It All Begins With Imaging

If You Can't See It, You Can't Diagnose or Treat It

The Expanding Role for Medical Physicists

Perry Sprawls, Ph.D.
Emory University, Atlanta
Sprawls Educational Foundation
www.sprawls.org

Our Objectives

Today

Thinking Together

Later

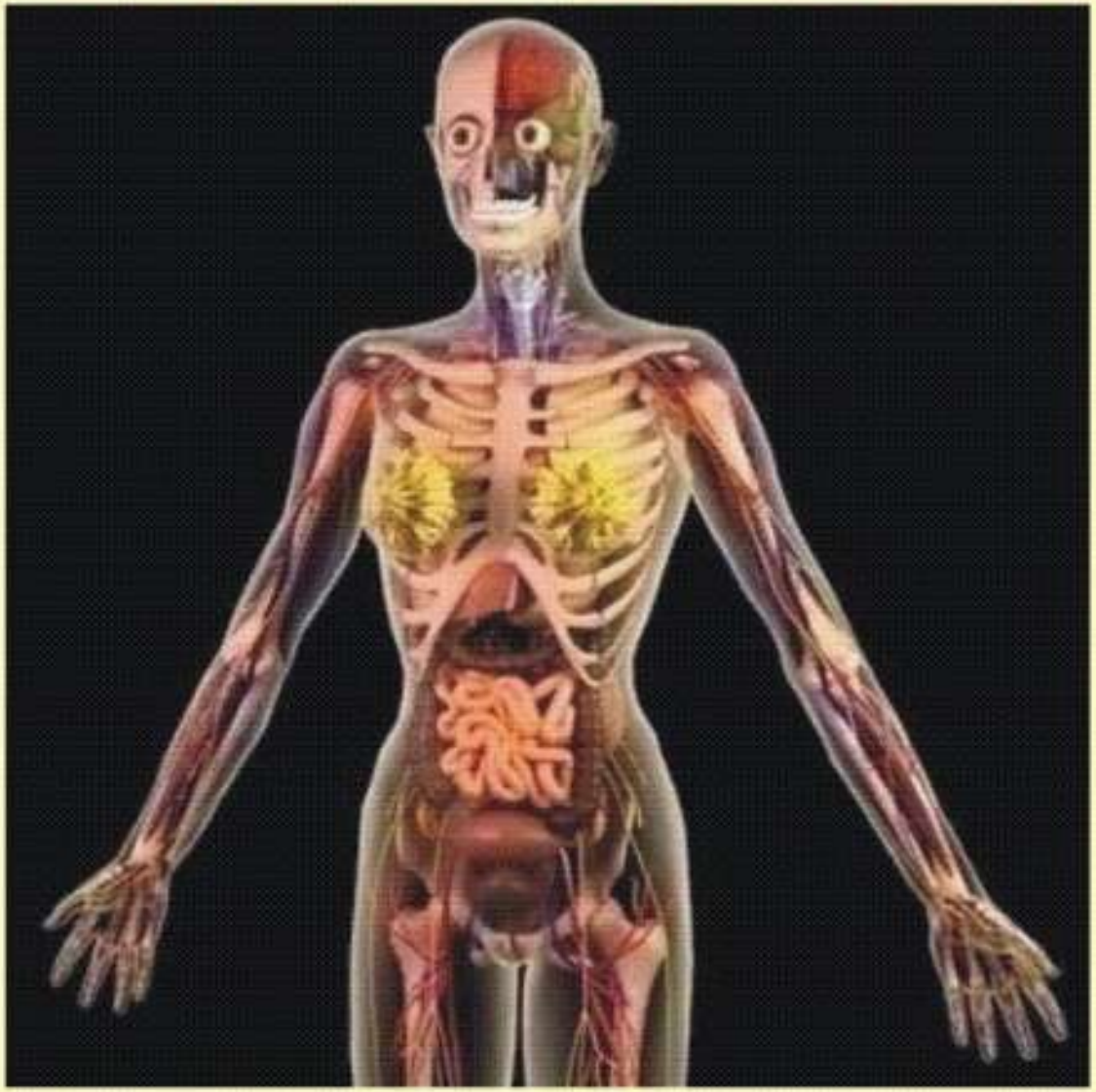
Review and Research

This Presentation
Online Modules
Textbooks

On the web at

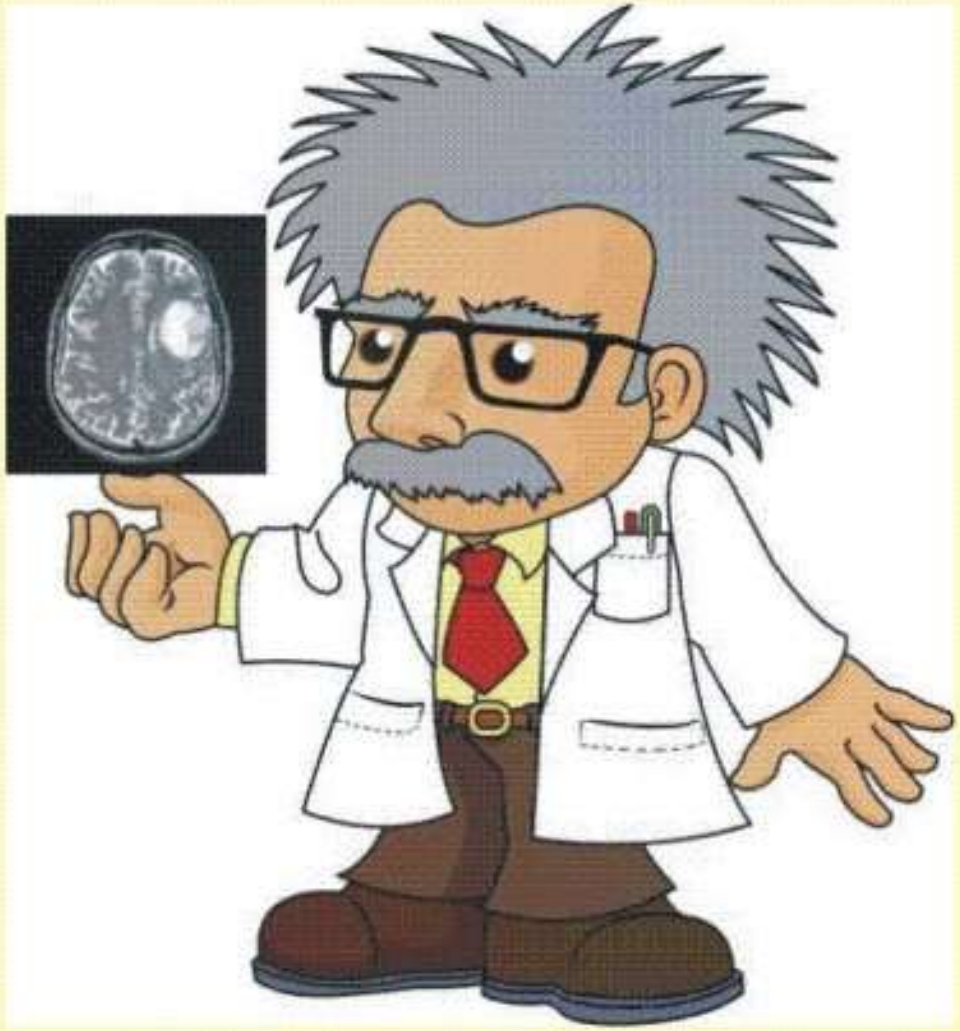
www.sprawls.org

Medicine's Great Challange



See Into the Human Body

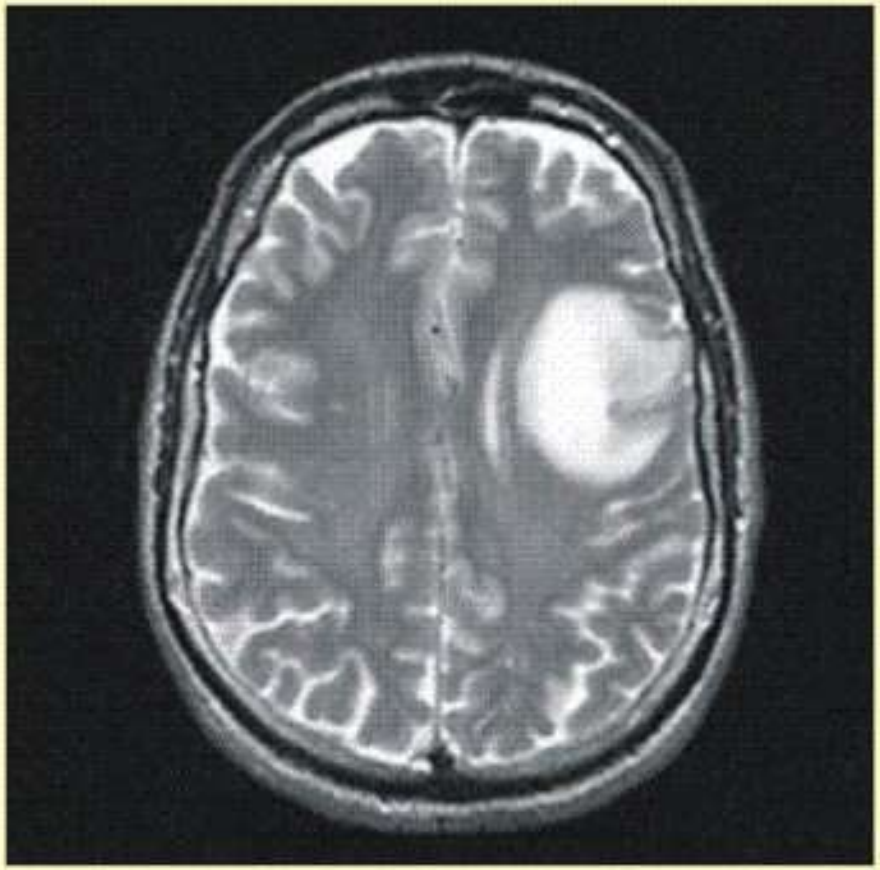
Medical Physicists

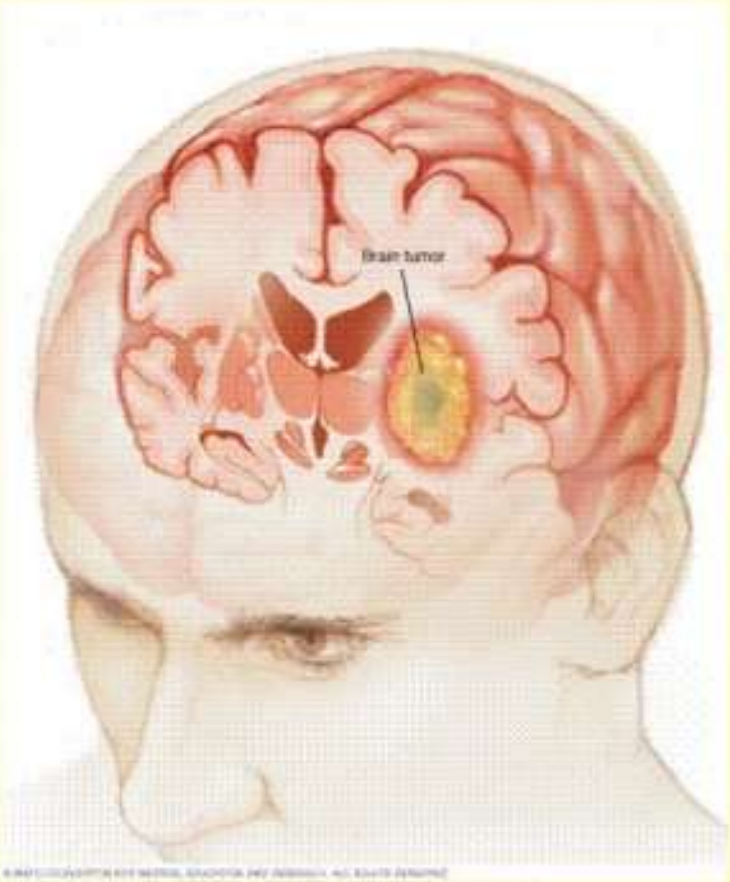


Provide Solutions

January 23, 1896

The Medical Image is a **Window** Into the Human Body





Sprawls

The Medical Image is a Window Into the Human Body

There is No Perfect Window

It is All About Visibility

Sprawls

What Determines
Medical Image Quality
VISIBILITY

Artifacts

Distortion

NOISE

BLUR

Contrast Sensitivity

Modality & Equipment Design Characteristics

Performance
QA & Maintenance

Operation
Techniques & Protocols

Technology **The Human Factor**

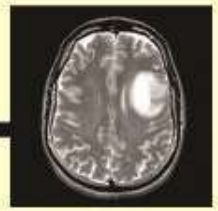
Sprawls

The Imaging Modalities

What is Different? What is Similar?

Radiography

MRI

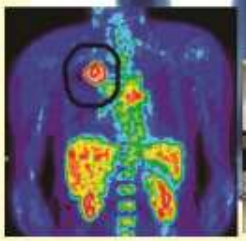


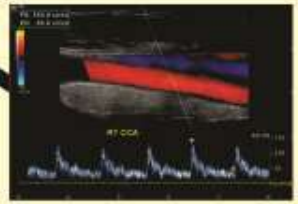
Computed Tomography

Fluoroscopy

Ultrasound

Mammography





Radionuclide, SPECT, PET

Sprawls

Transportation

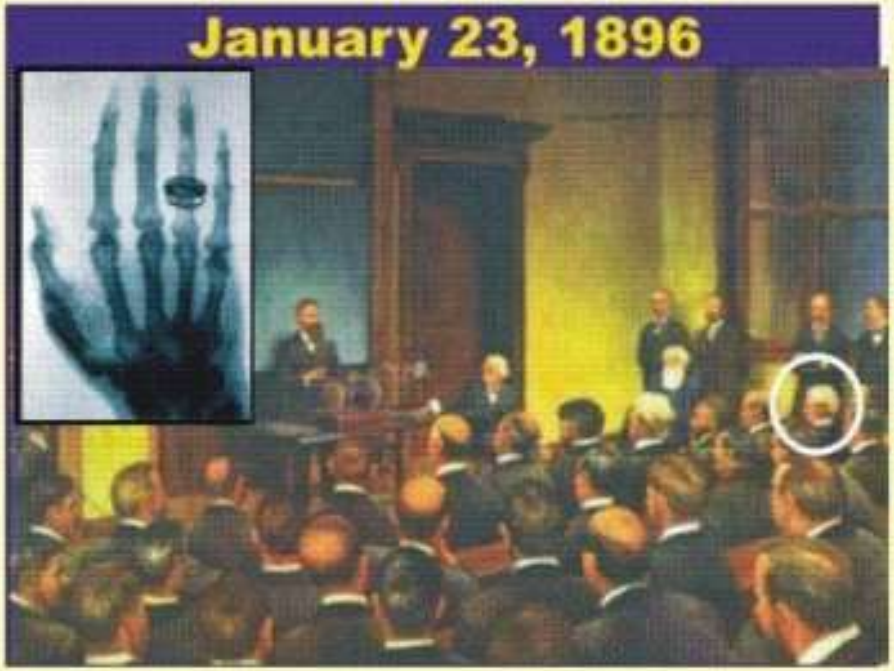
Increased Capability and Complexity

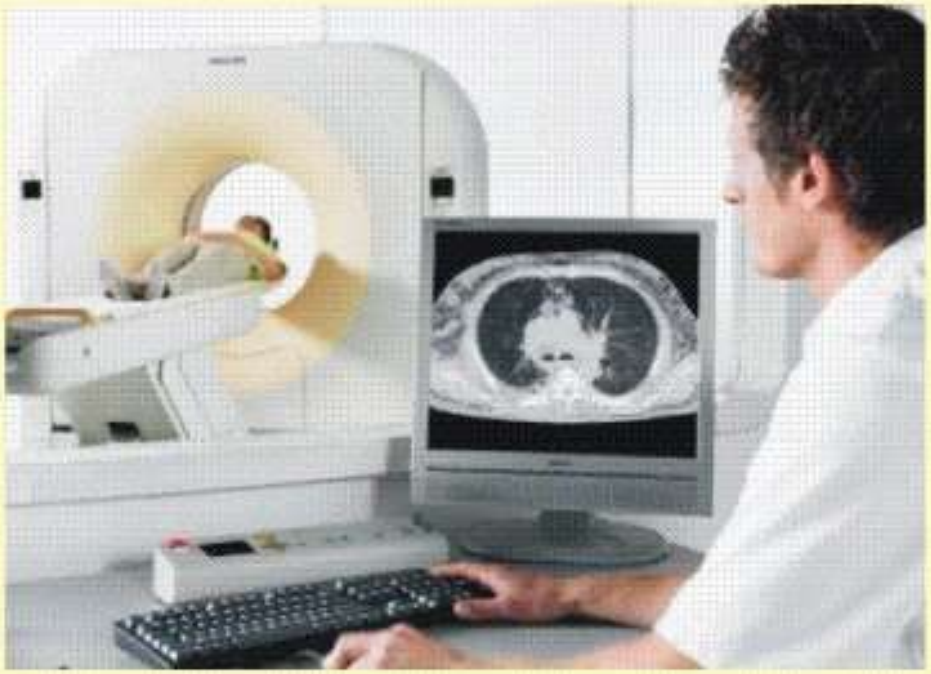
Time (Years)

Sprawls

Medical Imaging

Increased Capability and Complexity



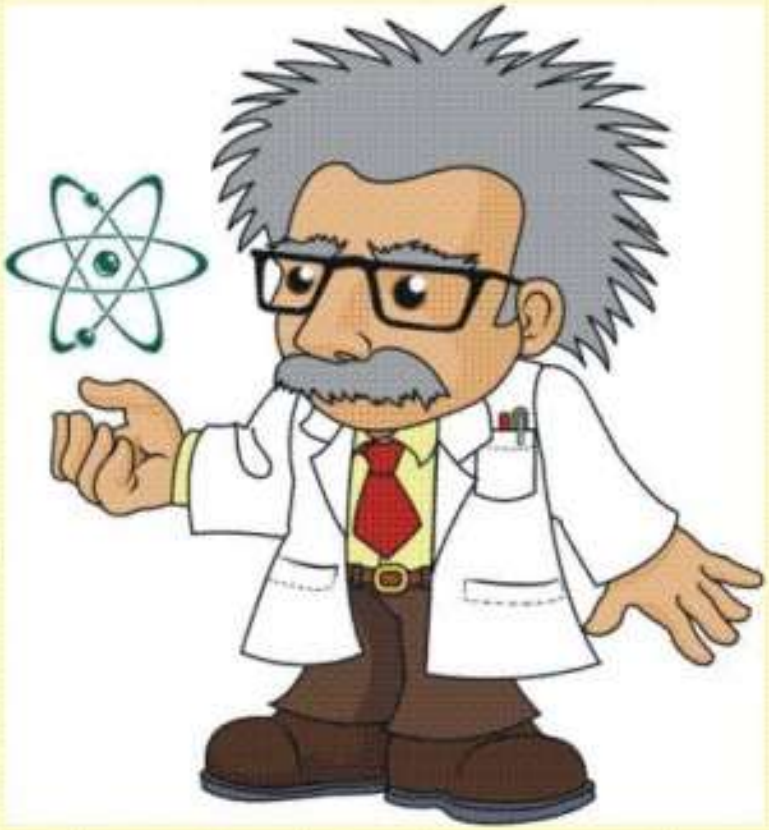


Time (Years)

Sprawls

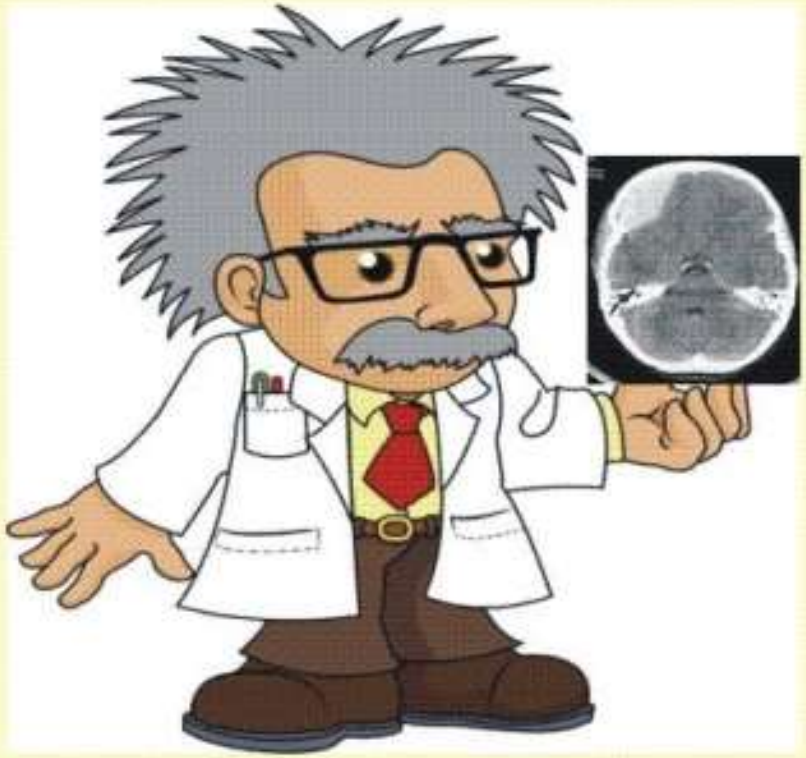
It All Begins With Imaging

The Expanding Role for Medical Physicists



Sprawls

Analyzing & Controling Image Quality

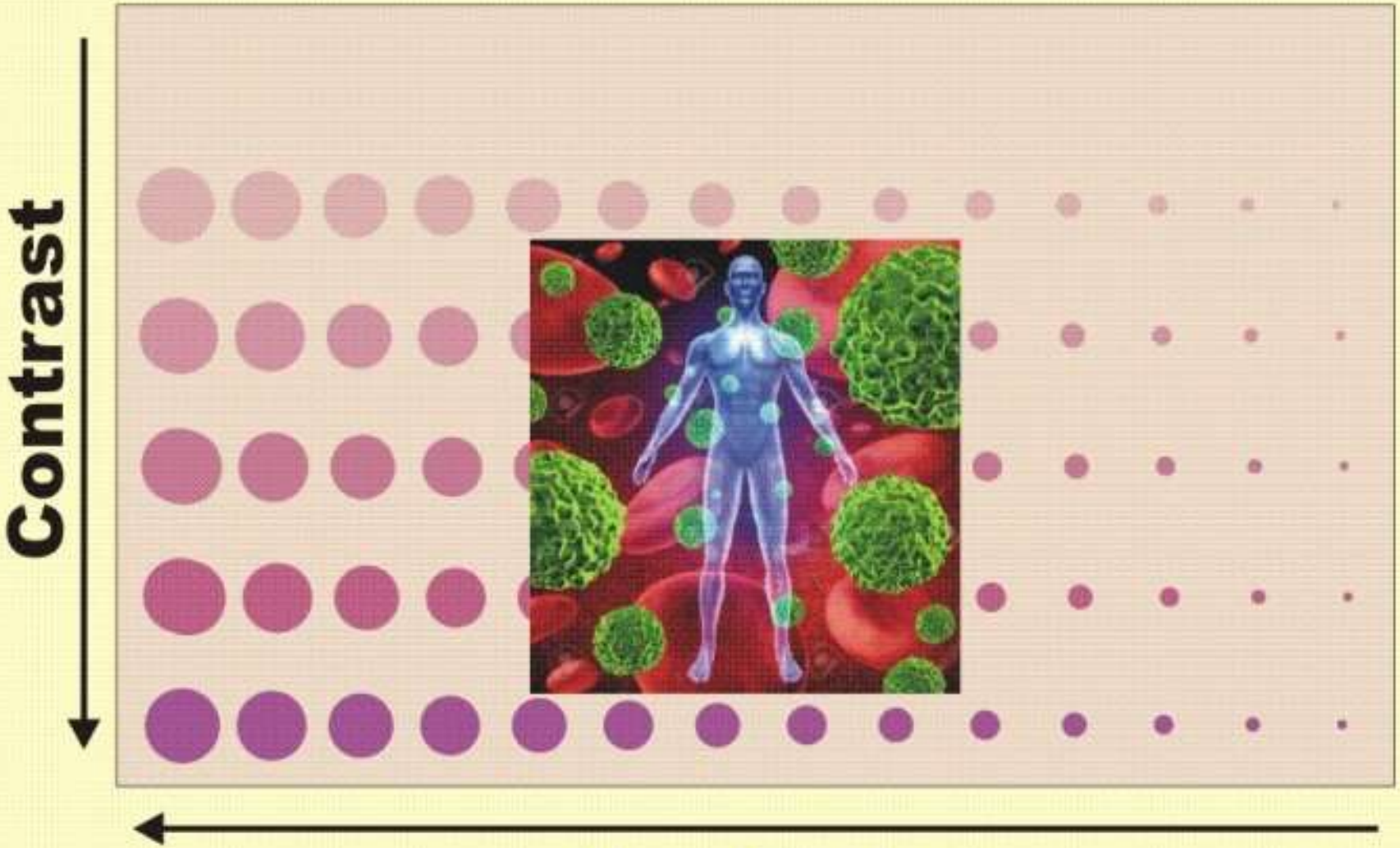


- Geometric
- Artifacts
- Noise
- Blur
- Contrast

Sprawls

Physical Characteristics of Objects

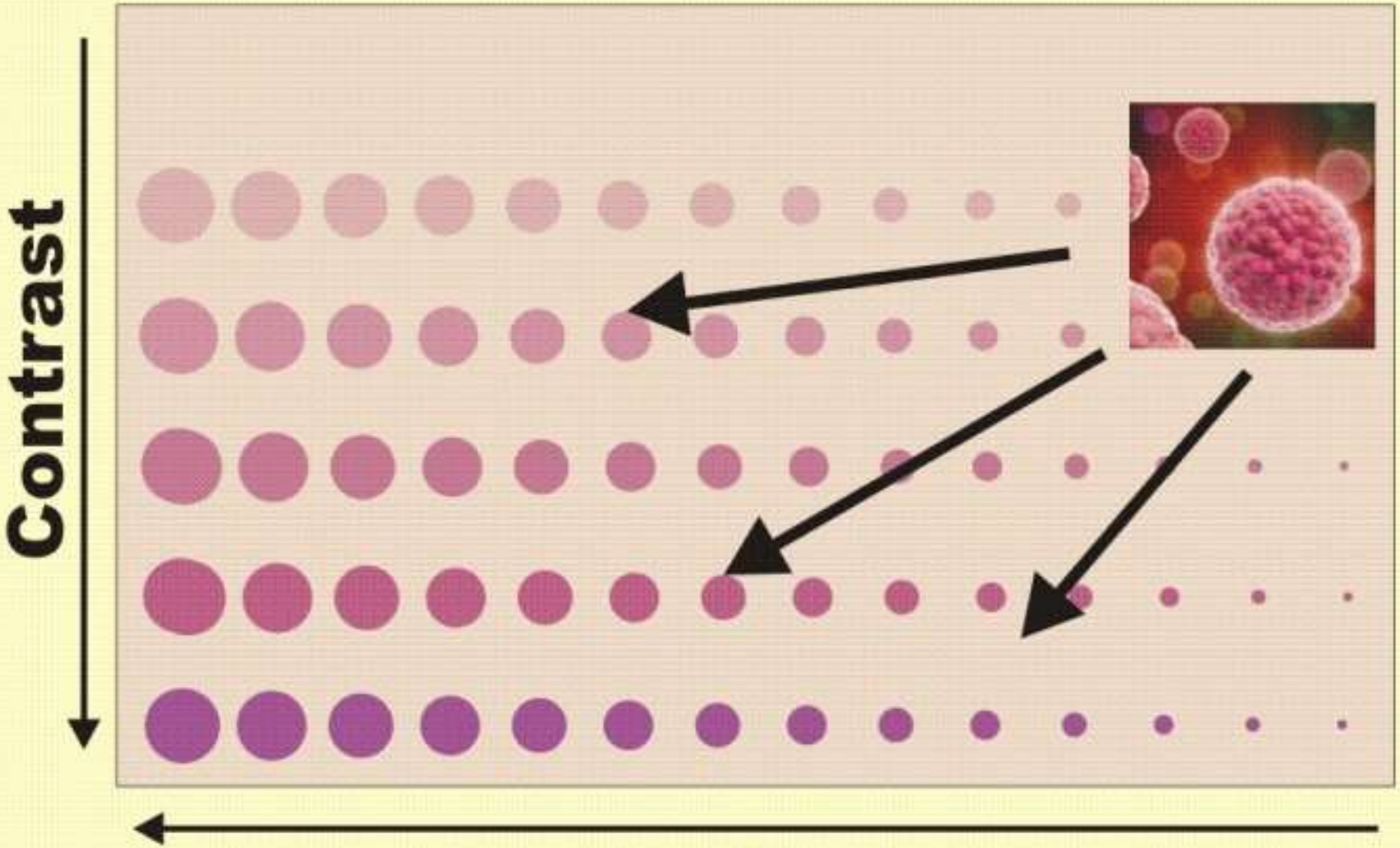
Effect on Visibility



Sprawls

Physical Growth of Cancer

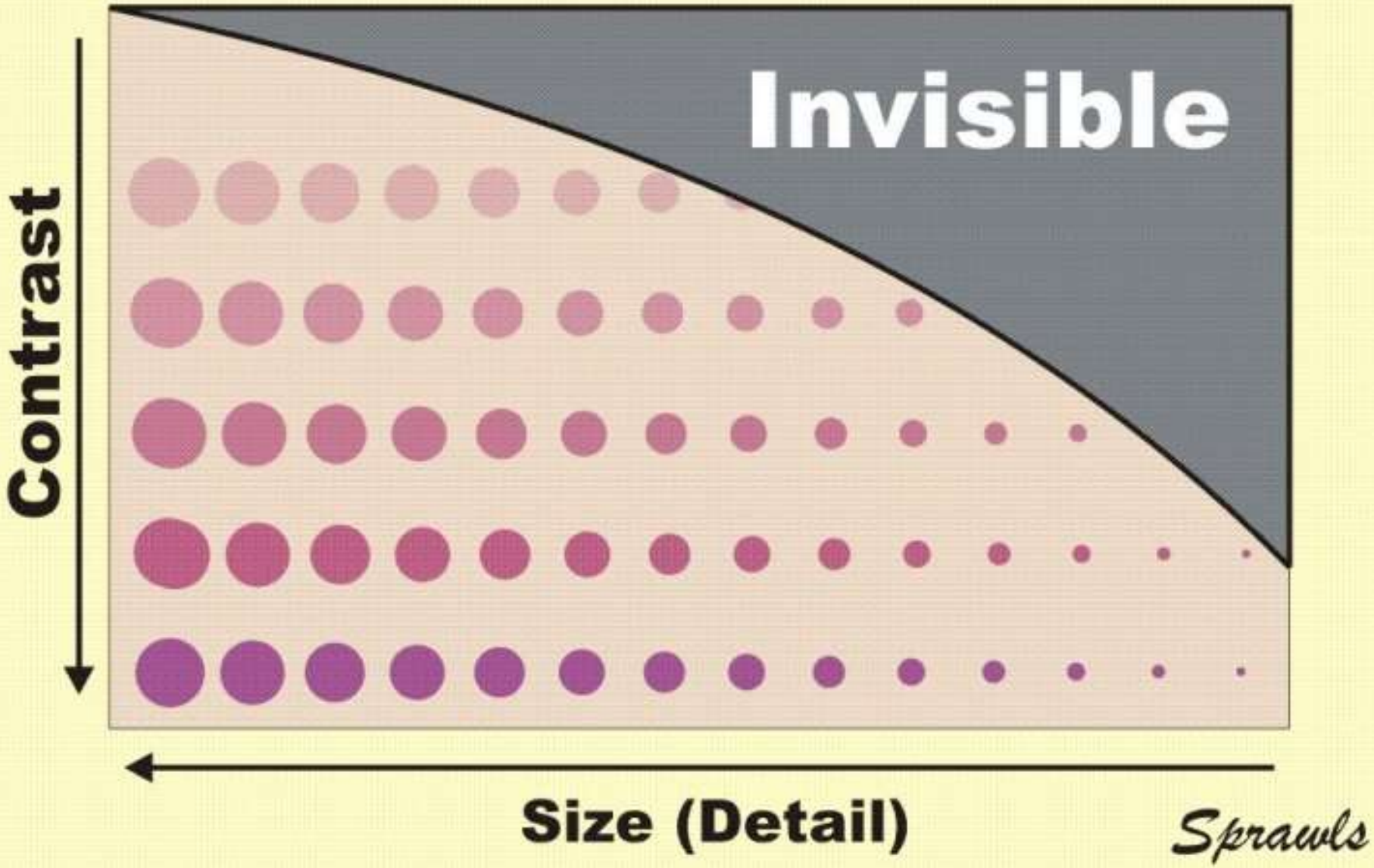
Effect on Visibility



Sprawls

Physical Characteristics of Objects

Effect on Visibility



VISION TEST

A

D

G

E

C

H

B

F

Sprawls

CONTRAST SENSITIVITY

A

D

G

E

C

H

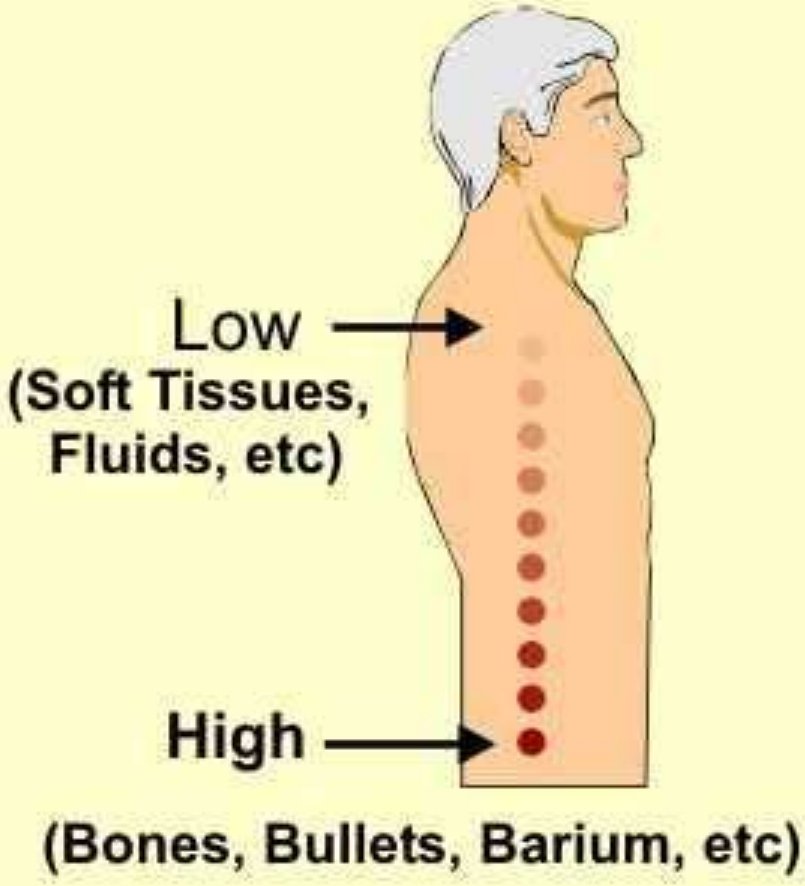
B

F

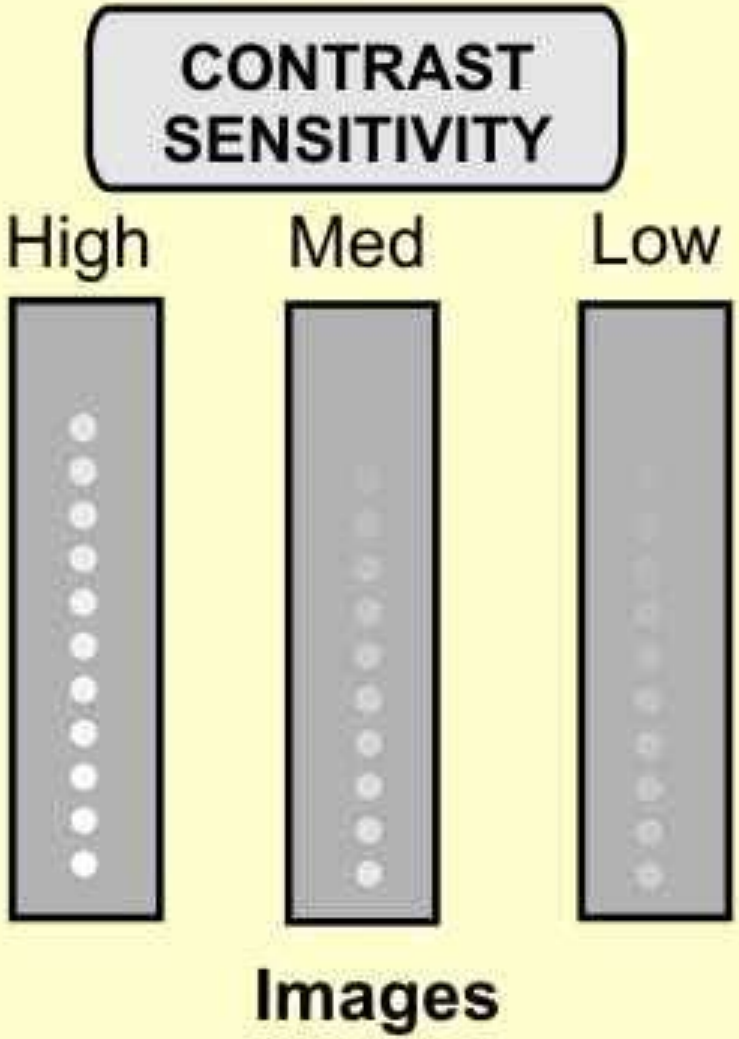
Sprawls

Objects in the Body

Physical Contrast



Imaging Procedure



Contrast

Contrast Sensitivity

Physical

Human Body

Imaging Procedure

Visual

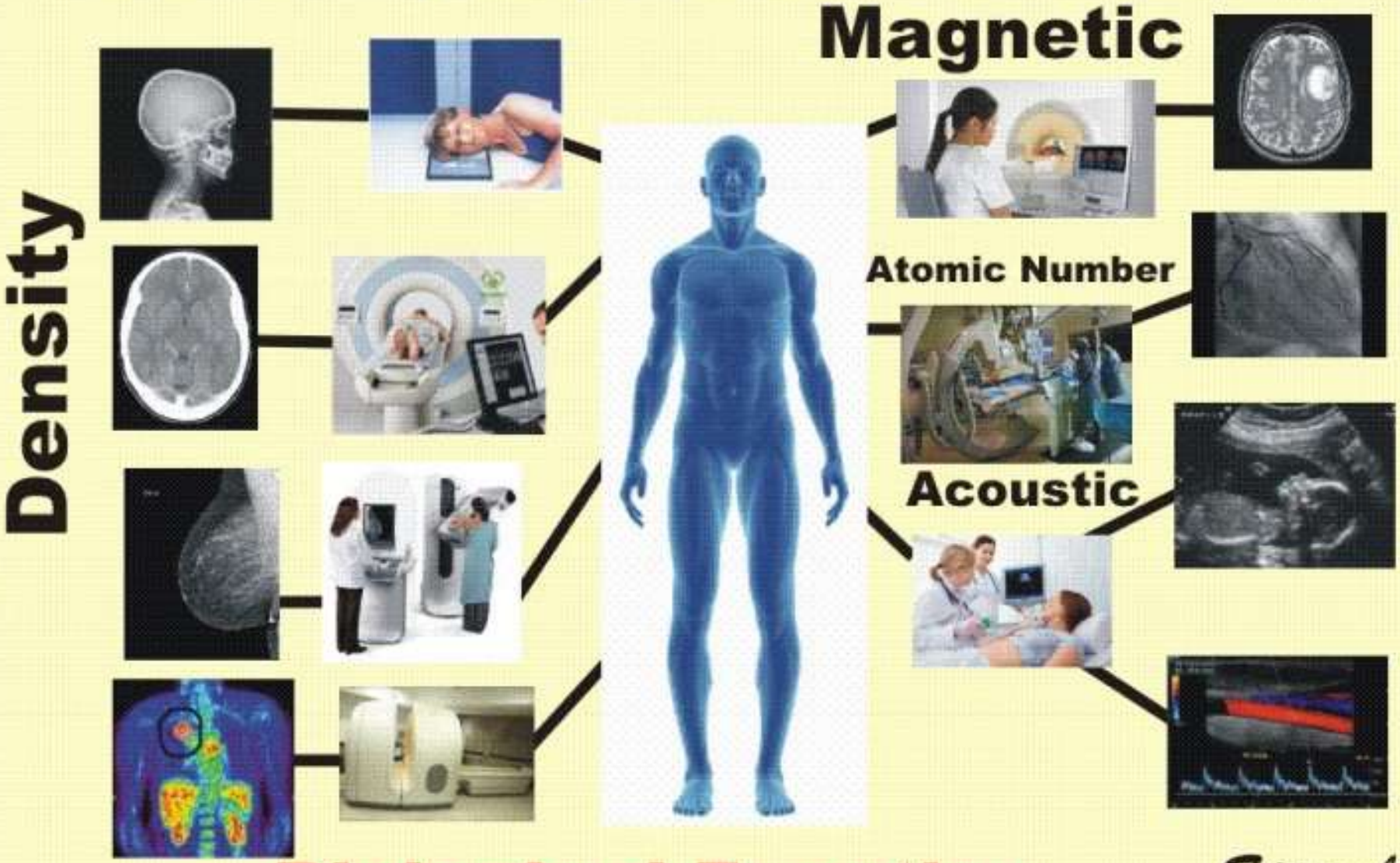
Image

Equipment + Protocol

Sprawls

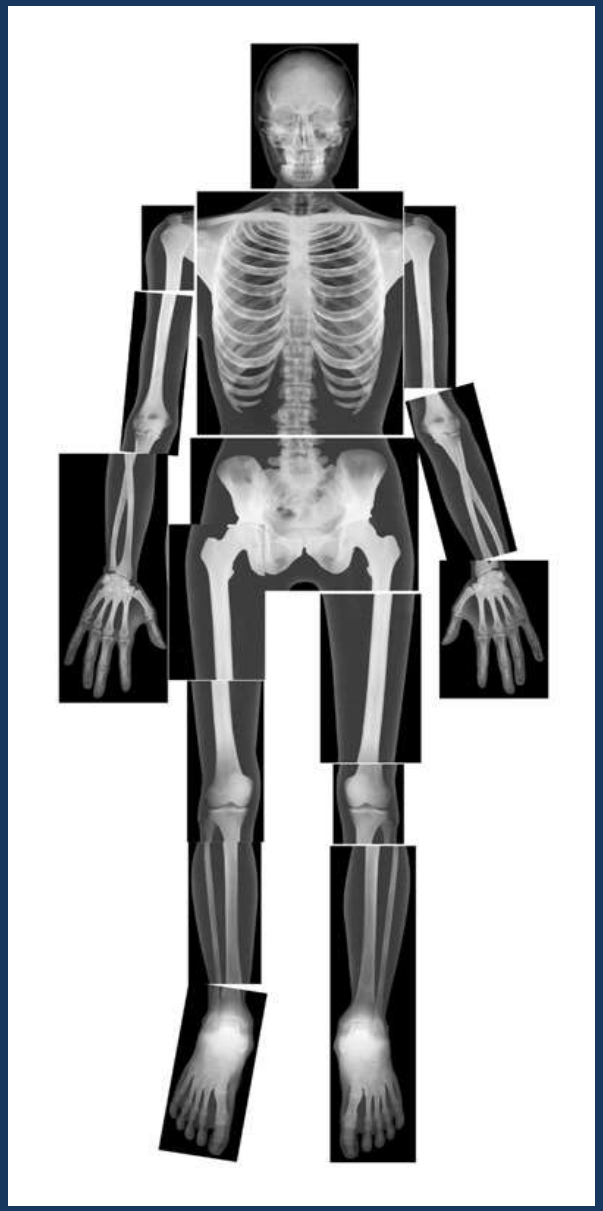
Imaging Modality Contrast

Visualizing Physical Characteristics



Biological Function

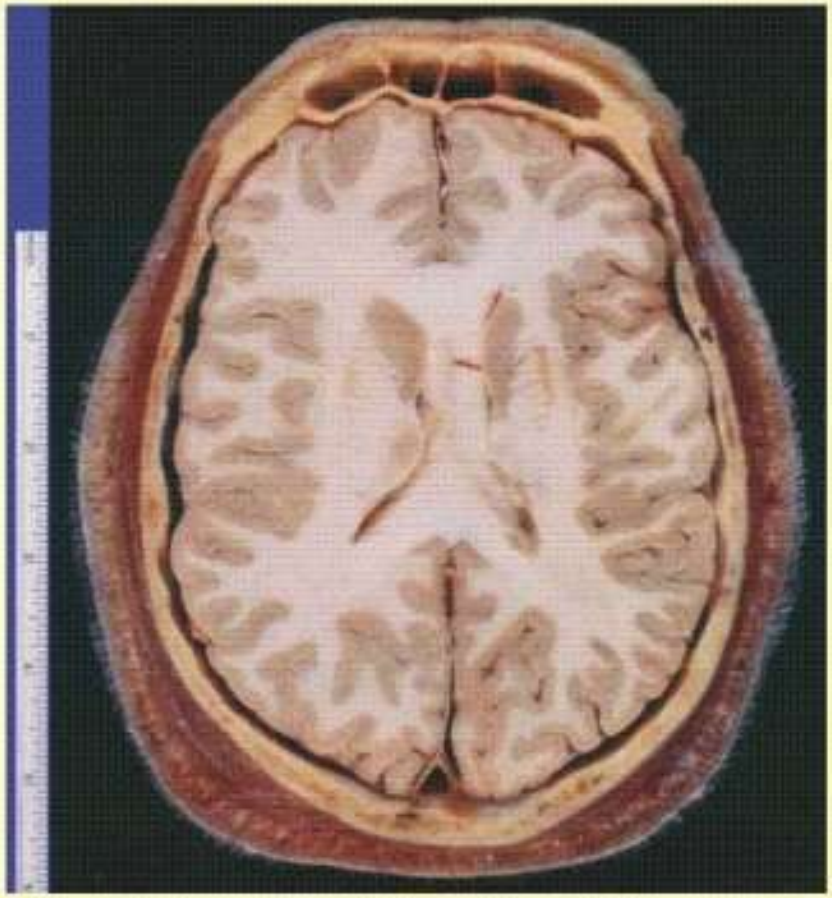
Sprawls

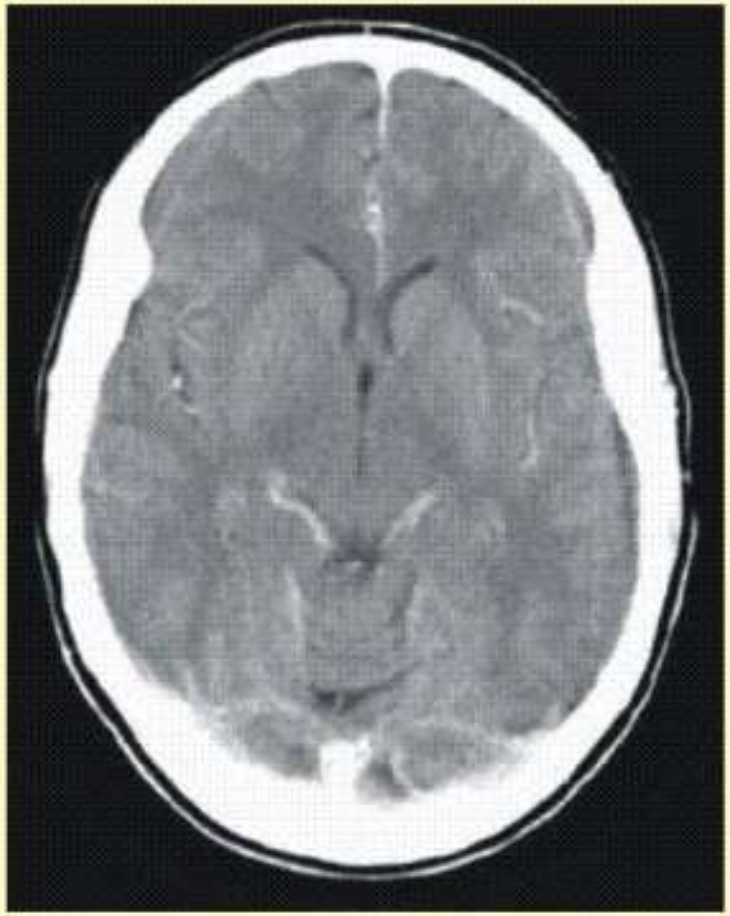


Computed Tomography

An Image of

Tissue Density





Atomic Number (Z)

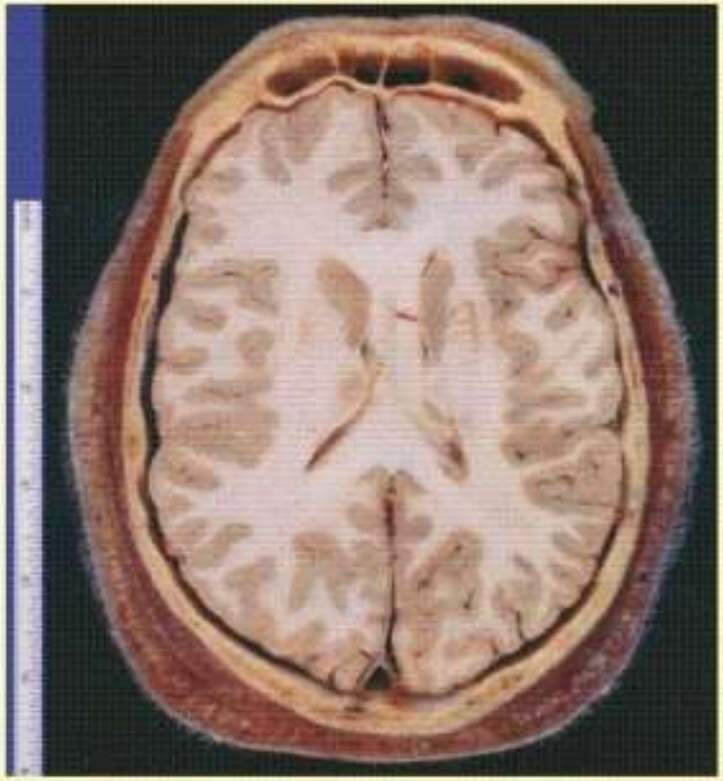
Sprawls

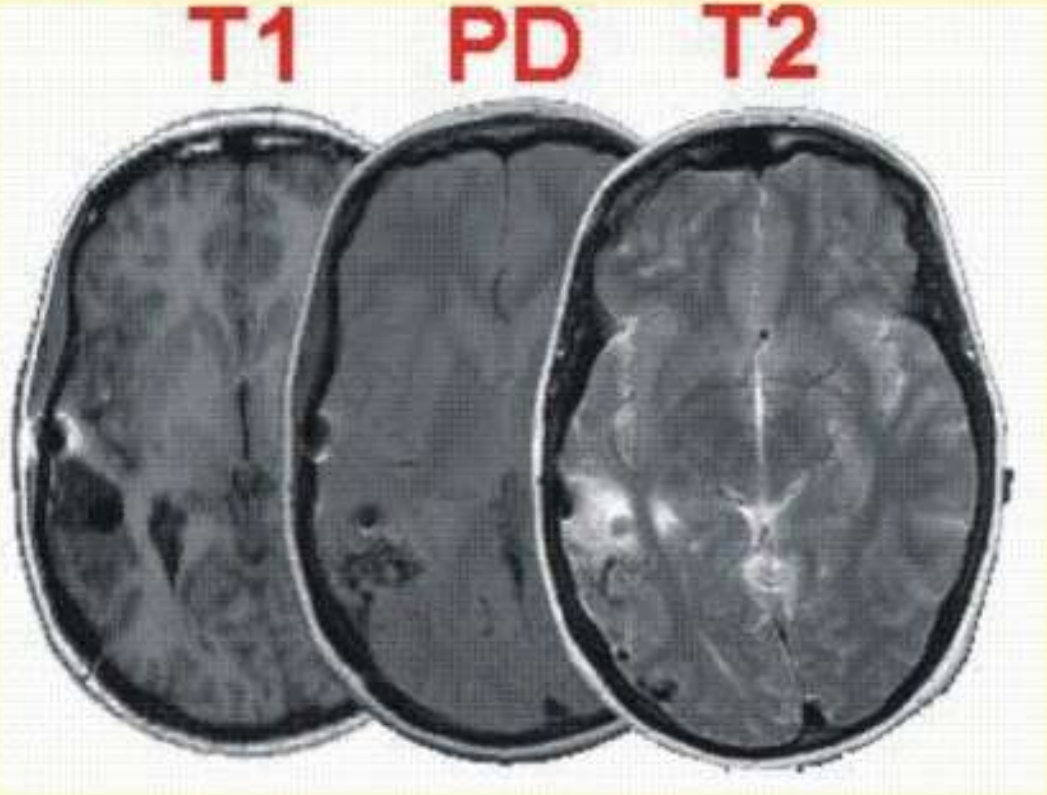
Magnetic Resonance Imaging

An Image of

Tissue

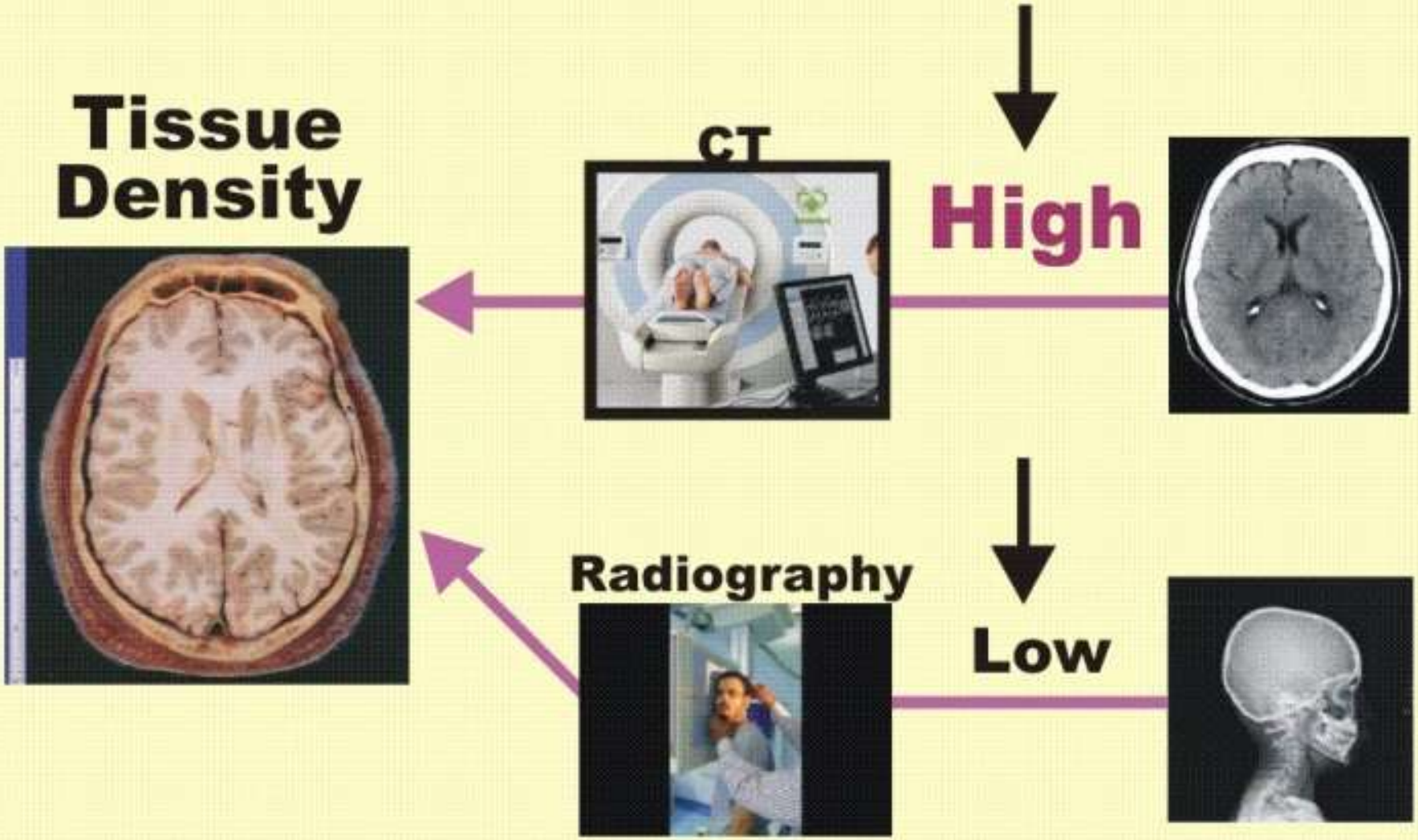
Magnetic Characteristics





Sprawls

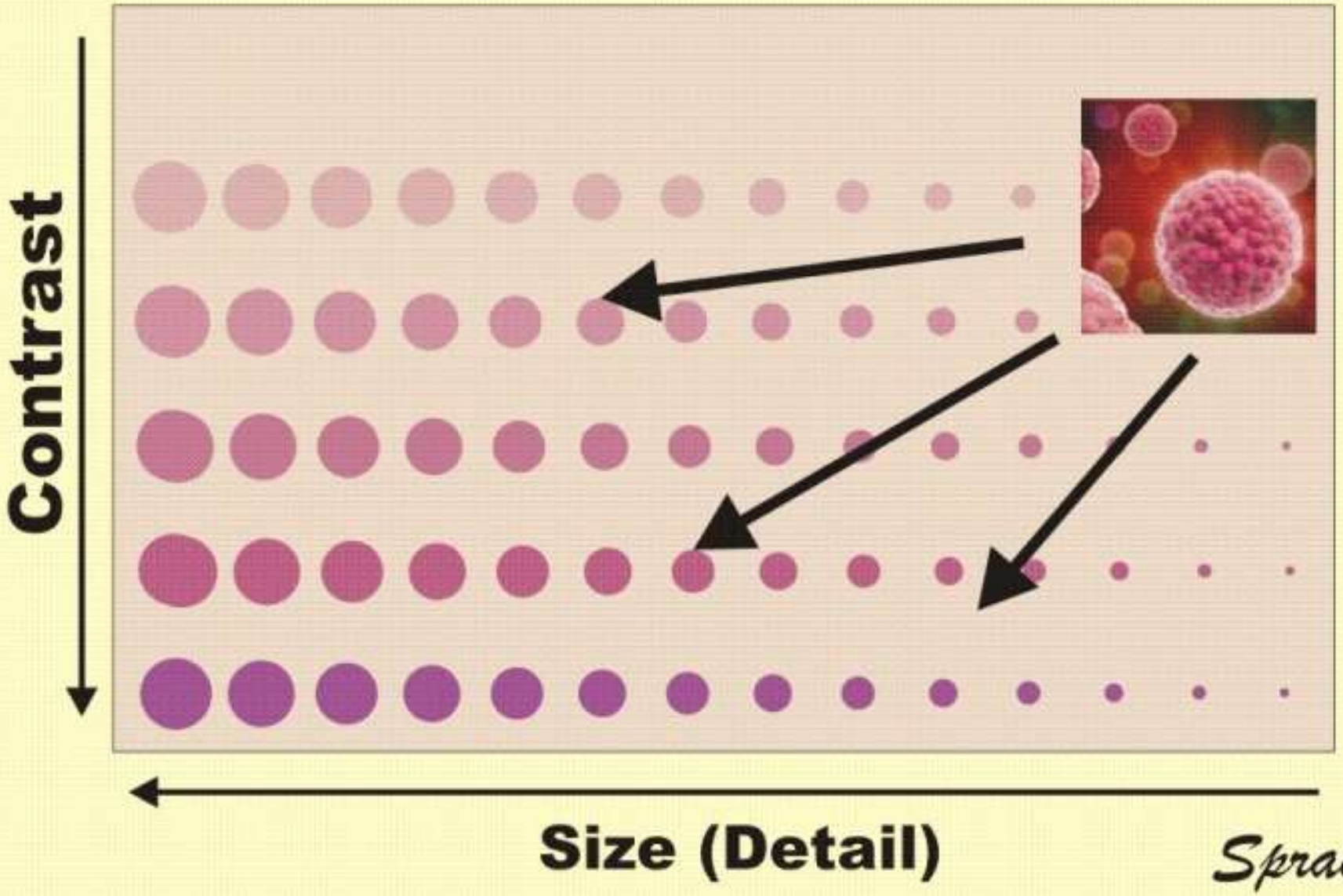
X-Ray Imaging Contrast Sensitivity



Sprawls

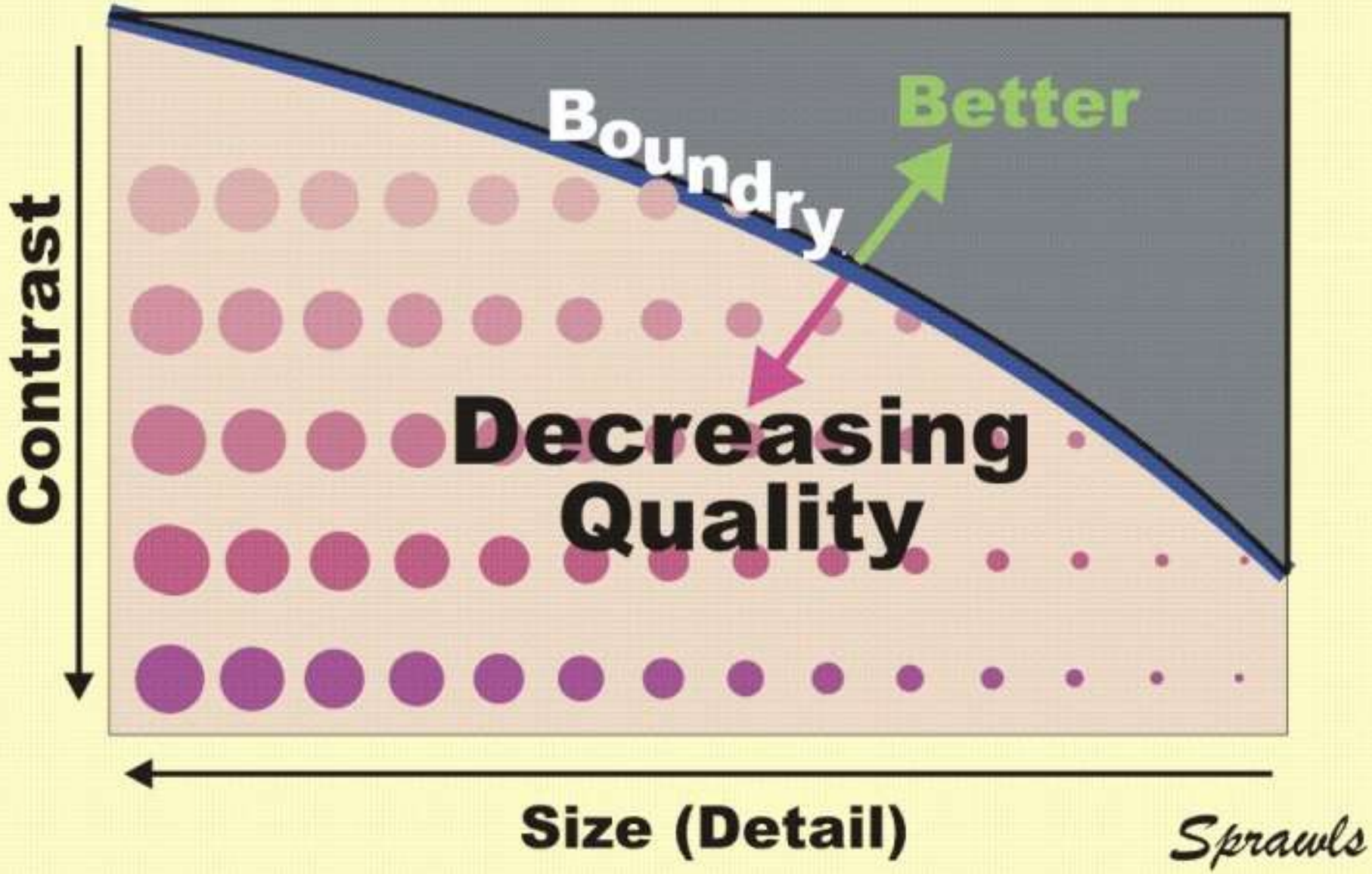
Physical Growth of Cancer

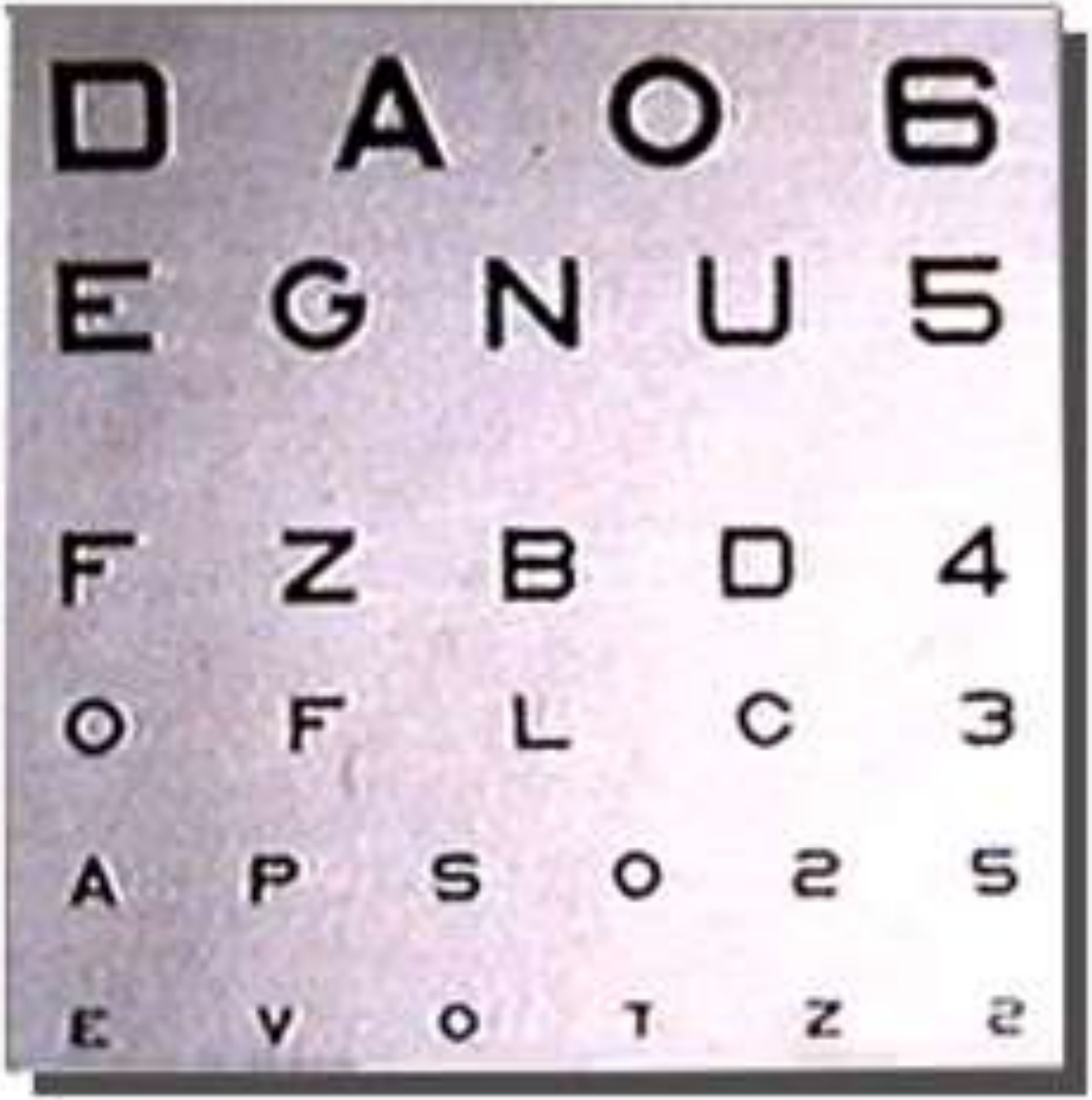
Effect on Visibility



Sprawls

Image Quality Is About Visibility

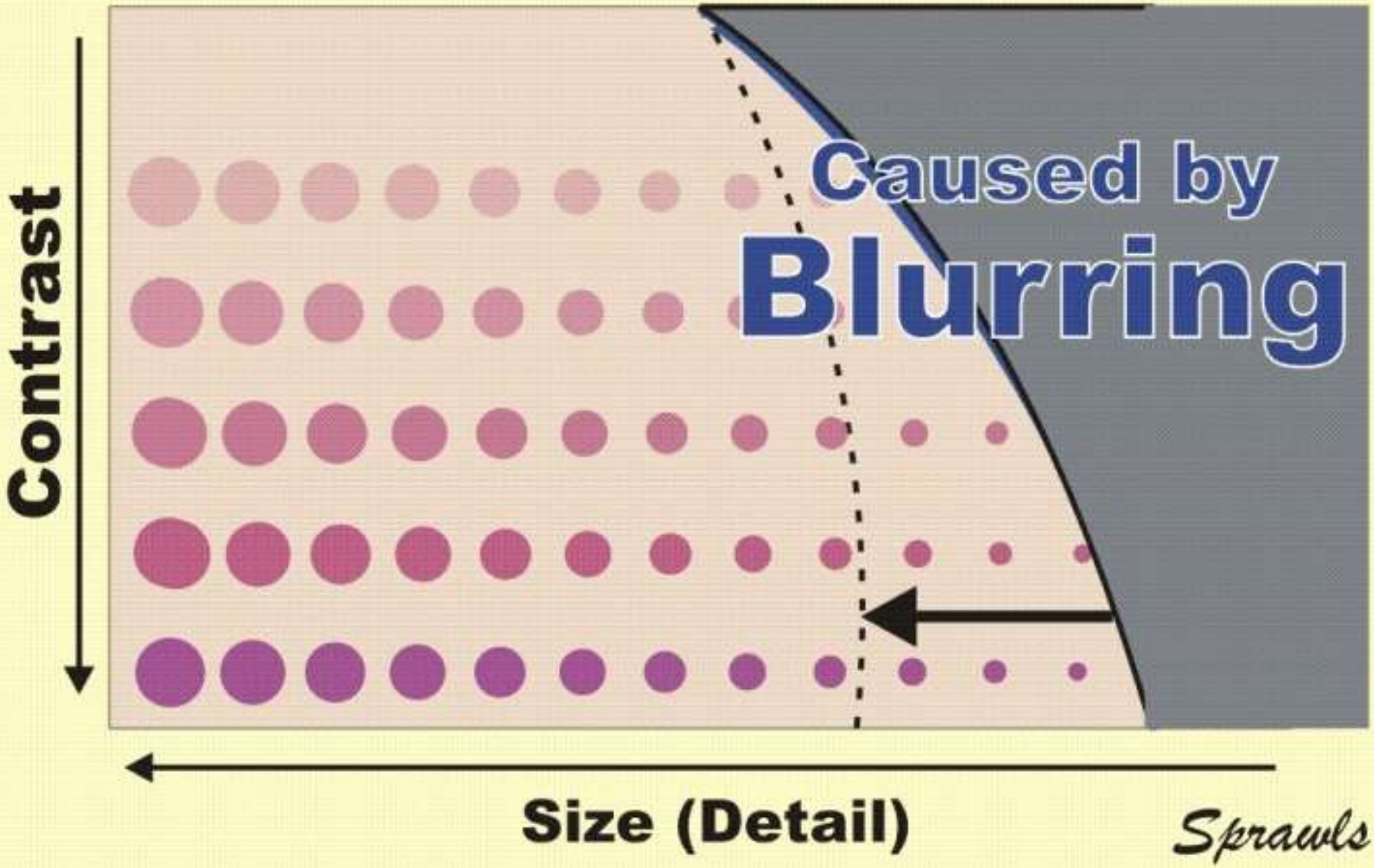



D A O 6
E G N U 5
F Z B D 4
O F L C 3
A P S O 2 5
E V O T Z 2

D A O 6
E G N U S

Physical Characteristics of Objects

Effect on Visibility



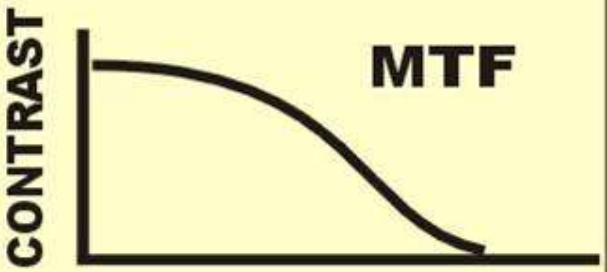
EFFECTS OF BLUR

VISIBILITY of DETAIL

OBJECT SIZE

IMAGE SHARPNESS

RESOLUTION



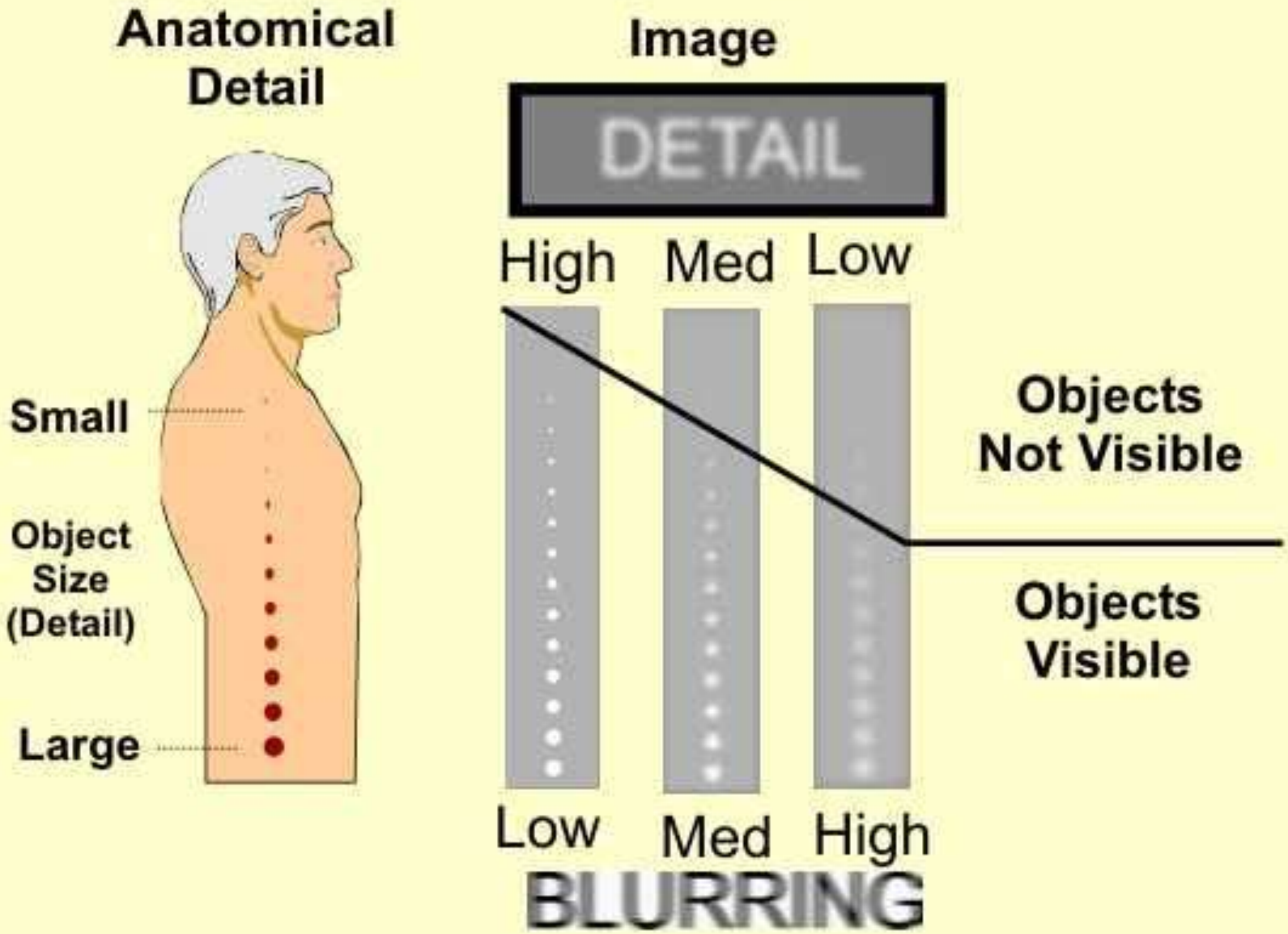
REDUCES

Sprawls

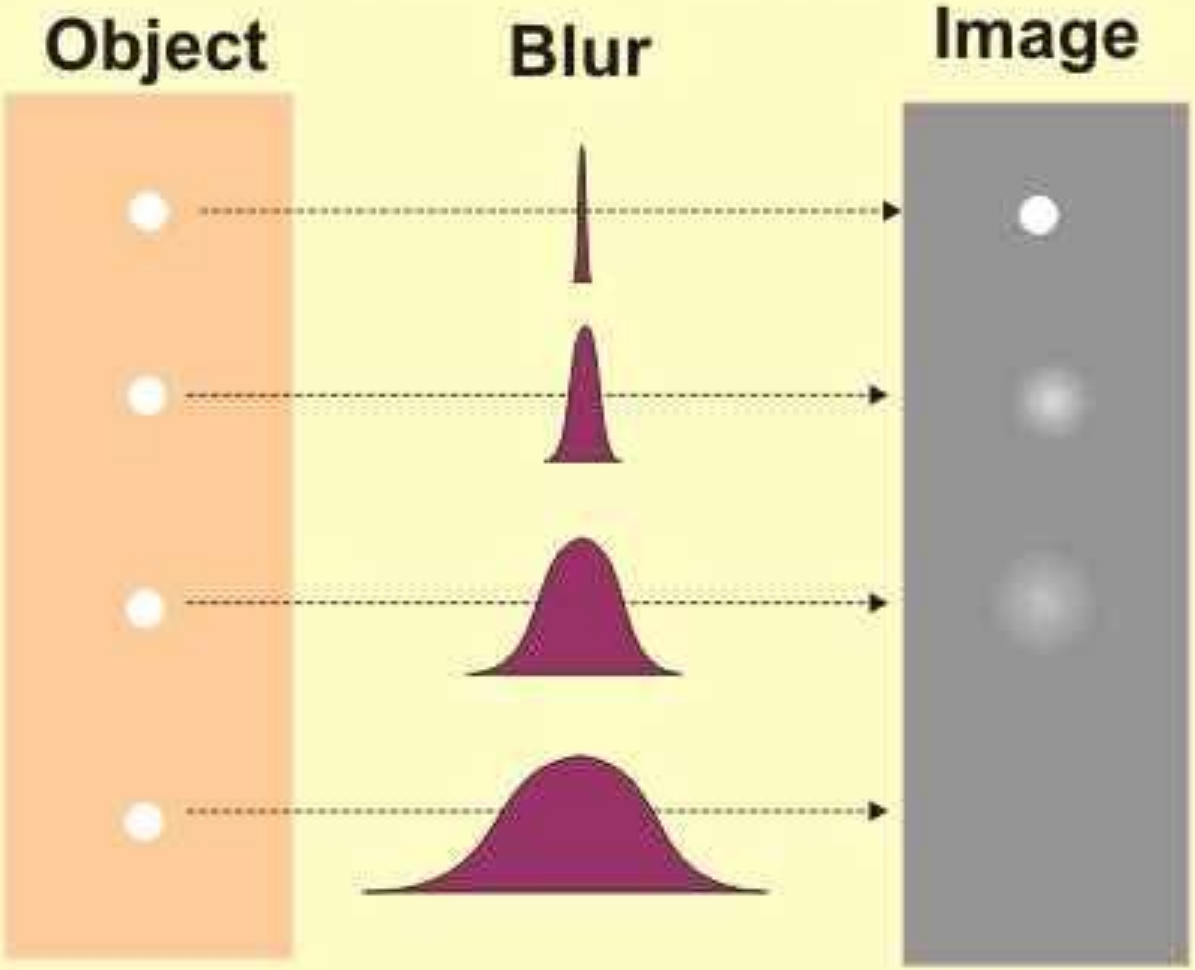
Line-Pair Test Objects

Used to measure the effect of blurring

Sprawls


Anatomical Detail
Small
Object Size (Detail)
Large
Image
DETAIL
High
Med
Low
Low
Med
High
BLURRING
Objects Not Visible
Objects Visible

Blurring
Reduces Visibility



Sprawls

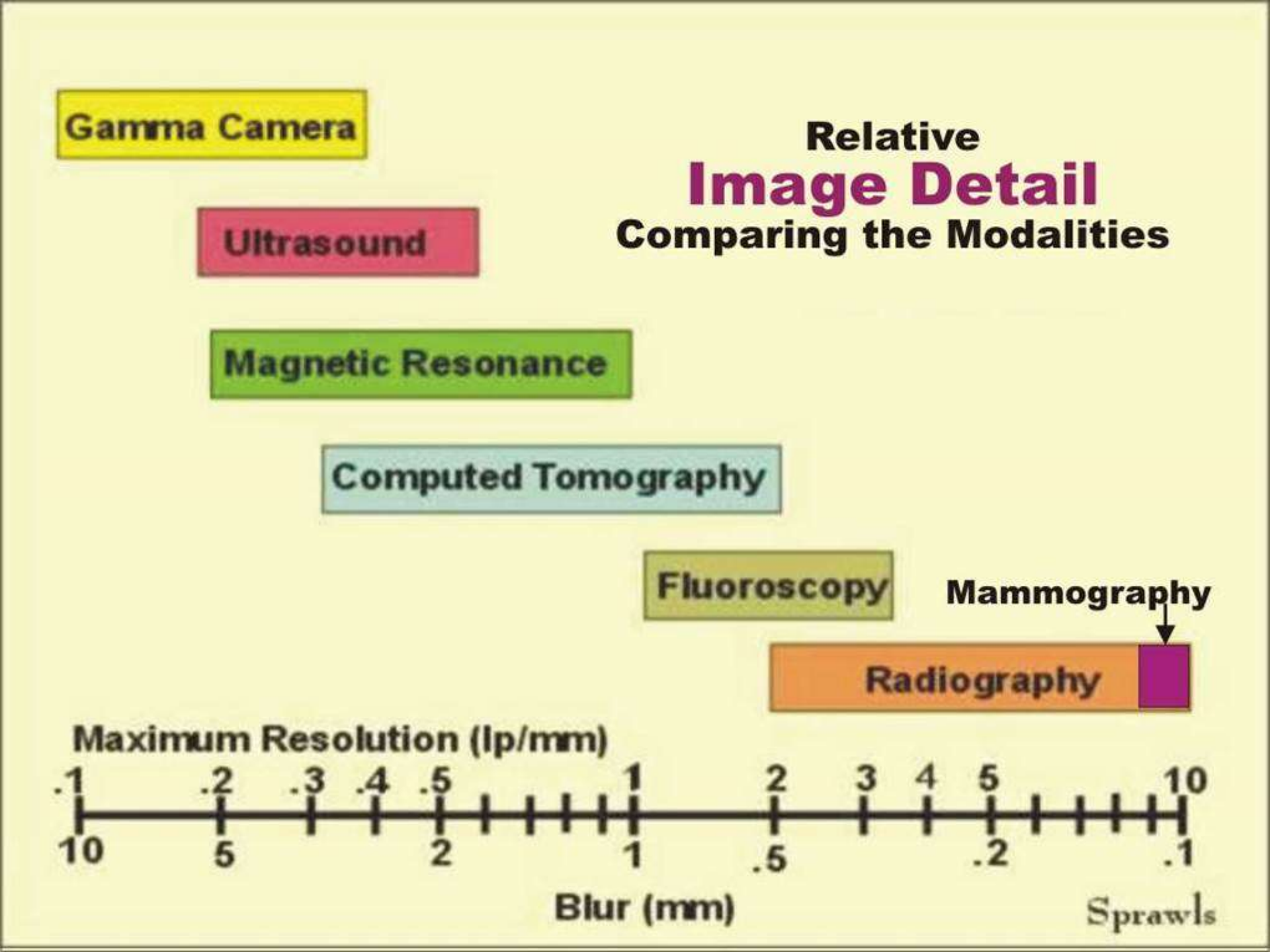

Relative
Image Detail
Comparing the Modalities
Gamma Camera
Ultrasound
Magnetic Resonance
Computed Tomography
Fluoroscopy
Mammography
Radiography
Maximum Resolution (lp/mm)
.1 .2 .3 .4 .5 1 2 3 4 5 10
10 5 2 1 .5 .2 .1
Blur (mm)
Sprawls

IMAGE NOISE

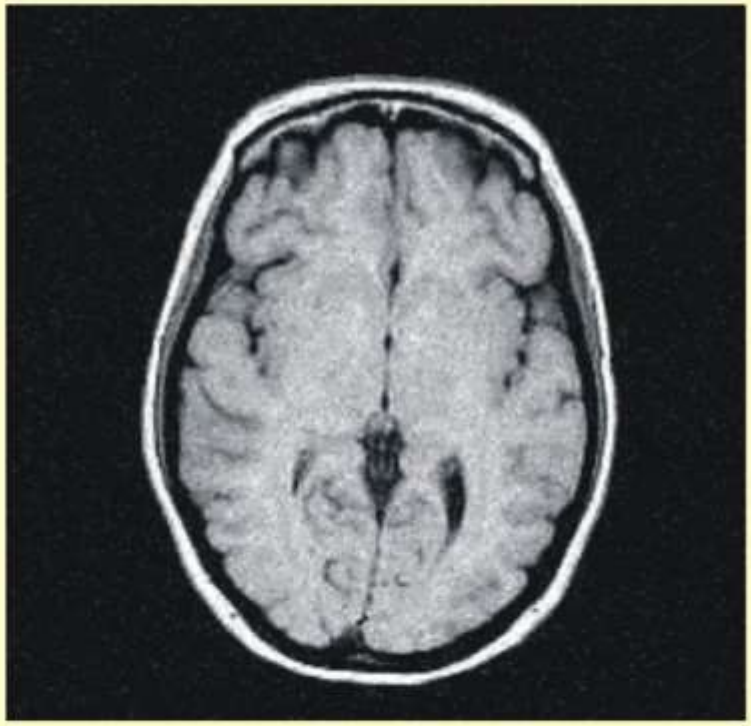
LOW

HIGH

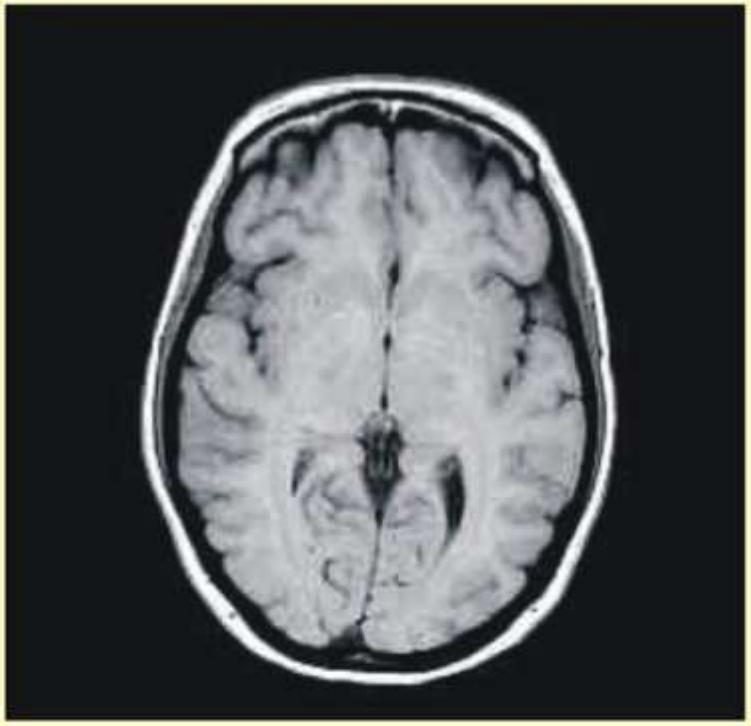
Sprawls

NOISE

HIGH NOISE



LOW NOISE



Sprawls

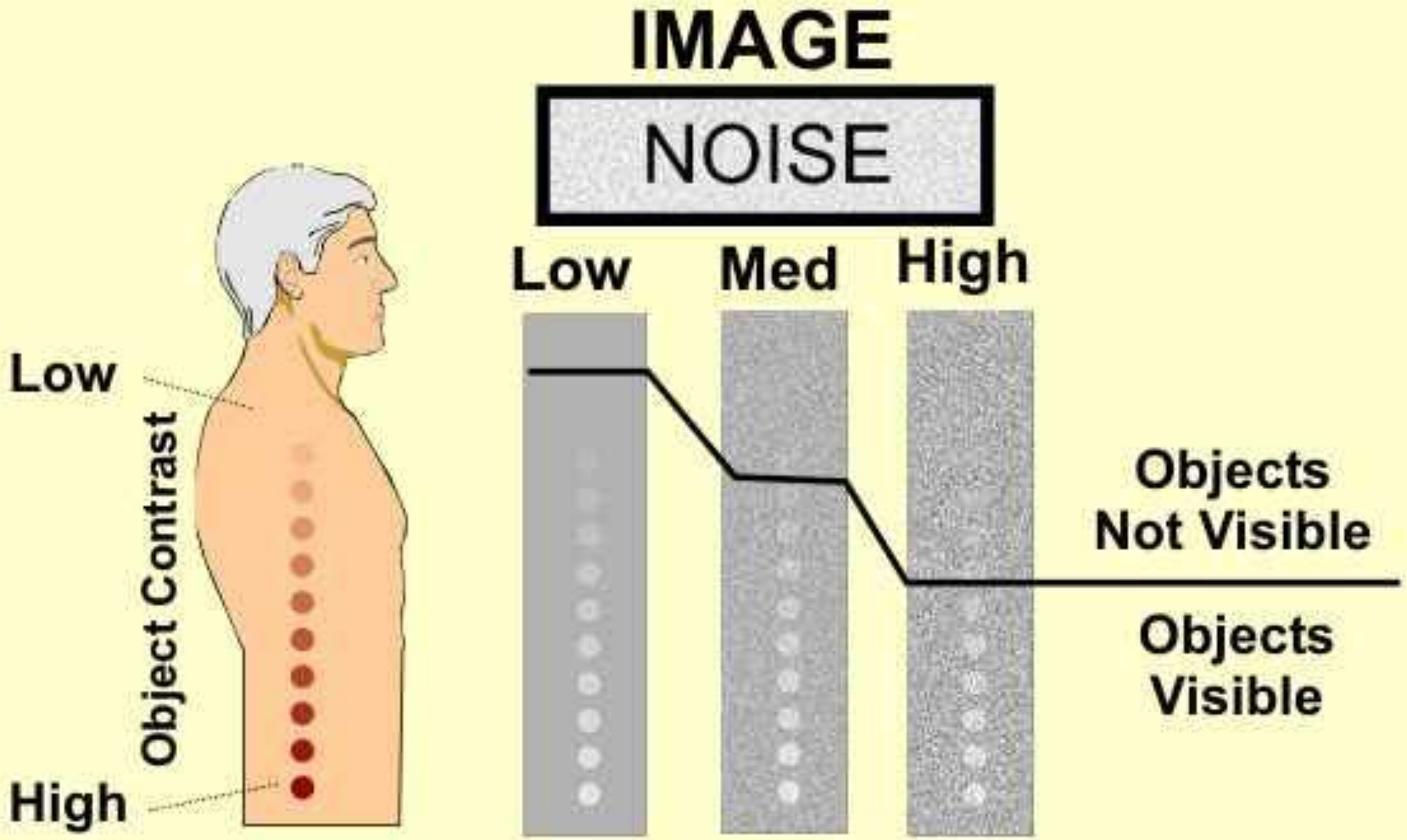
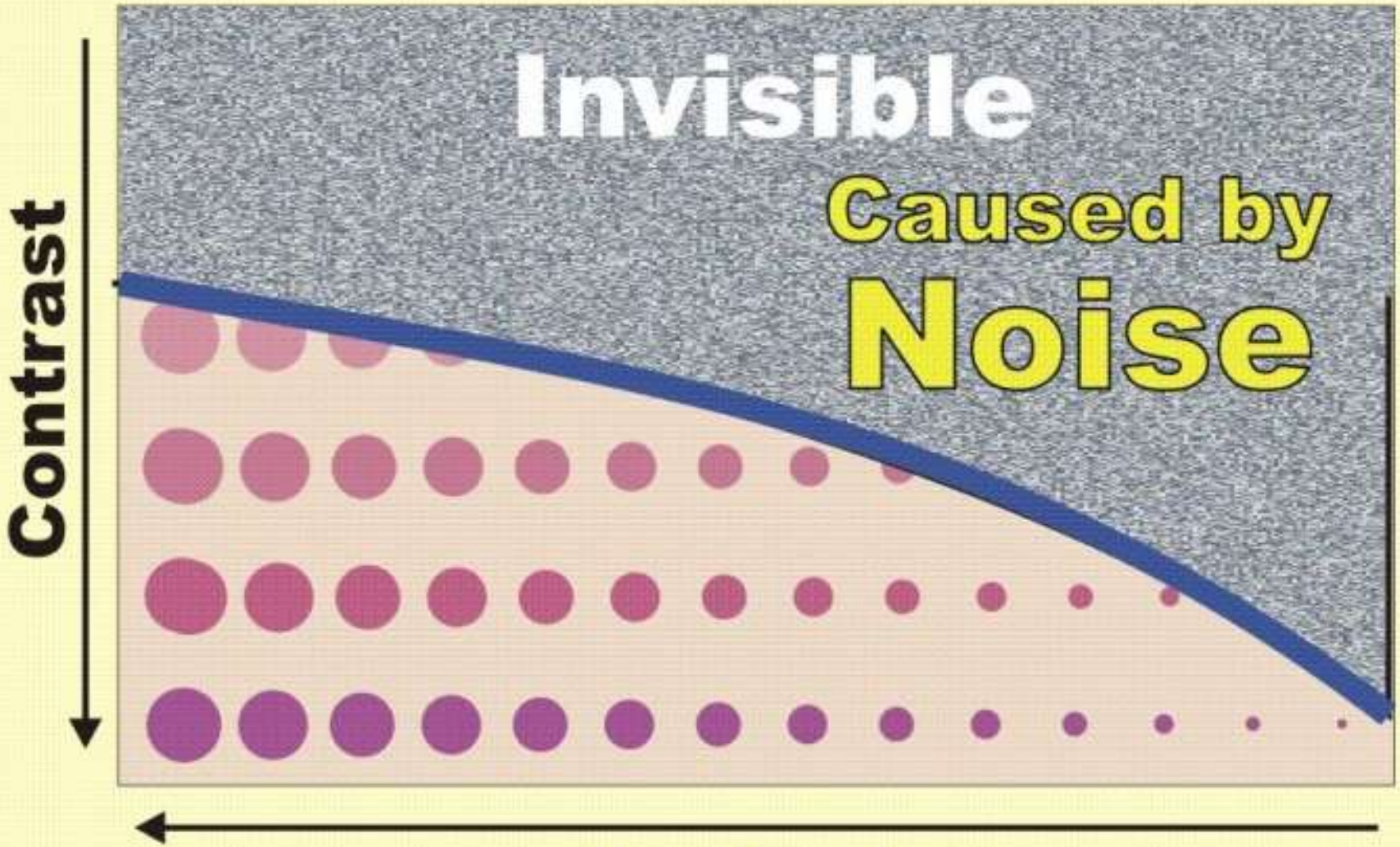


IMAGE
NOISE
Low
Med
High
Low
Object Contrast
High
Objects
Not Visible
Objects
Visible

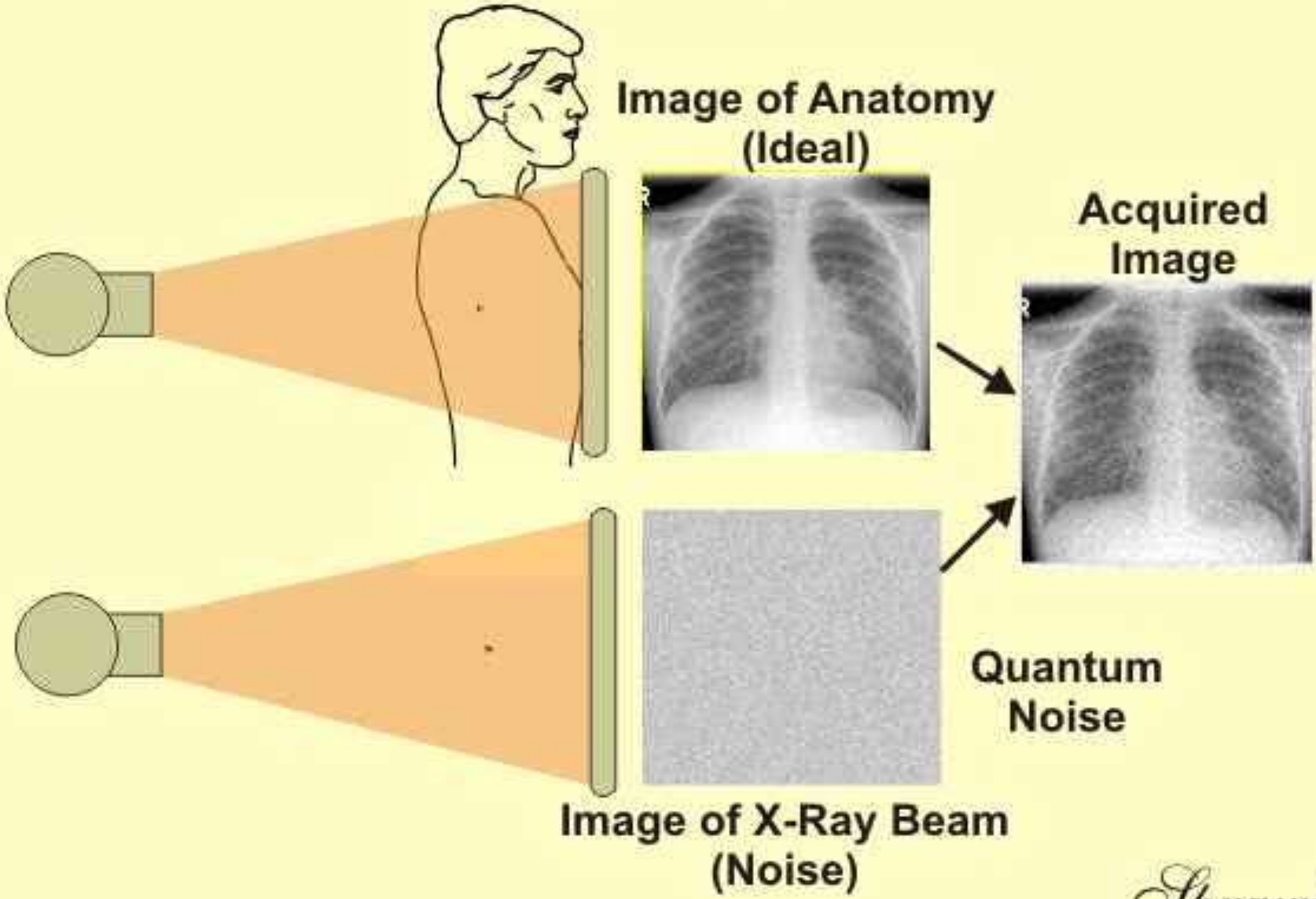
Physical Characteristics of Objects

Effect on Visibility



Sprawls

X-Ray Image Noise



Sprawls

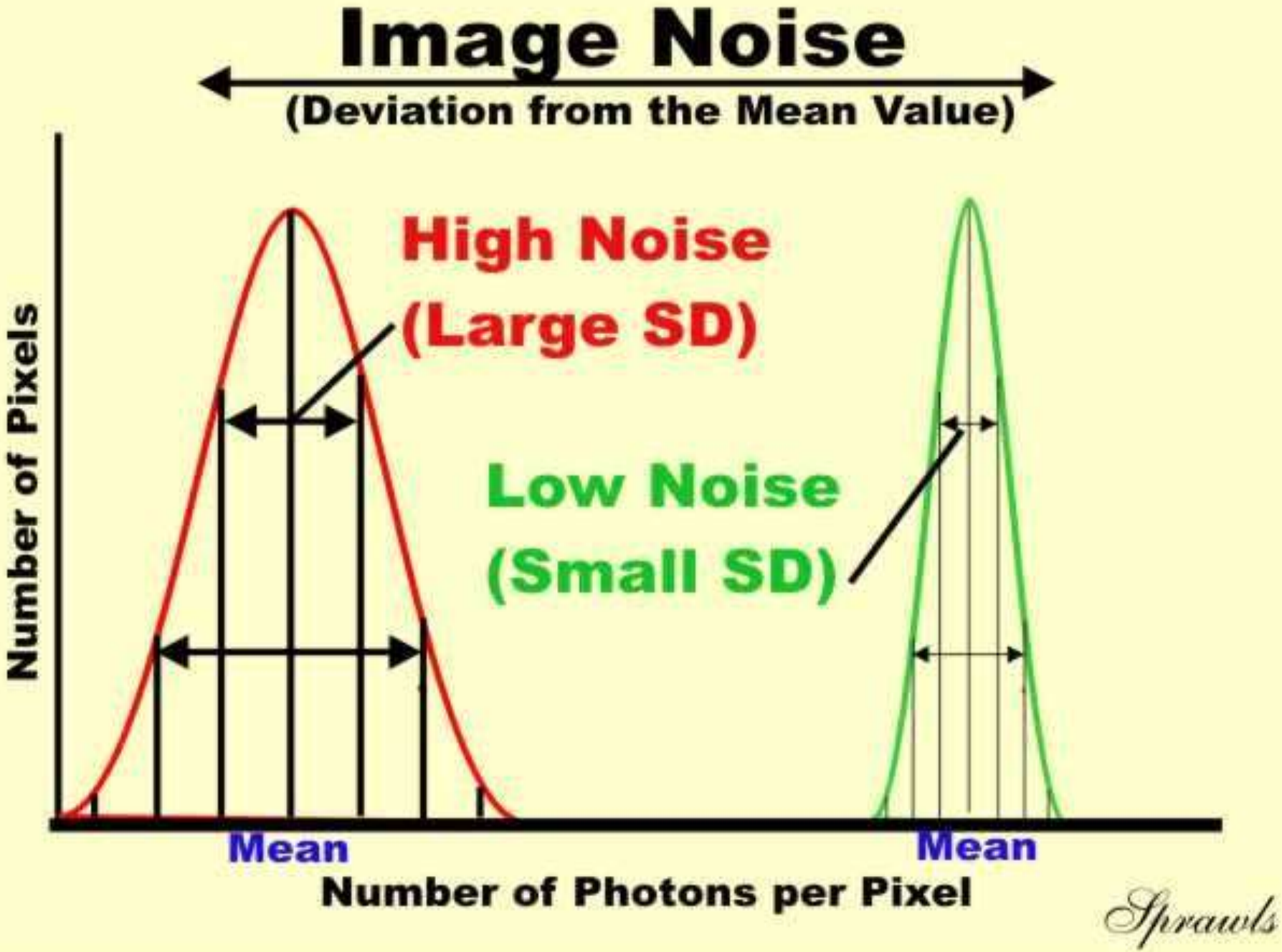
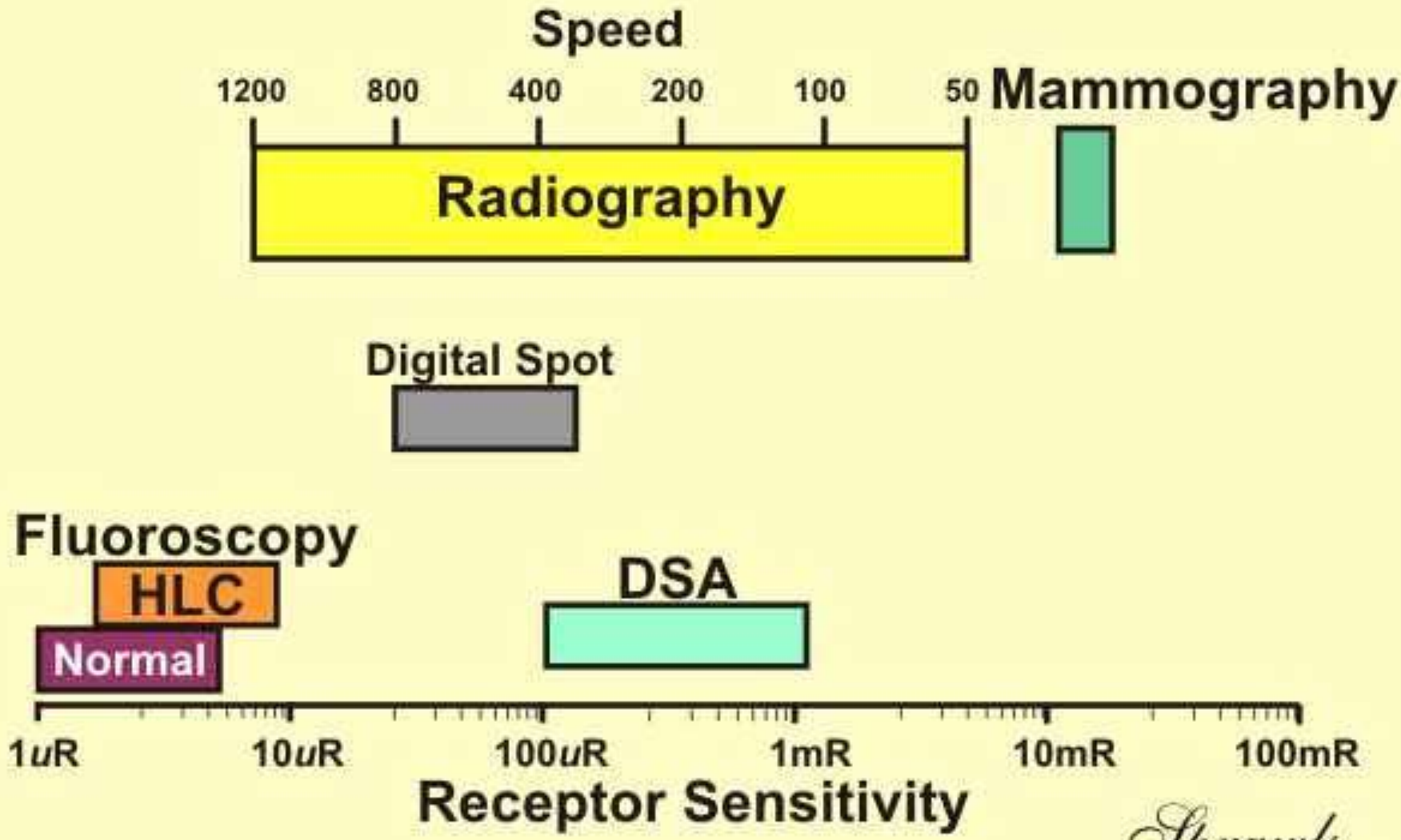
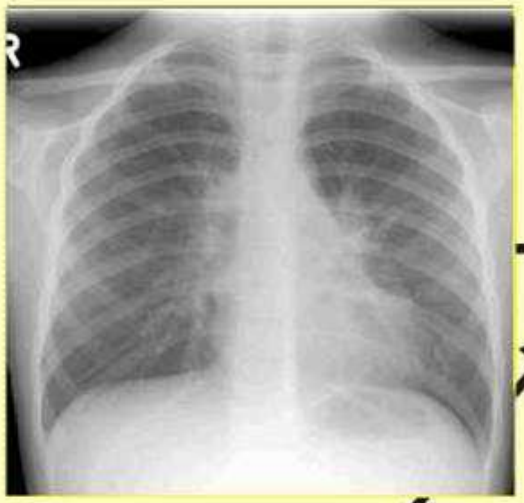


Image Noise
(Deviation from the Mean Value)
High Noise
(Large SD)
Low Noise
(Small SD)
Number of Pixels
Mean
Mean
Number of Photons per Pixel
Sprawls

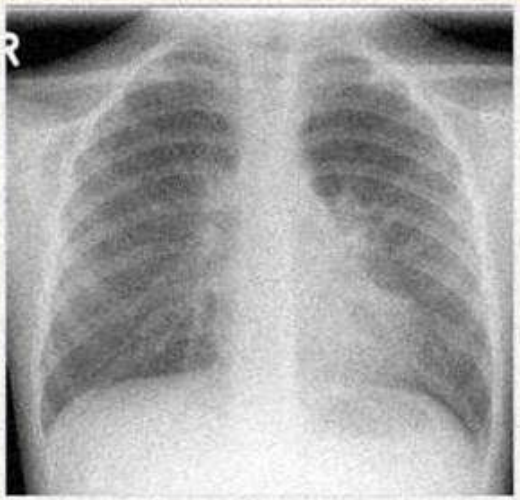
X-Ray Receptor Sensitivity



Visibility of Low Contrast Anatomy Limited By



NOISE



Electronic

Receptor/Display Structure

X-Ray Beam

Receptor Exposure

Reduced By

BLUR

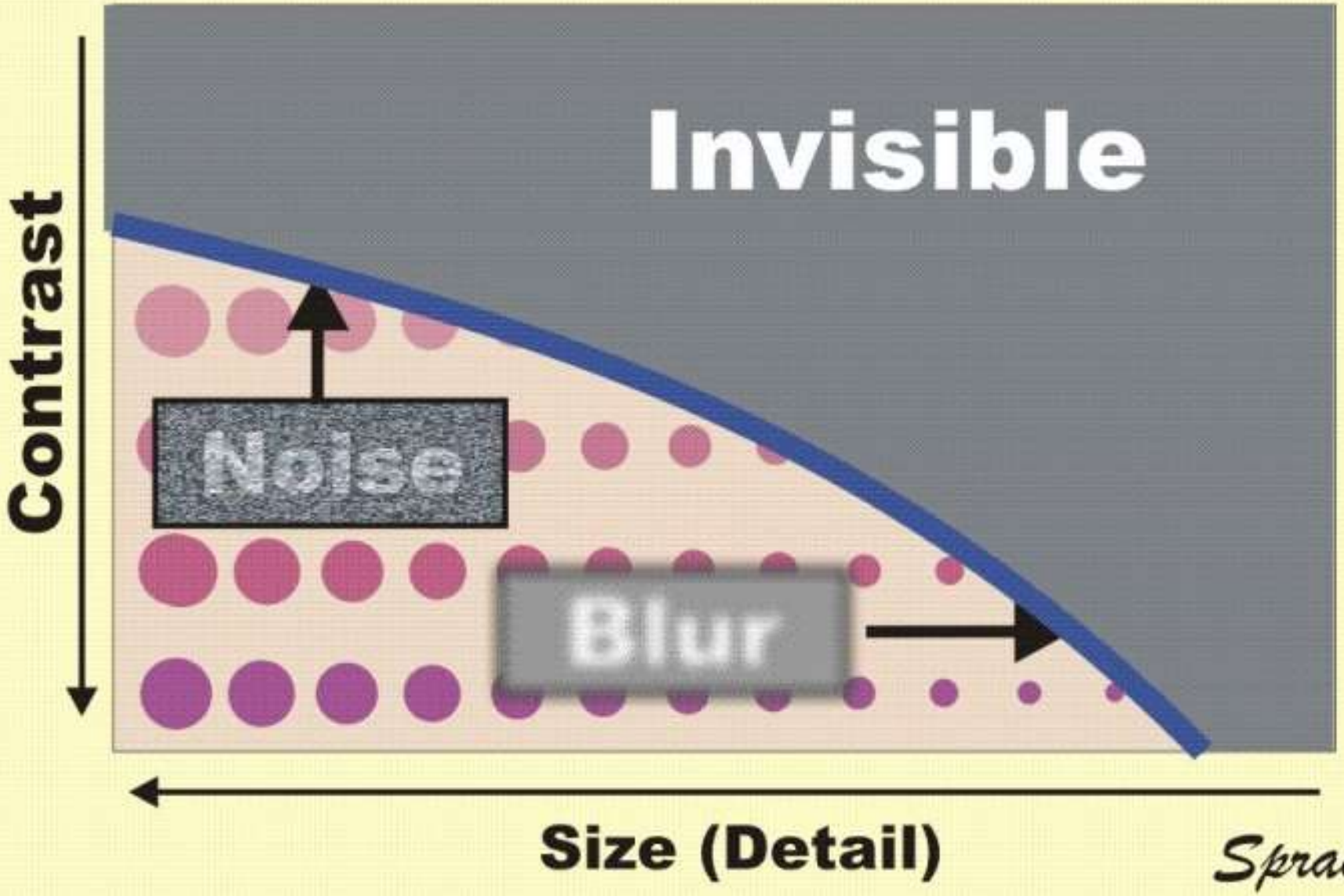
(Pixel Size)

Digital Processing

Sprawls

Physical Characteristics of Objects

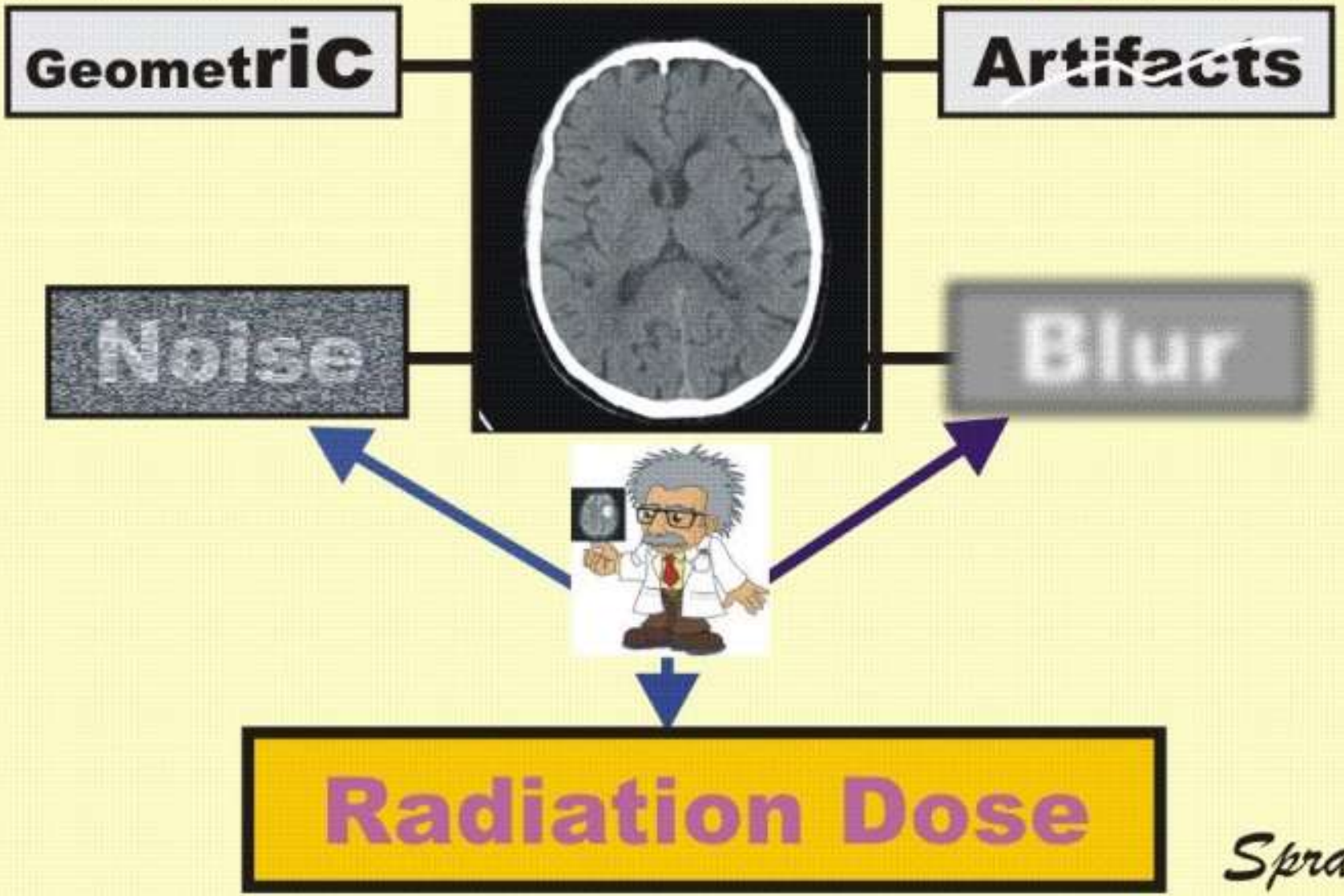
Effect on Visibility



Sprawls

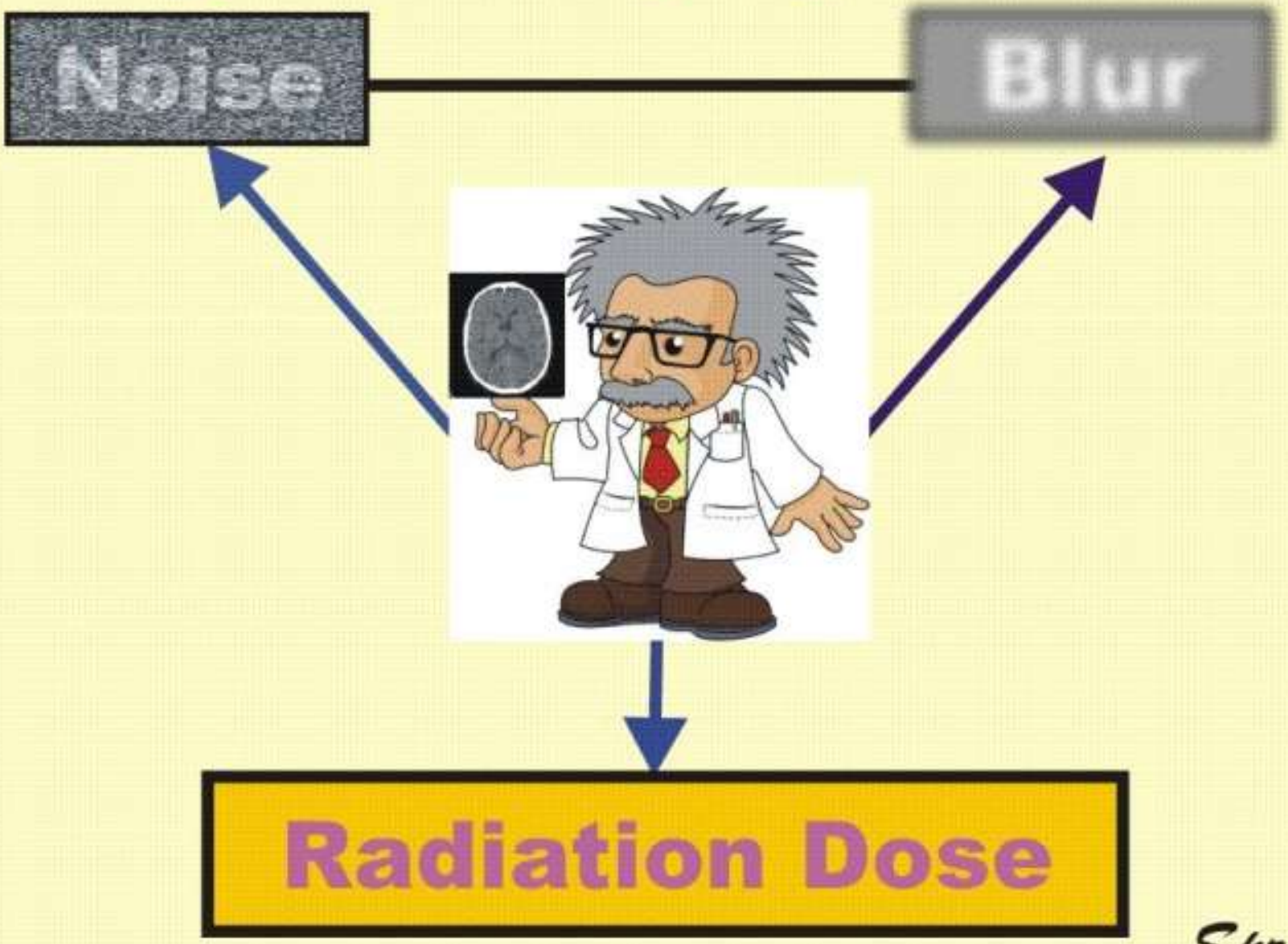
Image Quality Characteristics

That Affect Visibility



Sprawls

Image Quality Optimization



Sprawls

Role of Medical Physicist

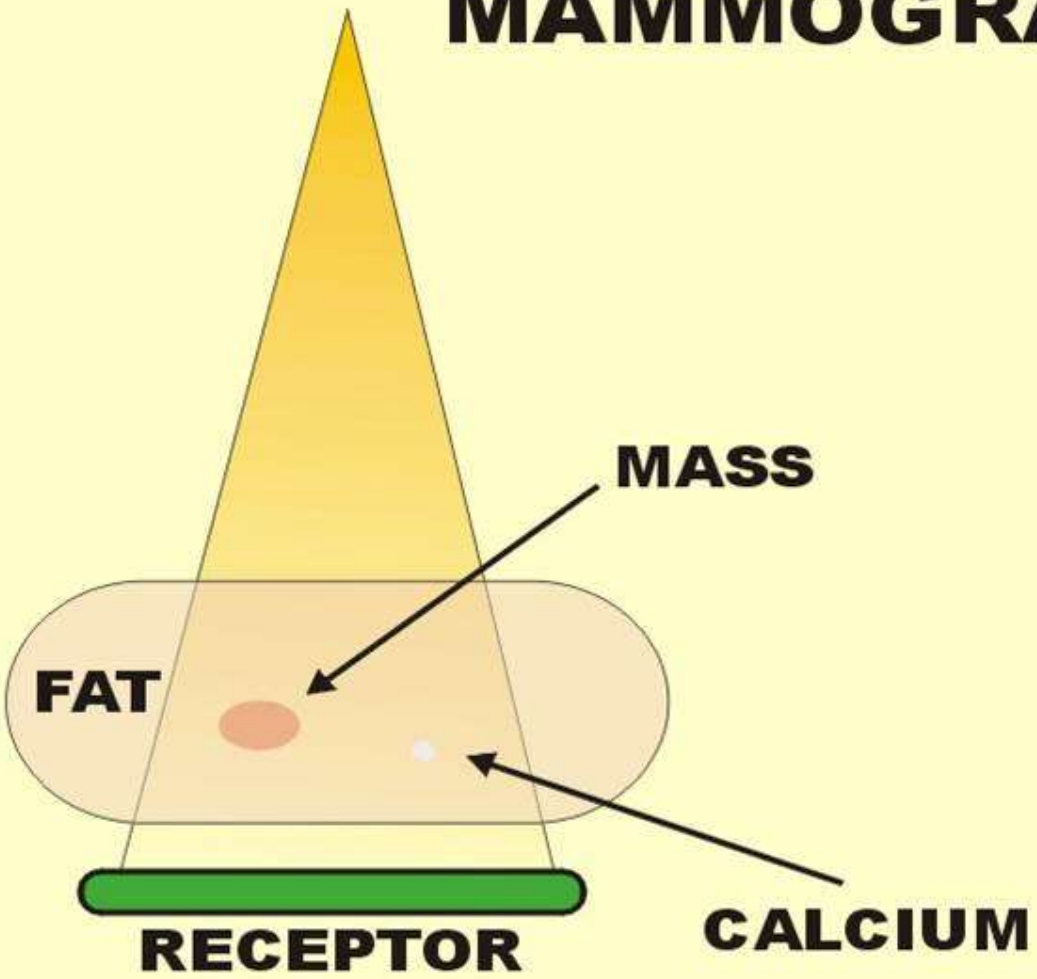
Mammography

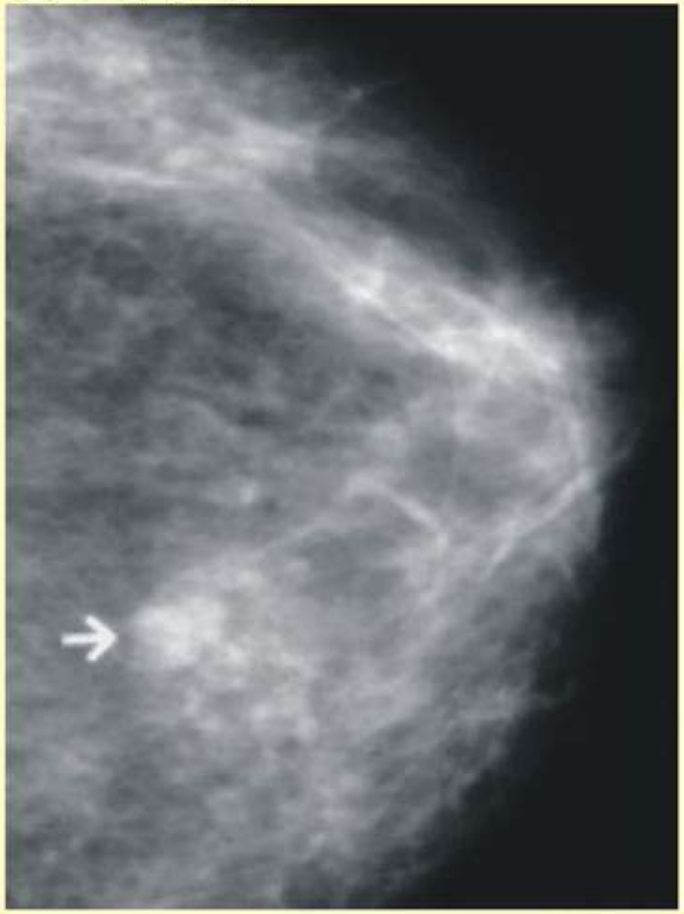
Procedure Protocol | **Equipment Performance** | **Image Quality & Dose**

Consult | **Evaluate** | **Analize**

Sprawls

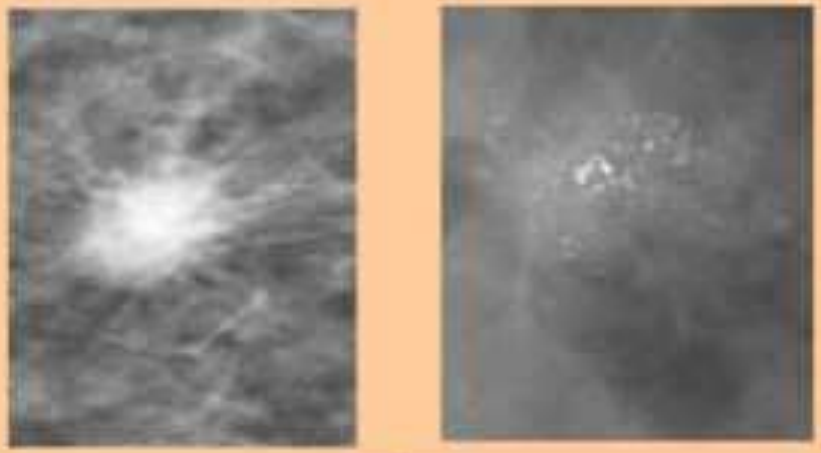
PHYSICAL CONTRAST in MAMMOGRAPHY





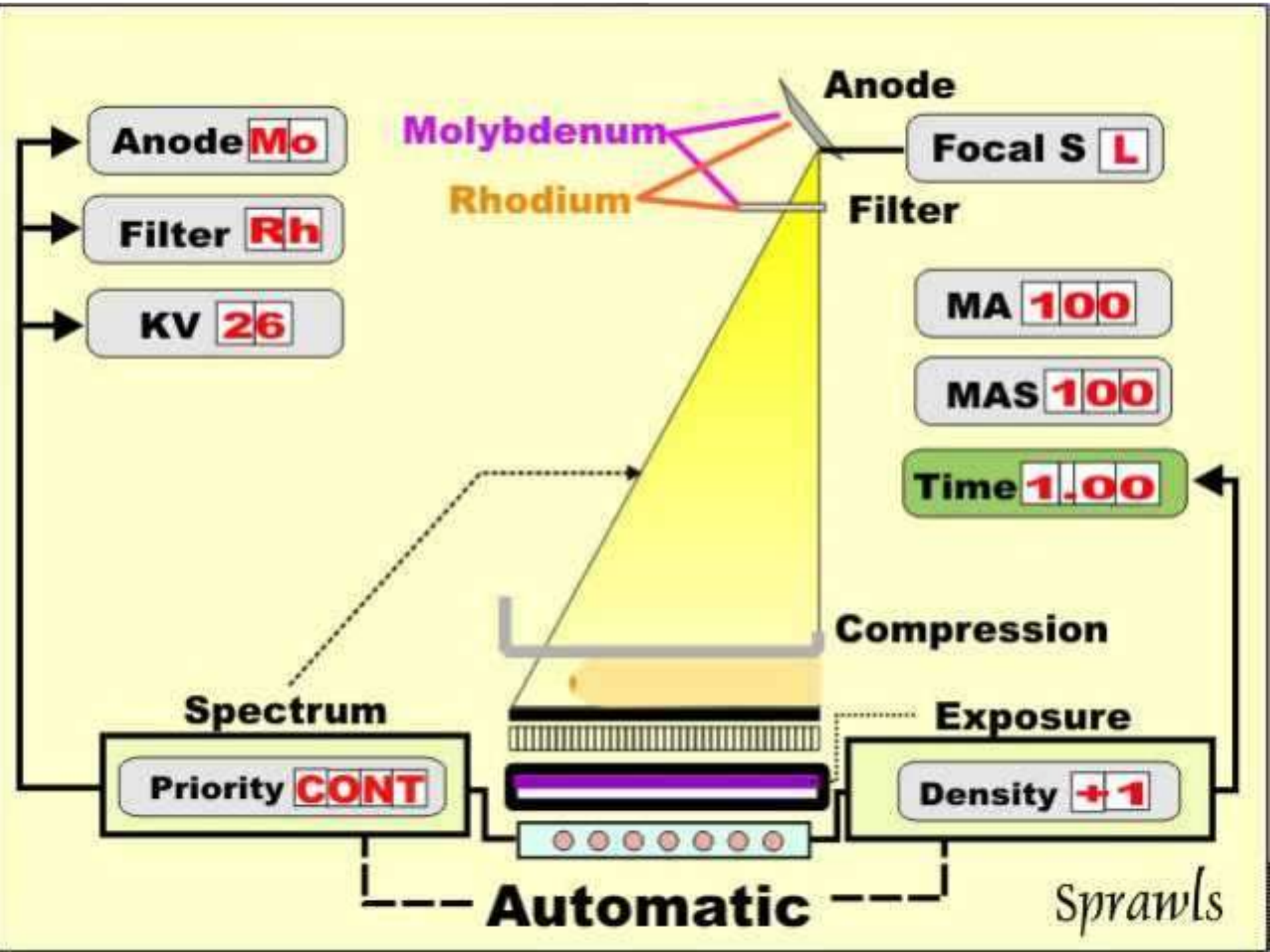
Sprawls

IMAGE QUALITY

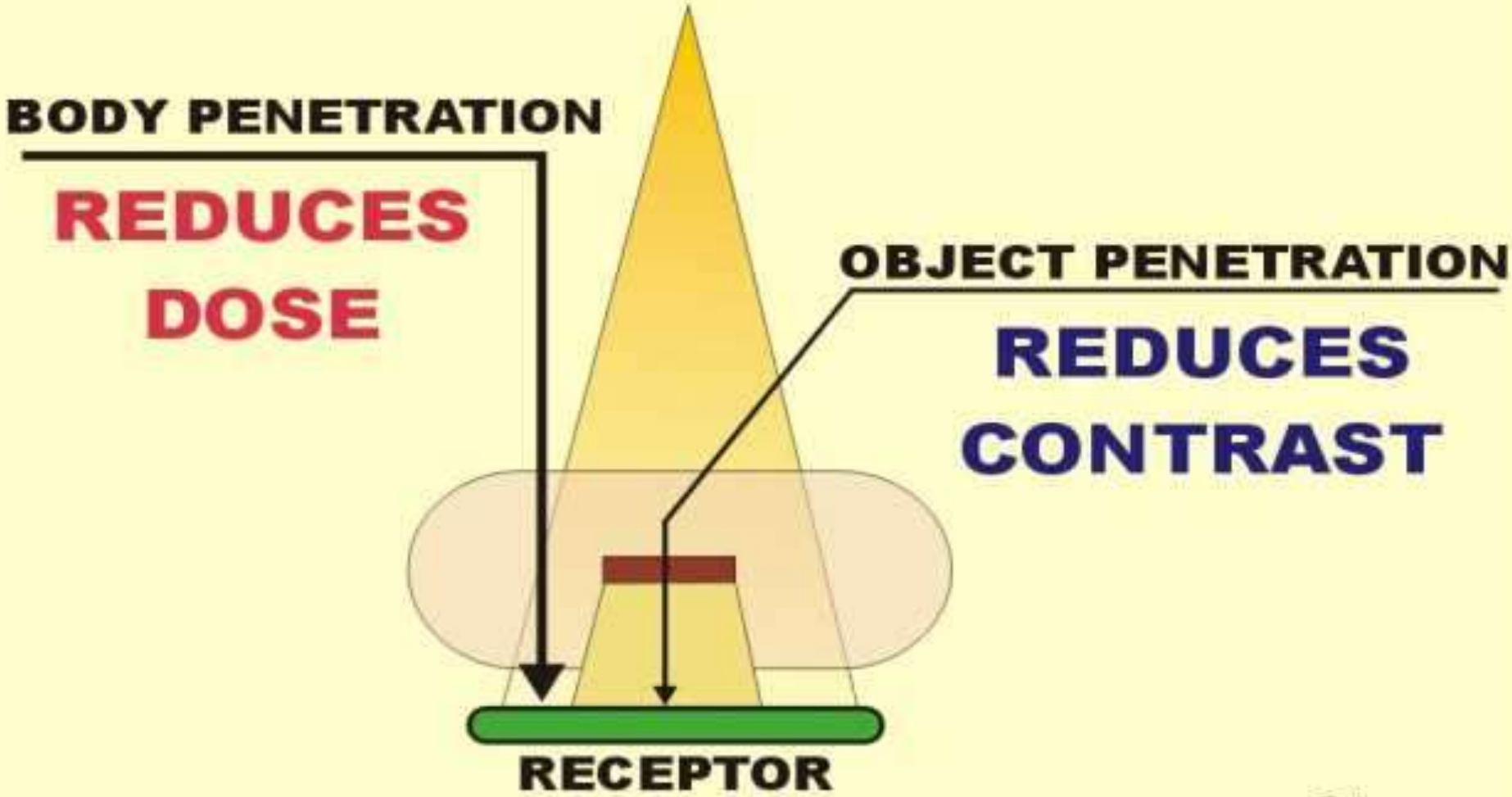


RADIATION DOSE

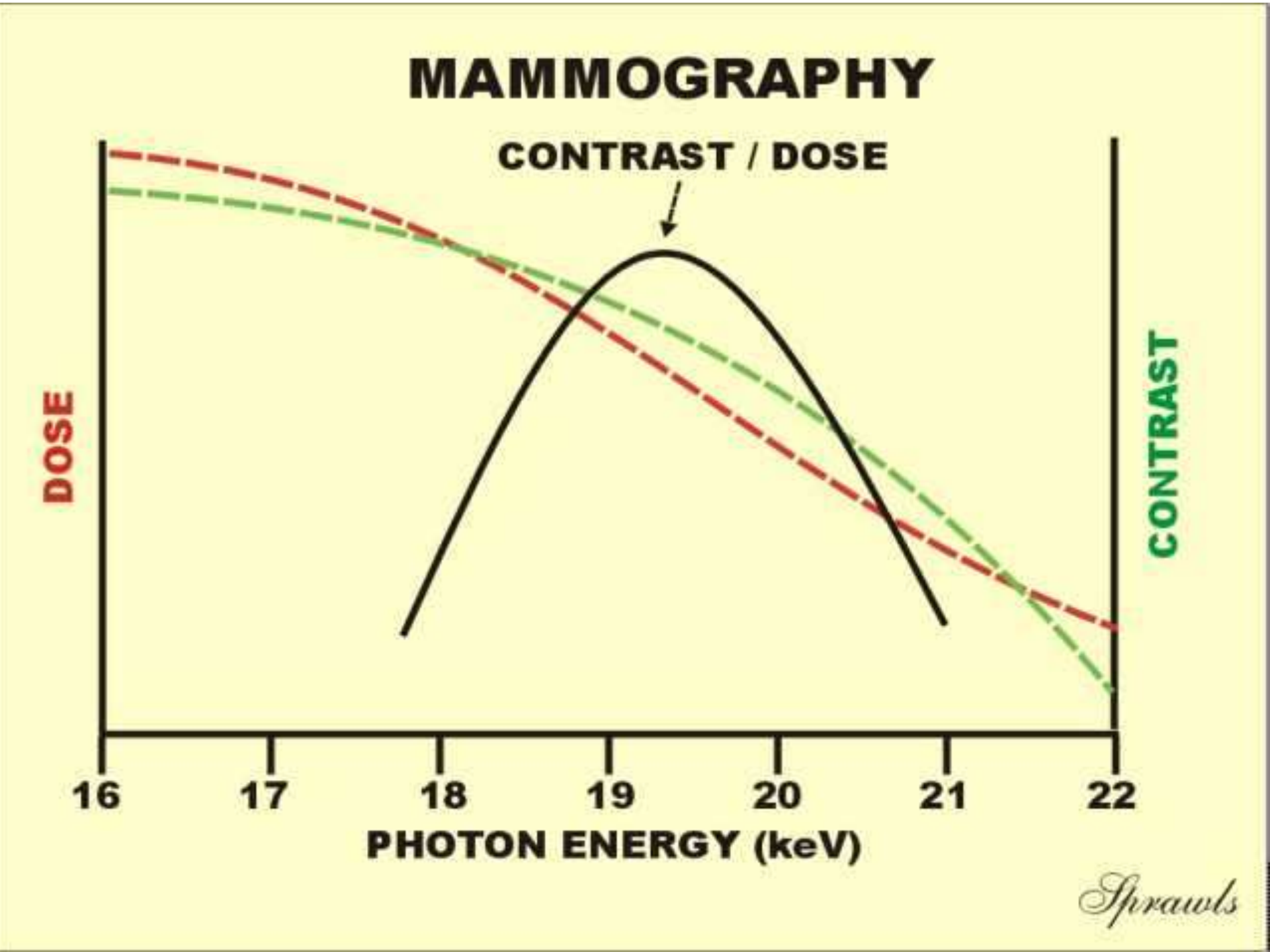
Sprawls


Anode
Molybdenum
Rhodium
Anode Mo
Filter Rh
KV 26
Focal S L
Filter
MA 100
MAS 100
Time 1.00
Compression
Spectrum
Exposure
Priority CONT
Density +1
Automatic
Sprawls

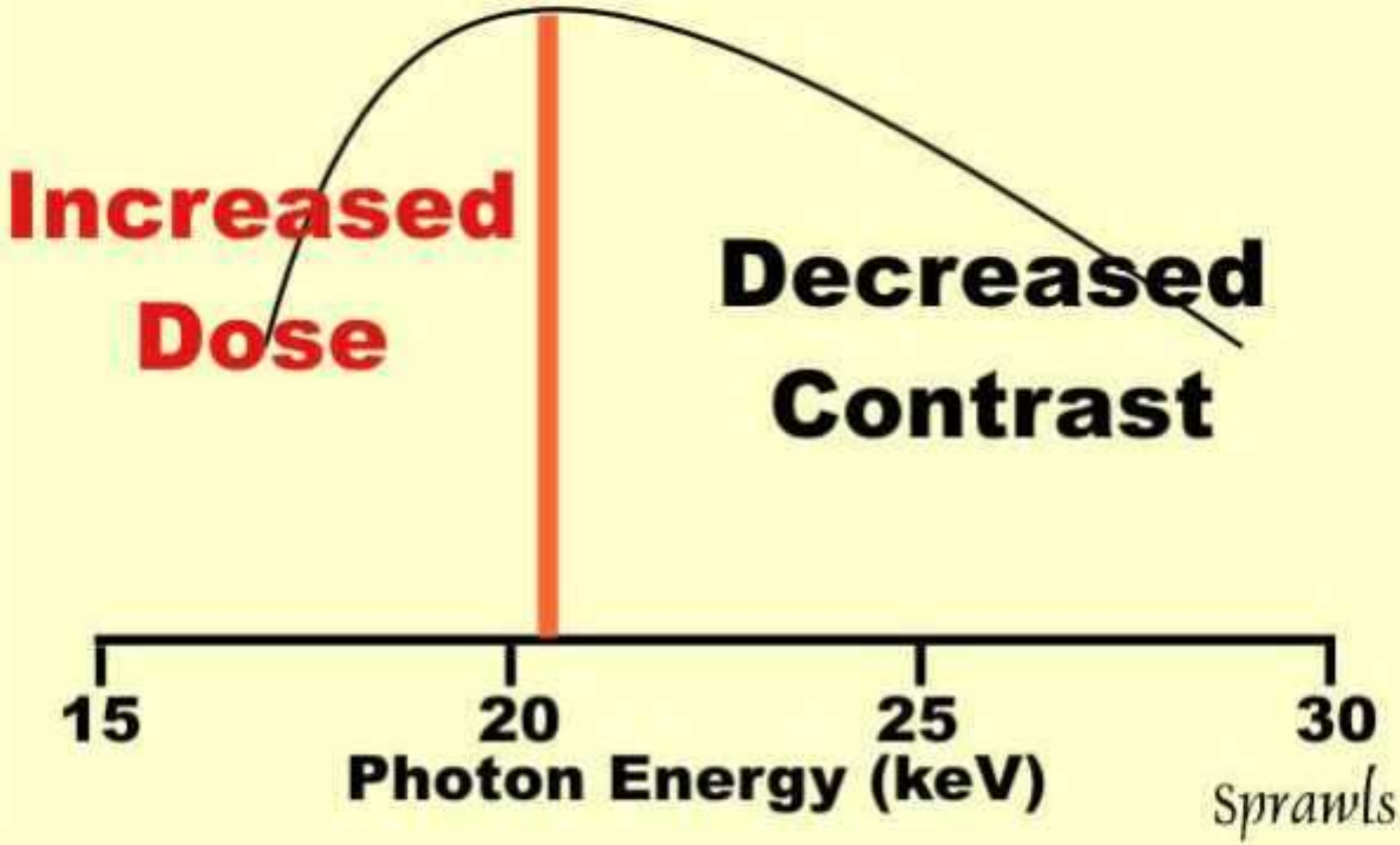
X-RAY BEAM PENETRATION



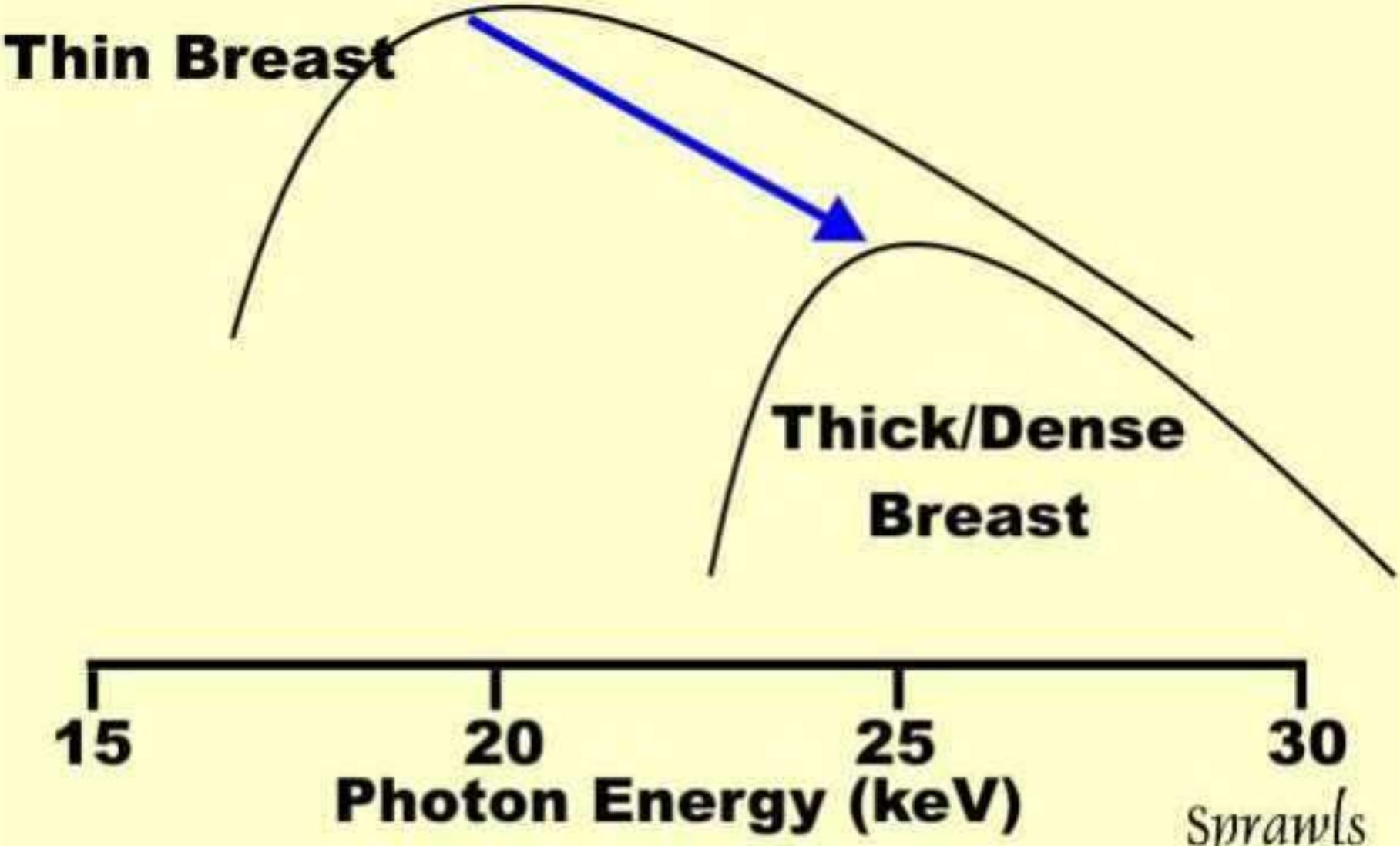
Sprawls


MAMMOGRAPHY
CONTRAST / DOSE
DOSE
CONTRAST
16
17
18
19
20
21
22
PHOTON ENERGY (keV)
Sprawls

Optimum Photon Eneregy

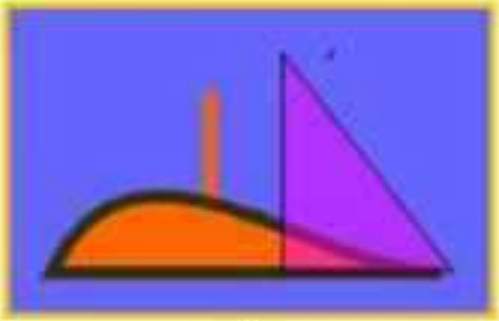


Optimum Photon Eneregy



FACTORS AFFECTING

THE X-RAY SPECTRUM



ANODE

MOLYBDENUM

RHODIUM

~~TUNGSTEN~~

FILTER

MOLYBDENUM

RHODIUM

~~ALUMINUM~~

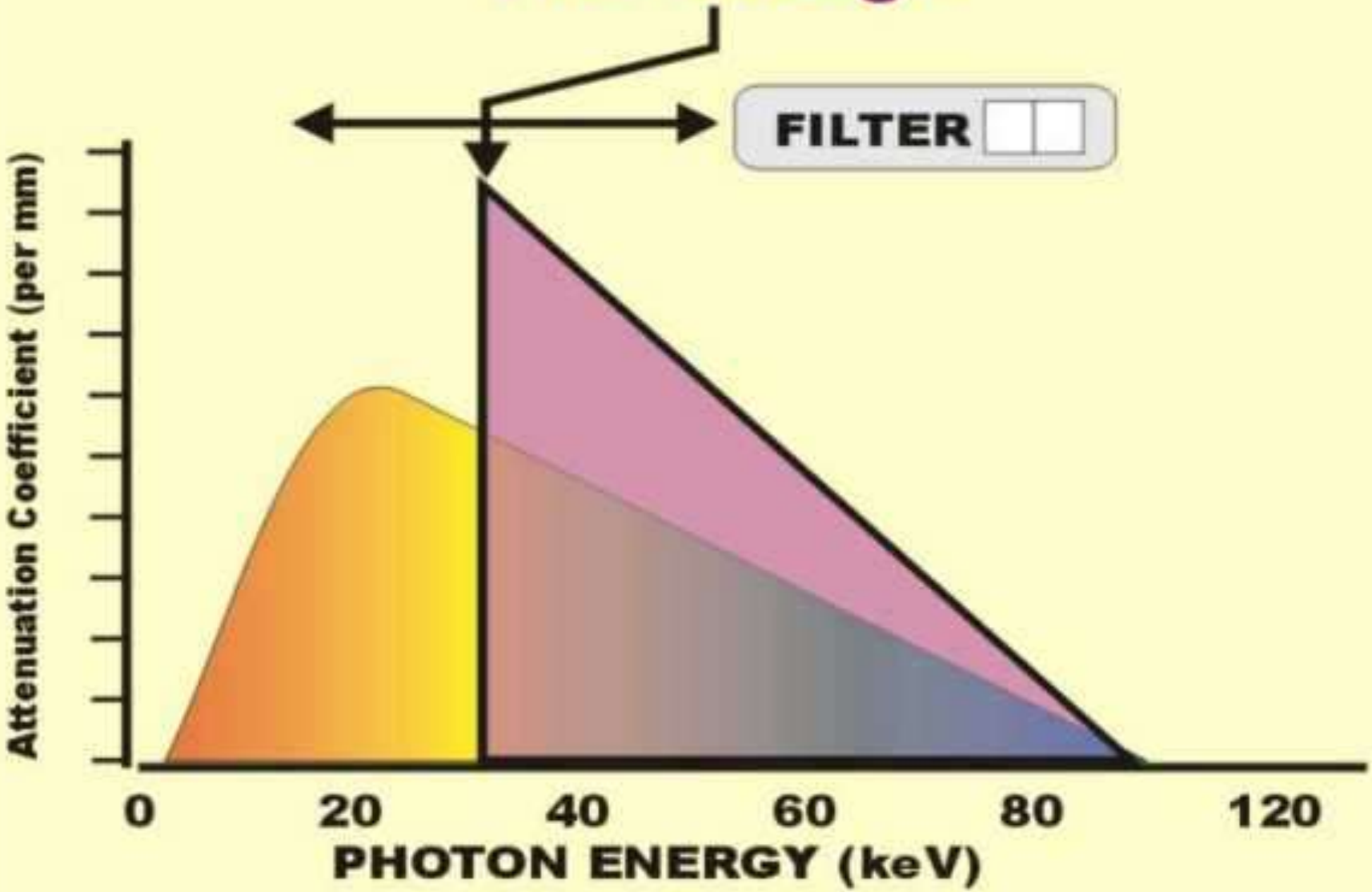
KV

30

24

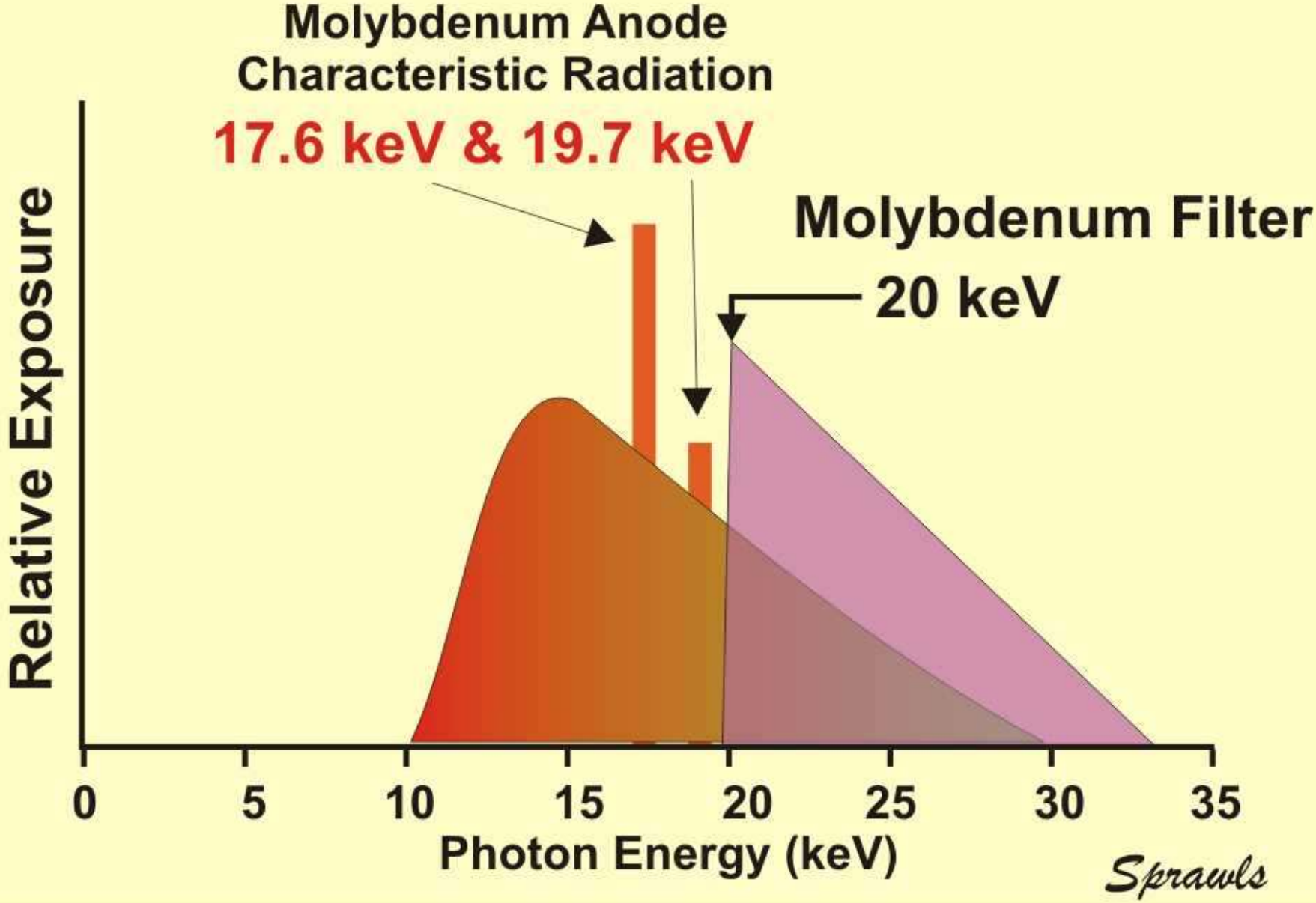
Sprawls

The K Edge

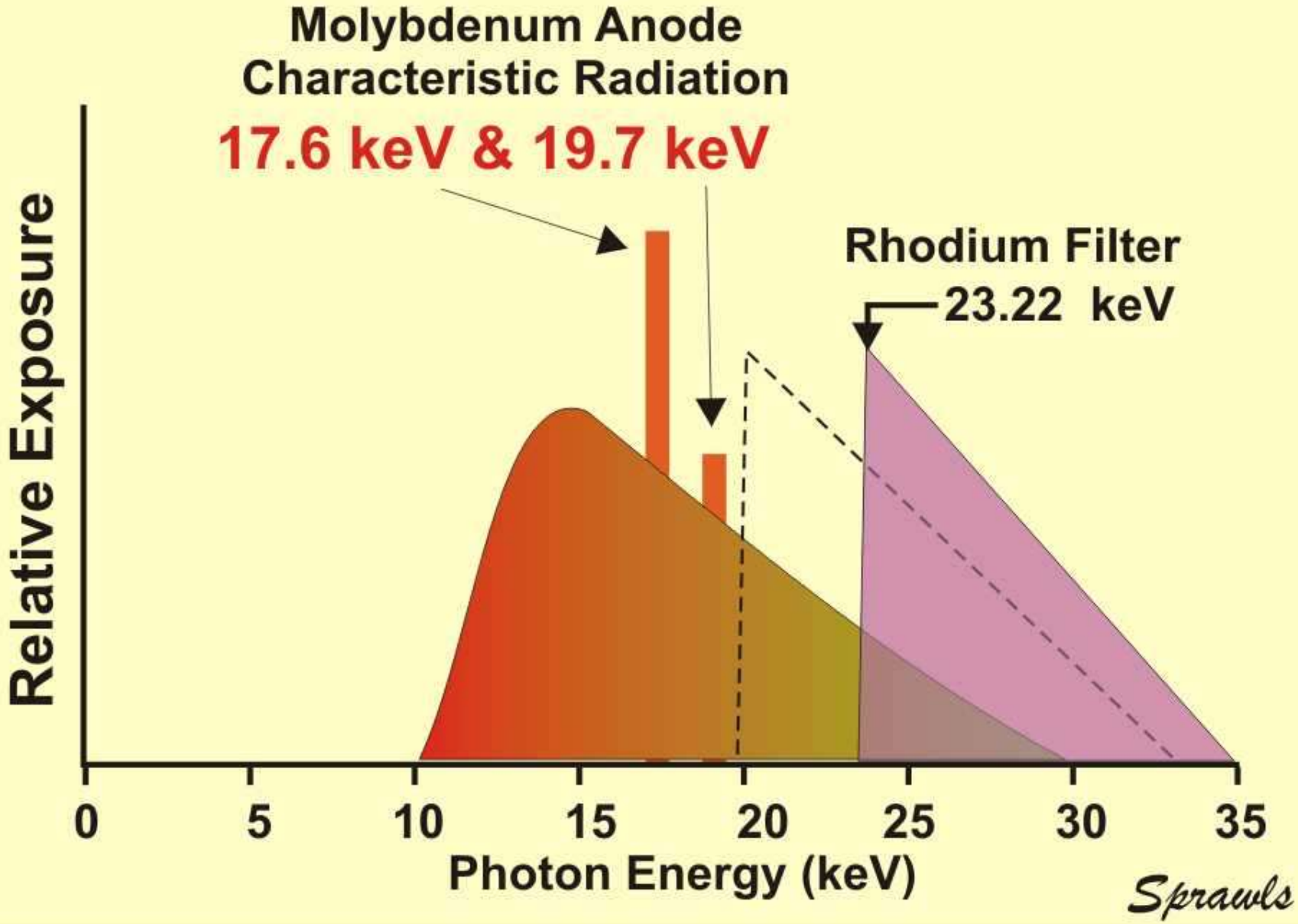


Sprawls

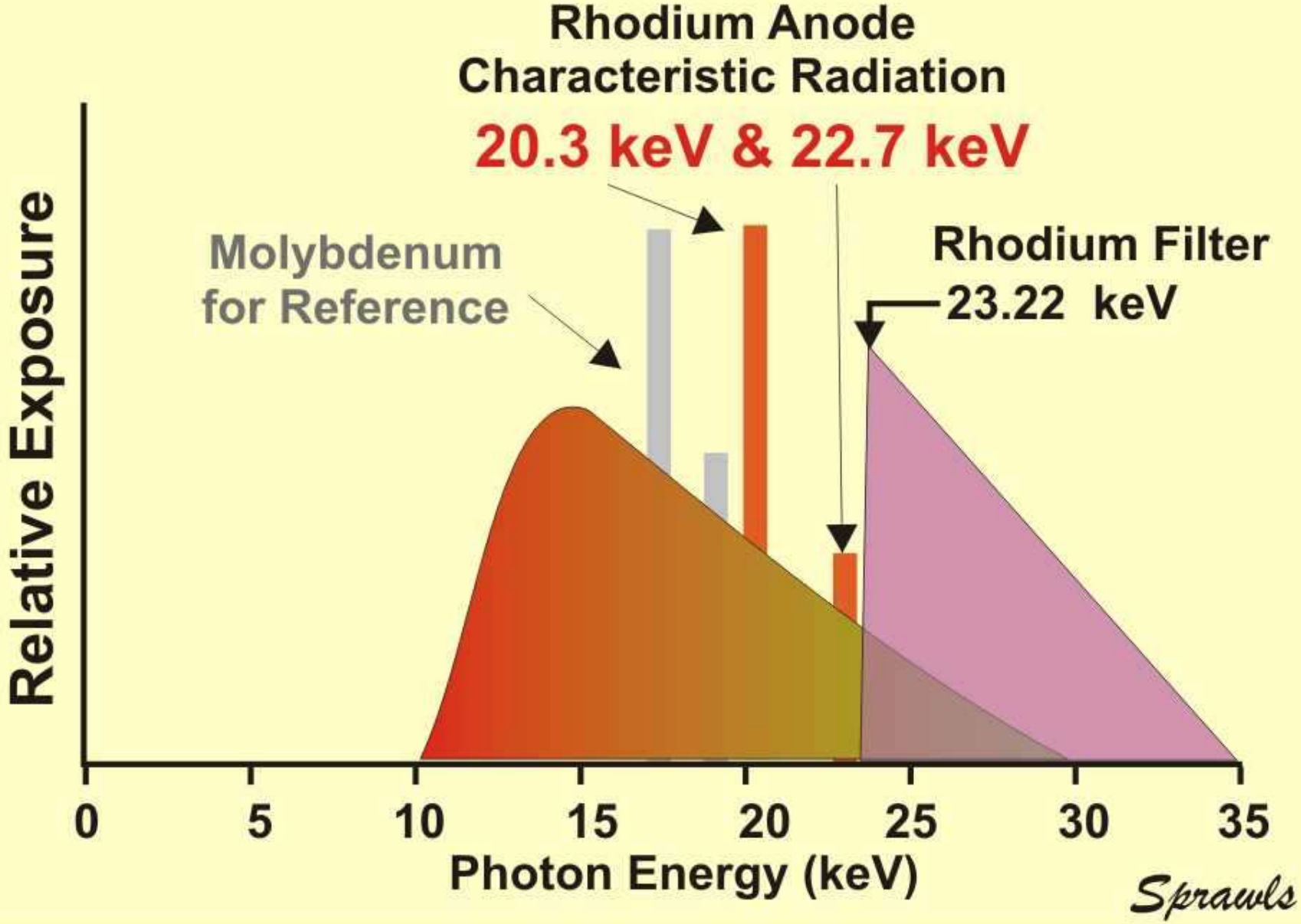
Moly/Moly Spectrum

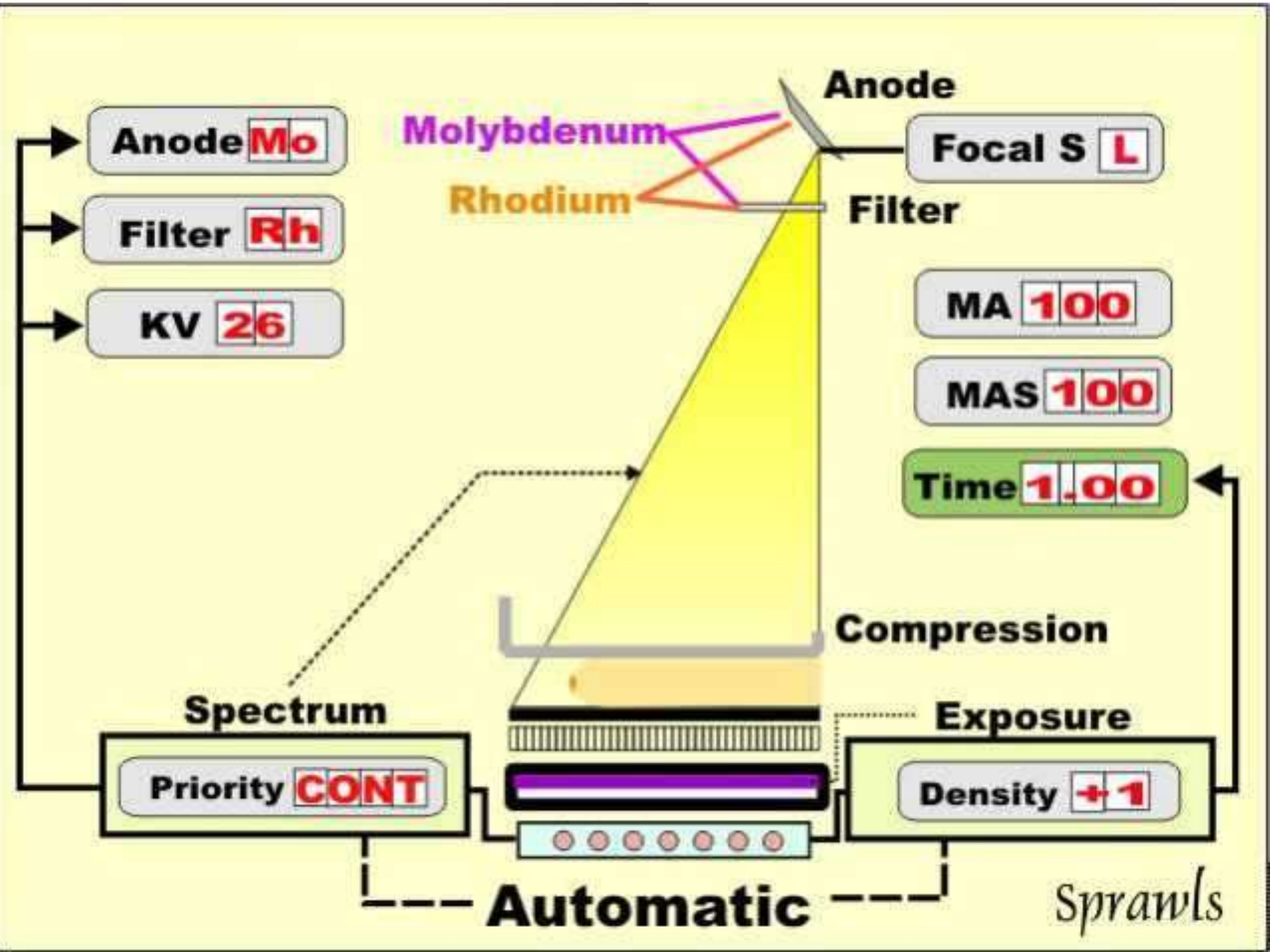


Moly/Rhodium Spectrum



Rhodium/Rhodium Spectrum




Anode
Molybdenum
Rhodium
Anode Mo
Filter Rh
KV 26
Focal S L
Filter
MA 100
MAS 100
Time 1.00
Compression
Spectrum
Exposure
Priority CONT
Density +1
Automatic
Sprawls

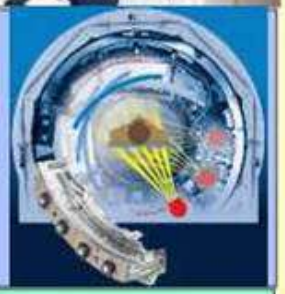
Computed Tomography

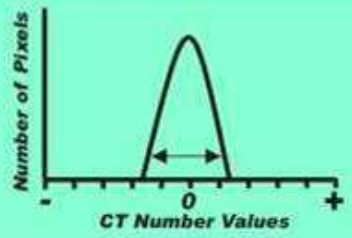
Image Characteristics and Quality

Radiation Dose

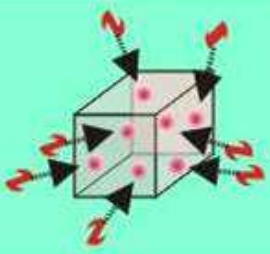
Imaging Protocols

Technology





Science



Sprawls

Role of Medical Physicist

Computed Tomography

Procedure Protocol | **Equipment Performance** | **Image Quality & Dose**

Consult | **Evaluate** | **Analize**

Sprawls

Image Quality

Equipment
Design
&
Performance

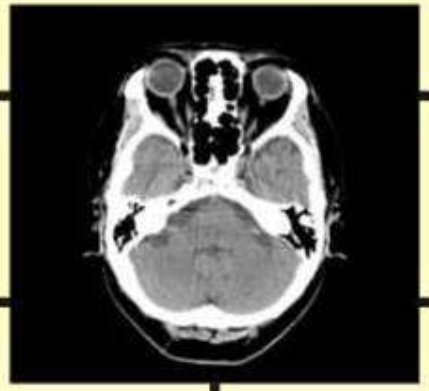
Adjustable Technique Factors

KV	MA	Time	Pitch
Slice Th.	Matrix	FOV	Beam W.
Focal Sp.	Recon. Filter	OO	OO
OO	OO	OO	OO

Procedure Protocol

Sprawls

CT Image Characteristics



Spatial

Artifacts

Detail

Noise

Contrast Sensitivity

KV	Pitch	Slice Th.	Window Width
MA	Beam Wid.	FOV	Window Level
Time	Filter	Matrix	Zoom

Major Protocol Factors

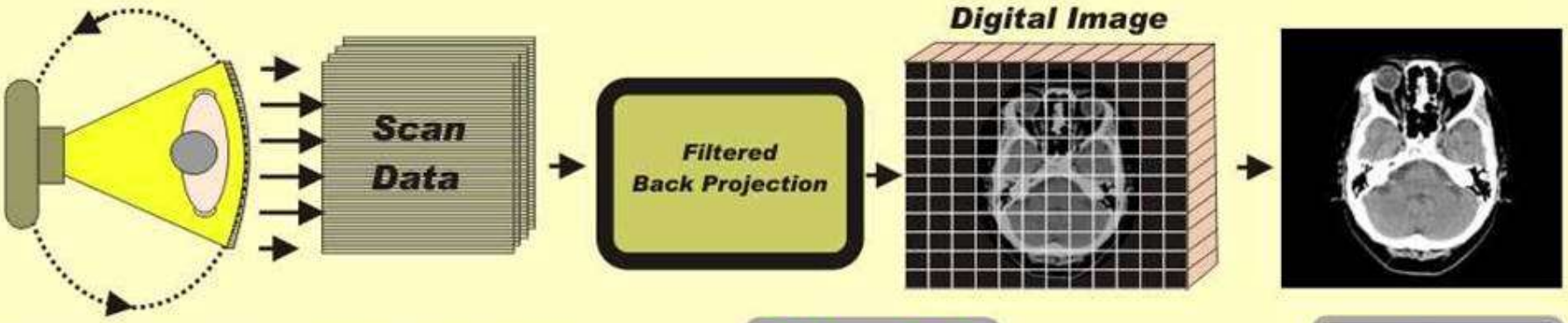
Sprawls

The Three Phases of CT Image Formation

Scan and Data Acquisition

Image Reconstruction

Digital/Analog Conversion and Display Control



KV

MA

Time

Pitch

Beam Wid.

Slice Th.

FOV

Matrix

Filter

Window Width

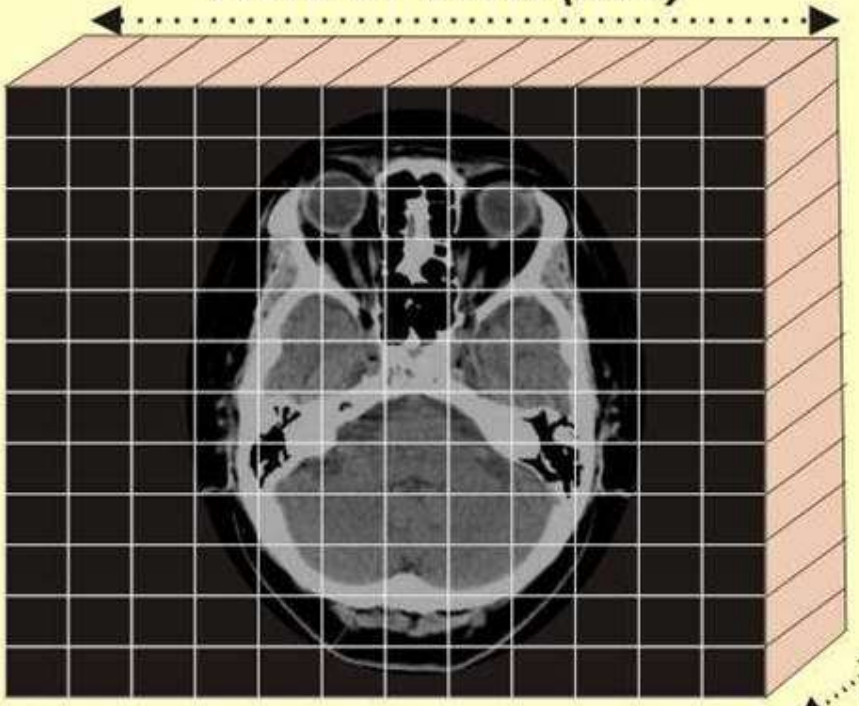
Window Level

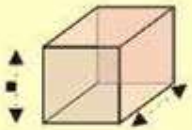
Zoom

Major Protocol Factors

Sprawls

CT Slice Divided into Matrix of Voxels

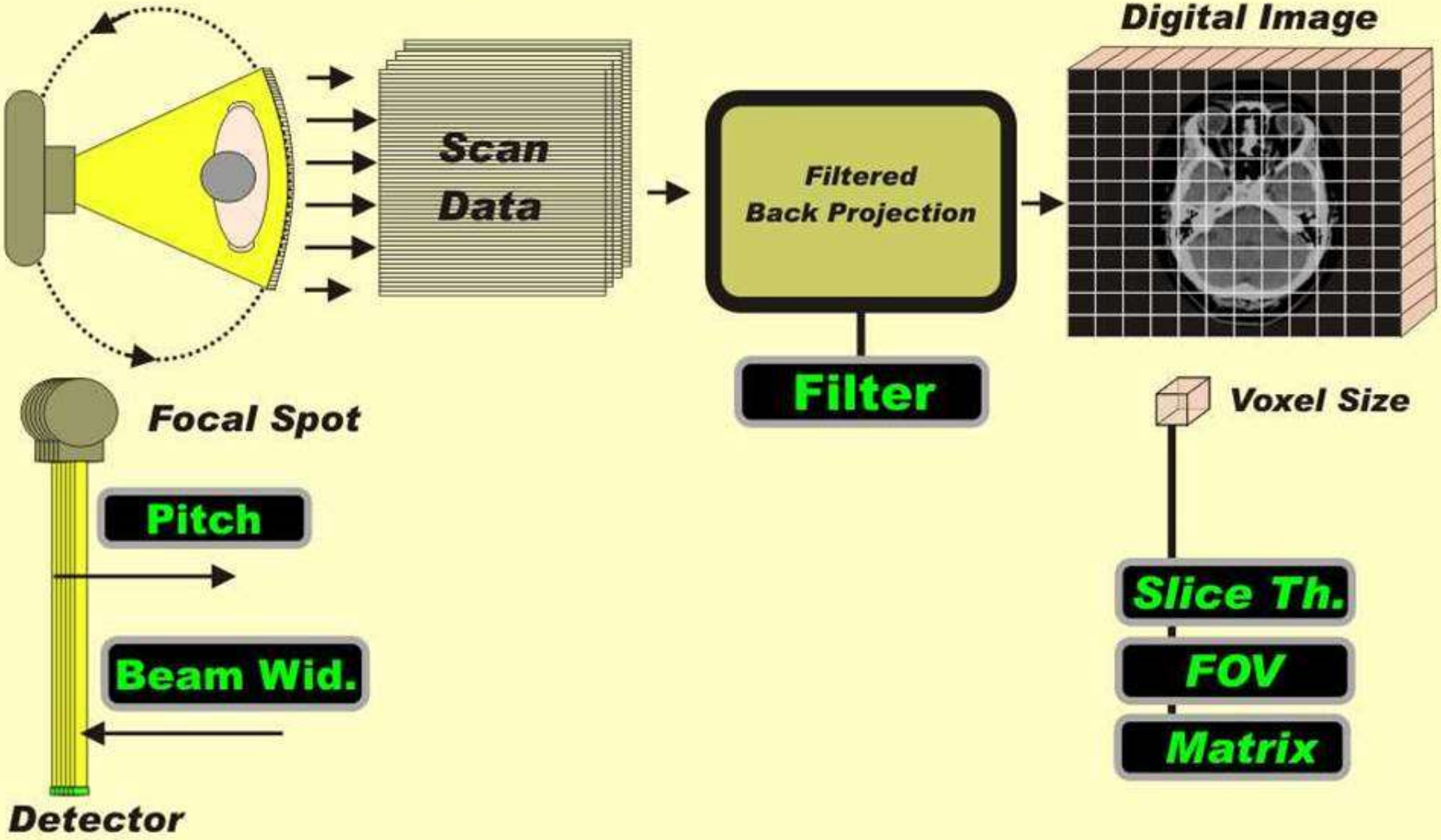


FOV ÷ **Matrix** · · · · ·  **Slice Th.**

Voxel Size Controlled By

Sprawls

Factors That Determine Image Detail (Sources of Blurring)



Sprawls

X-ray Photons Interact With Tissue in A Voxel

Radiation Dose

determined by

Concentration of Absorbed Energy

per voxel

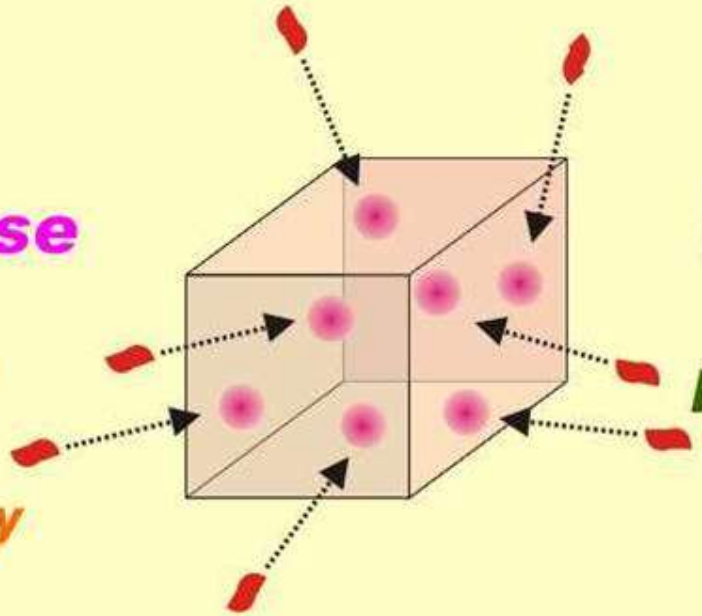


Image Noise

determined by

Number of Photons

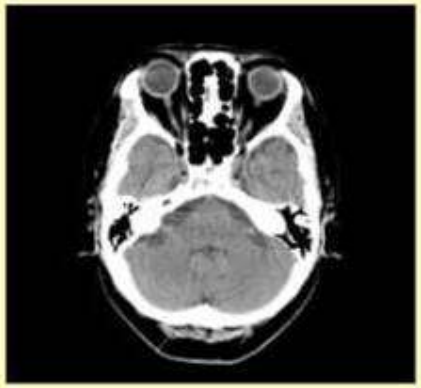
per voxel

Dose is increased by increasing number of photons.

Noise is reduced by increasing number of photons.

Sprawls

Two Major Image Quality Goals



High Detail — **Low Noise**

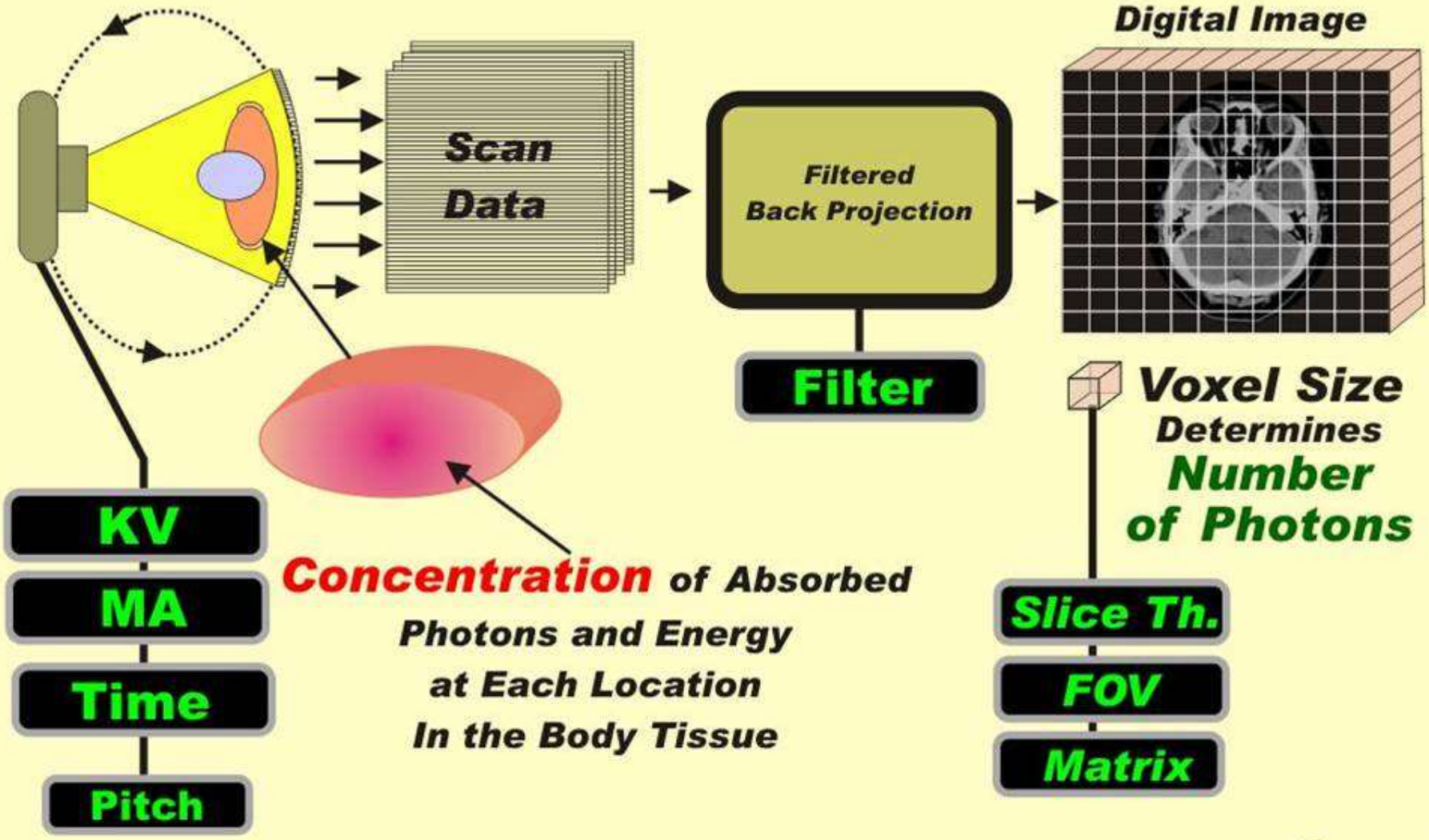
Voxel Size

- **FOV**
- **Matrix**
- **Slice Th.**

Protocol Factors

Sprawls

Factors That Determine Image Noise

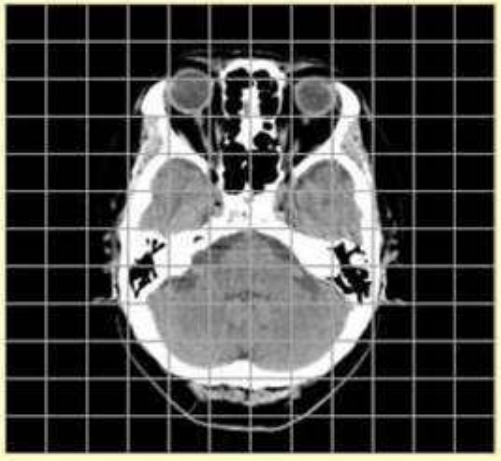


Sprawls

Effect of Matrix Size on Image Noise

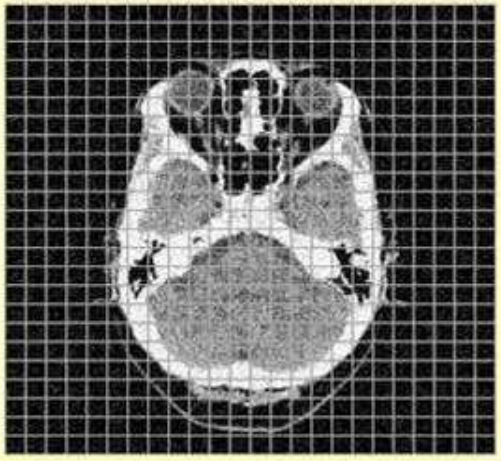
Small **Matrix** **Large**

Large Voxels



Low Noise

Small Voxels

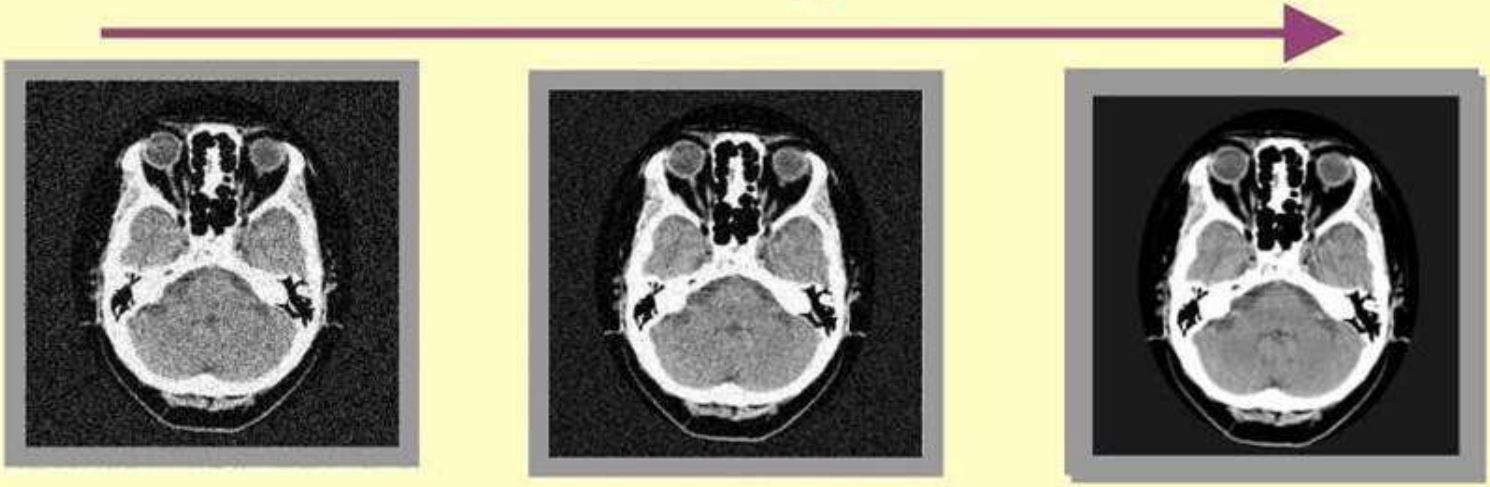


High Noise

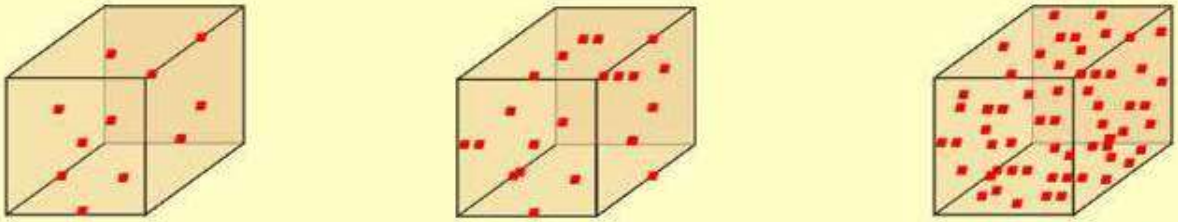
The same radiation dose for both images.

Sprawls

Decreasing Noise



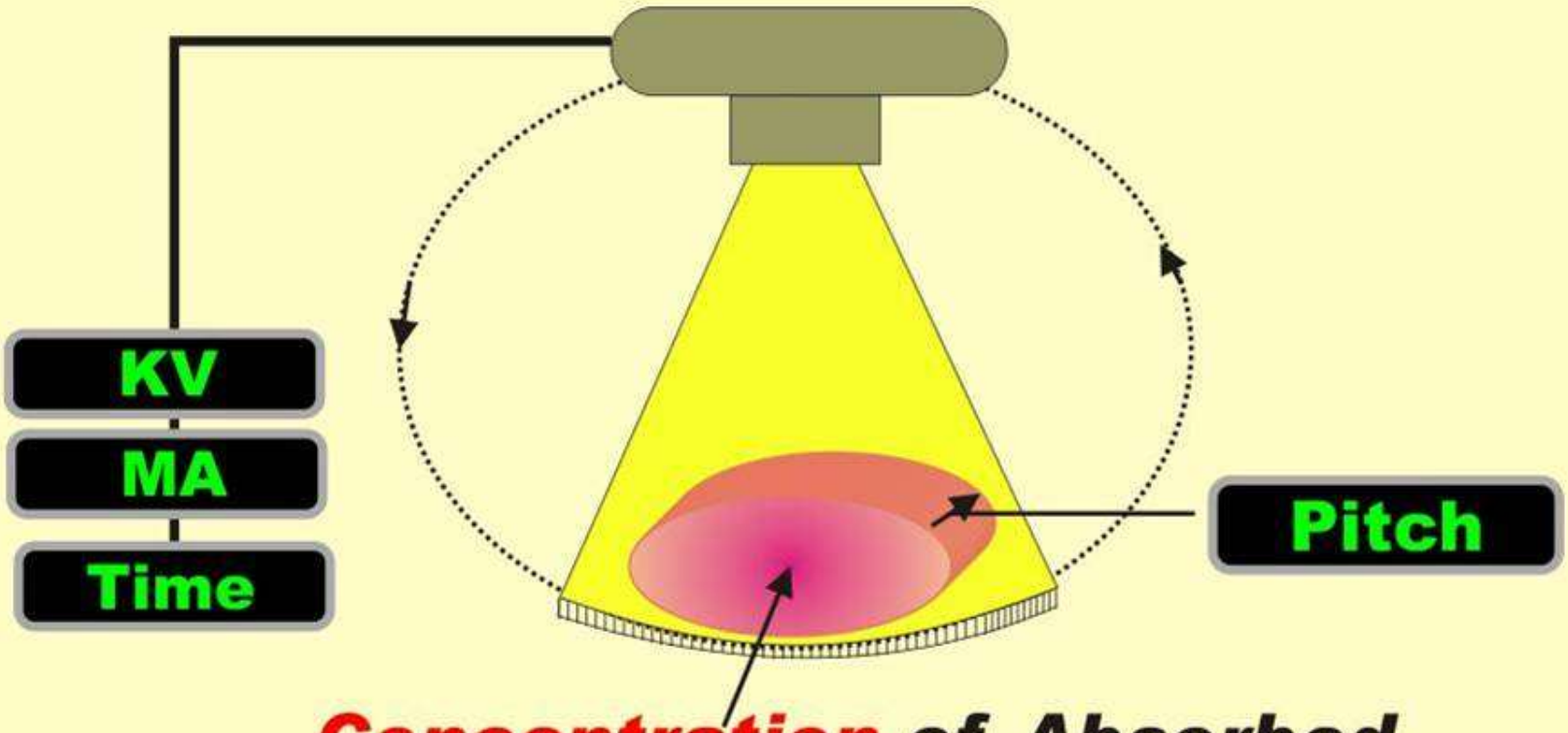
Requires Increased Photons Absorbed Per Voxel



Produces Increasing Dose

Sprawls

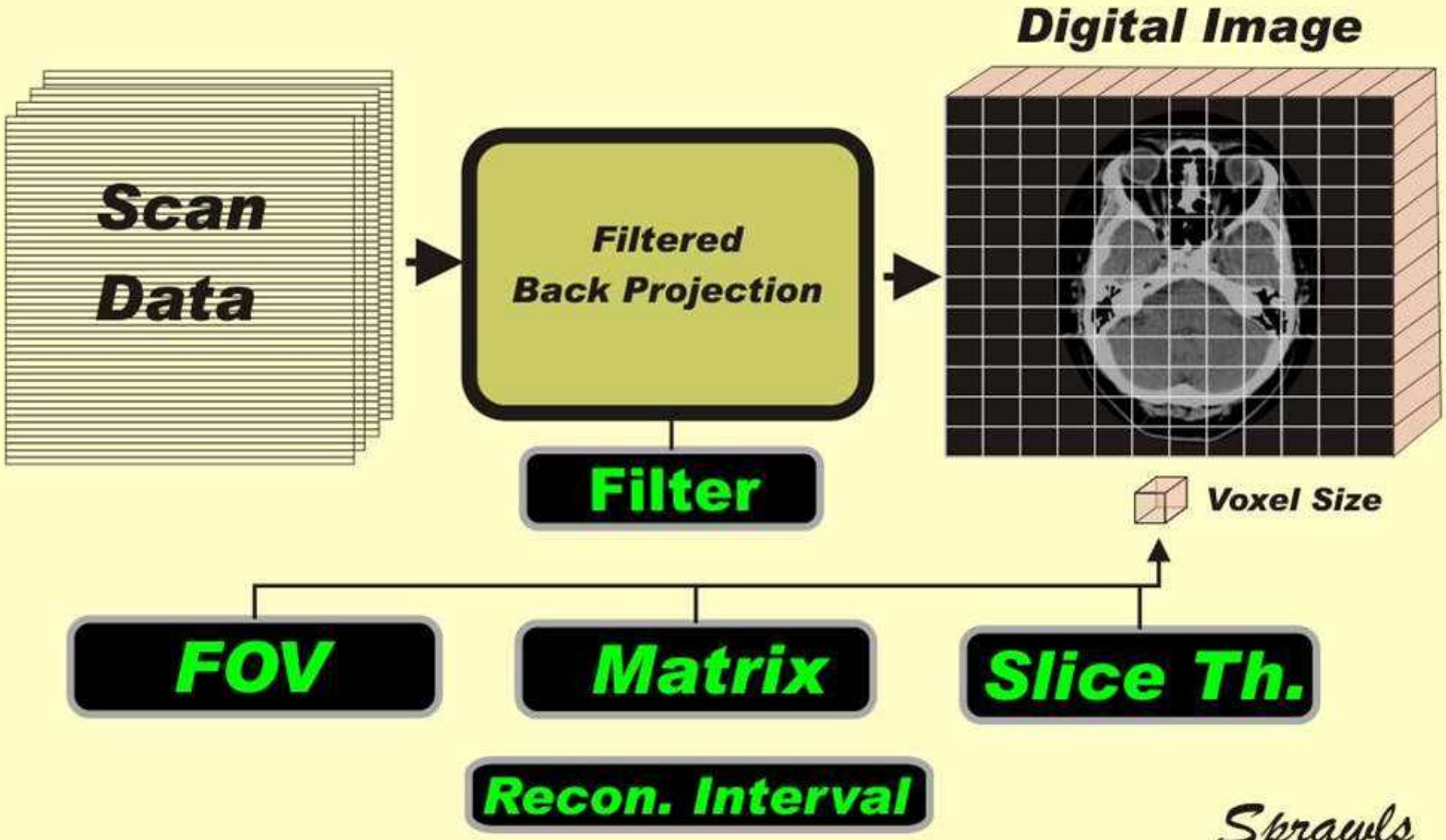
Factors That Determine Radiation Dose to Patient



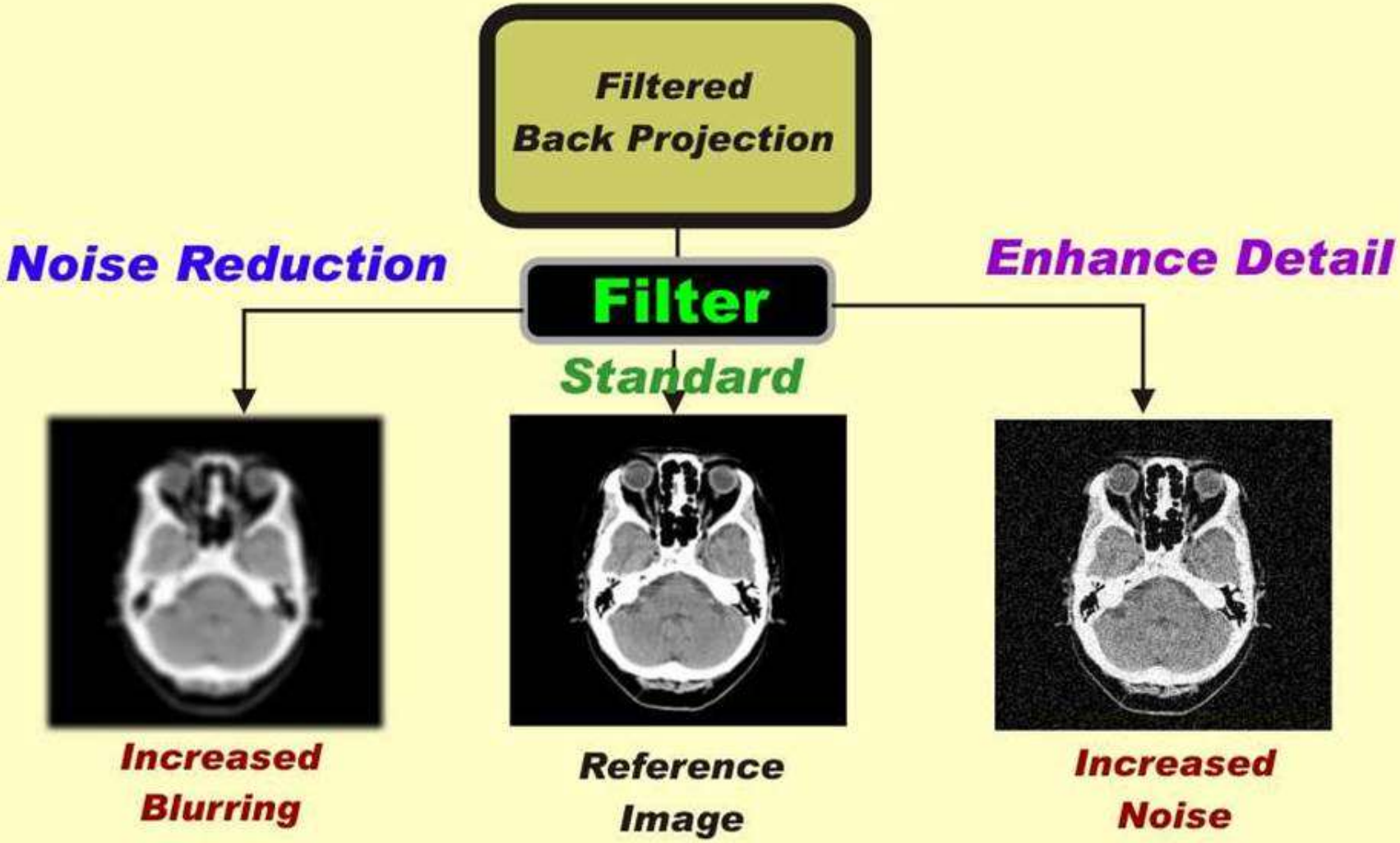
Concentration of Absorbed Photons and Energy at Each Location In the Body Tissue

Sprawls

CT Image Reconstruction



Reconstruction Filter Kernels



(Effects exaggerated for illustration here)

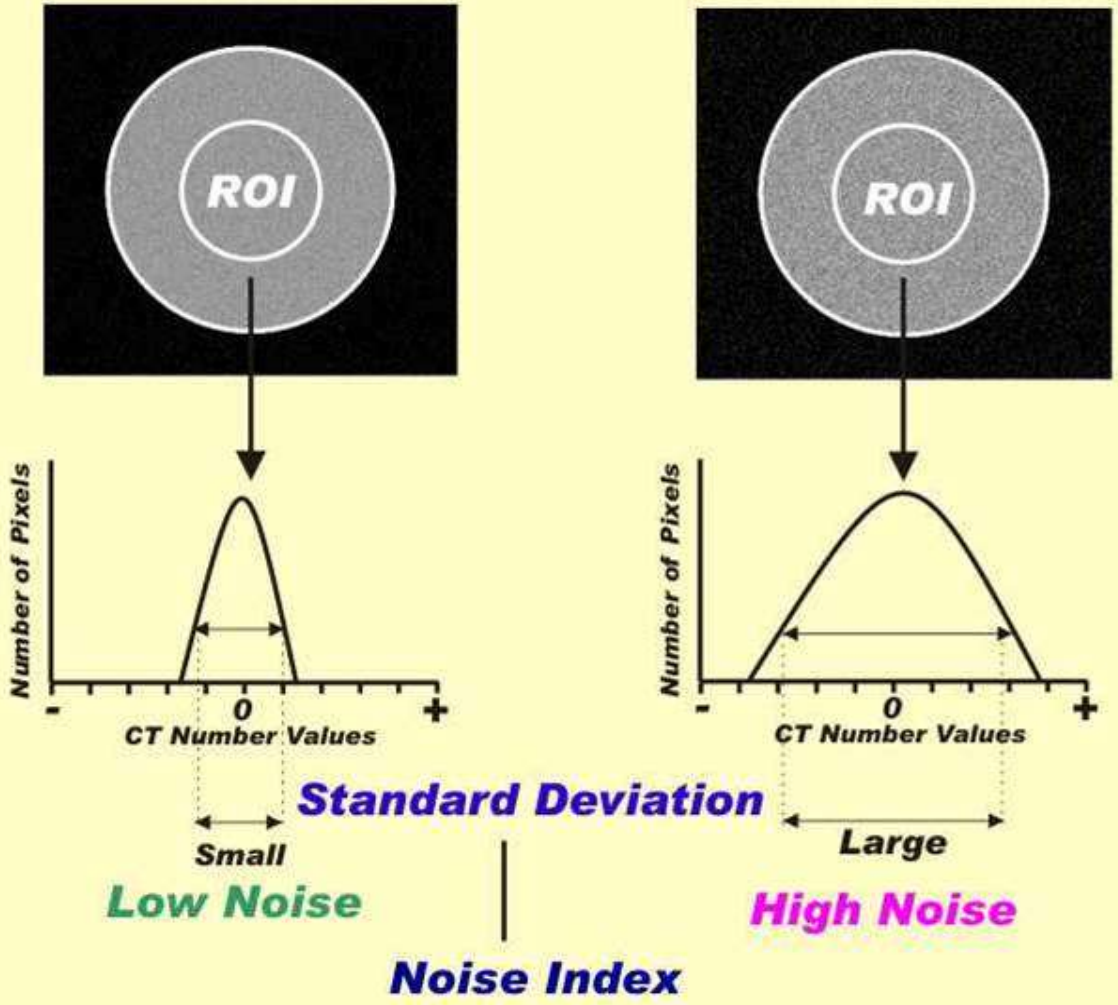
Sprawls

Measuring CT Image Noise

Images of Water

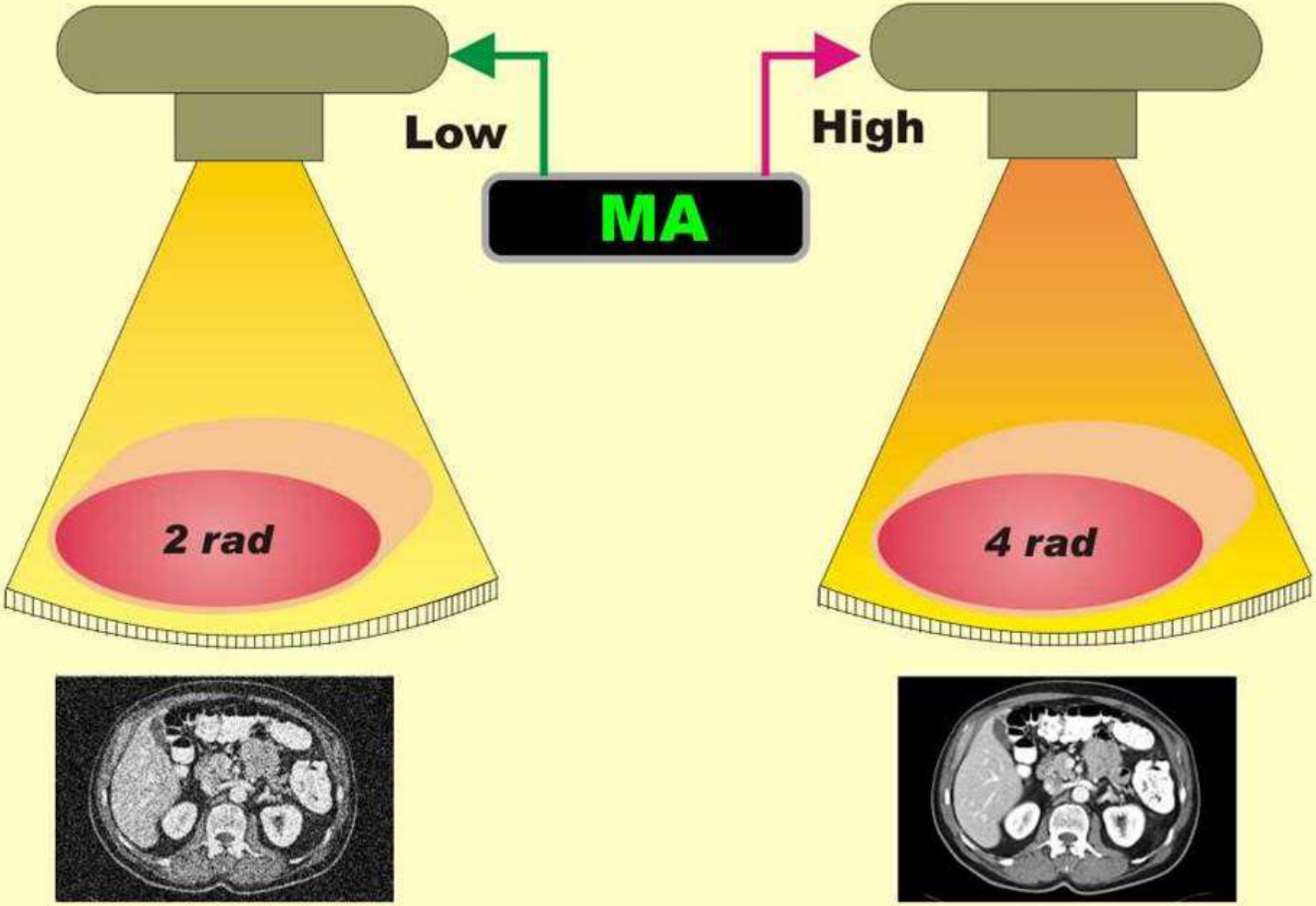
(CT Number = 0)

Distribution of CT Numbers within ROI



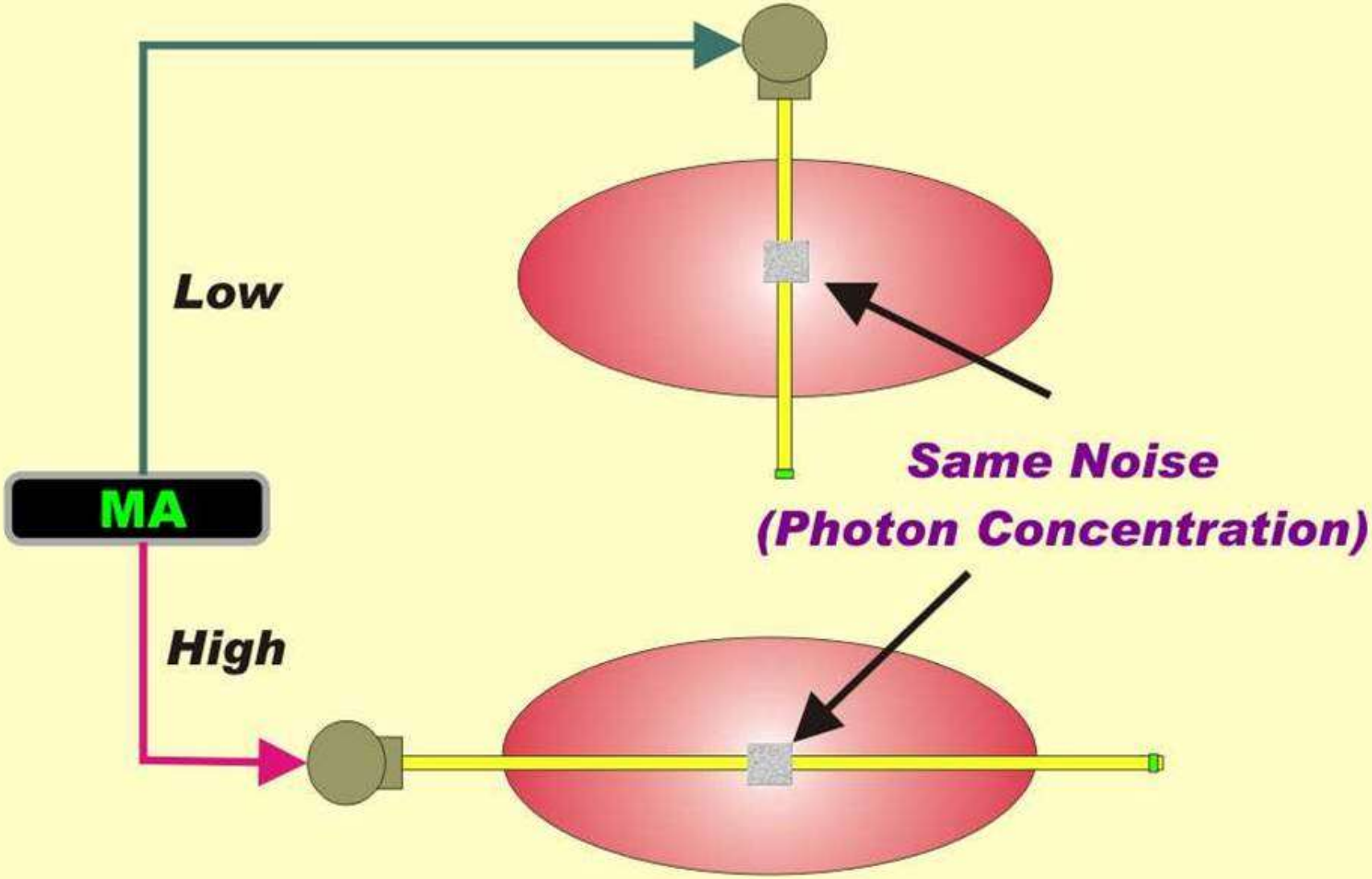
Sprawls

Effect of MA on Dose and Noise



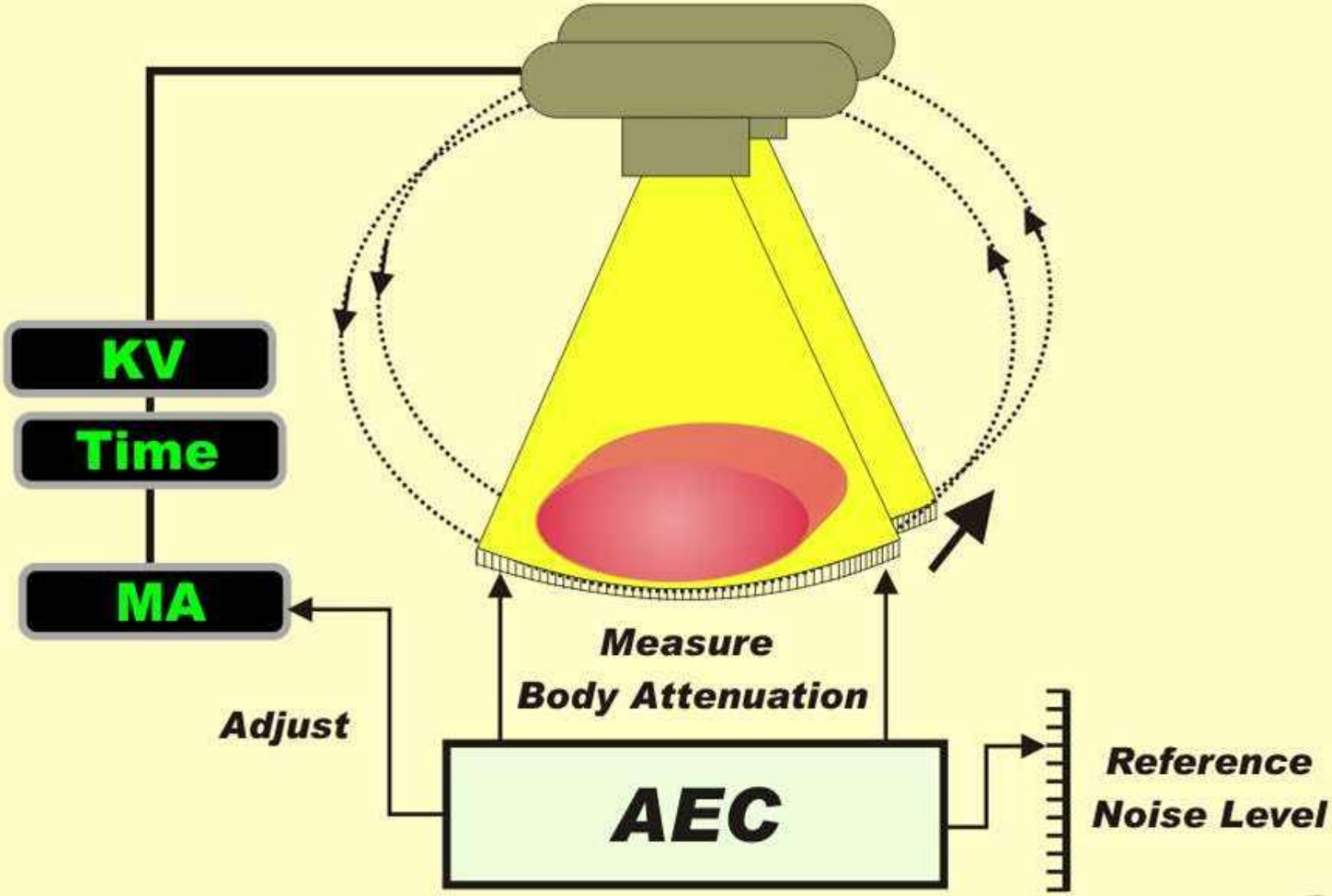
Sprawls

Fit MA to Body Attenuation



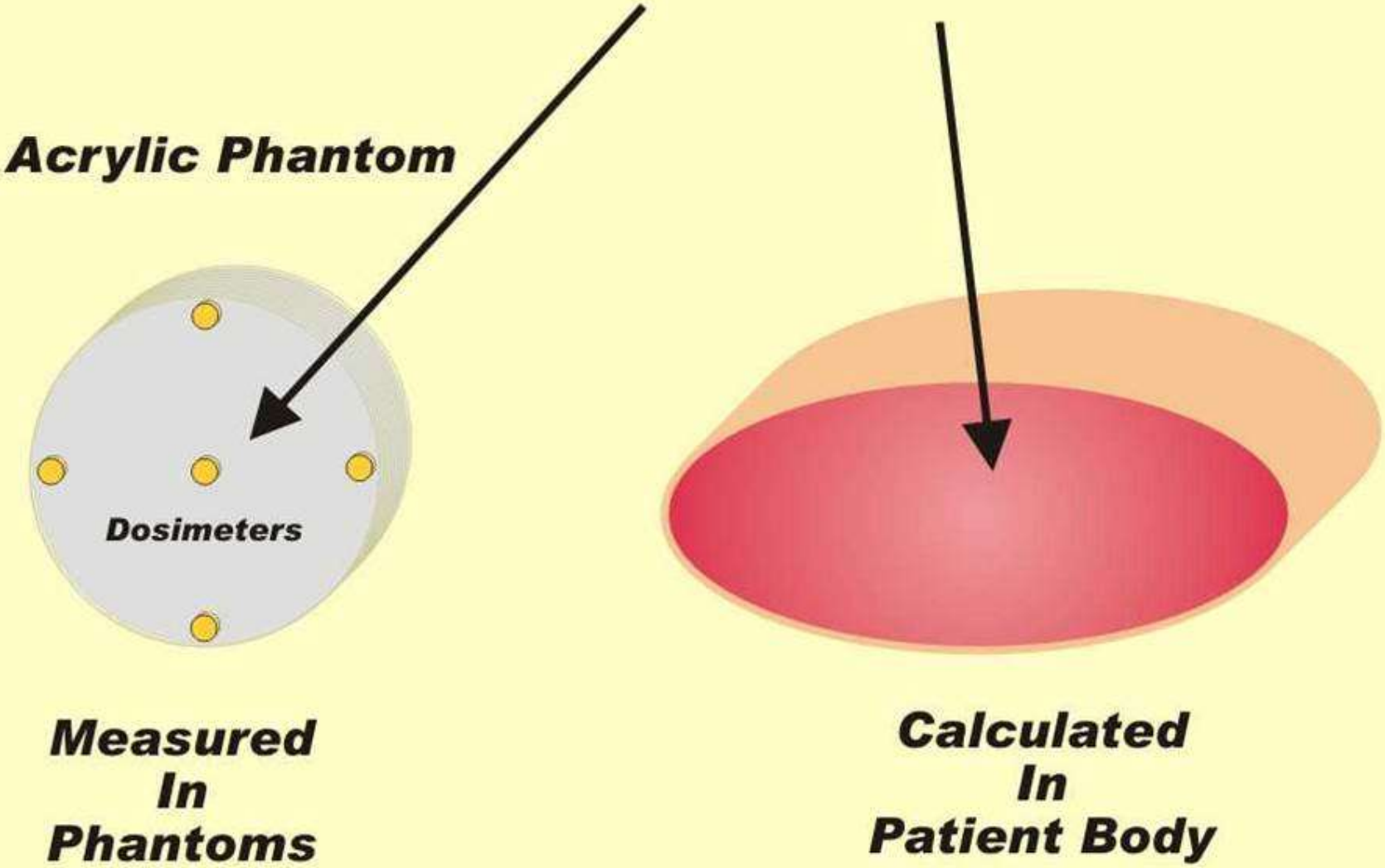
Sprawls

Automatic Exposure Control to Optimize Radiation Dose and Noise



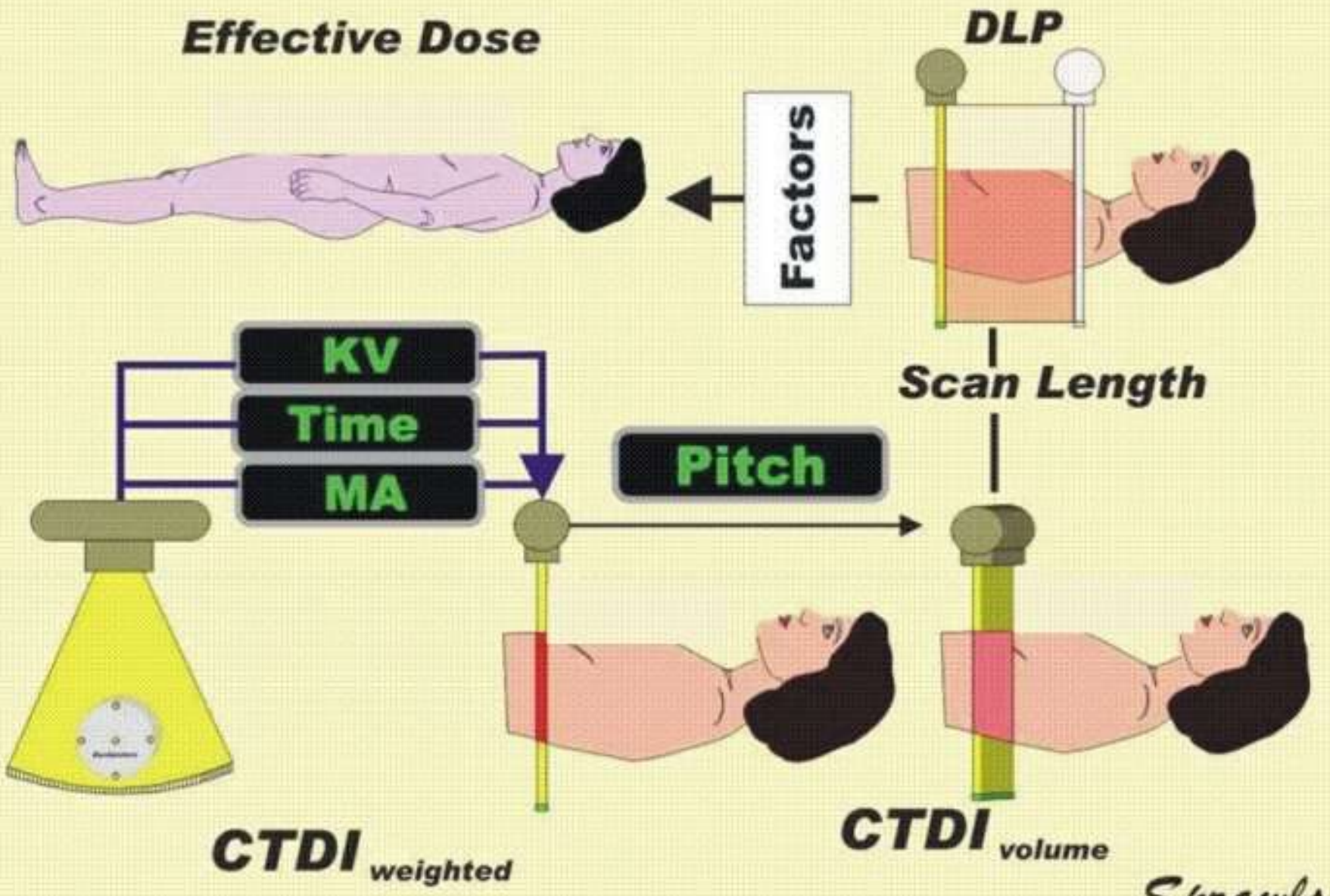
Sprawls

Computed Tomography Dose Index



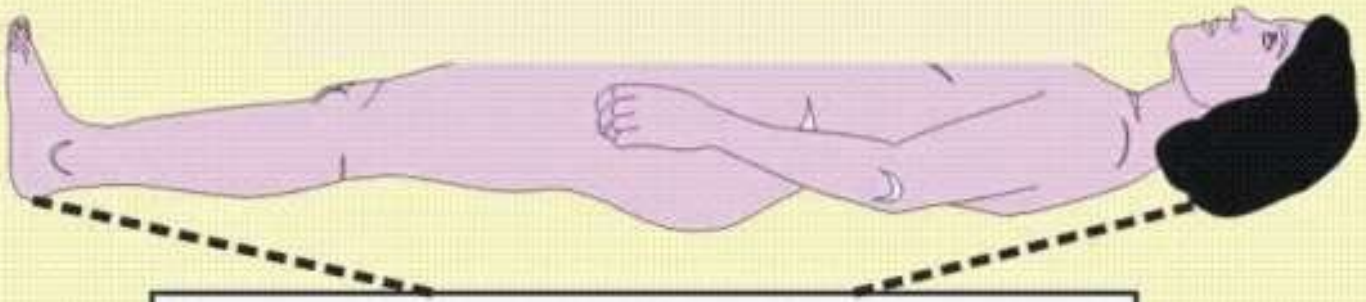
Sprawls

CT Dose Quantities

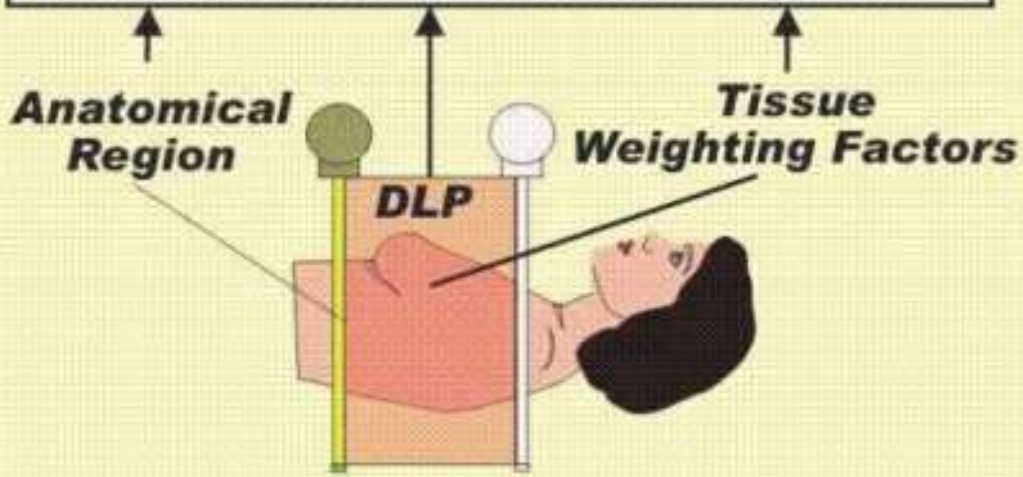


Effective Dose

"Equivalent Whole Body Dose"
used for
Estimation of Risks

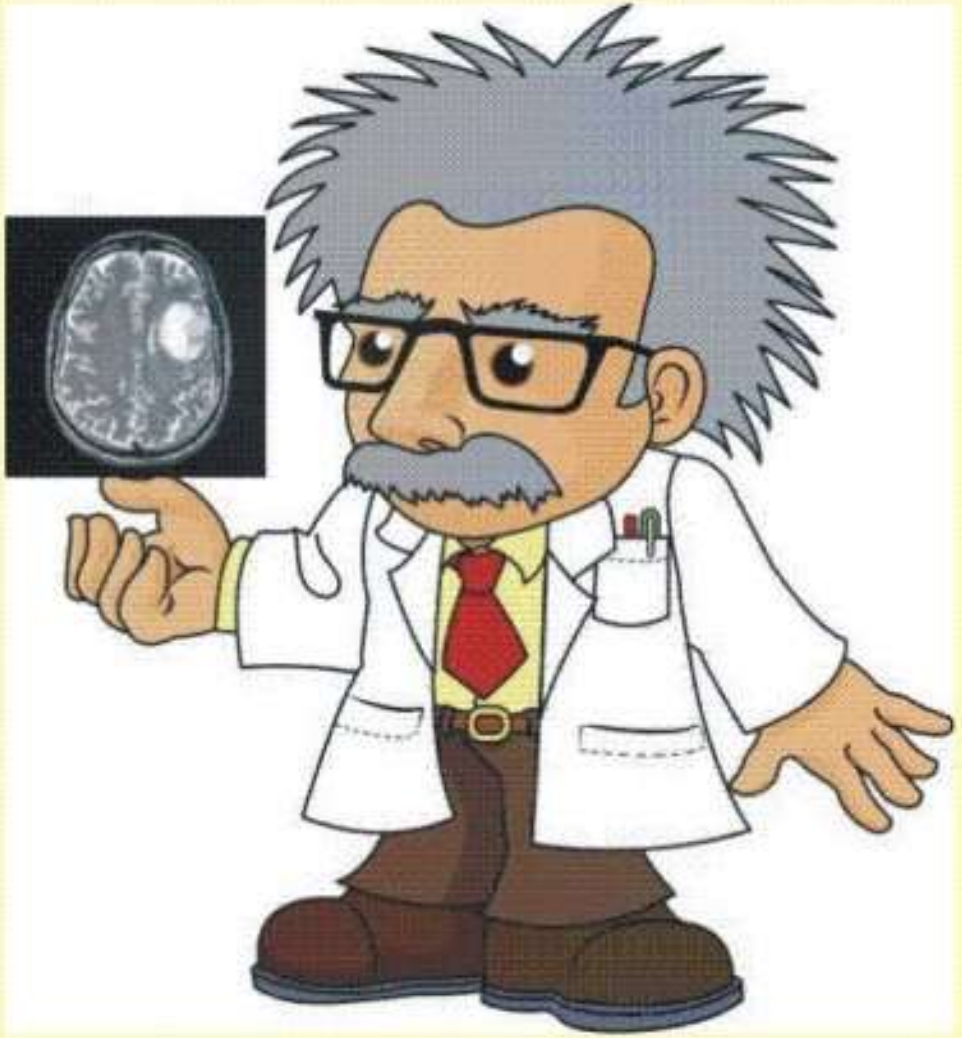


Calculation



Sprawls

Medical Physicists



Provide Solutions

Our Objectives

Today

Thinking Together

Later

Review and Research

This Presentation
Online Modules
Textbooks

On the web at

www.sprawls.org