University of Tripoli
Department of Nuclear Engineering
NE 639

THE PHYSICS OF RADIONUCLIDE IMAGING

Lecture 1

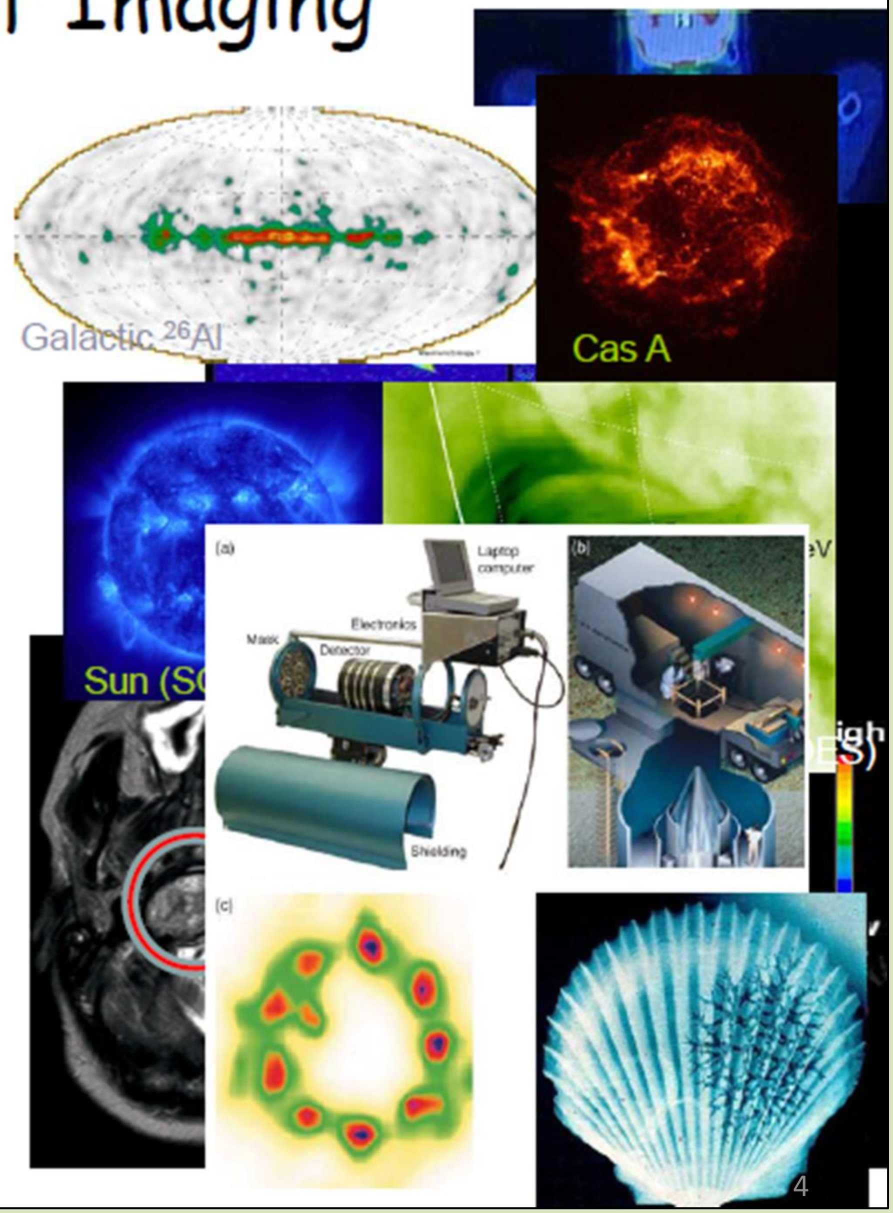
Course Introduction/General Introduction to Medical Imaging

Objective of Imaging

- ✓ Non-invasive way of looking at and into objects.
- ✓ Measure location, shape and extension of objects ("imaging")

Objective of Imaging

- Medical
  - Diagnostics
  - Monitor Therapy
  - Pharmaceutical development
  - Understanding of disease processes
- Biology
- Astrophysics
- Homeland Security
- Non-destructive assessment

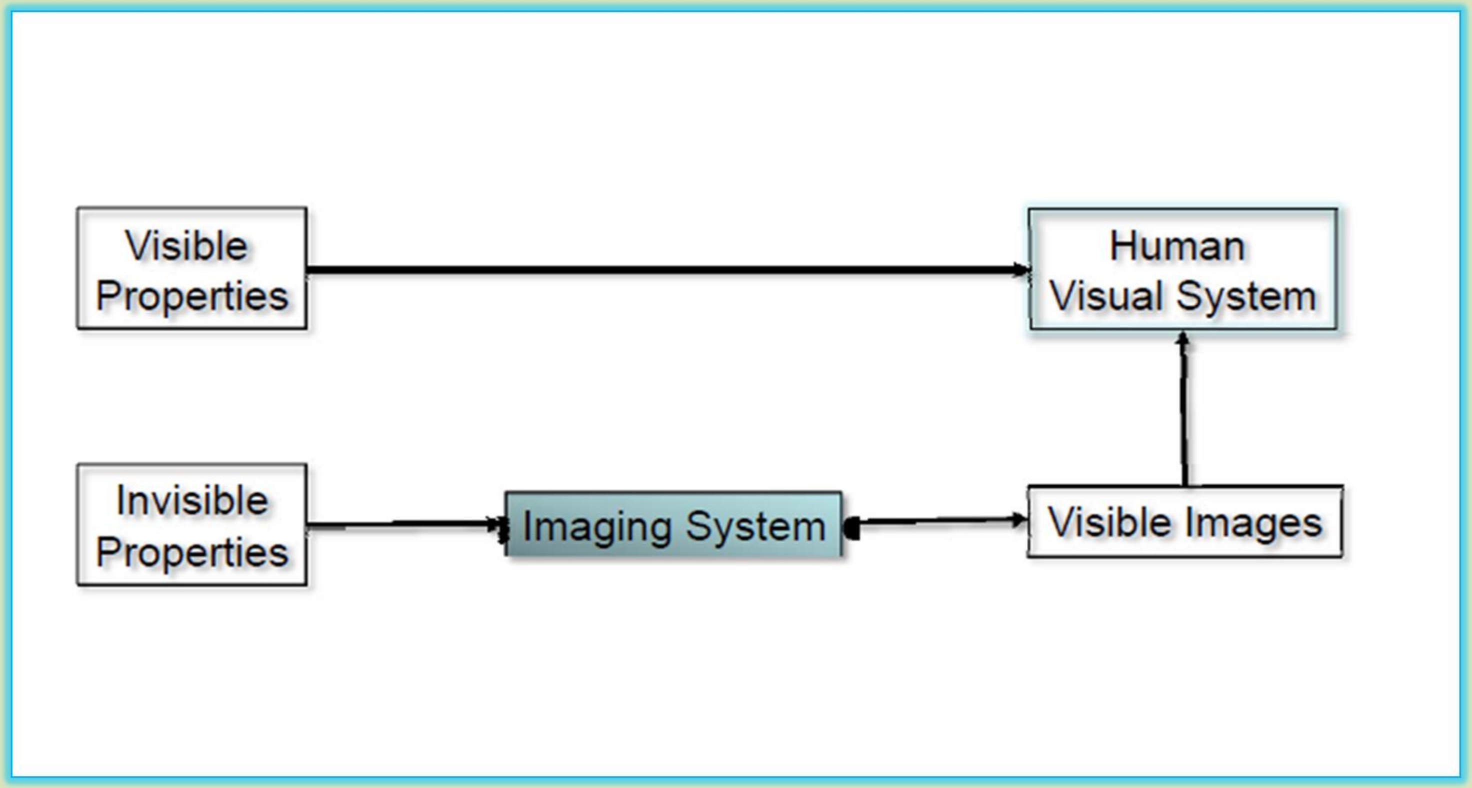


Why so many Imaging Concepts &Modalities?

- Bio-Medical Imaging:

Different modalities are based on different physical interactions of energy with biological tissue thus providing measurements of different physical properties of biological structures

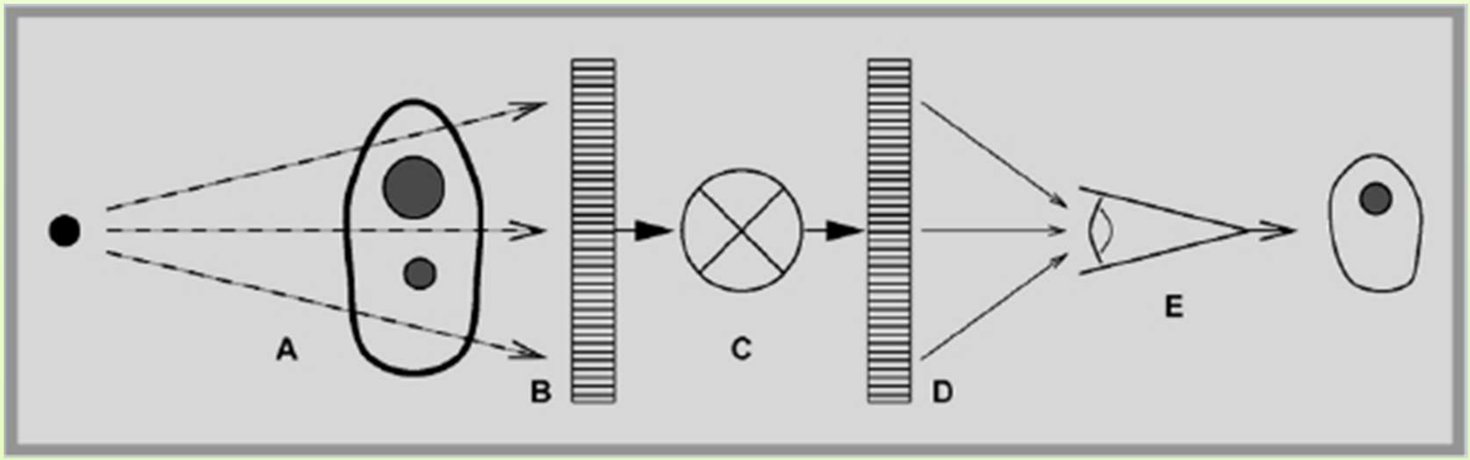
Imaging Systems as Visual Mapping Devices



General Models

Radiographic Imaging: (Transmission Imaging Model)

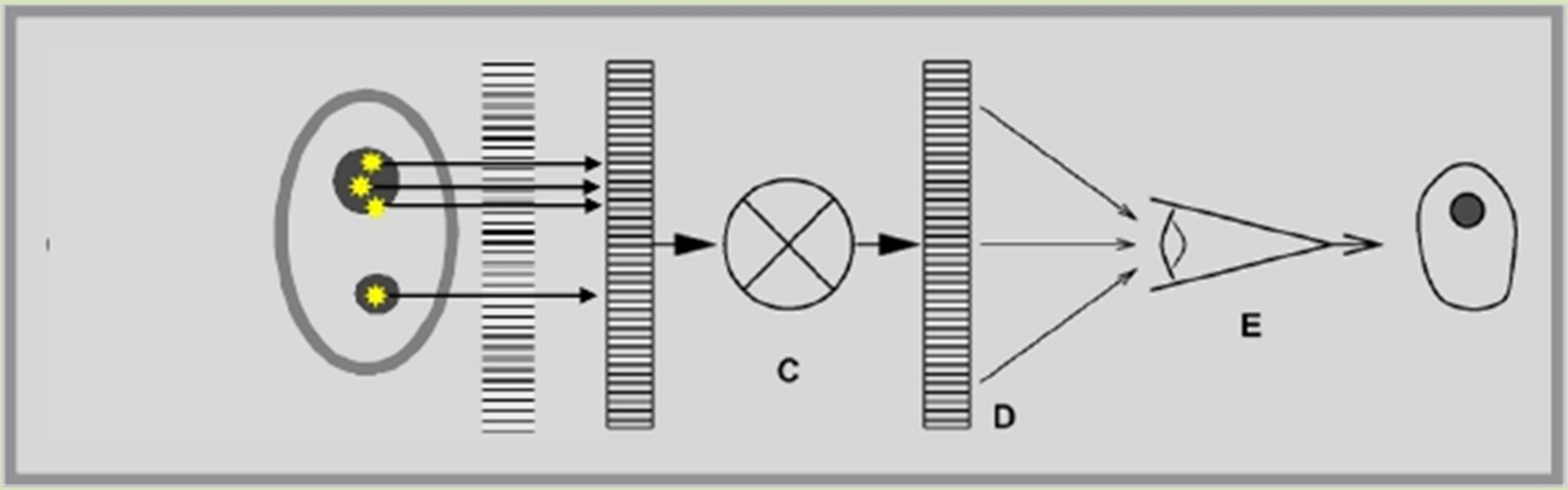
Subject contrast (A) recorded by the detector (B) is transformed (C) to display values presented (D) for the human visual system (E) and interpretation.



Radioisotope Imaging:
The detector records the radioactivity distribution by using a multi-hole collimator.

Radioisotope Imaging: (Emission Imaging)

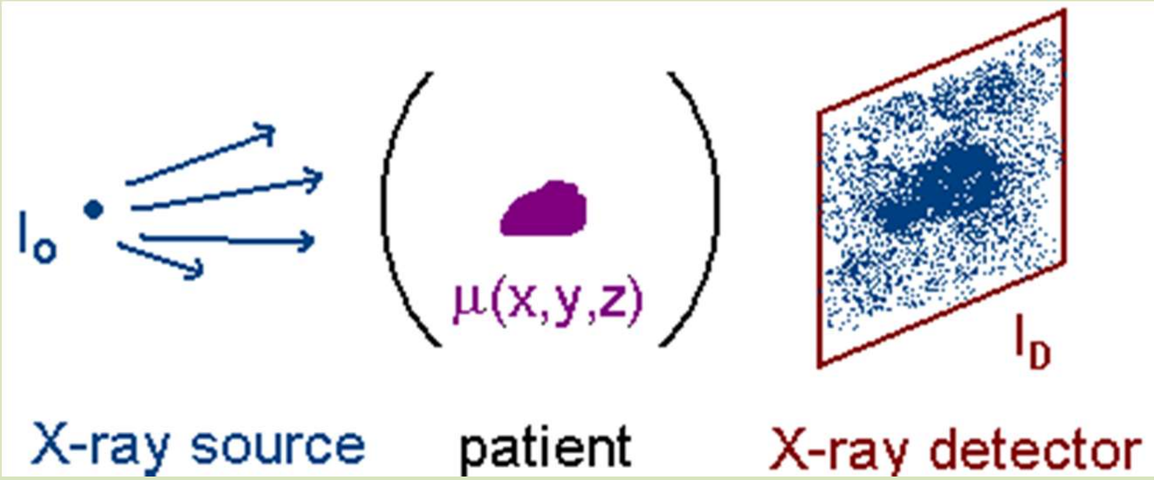
The detector records the radioactivity distribution by using a multi-hole collimator.



Overview on Imaging Modalities

- Radiography
- Mammography
- Computed Tomography
- Nuclear Medicine Planar imaging
- Single Photon Emission Computed Tomography
- Positron Emission Tomography
- Magnetic Resonance Imaging

Transmission imaging



attenuation coefficient

$$\mu(x, y, z) = \mathrm{f}(\text{electron density, } \mathrm{Z})$$

$$\mathrm{I_d} = \mathrm{I_o} e^{-\int \mu(x,y,z)\mathrm{dl}}$$

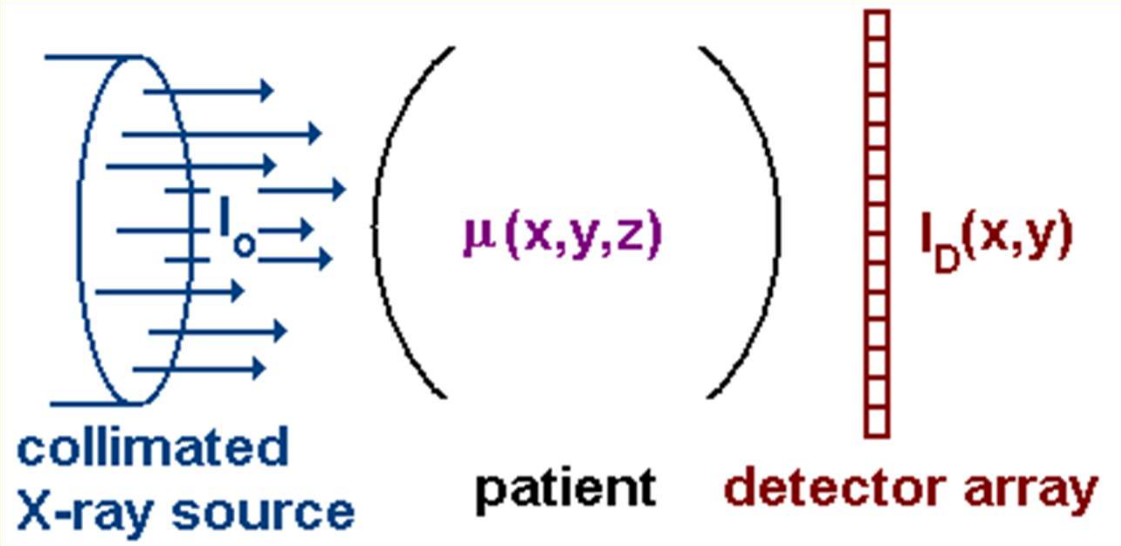
Measures line integrals of attenuation

Film shows intensity as a negative (dark areas, high x-ray detection

<u>Disadvantage</u>: Depth information lost

<u>Advantage</u>: Cheap, simple

Computerized Tomography (CT)



Result: $\mathrm{I_D}(x,y) \propto \mu(x,y)$

1972 Hounsfield announces findings at British Institute of Radiology
1979 Hounsfield, Cormack receive Nobel Prize in Medicine
(CT images computed to actually display attenuation coefficient μ(x,y))

Important Precursors:

1917 Radon: Characterized an image by its projections
1961 Oldendorf: Rotated patient instead of gantry

Radiography

- 1st medical imaging technology; Made possible by "discovery" of X-rays by Wilhelm Roentgen November 8, 1895.
- Roentgen made first radiographic images of human anatomy.
- Defined the field of radiology.

- Object-specific attenuation (or transmission) leads to measurable image contrast
- Requires external X-ray source, producing homogeneous distribution
- Detectors to measure heterogeneous distribution behind object that can be photographic film (screen-film radiography) or electronic detector system (i.e. digital radiography).

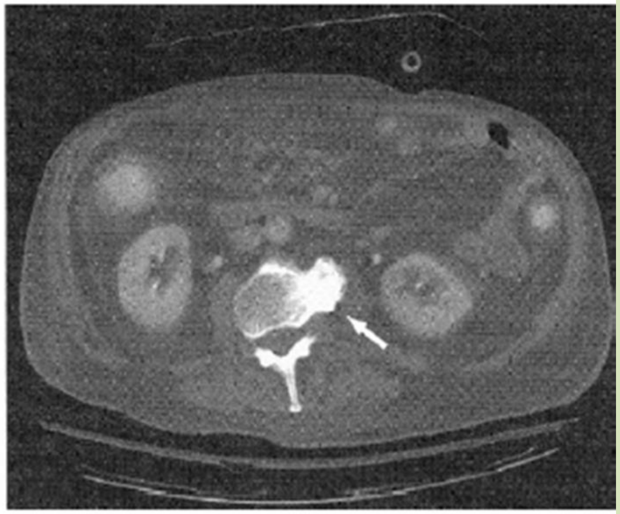
- Radiographic images are useful for a wide range of indications, including the diagnosis of broken bones, lung cancer, cardiovascular disorders, etc.

Mammography

- Radiography of the breast (therefore transmission projection imaging)
- Mainly soft tissue therefore low X-ray energies
- Specifically designed X-ray systems (Source, detector, arrangement)
- Used to screen asymptomatic women for breast cancer (screening mammography) and in case of symptoms such as lumps (diagnostic mammography)

Computed Tomography (CT)

- Tomography:(Tomo=slice/section; Graph=picture/presentation)
- Used in many technical and scientific areas
- Computed tomography implies X-ray transmission computed tomography
- Many 2D radiographs taken from large number of angles enable synthesized 3D images
- Developed in the 60's, available clinically in the 70's due to advances in computer processing power
- The advantage of a tomographic over a projection image is its ability to display the anatomy in a slice of tissue without over- or underlying structures.



(Ruptured disk adjacent to vertebral column

Nuclear Medicine Imaging - I.

Emission imaging

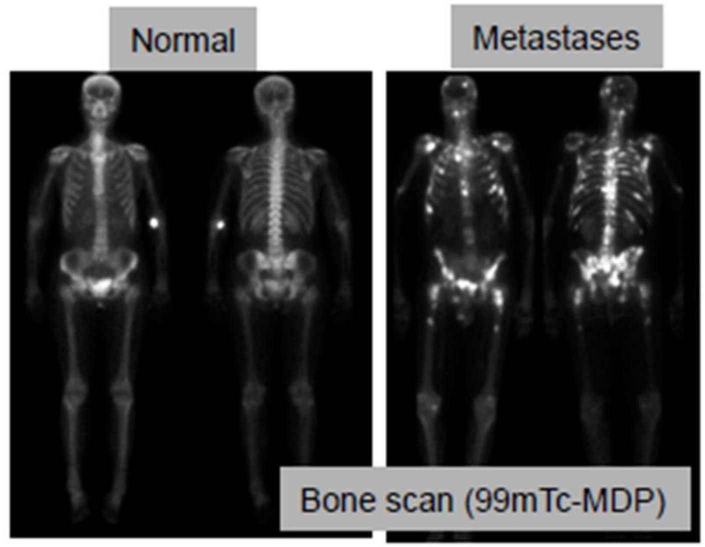
- In contrast to transmission imaging, emission imaging relies on the emission of specific (radioactive) tracers that are given to a patient.
- Enables functional imaging rather than anatomical imaging

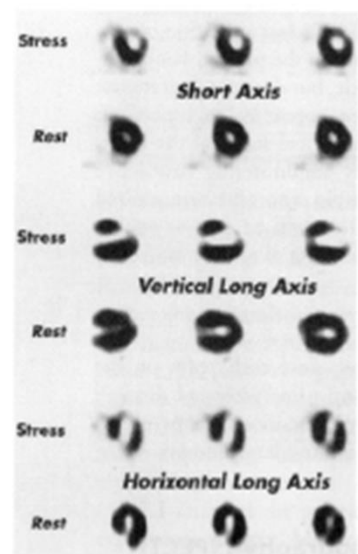
Planar imaging

- 2D projection of radioactivity distribution

Single-Photon Emission Computed Tomography (SPECT)

- Tomographic counterpart of planar imaging (as radiography and CT)
- Same radioactive isotopes and labels are being used as in planar imaging



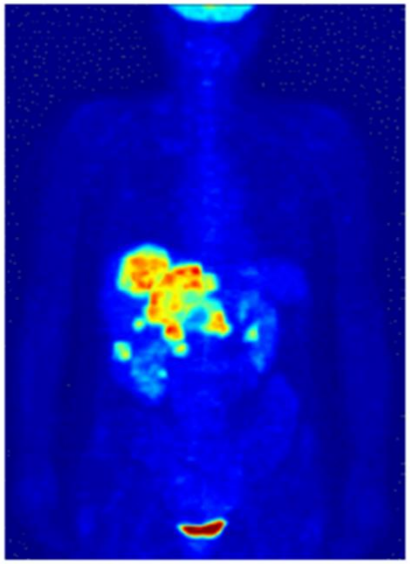


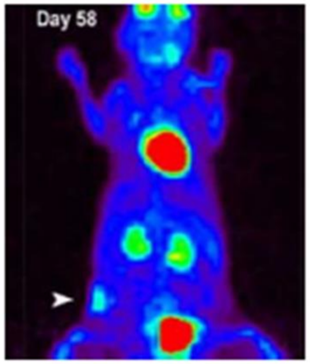
Myocardial perfusion stress test utilizing 201Tl

Nuclear Medicine Imaging - II.

- Positron Emission Tomography (PET)
  - Radioisotopes that decay by β^+ decay (such as ^{18}F or ^{15}O) emit a positron that annihilates with 2 characteristic 511 keV photons emitted in (almost) opposite directions.
  - Currently provides higher sensitivity (efficiency and resolution) than SPECT
  - Many emitters are physiologically relevant (C, O, F (substitute for hydroxyl)) and can be incorporated in many biochemicals
  - Most important radiopharmaceutical is ^{18}FDG (Fluorodeoxyglucose) which is concentrated in tissues of high glucose metabolism such as primary tumors and their metastases.
  - Very high sensitivity to sub-picomolar concentrations

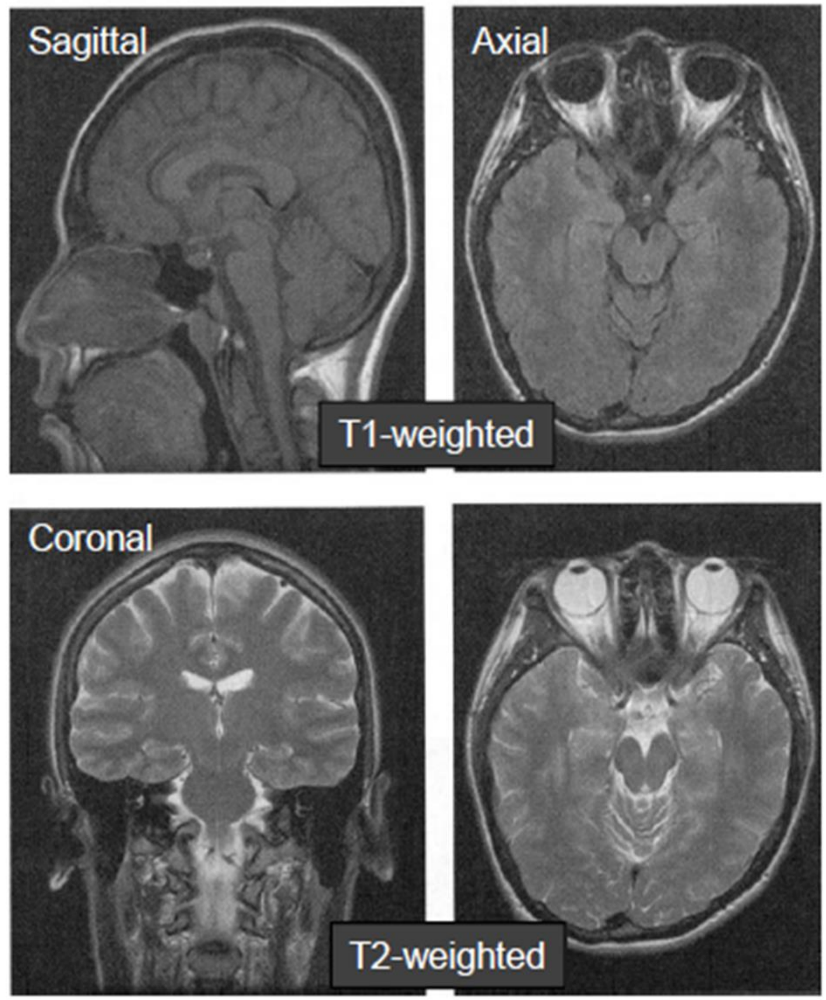
Malignant Melanoma. 18F deoxyglucose makes extensive metastastic disease visible.





Magnetic Resonance Imaging

- MRI relies on nuclear magnetic resonance properties of the proton (mainly) using strong magnetic fields
- The proton has a magnetic moment and when placed in a strong magnetic field (e.g. 1.5 T) the proton will absorb radio and wave energy at the resonance frequency of 63 MHz
- The re-emission time or relaxation time depends on magnetic properties of close environment.
- By slightly changing the magnetic field strength in patient, the resonance frequency changes and magnetic properties can be determined position-dependently enabling 3D imaging (and tomography)
- Due to different magnetic properties of tissue such as fat, white and gray matter in the brain, cancer, etc., high sensitivity to anatomical variations.



Sensitivity

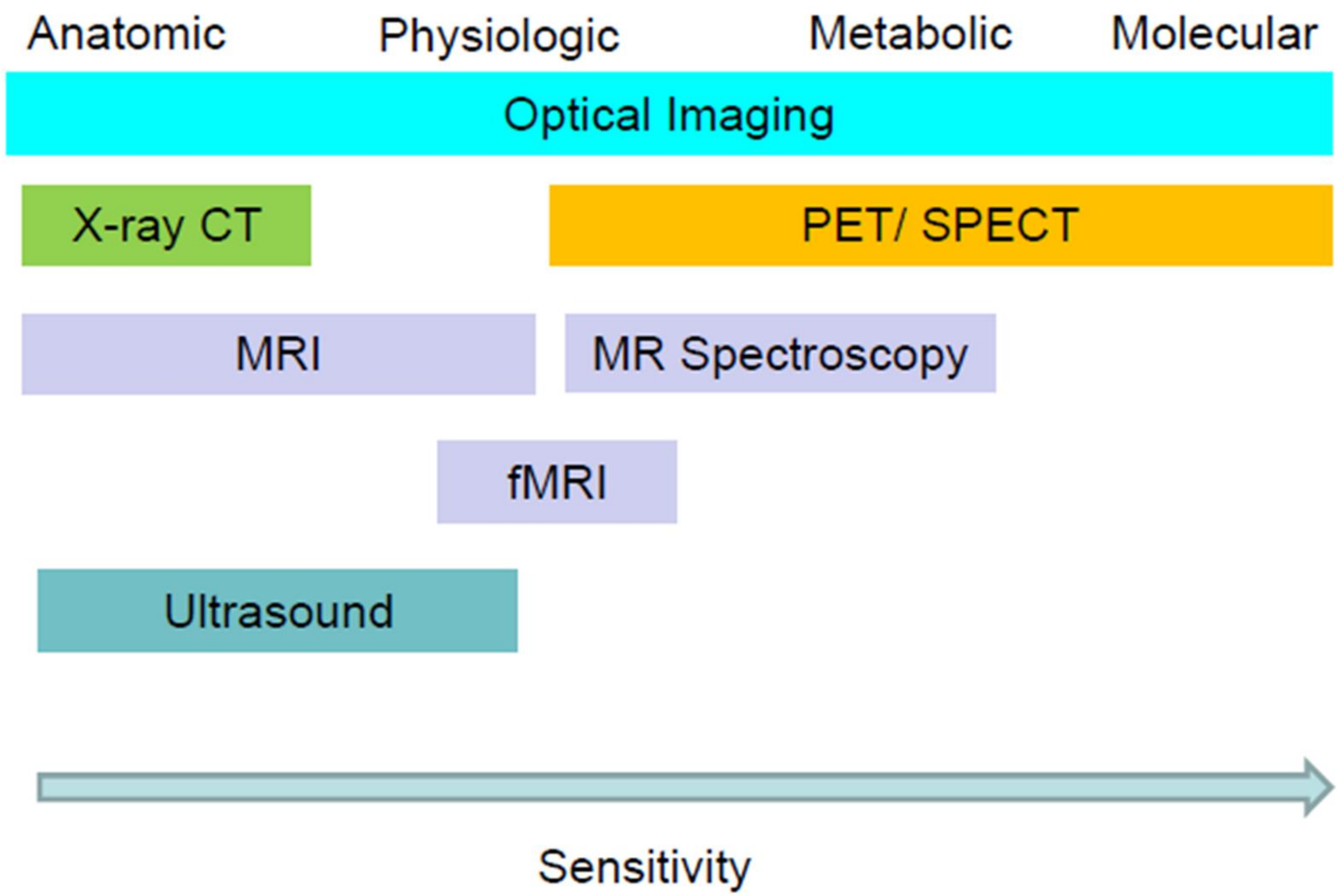


Image Properties

Contrast

- Difference in gray scale of the image
- X-ray:
  - Difference in X-ray attenuation in tissue
- Nuclear Medicine:
  - Difference in tracer concentration (depending on specificity/ uptake of radiopharmaceutical)
- MRI:
  - Difference in proton density and relaxation time (decay time of excited configuration)

Resolution

- Smallest object that a system can resolve

Limiting Spatial Resolution

Modality	Δ (mm)	Comments
Screen film radiography	0.08	Limited by focal spot and detector resolution
Digital radiography	0.17	Limited by size of detector elements
Fluoroscopy	0.125	Limited by detector and focal spot
Screen film mammography	0.03	Highest resolution modality in radiology
Digital mammography	0.05–0.10	Limited by size of detector elements
Computed tomography	0.4	About ½-mm pixels
Nuclear medicine planar imaging	7	Spatial resolution degrades substantially with distance from detector
Single photon emission computed tomography	7	Spatial resolution worst toward the center of cross-sectional image slice
Positron emission tomography	5	Better spatial resolution than with the other nuclear imaging modalities
Magnetic resonance imaging	1.0	Resolution can improve at higher magnetic fields
Ultrasound imaging (5 MHz)	0.3	Limited by wavelength of sound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