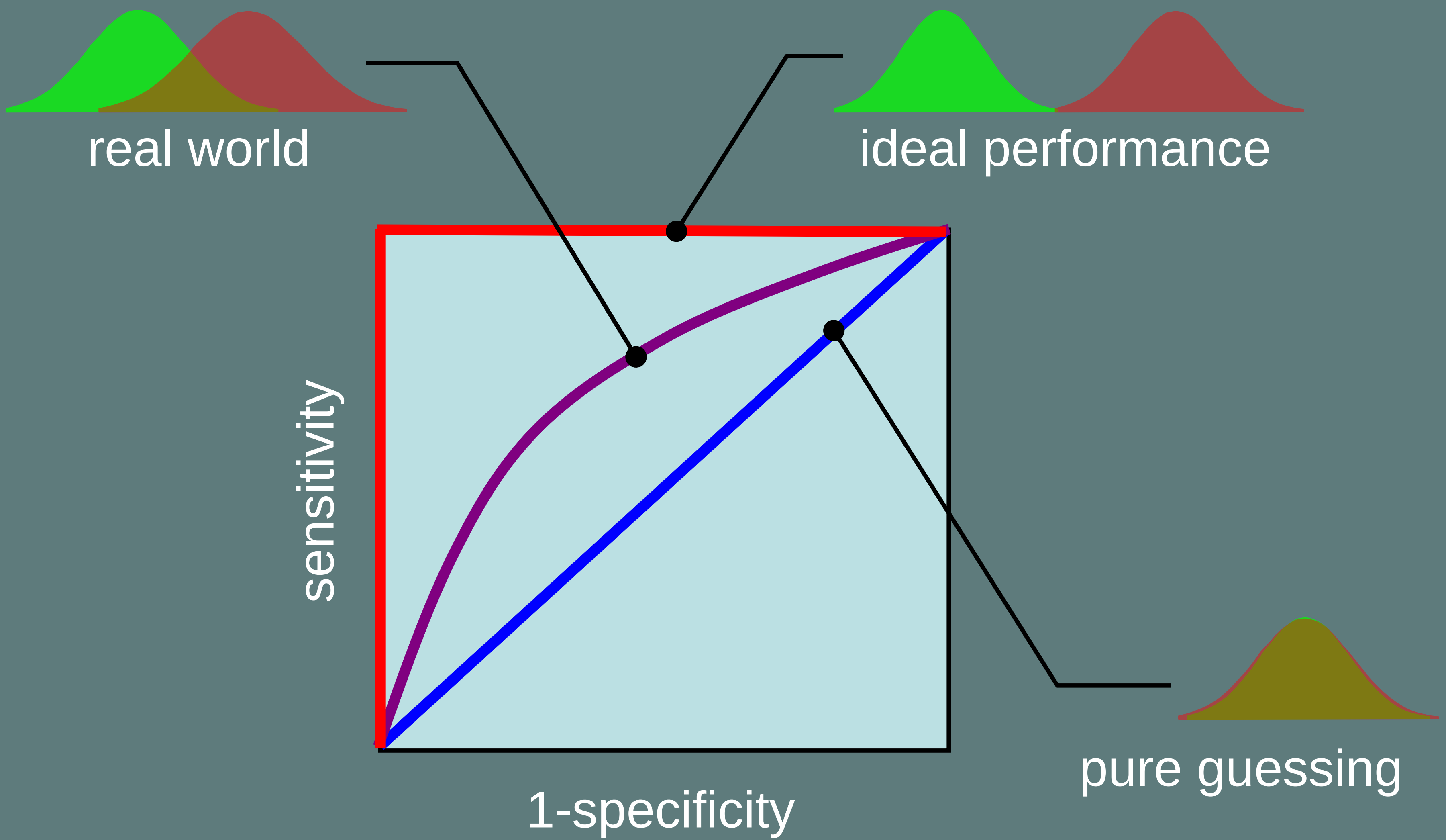


Sliding the decision threshold (t), one trades off sensitivity and specificity.





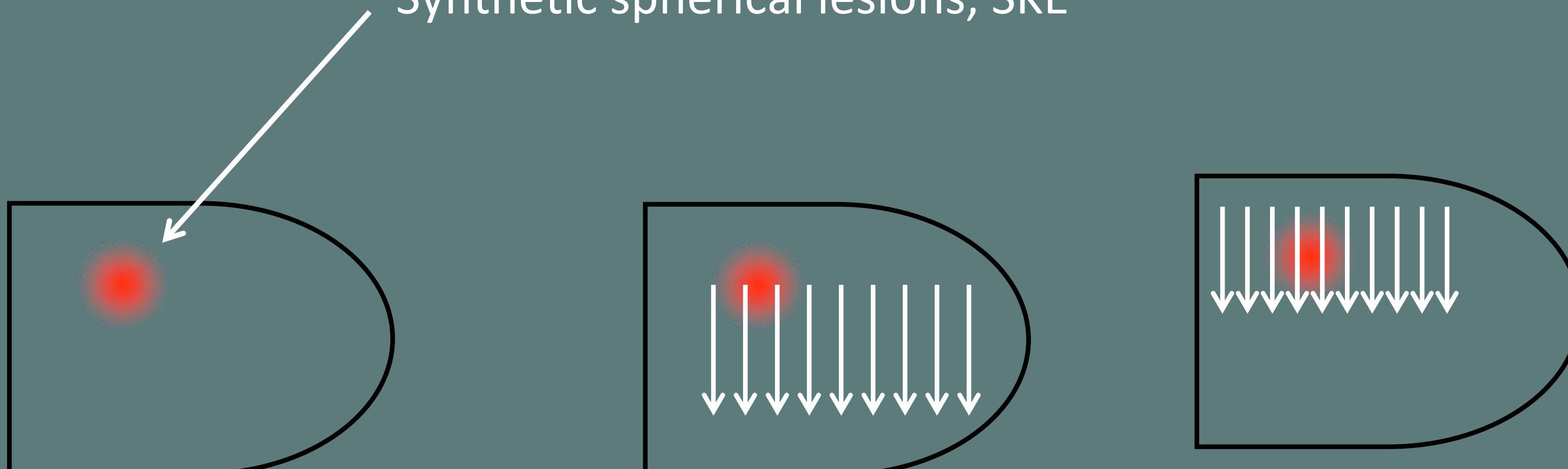
receiver operating characteristic (ROC) curve



Nathan Packard

Computer Observer Studies

Synthetic spherical lesions, SKE



Breast CT data

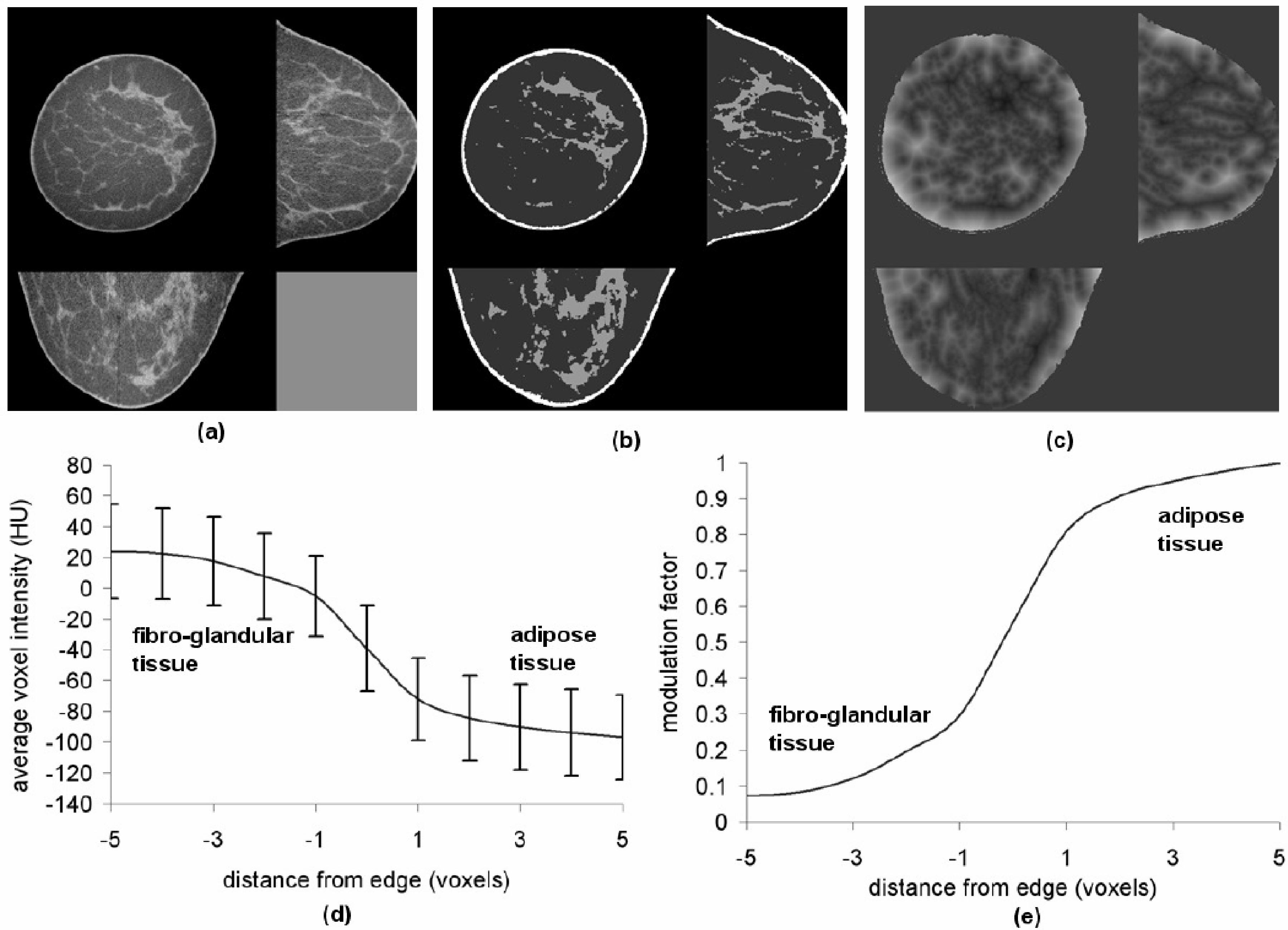
Projection Images

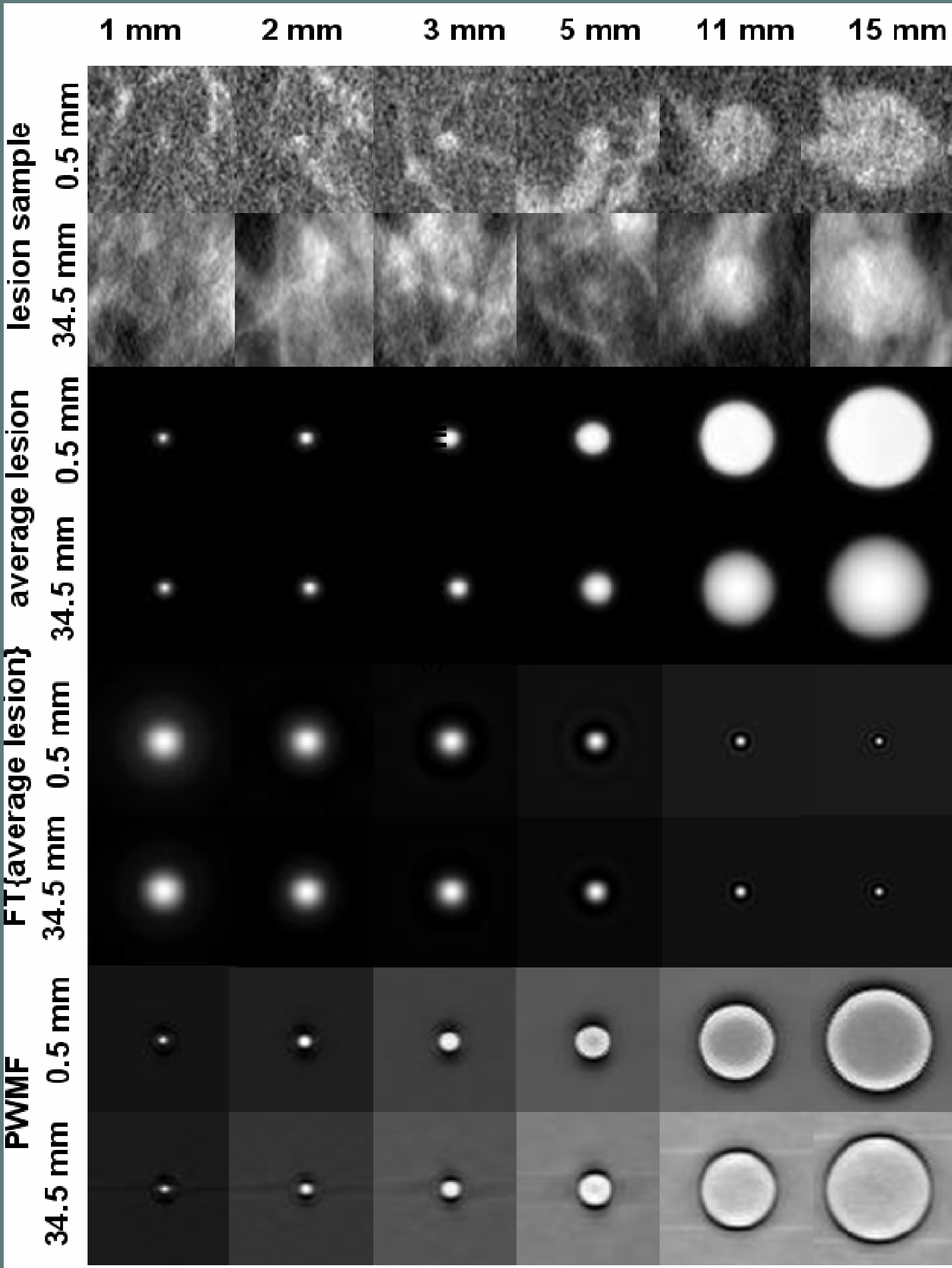
~mammography

Projection Images

~mammography

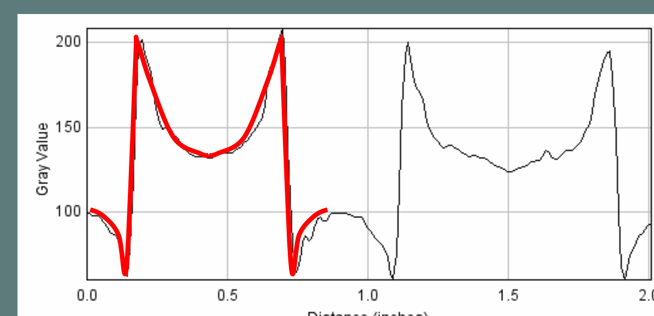
Breast CT image Segmentation 3D Distance to edge

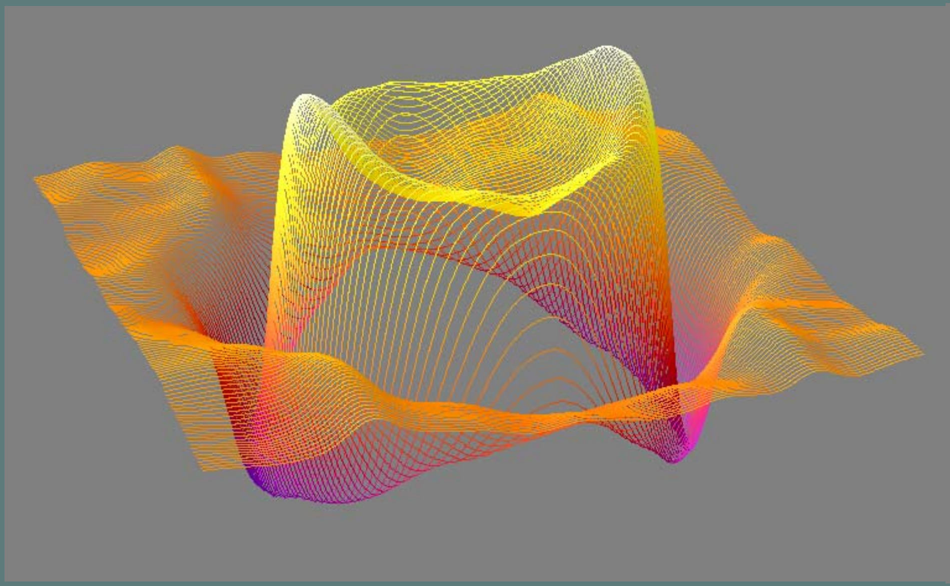




Pre-whitened Matched Filter

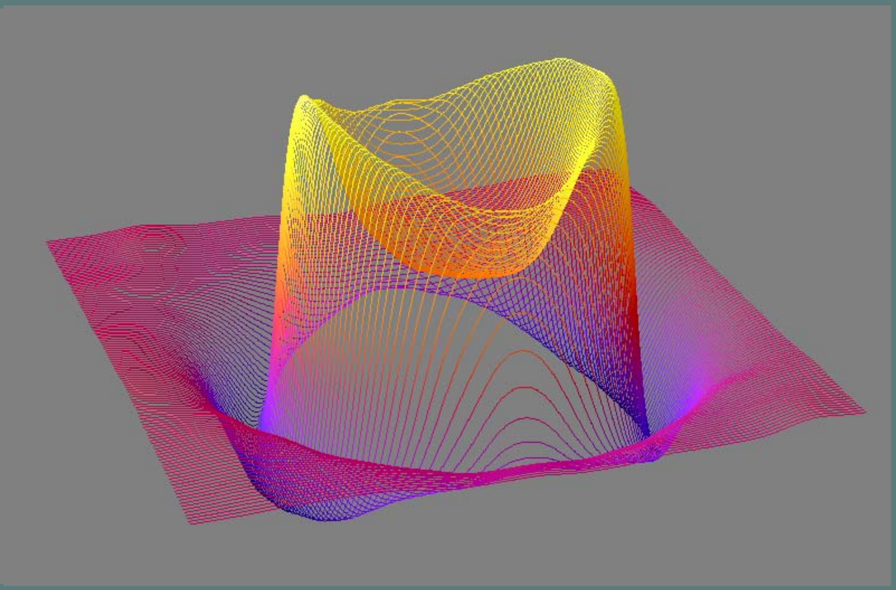
$$\mathrm{PWMF} = \mathrm{FT}^{-1}\left\{ \frac{\mathrm{FT}\{\overline{S}(x,y)\}}{\overline{PS}(x,y)} \right\}$$





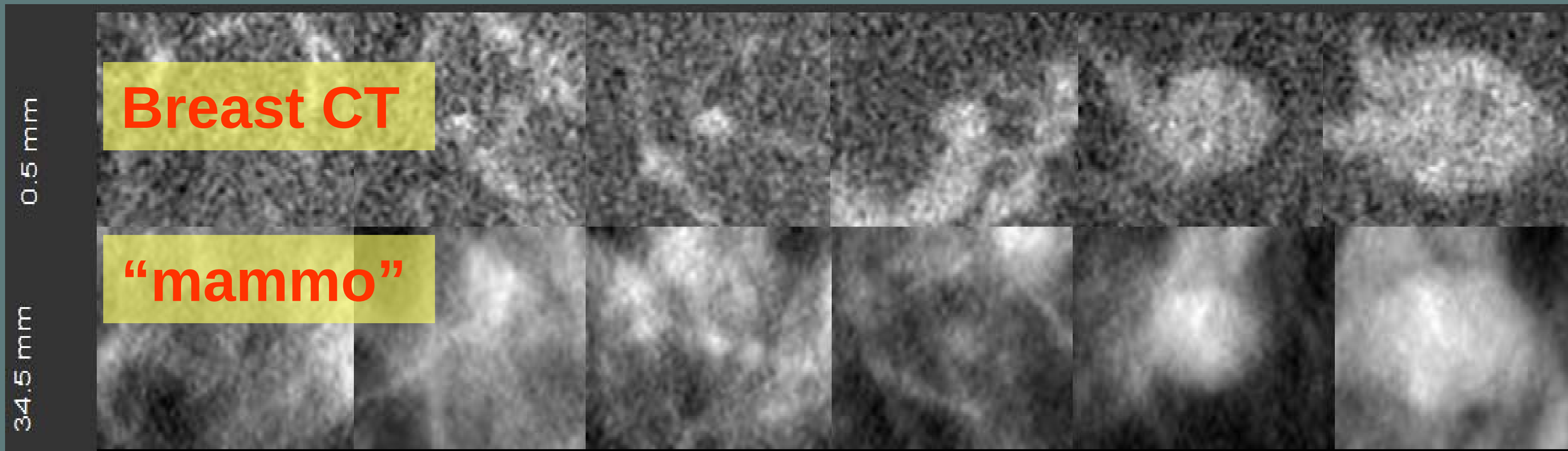
Prewhitened Matched Filter

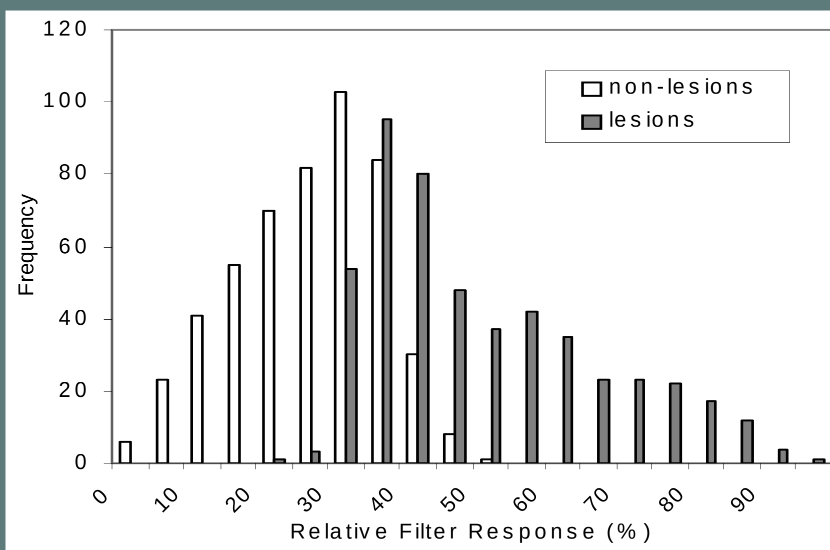
Thick Slices (Mammo)

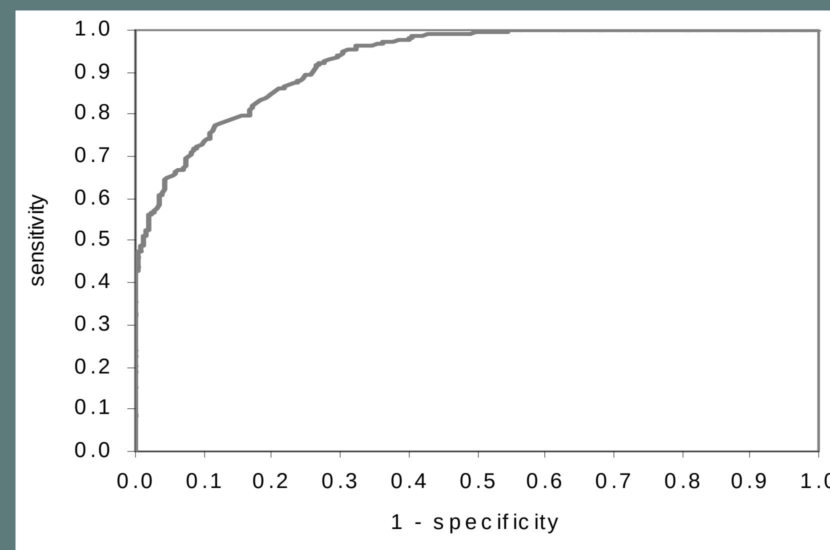


Prewhitened Matched Filter

Thin Slices (breast CT)

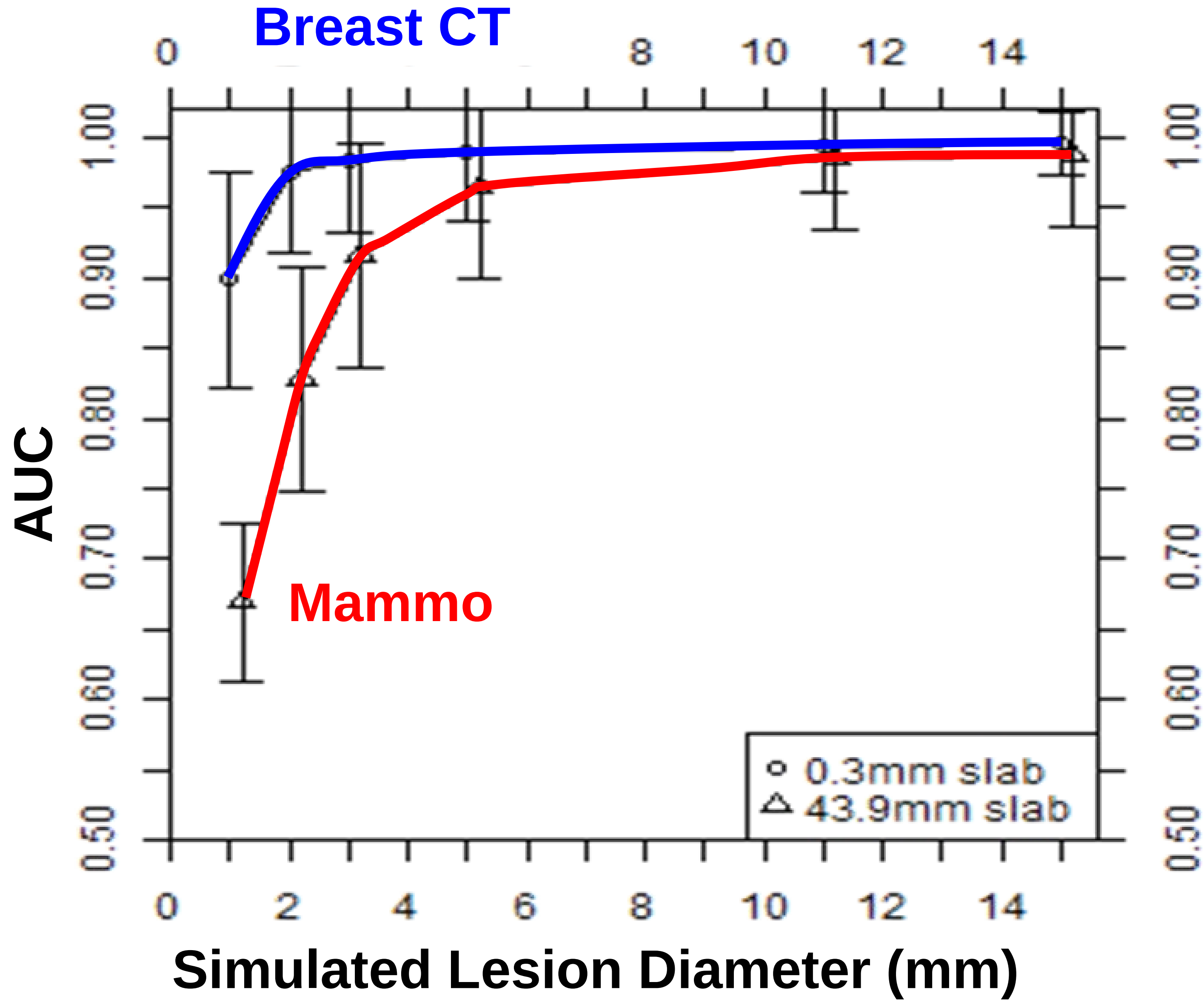




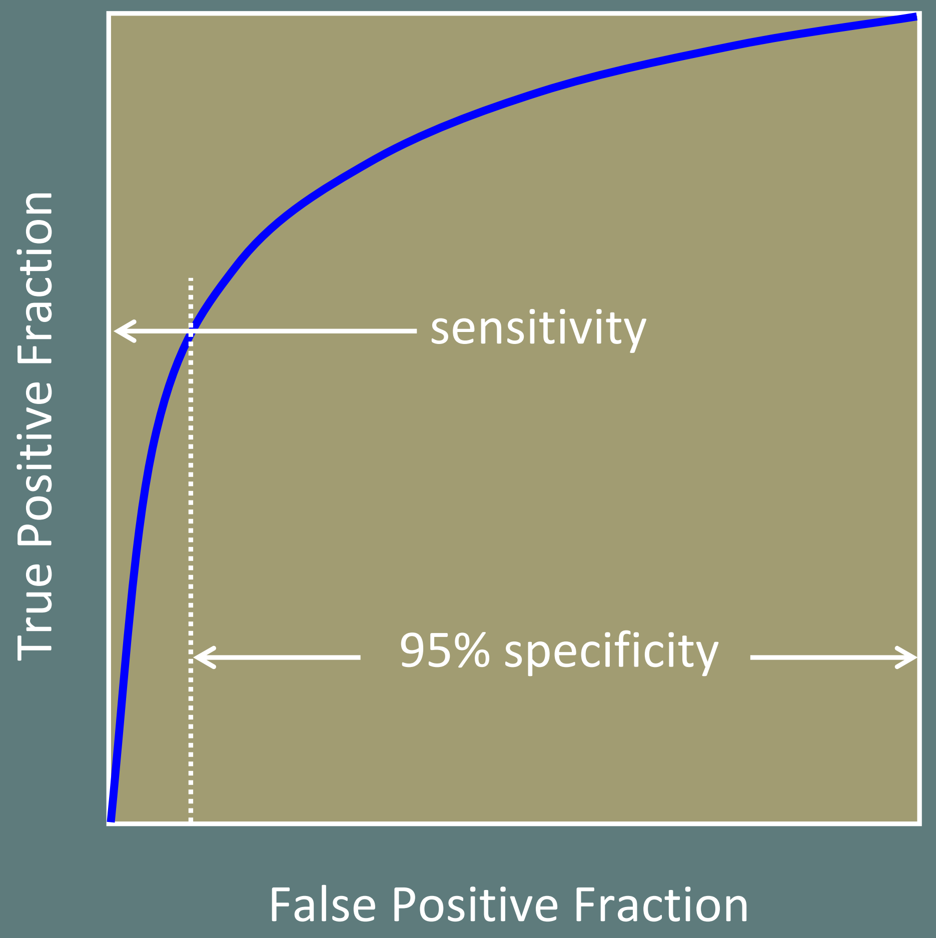


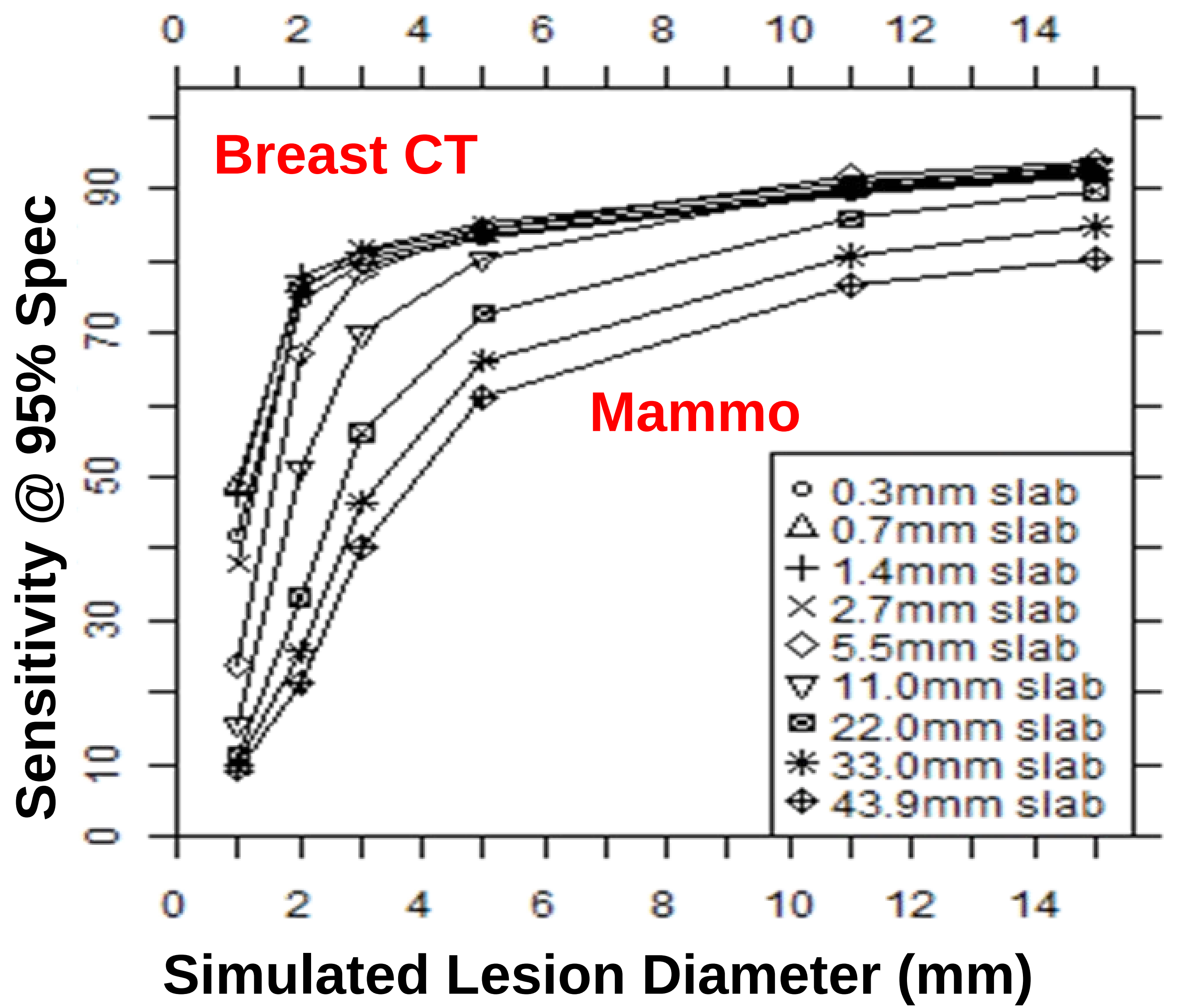
Pre-whitened matched filter – “ideal observer”

1000 true and 1000 non-lesions per bCT – ~380 bCT data sets

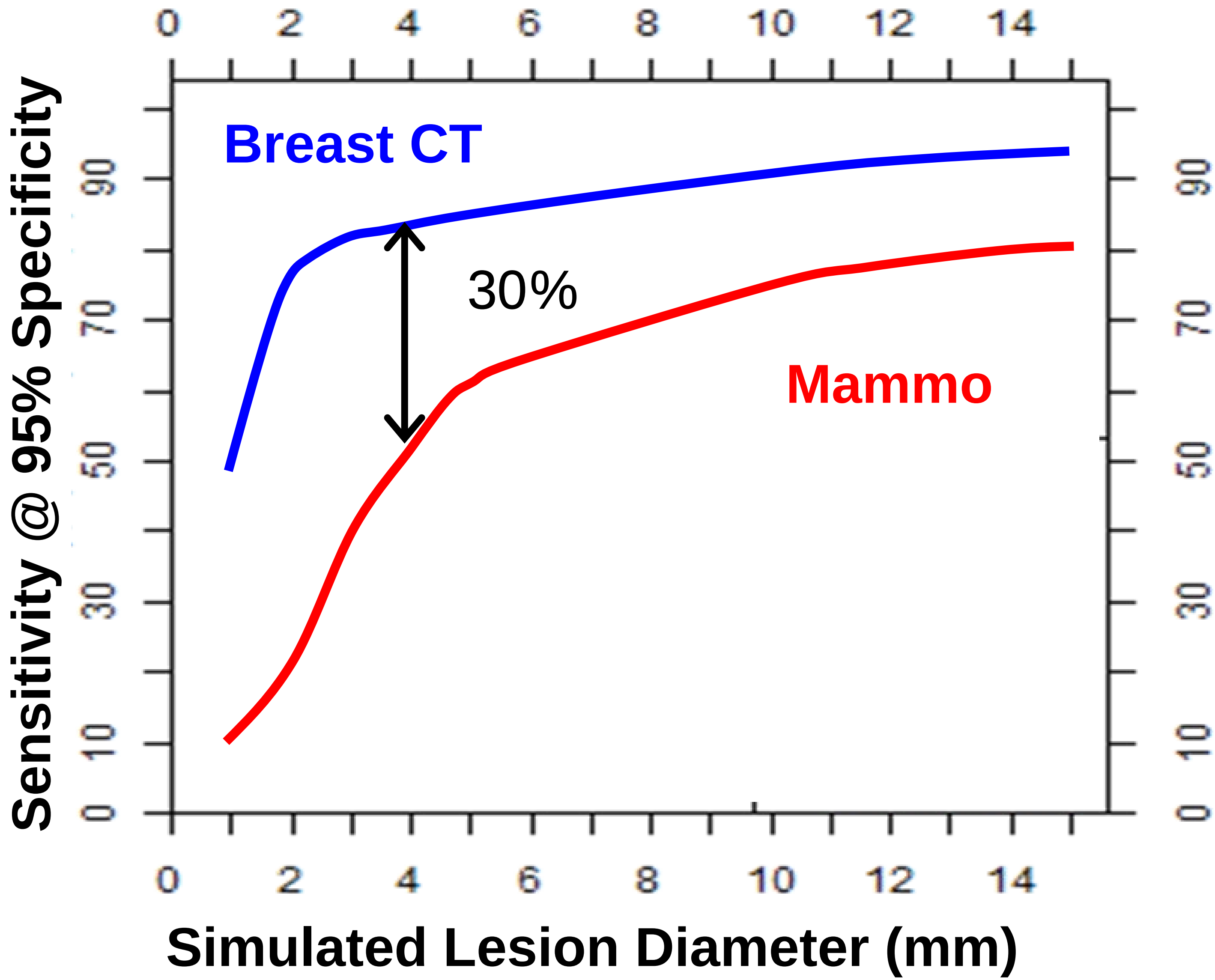

Breast CT
Mammo
AUC
Simulated Lesion Diameter (mm)
0.3mm slab
43.9mm slab
0
2
4
6
8
10
12
14
0.50
0.60
0.70
0.80
0.90
1.00

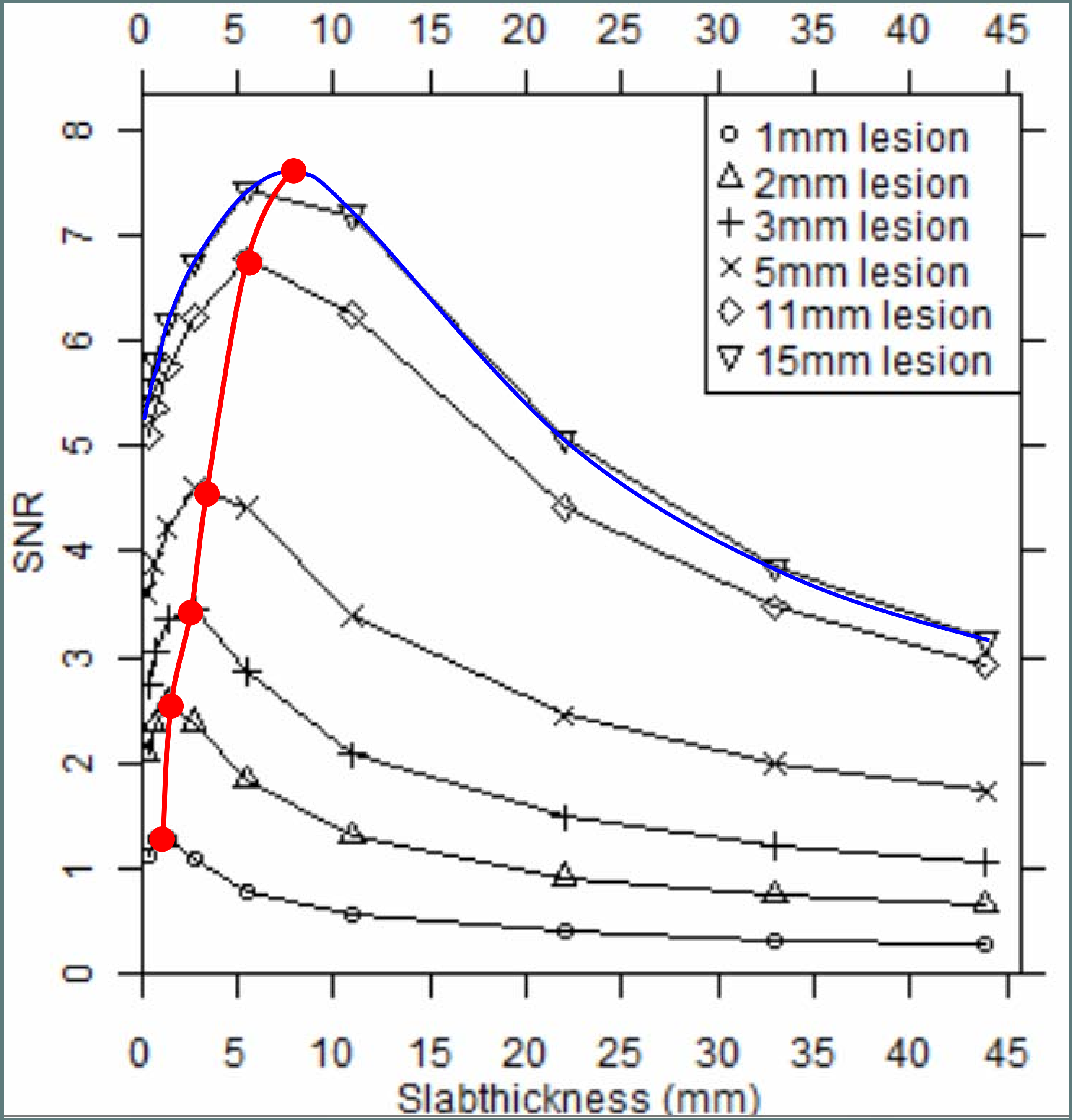
Receiver Operating Characteristic (ROC) Curve



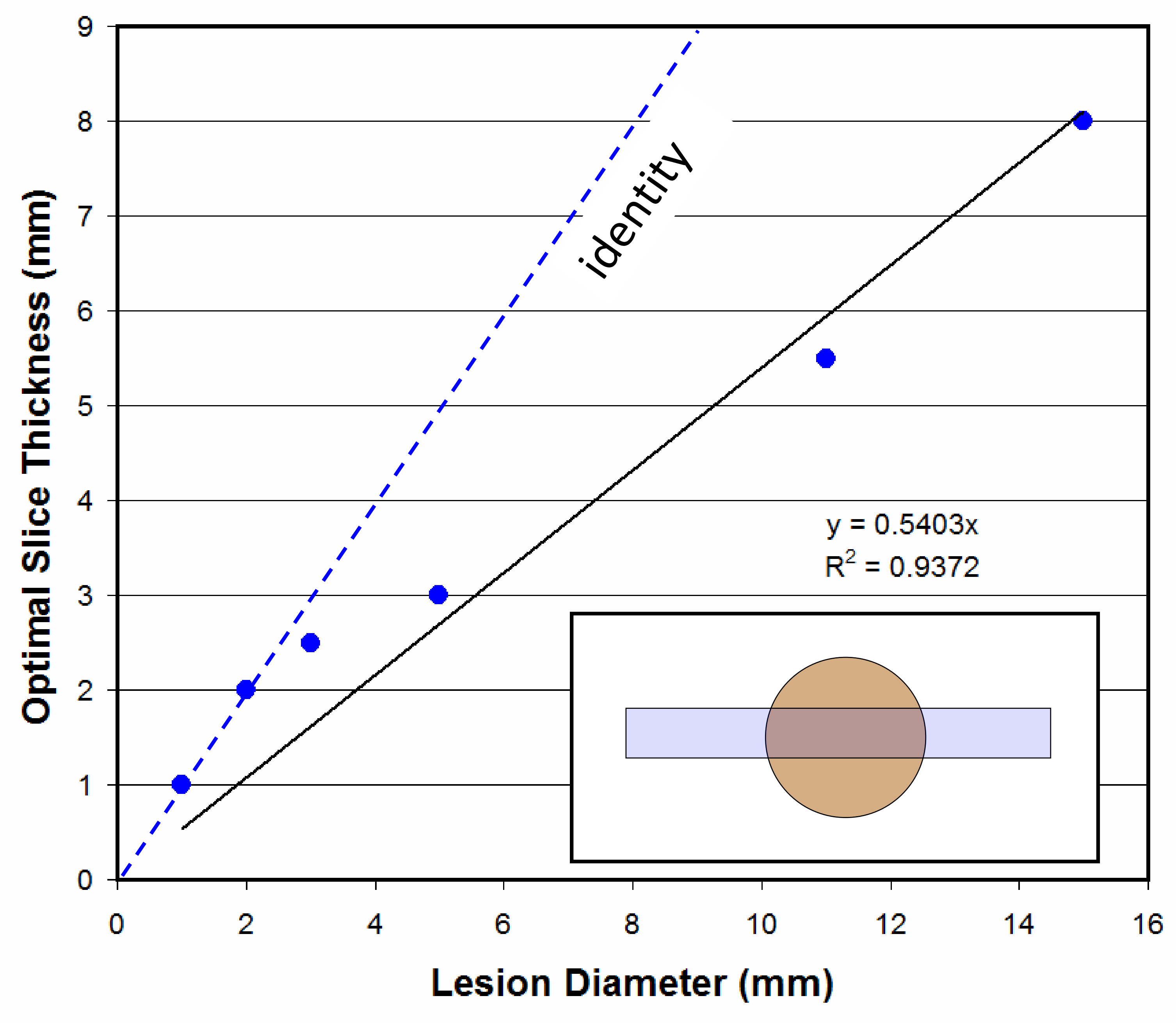


Breast CT
Mammo
0.3mm slab
0.7mm slab
1.4mm slab
2.7mm slab
5.5mm slab
11.0mm slab
22.0mm slab
33.0mm slab
43.9mm slab
Sensitivity @ 95% Spec
Simulated Lesion Diameter (mm)


Breast CT
30%
Mammo
Sensitivity @ 95% Specificity
Simulated Lesion Diameter (mm)
0
2
4
6
8
10
12
14
0
10
30
50
70
90



1mm lesion
2mm lesion
3mm lesion
5mm lesion
11mm lesion
15mm lesion
SNR
Slabthickness (mm)
0
5
10
15
20
25
30
35
40
45
0
1
2
3
4
5
6
7
8


Optimal Slice Thickness (mm)
0
1
2
3
4
5
6
7
8
9
identity
y = 0.5403x
R^2 = 0.9372
0
2
4
6
8
10
12
14
16
Lesion Diameter (mm)

Katie Metheany

Lin Chen

Anita Nosratieh

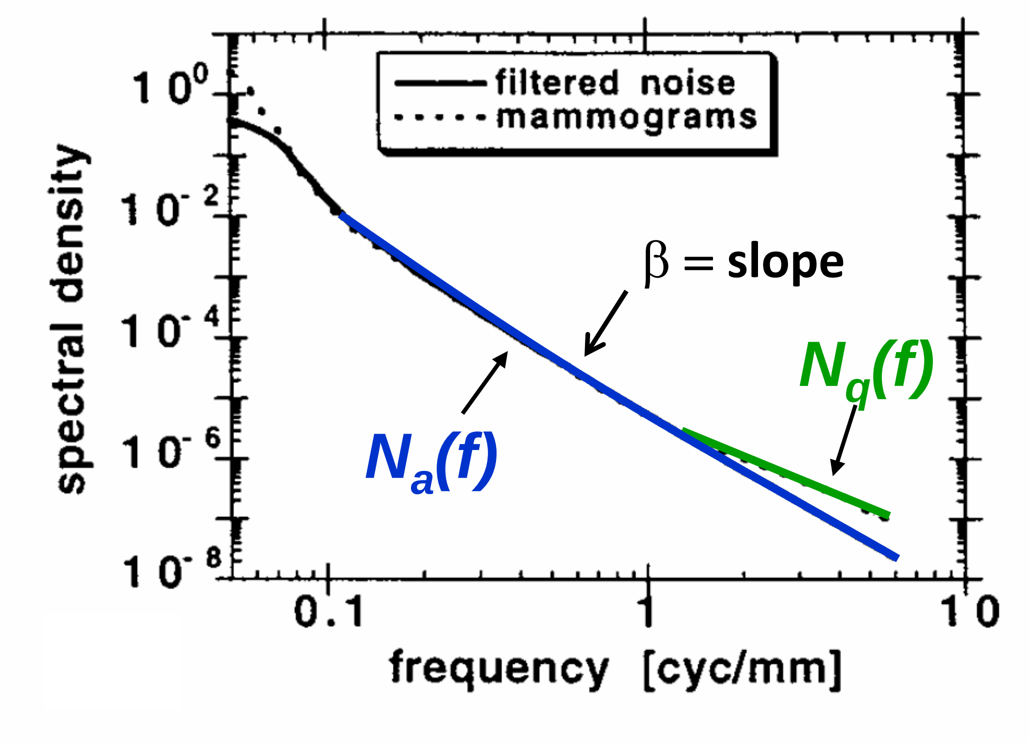
Evaluation of Anatomical NPS

total noise

anatomical noise

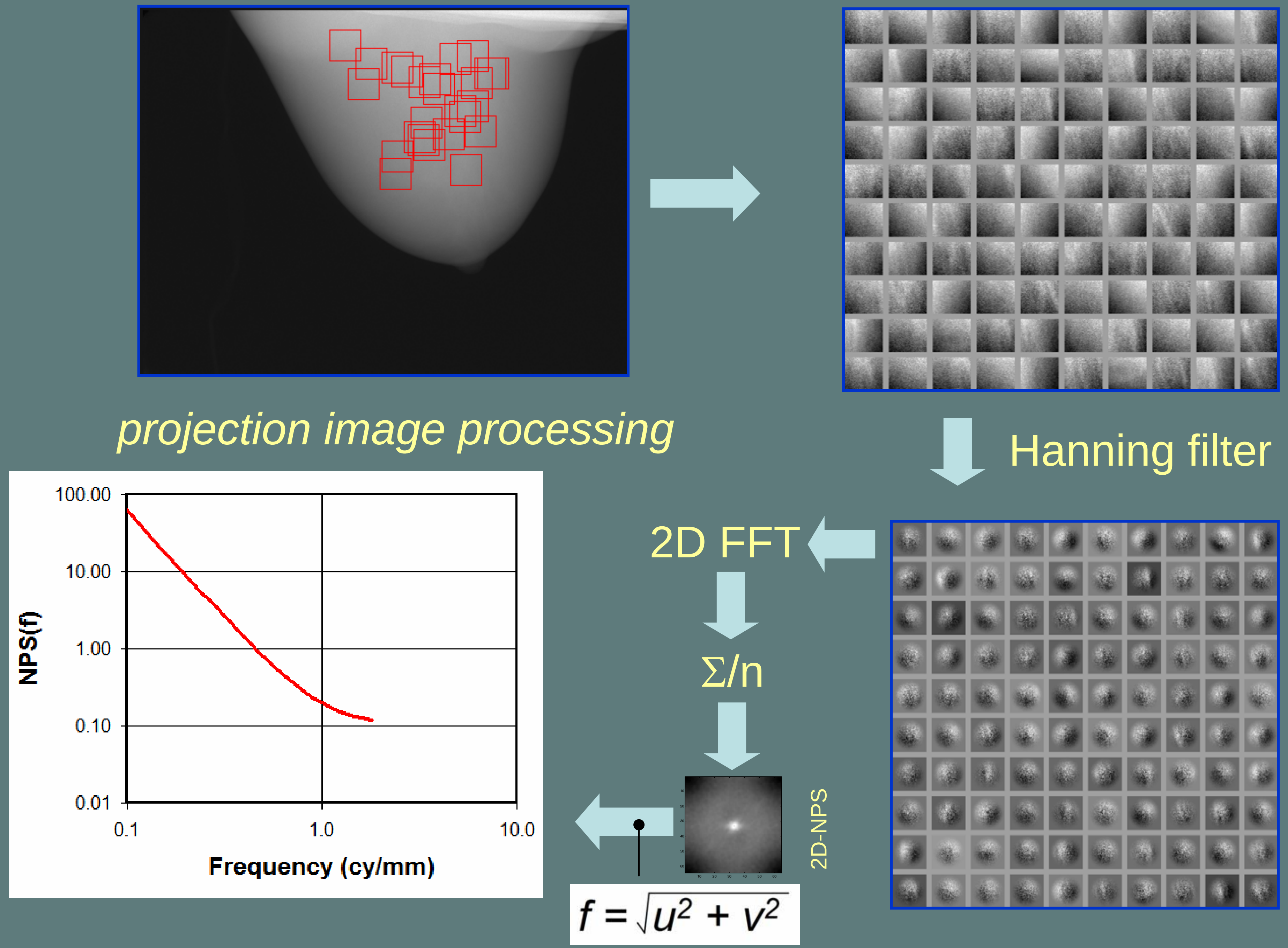
quantum noise

$$NPS(f) = NPS_a(f) + NPS_q(f) \qquad NPS_a(f) = \alpha f^{-\beta}$$

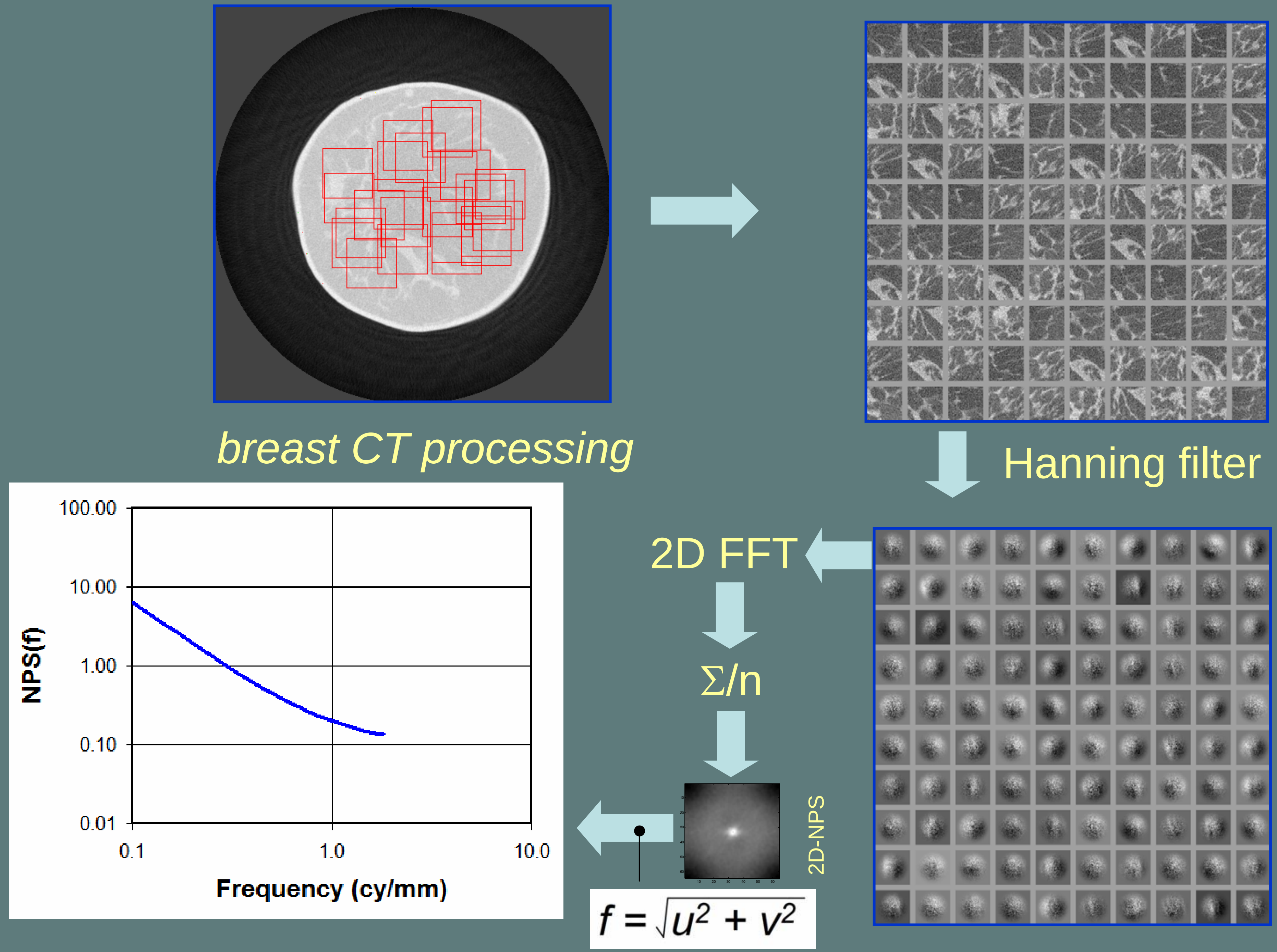


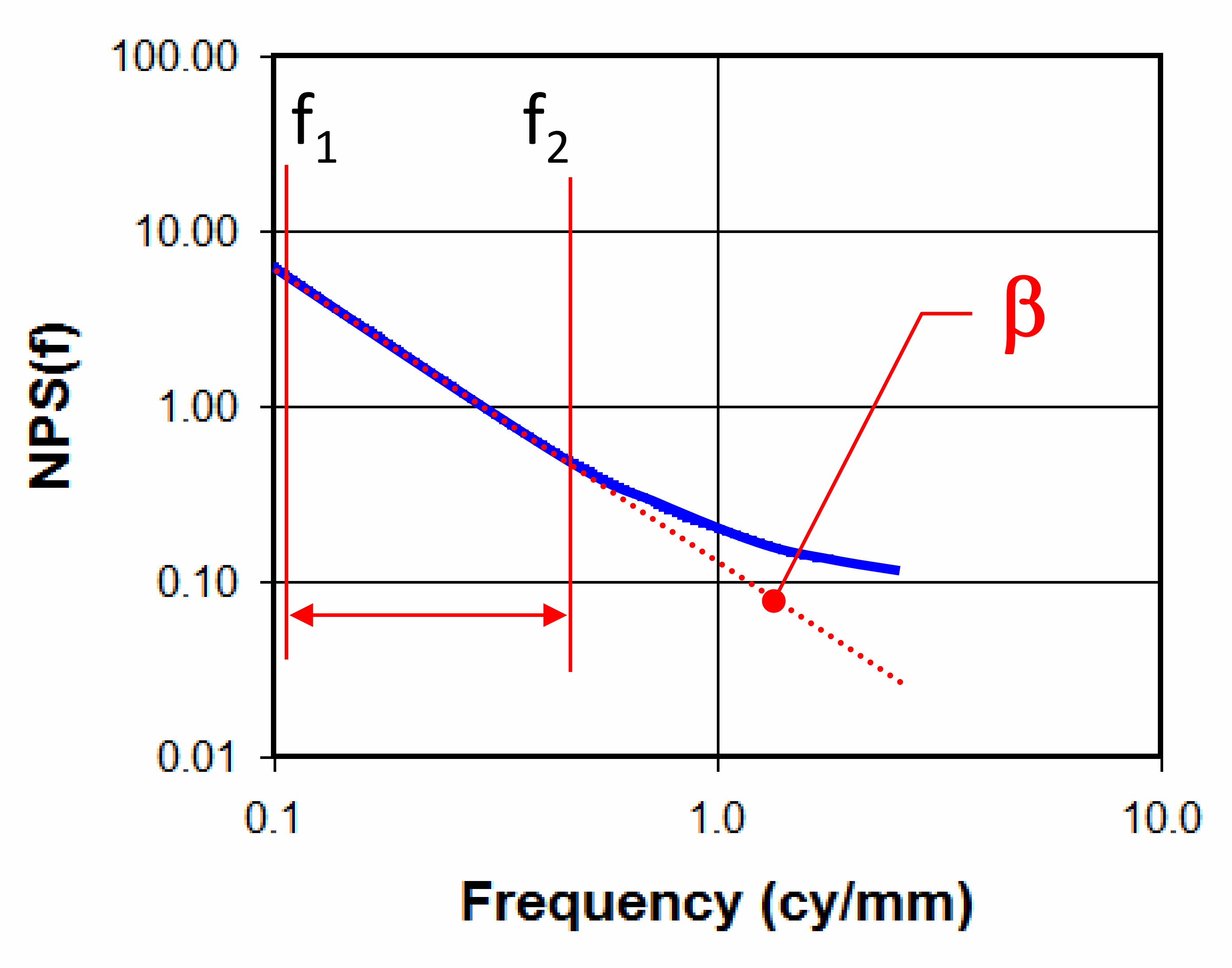
Burgess, et al

A. E. Burgess, F. L. Jacobson, and P. F. Judy, "Human observer detection experiments with mammograms and power-law noise," Med. Phys. 28, 419–437 (2001).



projection image processing
Hanning filter
2D FFT
Σ/n
2D-NPS
$f = \sqrt{u^2 + v^2}$
NPS(f)
100.00
10.00
1.00
0.10
0.01
0.1
1.0
10.0
Frequency (cy/mm)


breast CT processing
Hanning filter
2D FFT
Σ/n
2D-NPS
$f = \sqrt{u^2 + v^2}$
NPS(f)
100.00
10.00
1.00
0.10
0.01
0.1
1.0
10.0
Frequency (cy/mm)


100.00
10.00
1.00
0.10
0.01
NPS(f)
f_1
f_2
β
0.1
1.0
10.0
Frequency (cy/mm)

Characterizing anatomical variability in breast CT images

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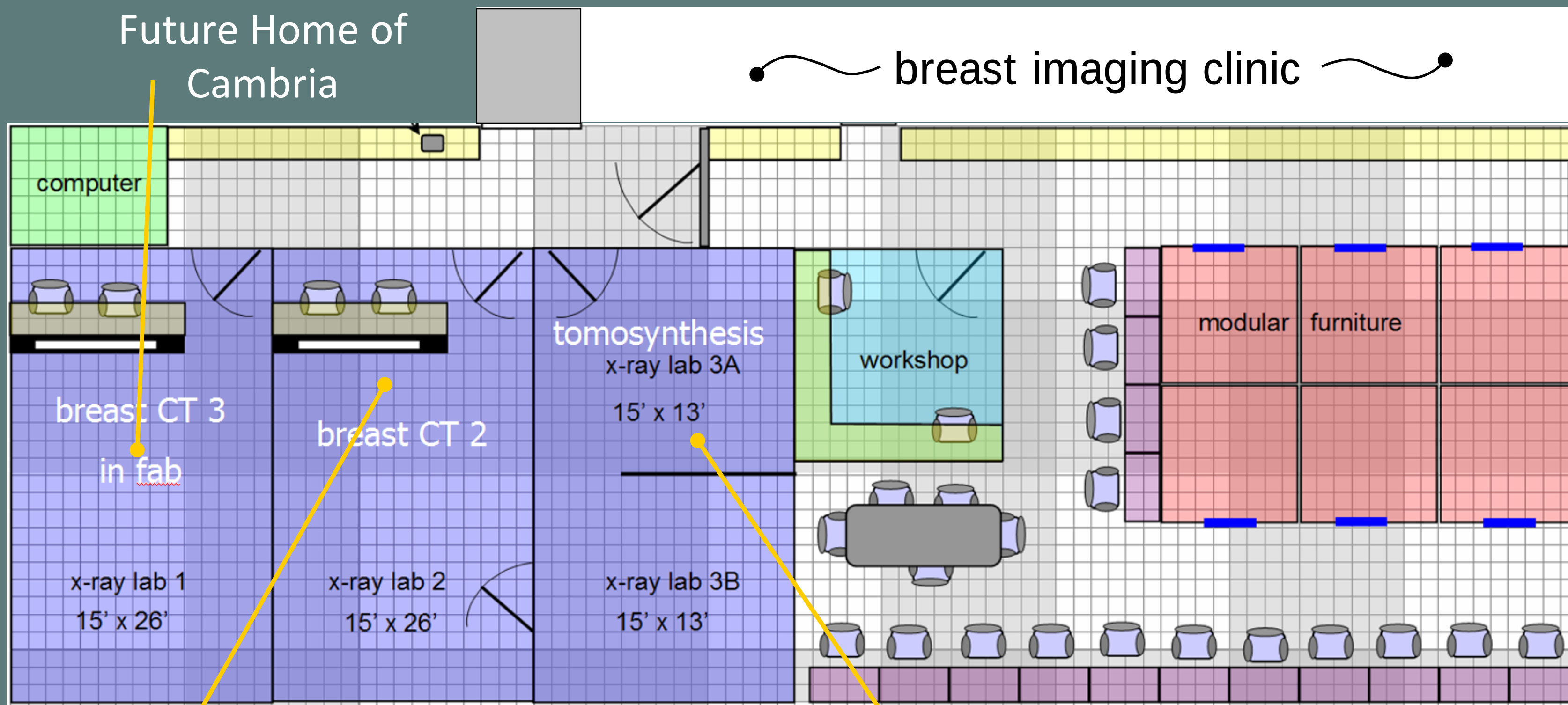
University of California Davis Medical Center, Sacramento, California 95817

(Received 29 October 2007; revised 19 June 2008; accepted for publication 20 June 2008; published 24 September 2008)

$$\beta_{bCT} = \beta_{mammo} - 1$$

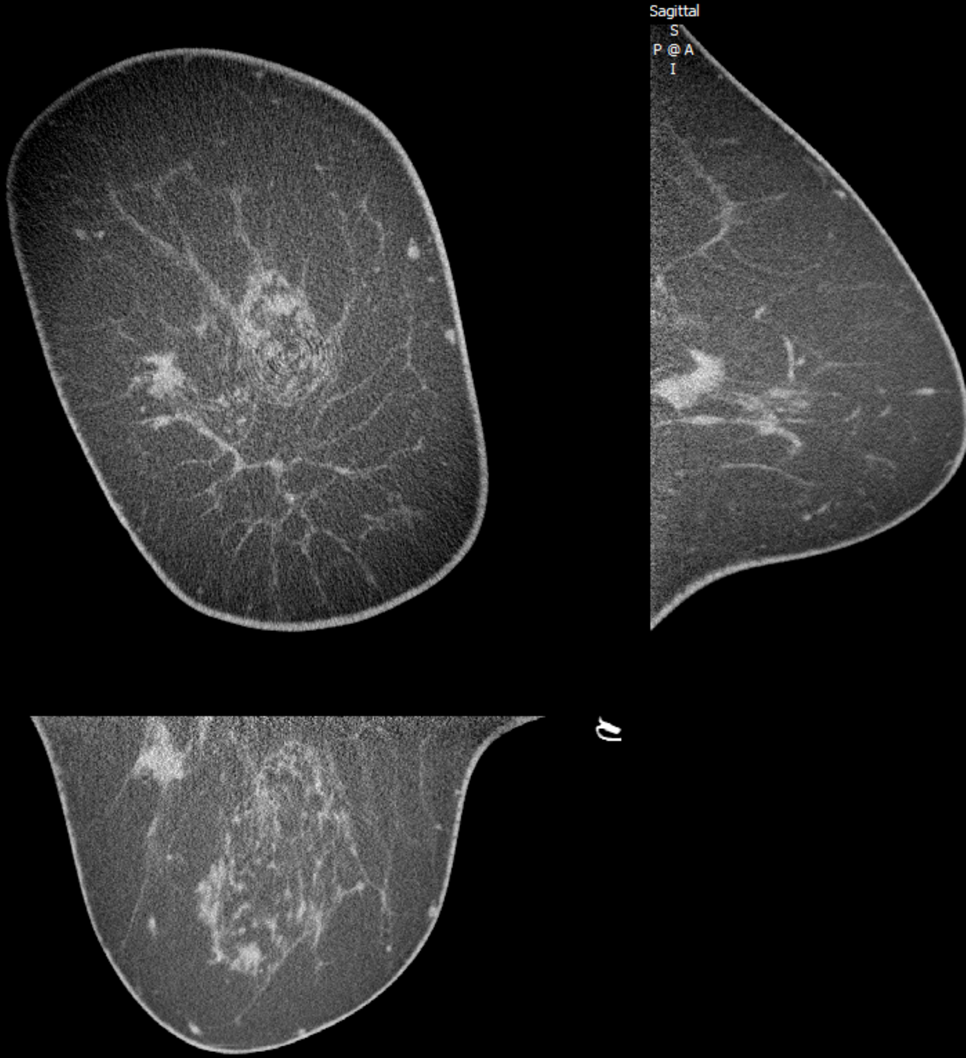
Modality	N	Average exponent	Standard deviation
Mammograms (Burgess *et al.*)	213	2.83	0.35
bCT Slices	43	1.86	0.38
Mammograms	6	3.01	0.32
bCT Slices	6	1.99	0.33

Future Home of Cambria

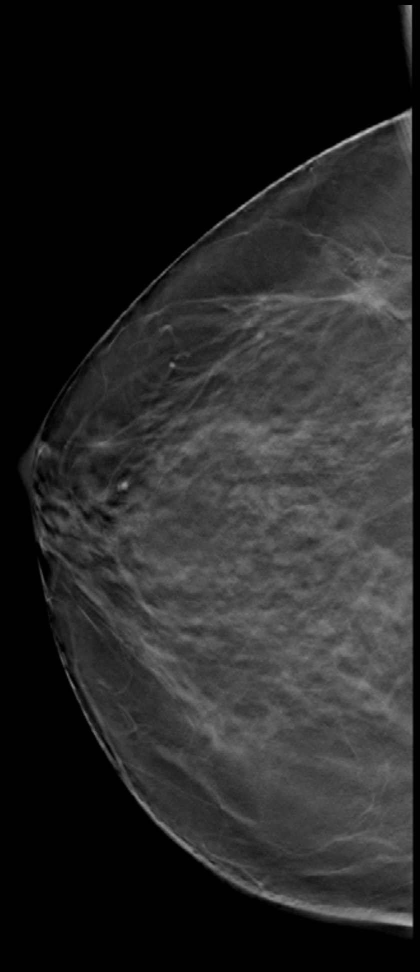


Bodega breast CT system

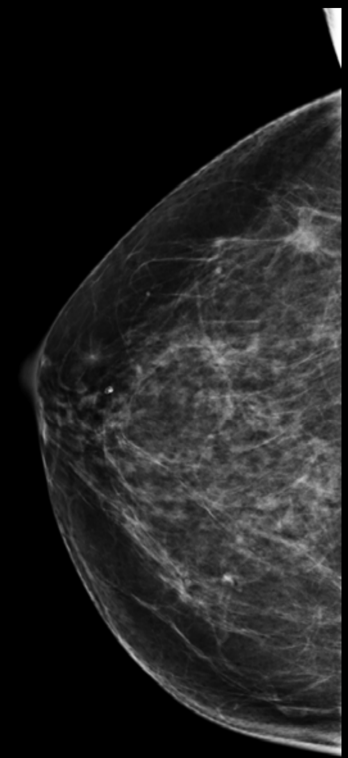
Hologic (beta) Tomosynthesis System



breast CT

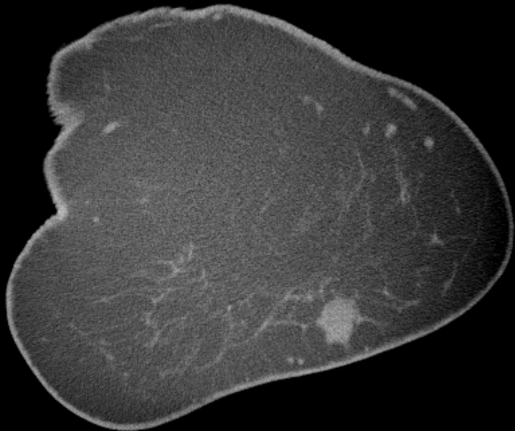


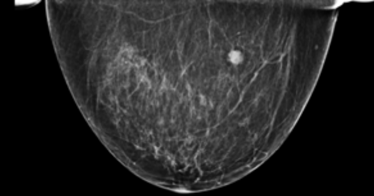
cc tomosynthesis



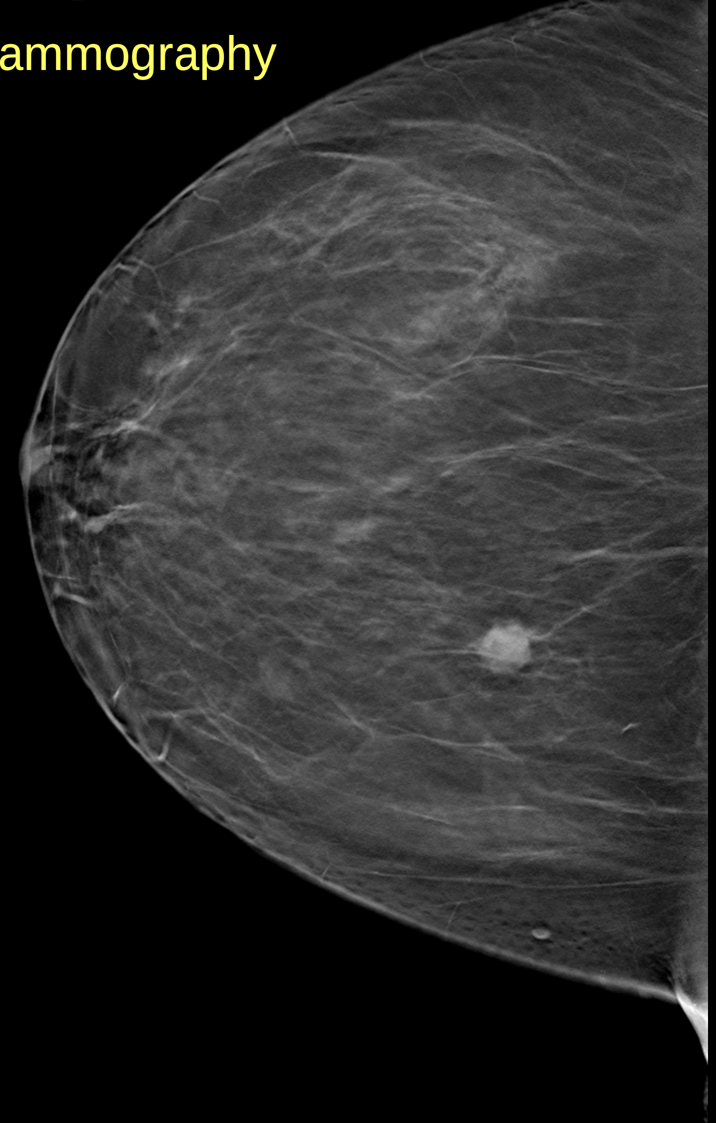
cc mammography

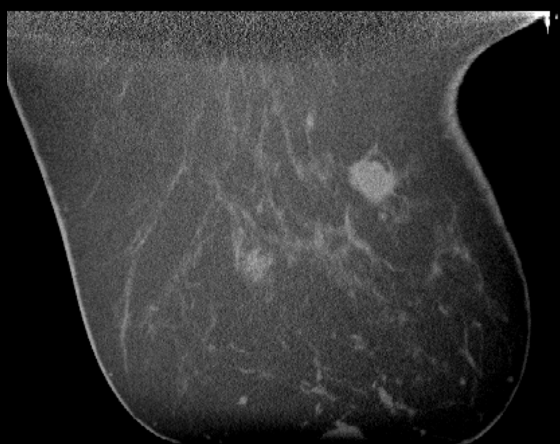
Pt 207 T3-IMC

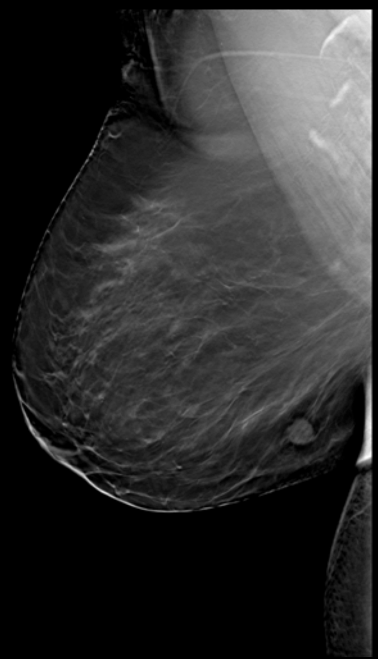




mammography





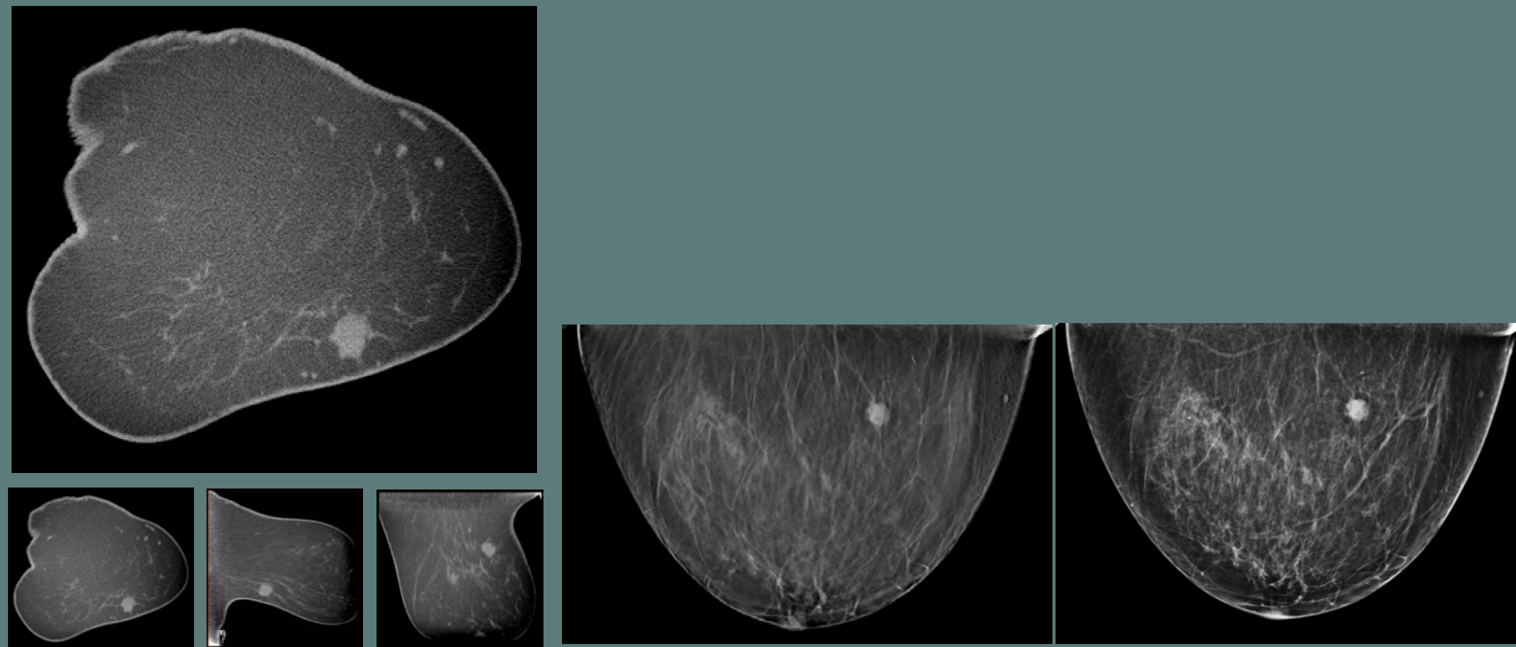


breast CT

Pt 224 Rt IDC

mlo tomosynthesis

cc tomosynthesis



	β_{BCT}			β_{Tomo}	β_{Mammo}
	Coronal	Sagittal	Axial		
Average	1.69	1.90	1.85	2.80	3.02
std	0.35	0.39	0.40	0.31	0.24

N=17 patients

Breast CT (with PET) for Screening, Diagnosis, and Breast Cancer Treatment

Motivation / System Design & Fabrication

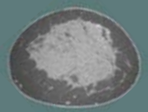
Breast CT Imaging

Radiation Dosimetry

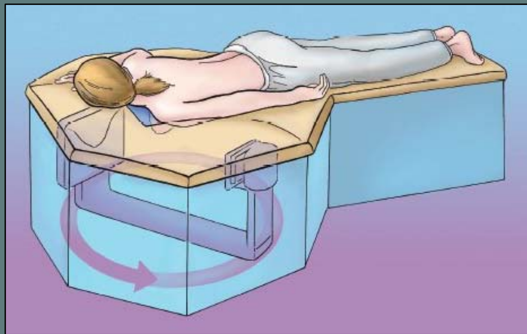
Image Quality Evaluation

Breast Image Analyses

Biopsy and Cancer Therapy

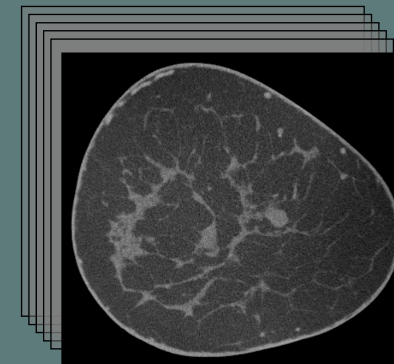


Summary

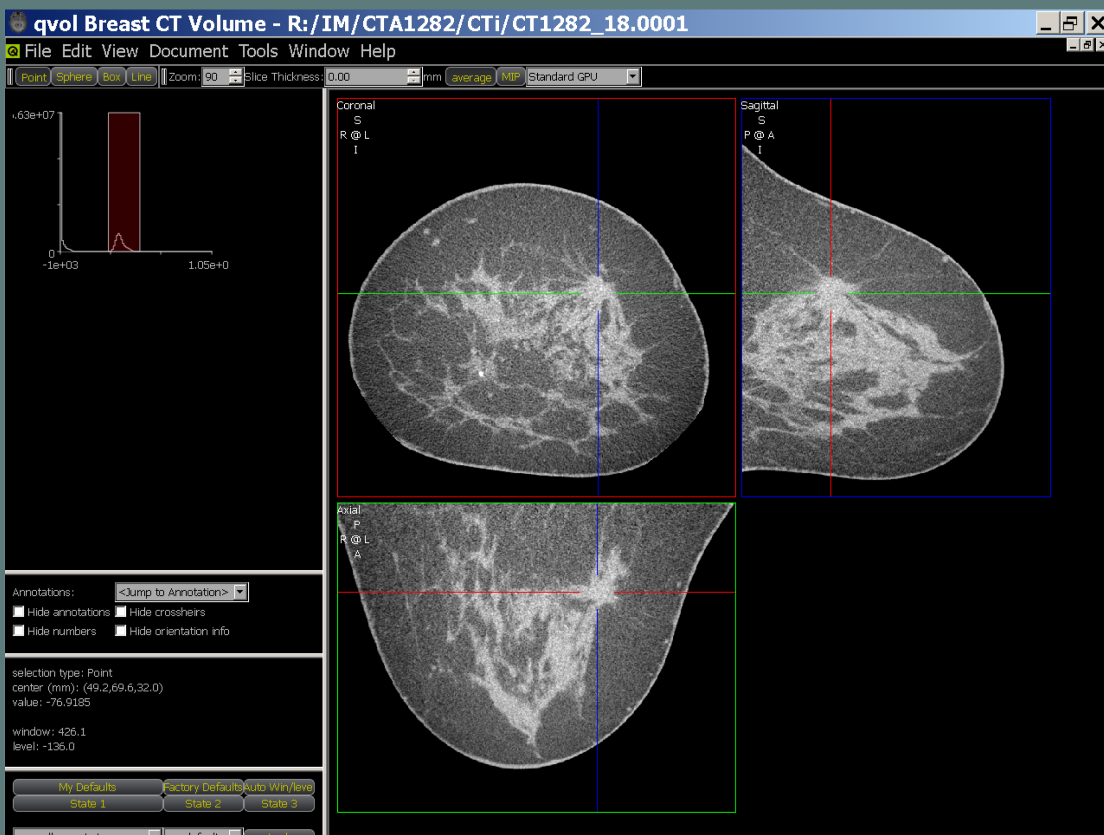


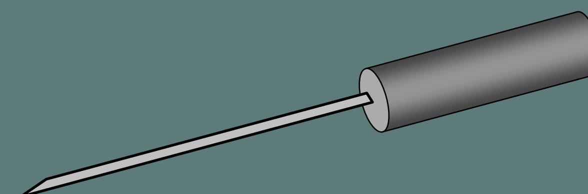
breast CT platform

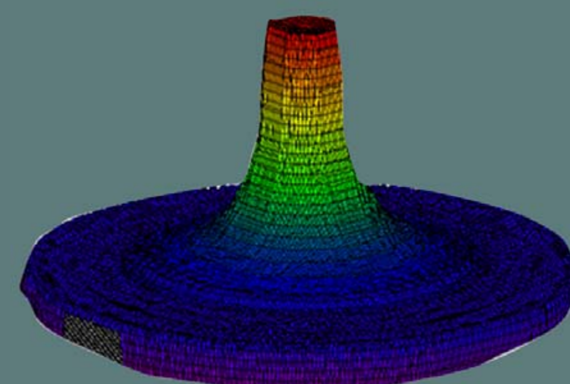
breast cancer screening and diagnosis



breast CT data (512^3)





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John McGahan


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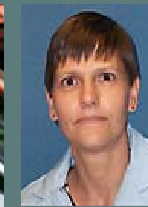
Norbert Pelc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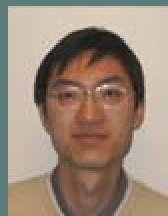
Bruce Hasegawa


Alex Kwan


Hong Zhou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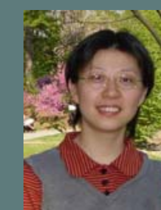
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John Brock

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