

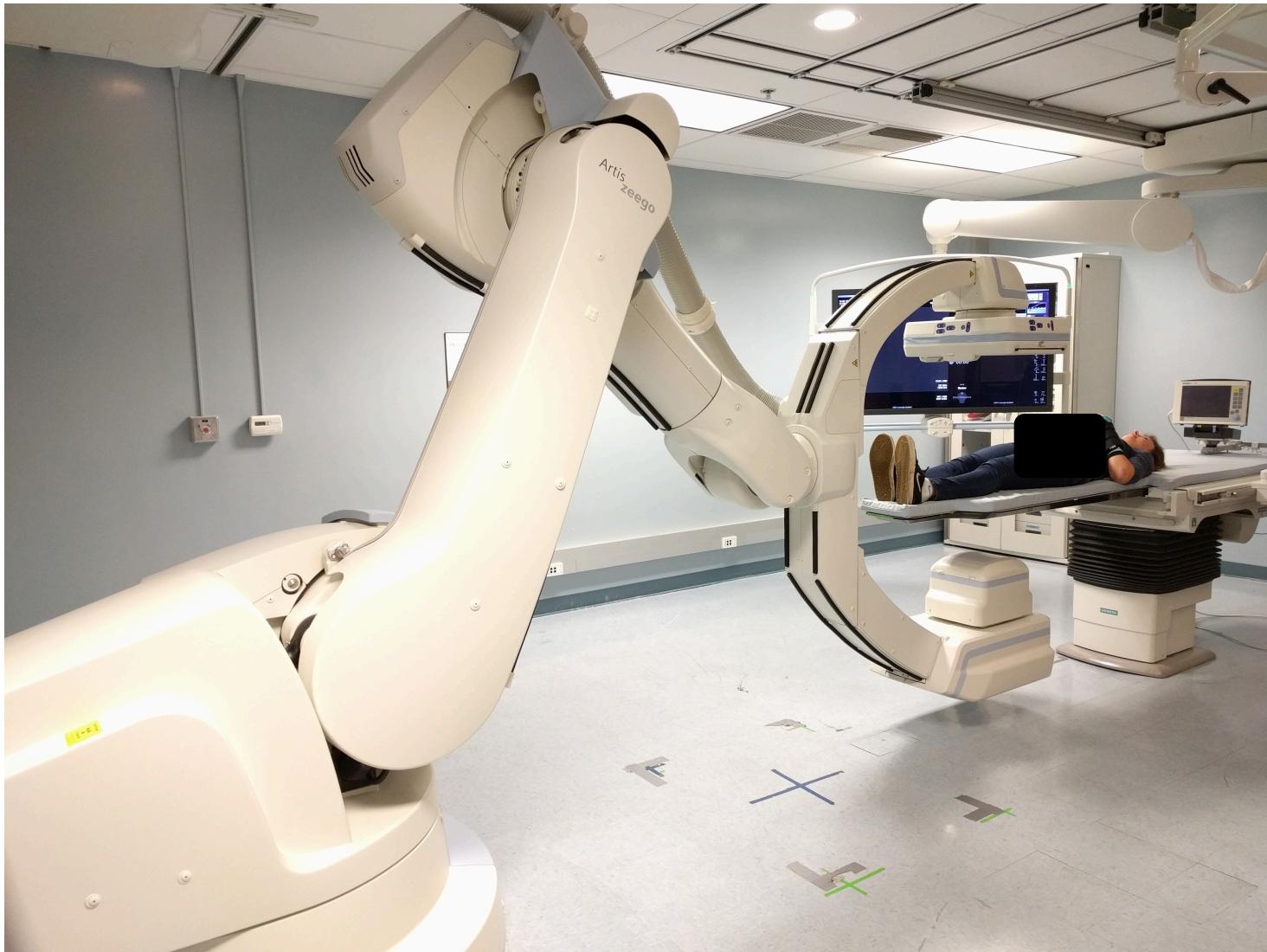
# Introduction to X-ray-based Imaging

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# Acknowledgments

- Stanford
  - Kerstin Müller
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  - Siemens Healthcare GmbH

# Zeego Lab – S088



Cone-Beam Computed Tomography (CBCT)  
C-arm Computed Tomography (C-arm CT)

# Machine and Images

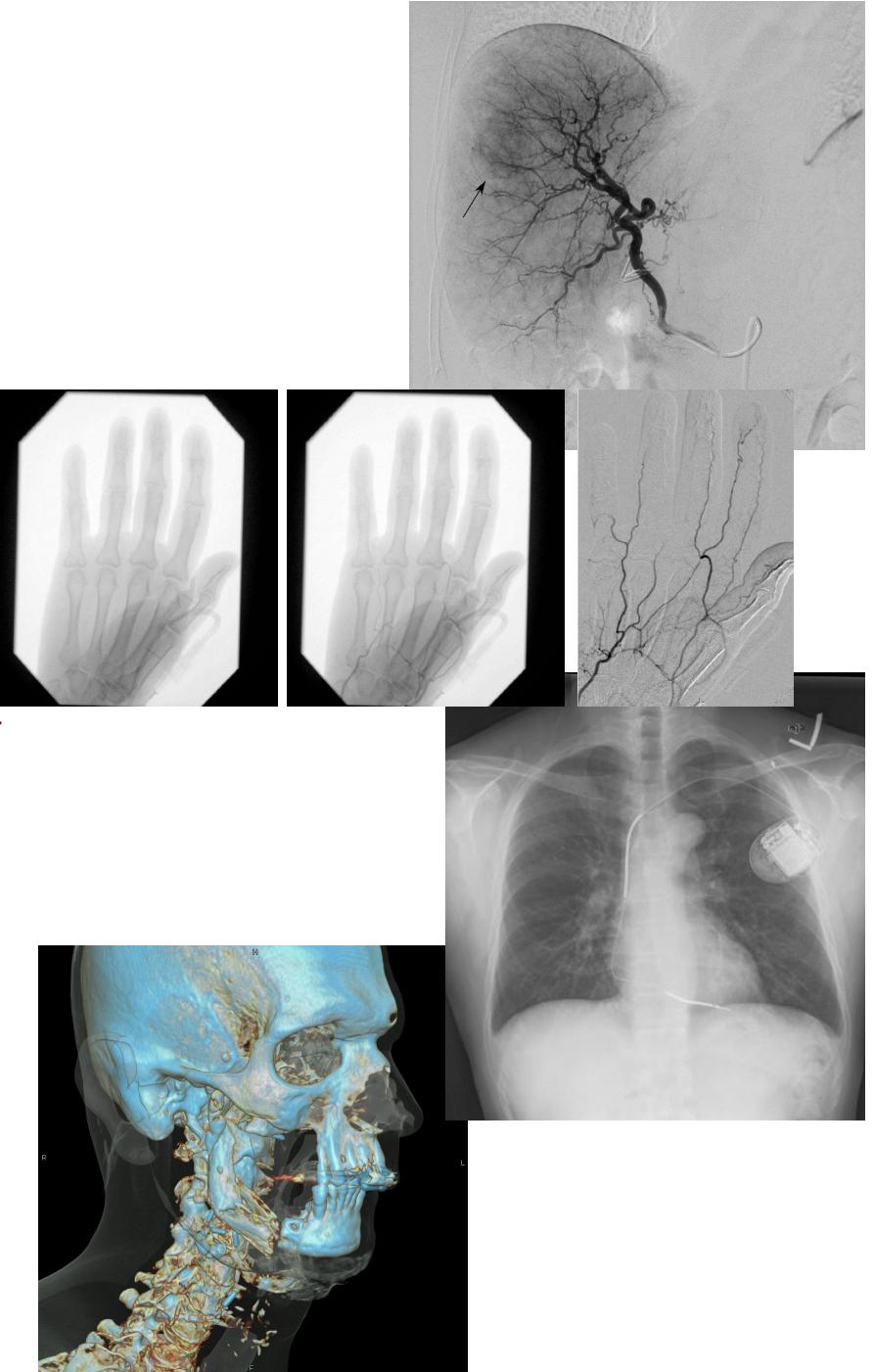
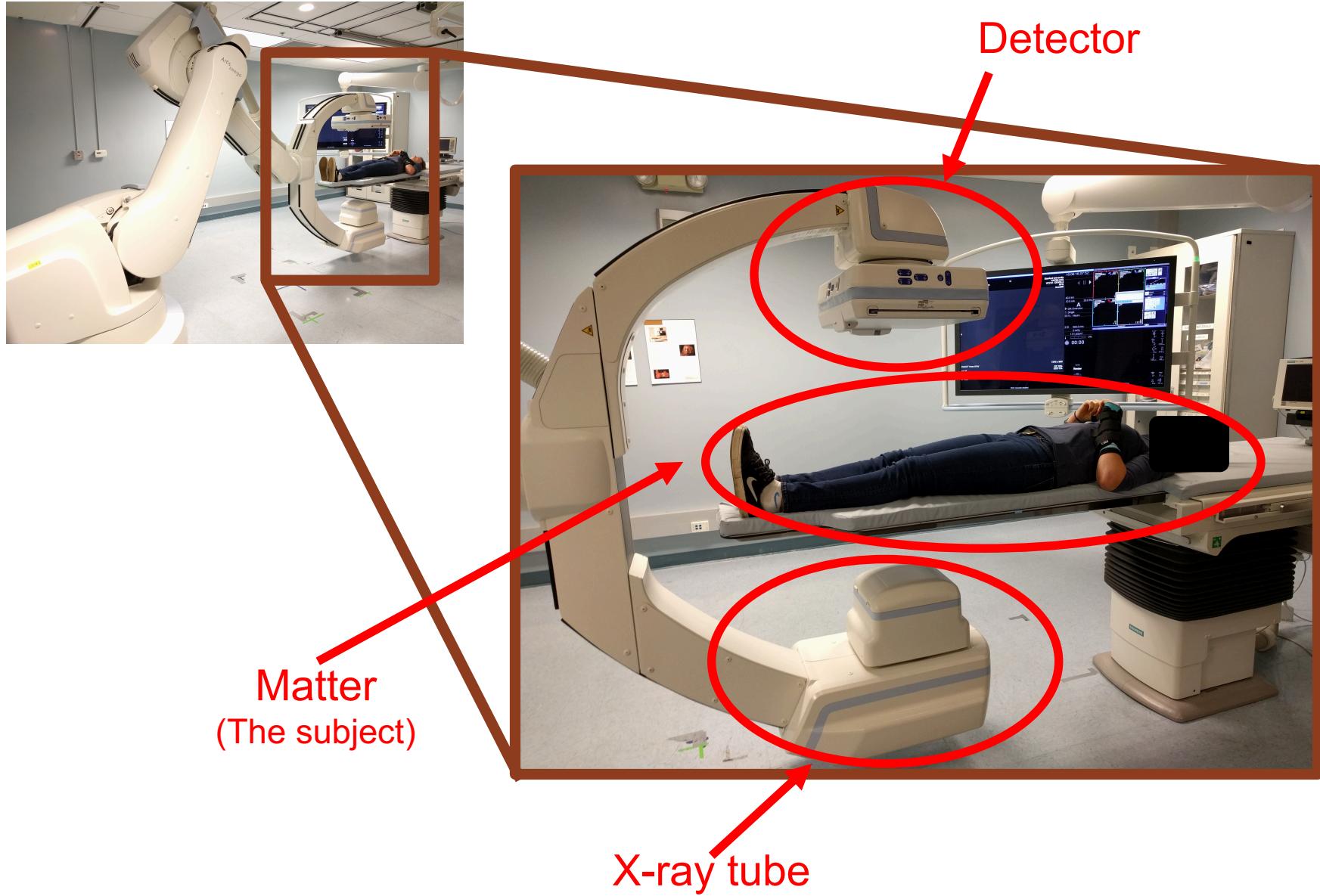


Image source: Siemens Healthcare, Erlangen, Germany and N. Kothary

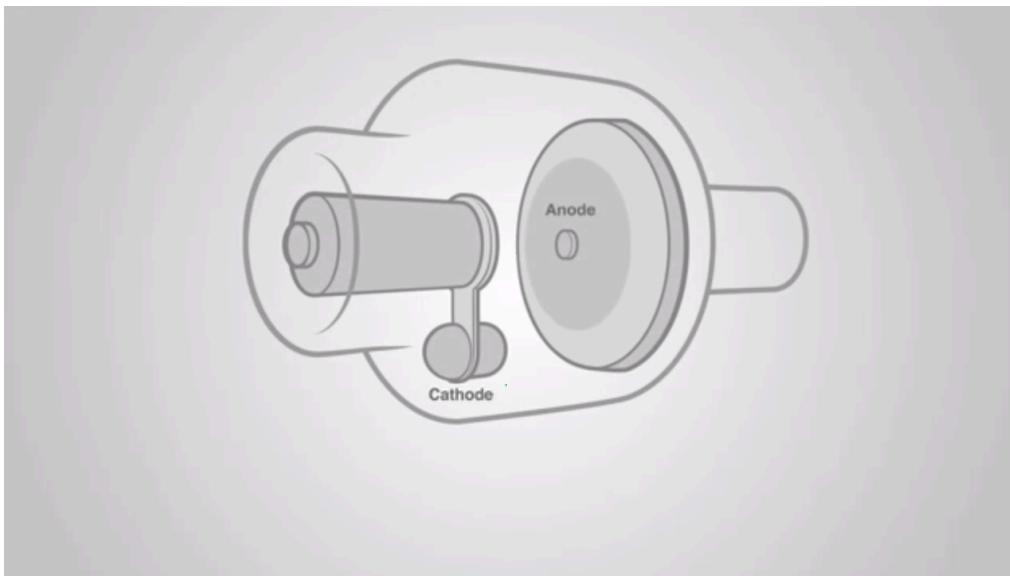
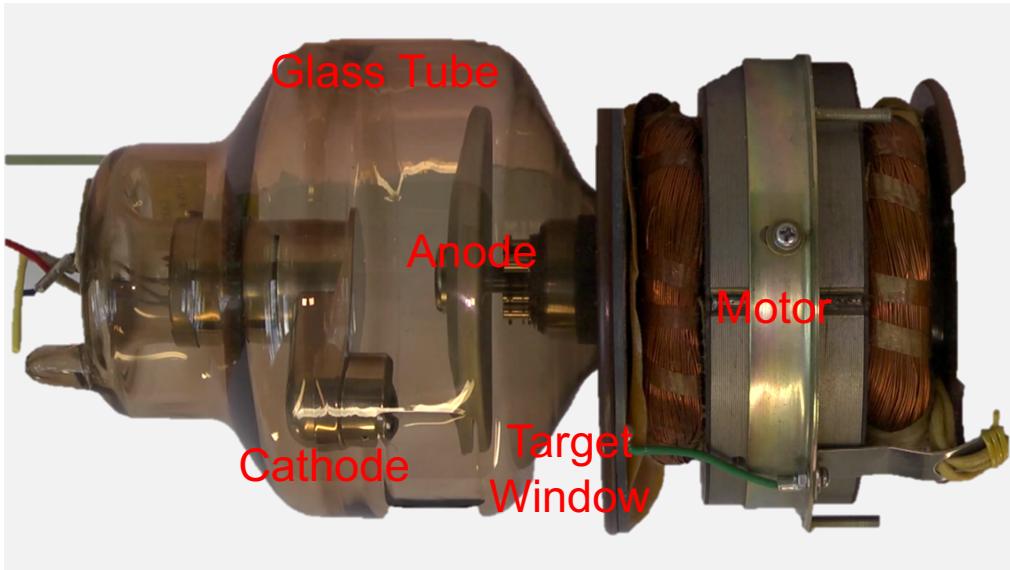
# The imaging system: X-ray Tube, Detector and Subject





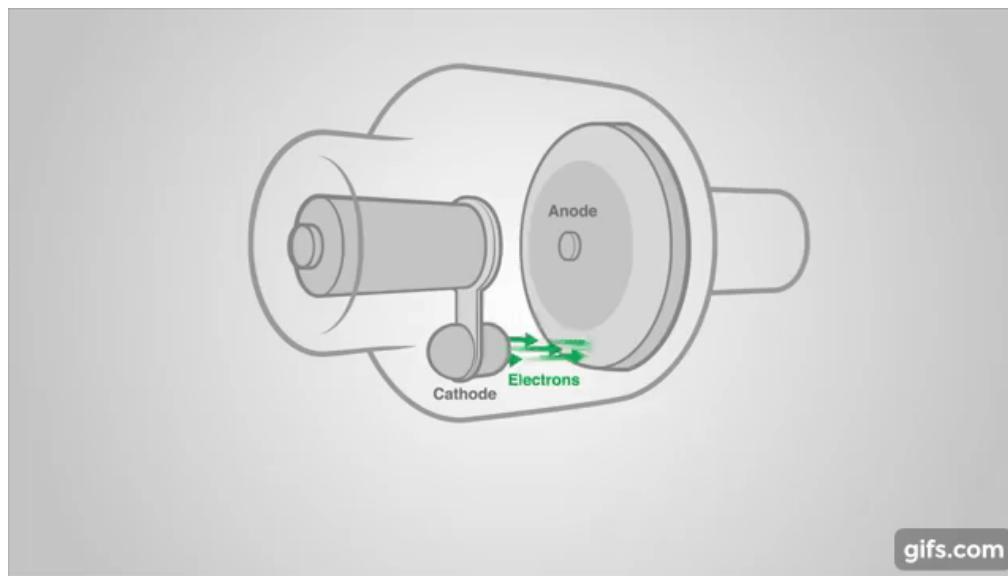
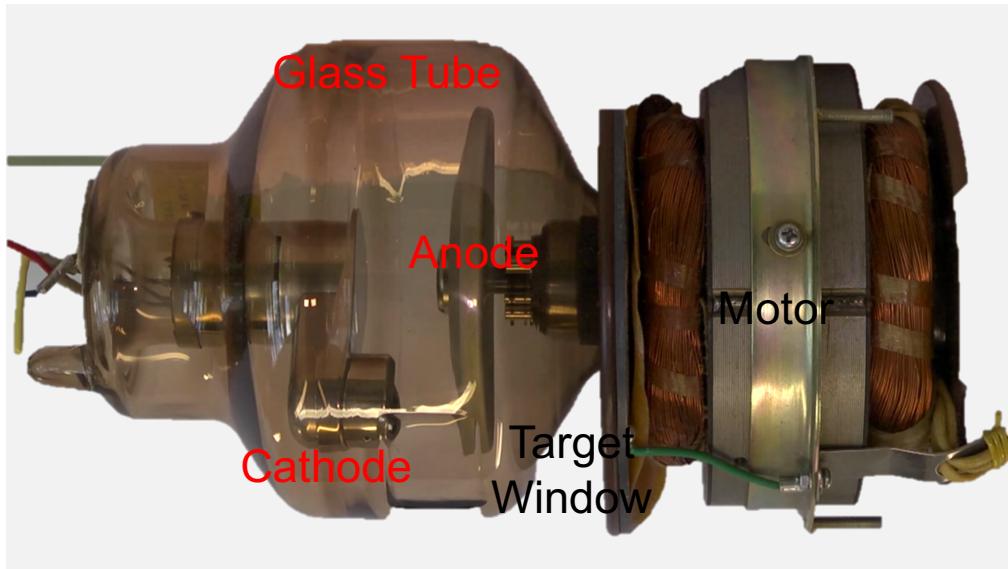
# The X-ray Tube

# X-ray Tube



[https://www.youtube.com/watch?v=3\\_bZCA7tlFQ](https://www.youtube.com/watch?v=3_bZCA7tlFQ)

# X-ray Tube

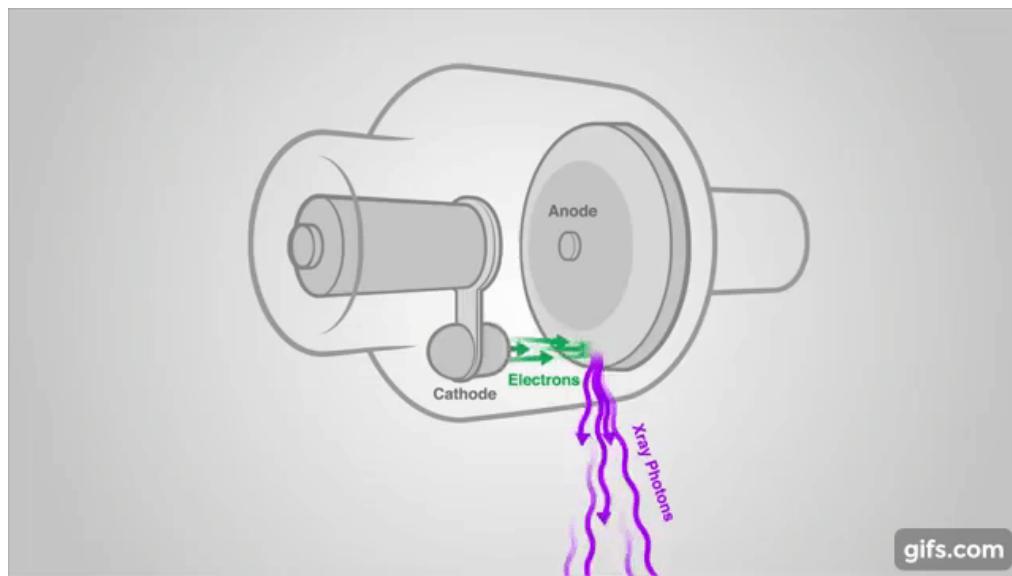
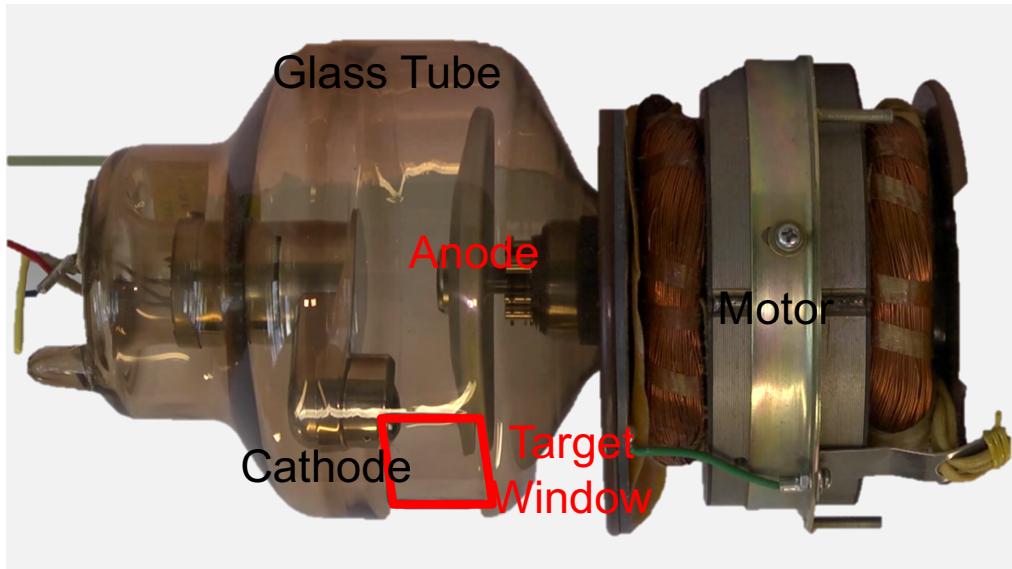


- Accelerating voltage:
  - 20-150 kVp
- Electron current:
  - 0.1-1.0A
- Vacuum in glass tube to avoid collision with air particles

gifs.com

[https://www.youtube.com/watch?v=3\\_bZCA7tlFQ](https://www.youtube.com/watch?v=3_bZCA7tlFQ)

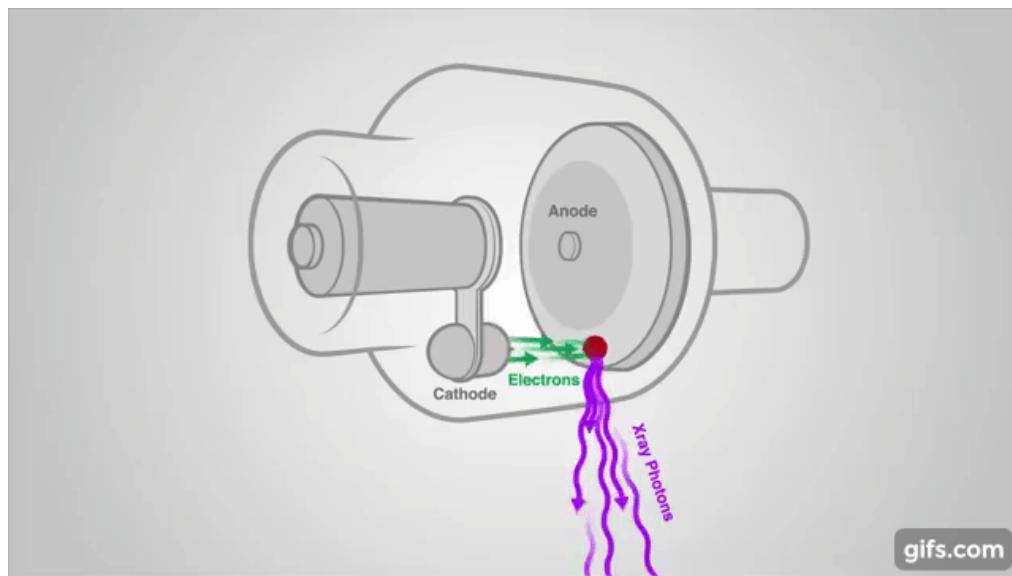
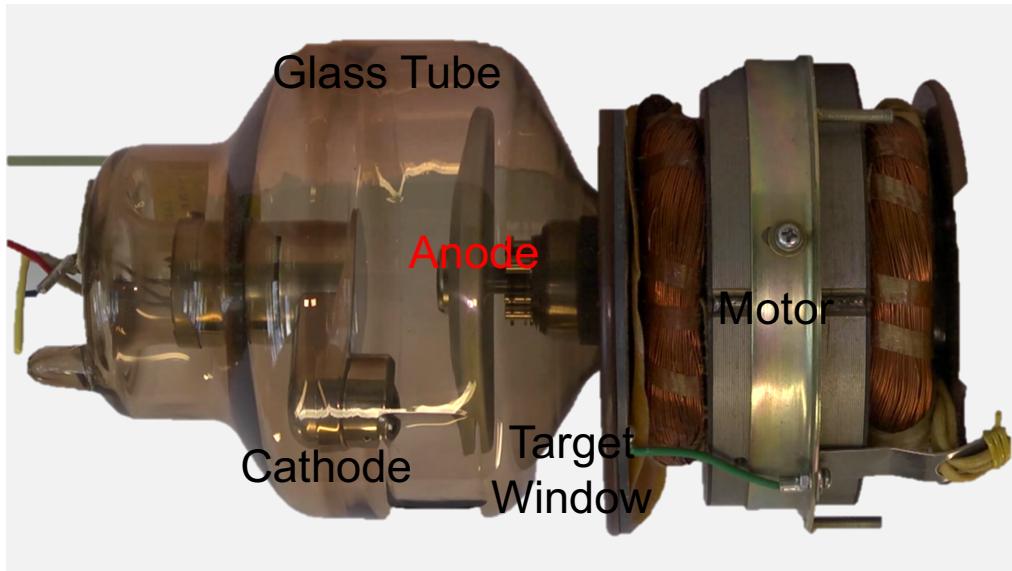
# X-ray Tube



- The angle of the anode directs X-rays towards target window
- 1% of  $e^-$  energy becomes X-rays

[https://www.youtube.com/watch?v=3\\_bZCA7tlFQ](https://www.youtube.com/watch?v=3_bZCA7tlFQ)

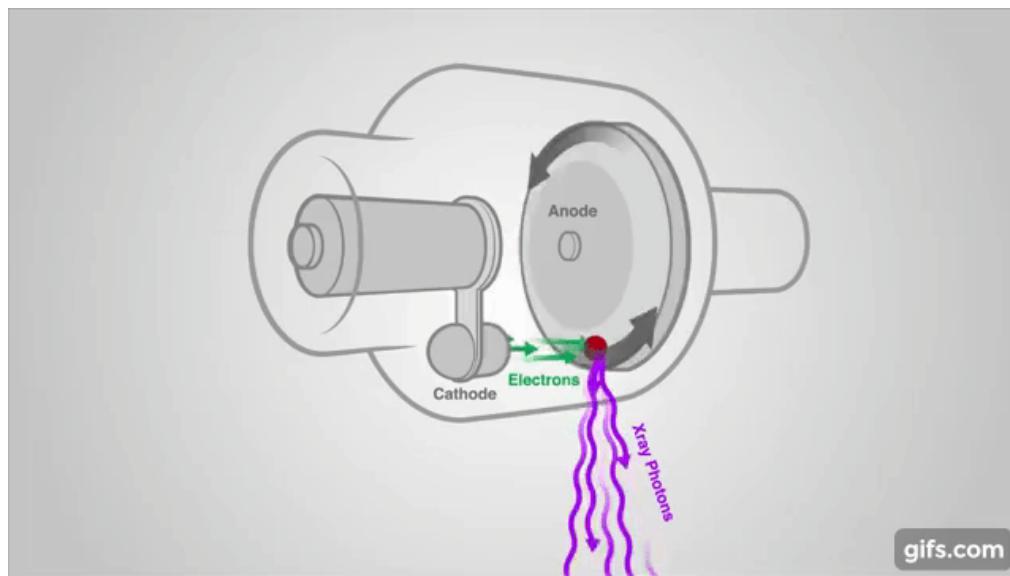
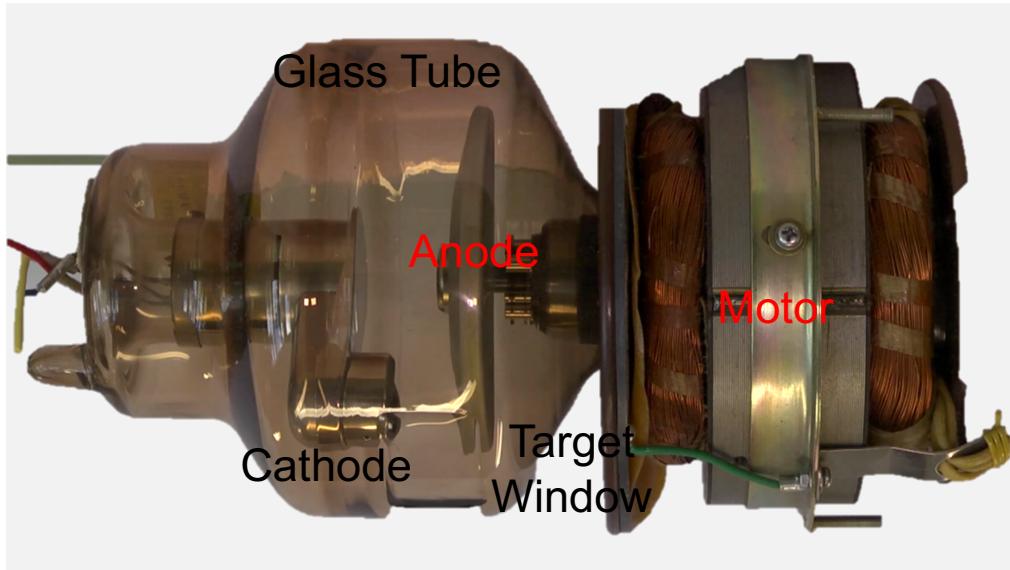
# X-ray Tube



- 99% of  $e^-$  energy is converted to heat

[https://www.youtube.com/watch?v=3\\_bZCA7tlFQ](https://www.youtube.com/watch?v=3_bZCA7tlFQ)

# X-ray Tube



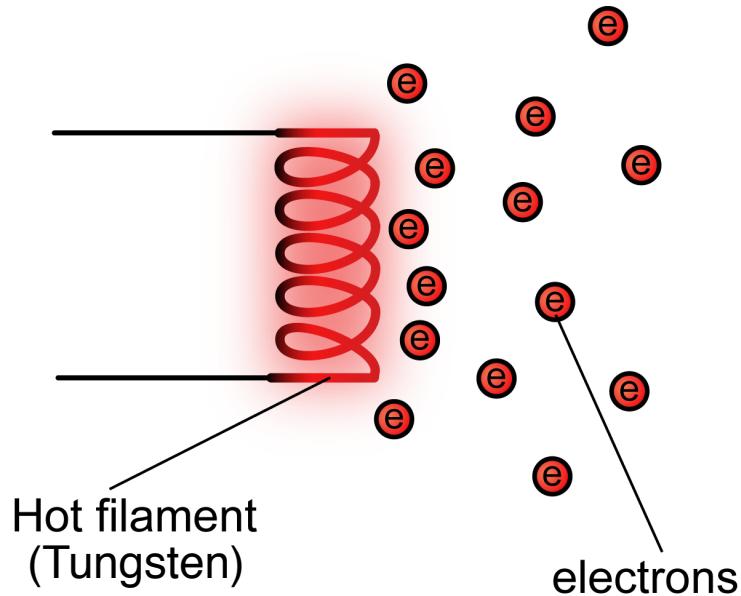
- The motor rotates the anode to change hit spot

[https://www.youtube.com/watch?v=3\\_bZCA7tlFQ](https://www.youtube.com/watch?v=3_bZCA7tlFQ)

# What happens at the cathode?



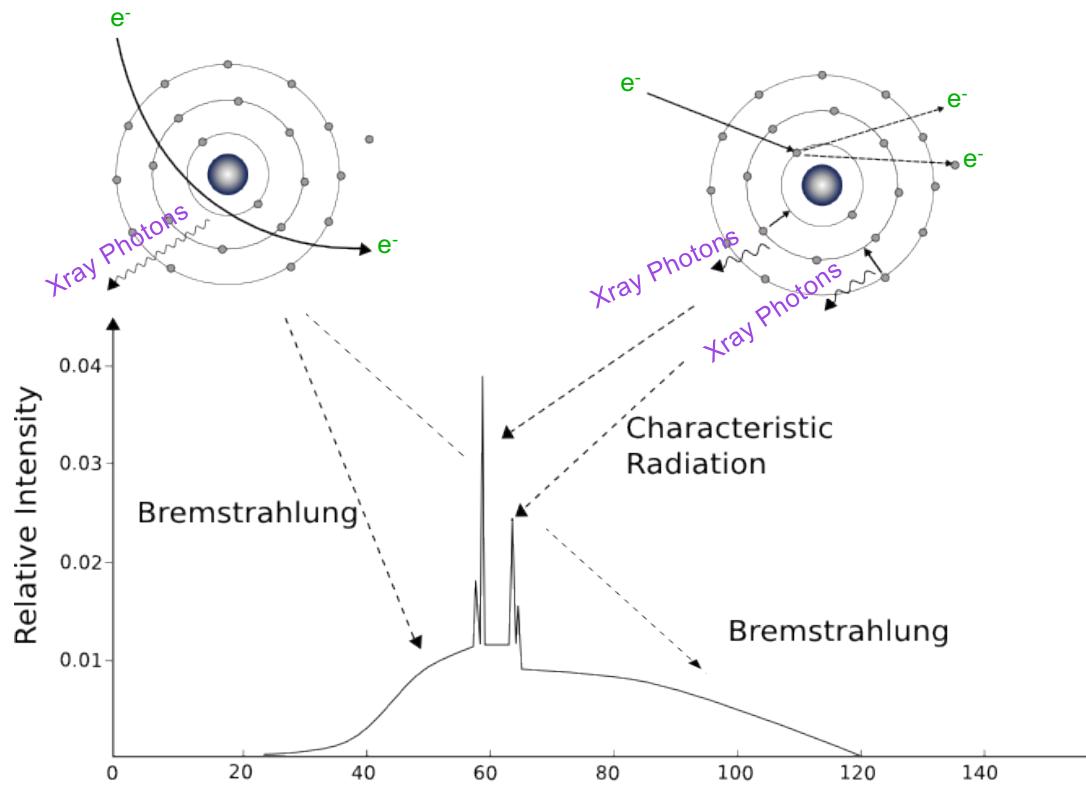
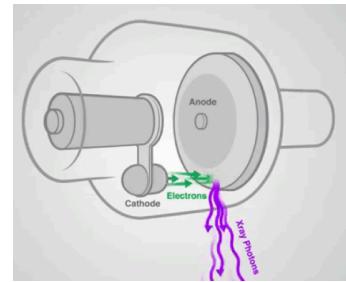
- $e^-$  production!
- How? Thermionic emission:



# What happens at the anode?

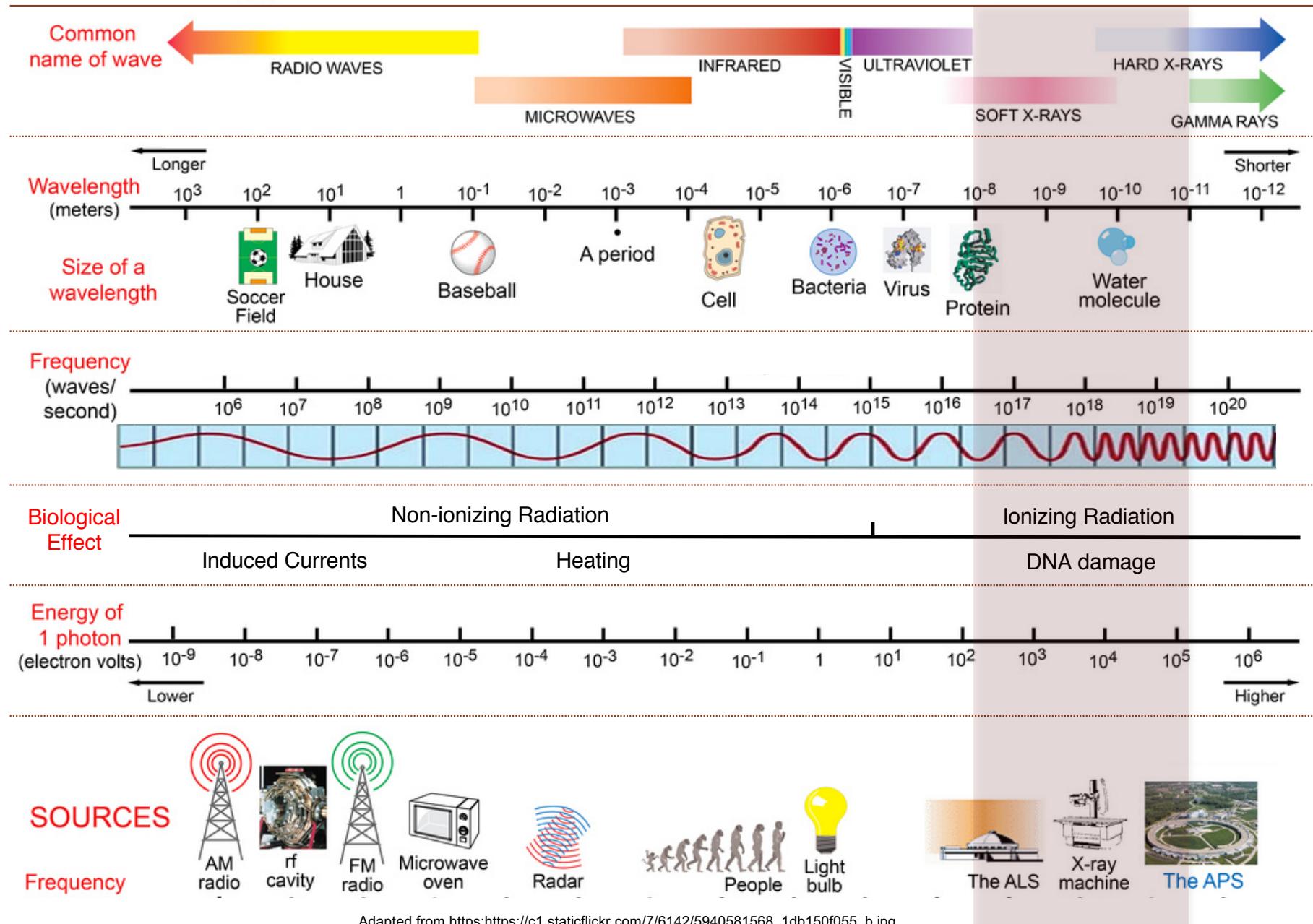


- X-ray production!
- How?



# Characteristics of X-rays

## ELECTROMAGNETIC SPECTRUM



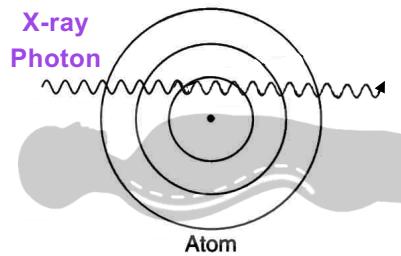


# Interaction with Matter (The Subject)

# X-ray interaction with matter

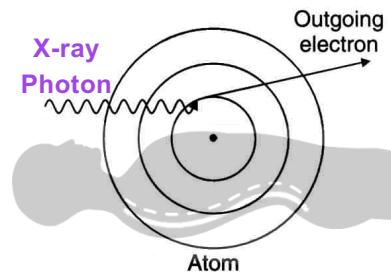


## 1. TRANSMITTED PHOTONS



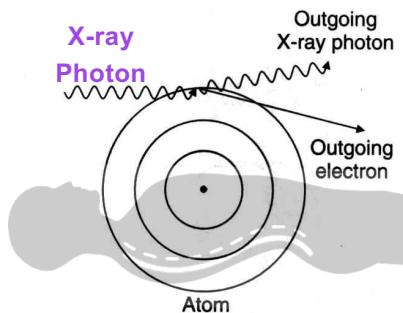
- Photon does not interact with matter and goes to detector

## 2. PHOTOELECTRIC ABSORPTION



- Photon absorbed in body
- Electron scatters again until it loses all its energy  
→ free radicals → DNA damage

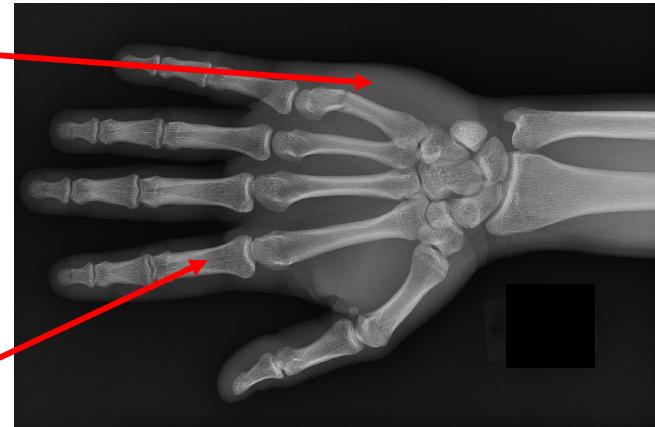
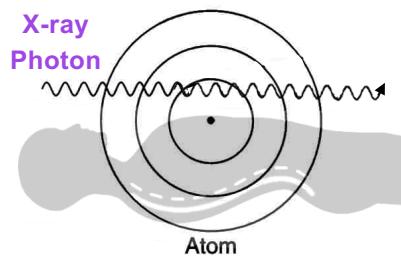
## 3. COMPTON SCATTERING



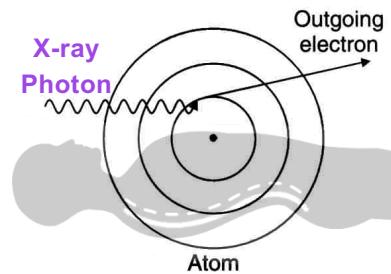
- Photon goes to detector (noise) or around (radiations for operators)
- Electron scatters again until it loses energy  
→ free radicals → DNA damage

# X-ray attenuation

## 1. TRANSMITTED PHOTONS

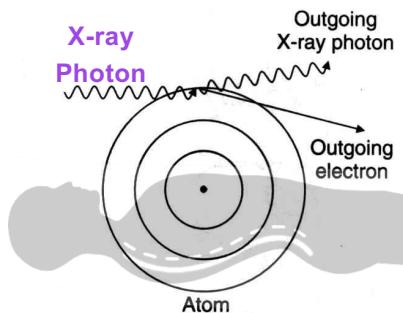


## 2. PHOTOELECTRIC ABSORPTION



[CONTRAST]

## 3. COMPTON SCATTERING



[NOISE]

## ATTENUATION

Total reduction in number of X-rays  
in beam after passing through tissue

$$I = \int_0^{E_{max}} I_0(E) \cdot e^{-\int \mu dx} dE$$

[LAMBERT BEER'S LAW]

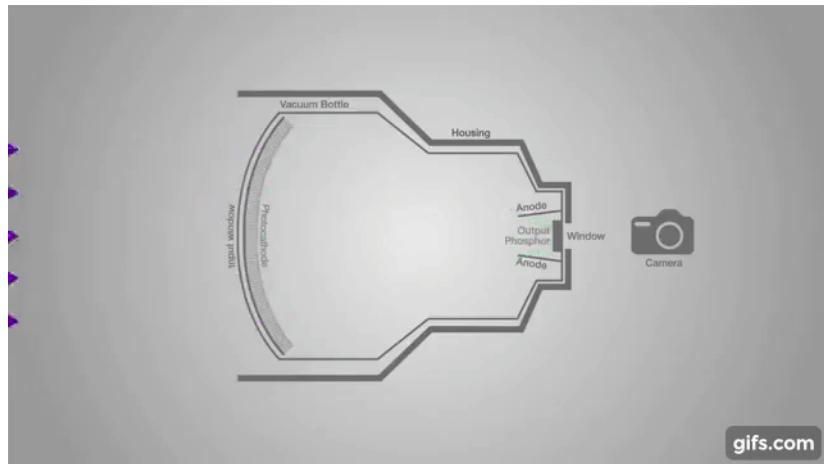


# The Detector

# Analog and digital detectors

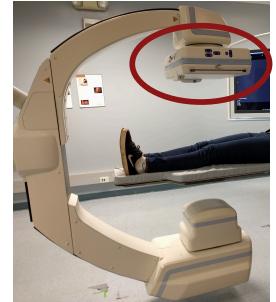


## IMAGE INTENSIFIER

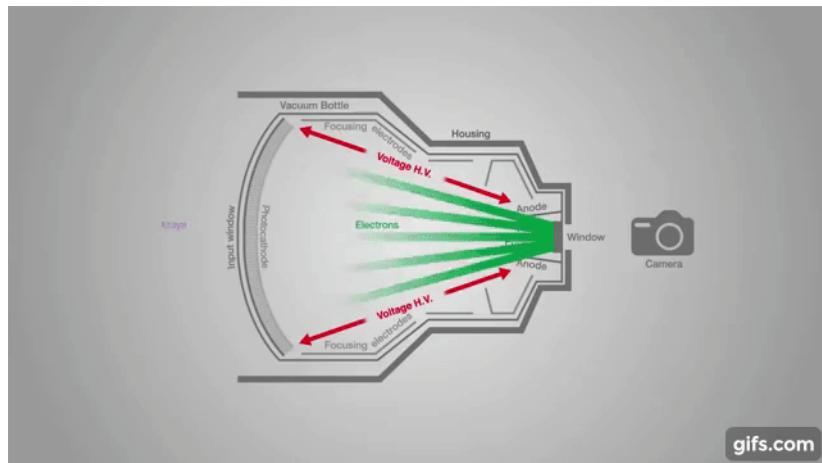


<https://www.youtube.com/watch?v=BQ0PZGnC334>

# Analog and digital detectors



## IMAGE INTENSIFIER

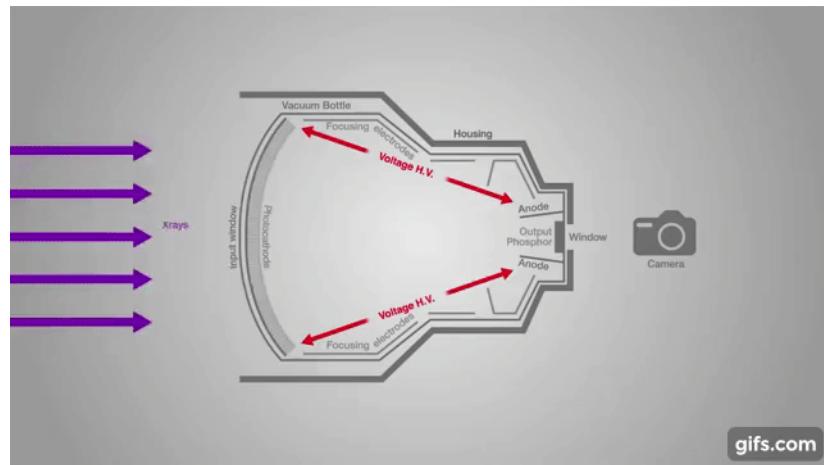


<https://www.youtube.com/watch?v=BQ0PZGnC334>

# Analog and digital detectors



## IMAGE INTENSIFIER

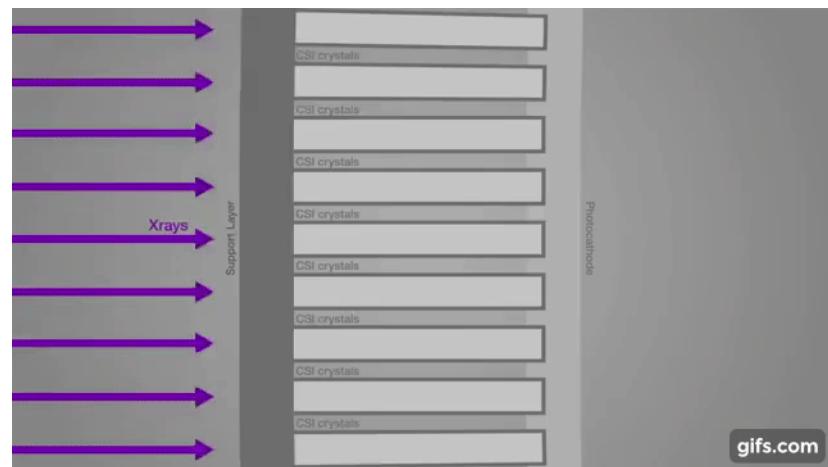


<https://www.youtube.com/watch?v=BQ0PZGnC334>

# Analog and digital detectors



## IMAGE INTENSIFIER

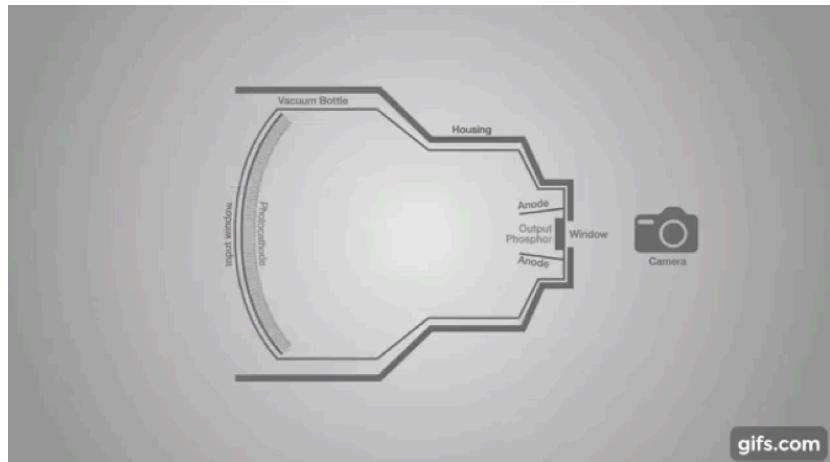


<https://www.youtube.com/watch?v=BQ0PZGnC334>

# Analog and digital detectors



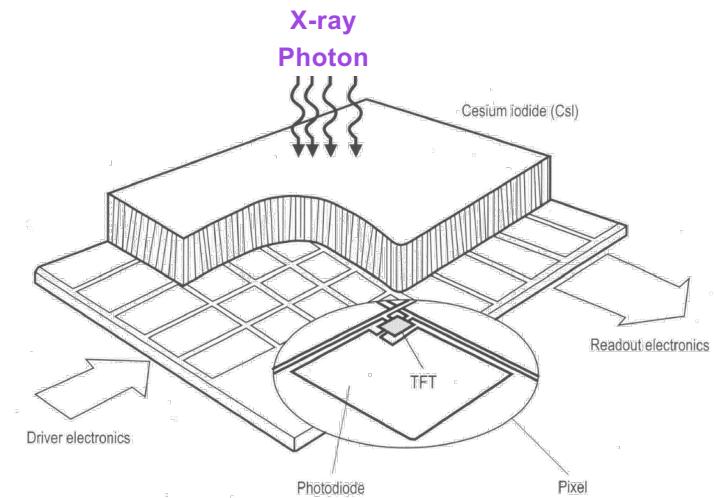
## IMAGE INTENSIFIER



<https://www.youtube.com/watch?v=BQ0PZGnC334>

- X-rays → Light → Electrons → Light → Image
- Introduced in the 1940s

## FLAT PANEL DETECTOR

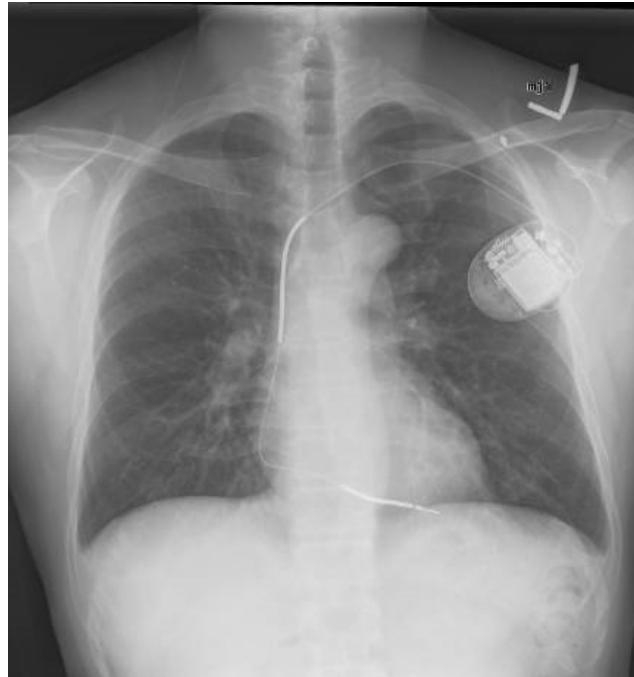


- X-rays → Light → Electrons → Image
- Introduced in the 1990s
- Images are digitalized and thus easily viewed, shared, stored

# The Image

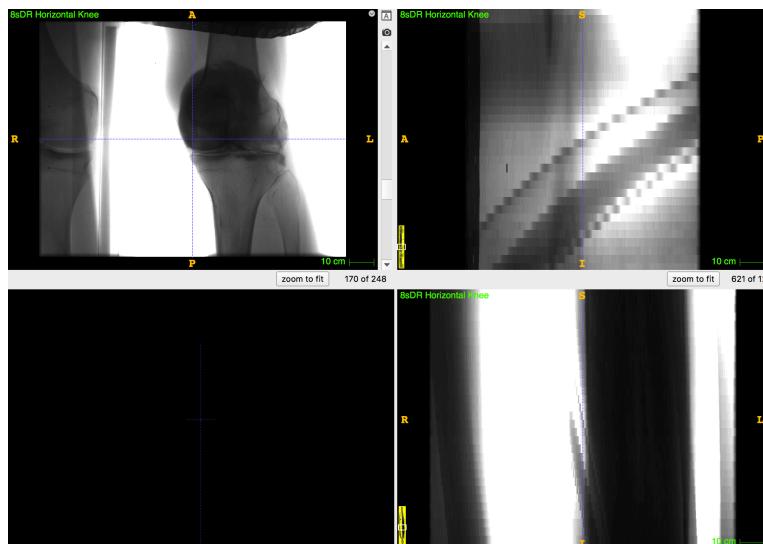
## 2D and 3D images (Zeego system)

- 2D images are directly digitalized from the Flat Panel Detector
  - Matrix size: 1920x1920 / Pixel size: 150x150µm

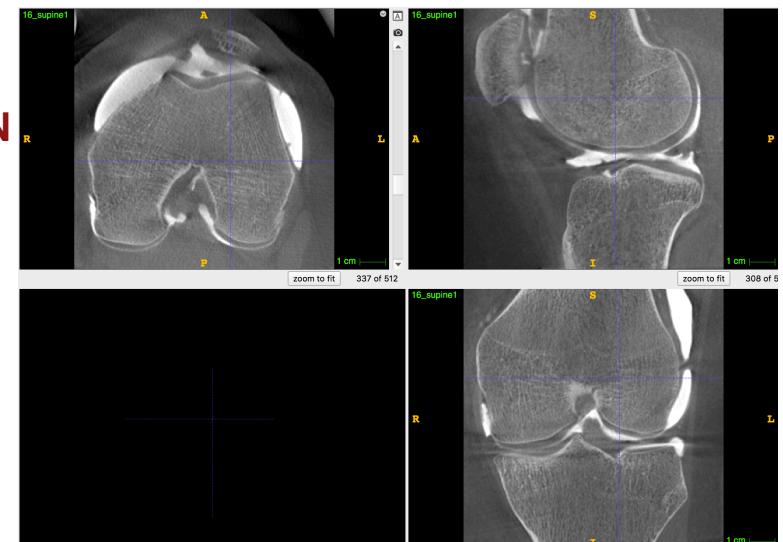


# 2D and 3D images (Zeego system)

- 2D images are directly digitalized from the Flat Panel Detector
  - Matrix size: 1920x1920 / Pixel size: 150x150µm
- 3D images are a sequence of 2D image acquired over 200°
  - We need to reconstruct the volume
    - Matrix size: 512x512x512 / Pixel size: 200x200µm



BACK  
PROJECTION



[ Back Projection works like Sudoku or Crosswords!

Example here: <https://www.youtube.com/watch?v=GGR6NTAvPao>]

# X-ray Applications

# 2D X-ray applications

## RADIOGRAPHY



## FLUOROSCOPY

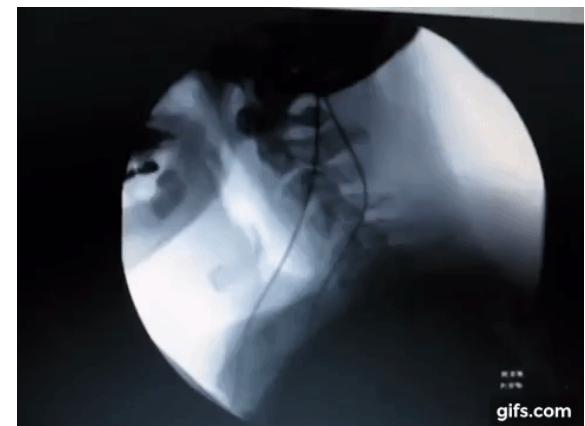


Image source: Siemens Healthcare, Erlangen, Germany and N. Kothary

# 3D X-ray applications

## COMPUTED TOMOGRAPHY



## CONE BEAM CT

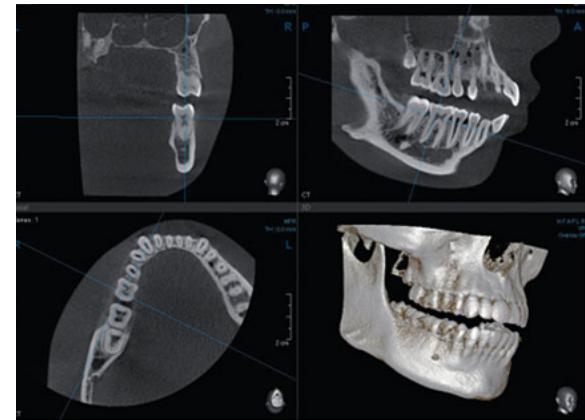
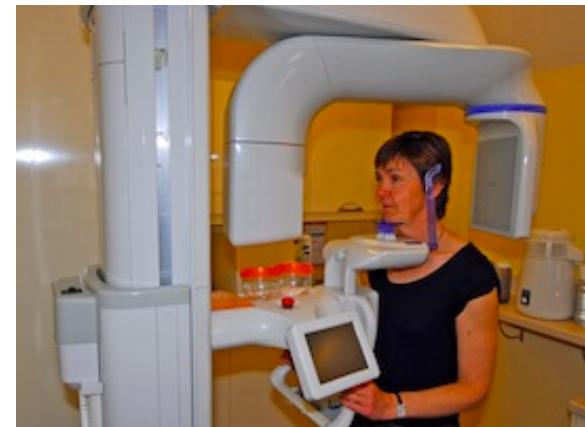


Image source: Siemens Healthcare, Erlangen, Germany and N. Kothary

# Radiology Safety

# Principle and Practice

- ALARA (As Low As Reasonably Achievable) principle
  - To ensure that radiation dose to workers, members of the public, and to the environment is as low as reasonably achievable
  - Distance: inverse square law
  - Time: reduce time exposure to X-ray
  - Shielding: use lead apron, movable led walls, plexiglass

PAY ATTENTION TO  
SAFETY SIGNS



WEAR LEAD  
APRON

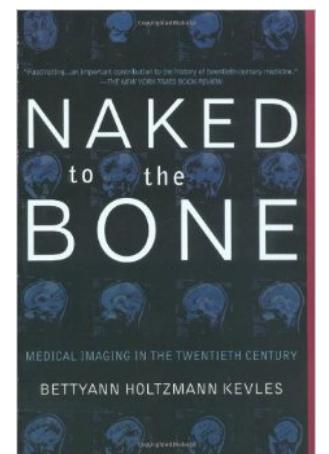


WEAR DOSIMETER  
BADGE



# Did you know?

## (Curious historical facts about X-rays)



## Did you know?

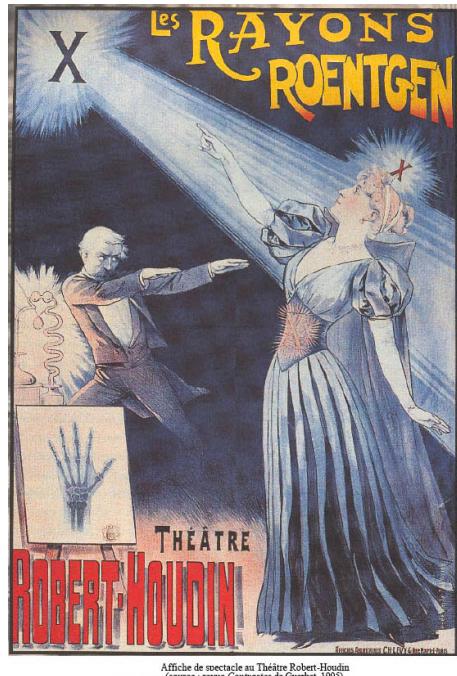
- 1895: Wilhelm Conrad Röntgen discovers X-rays



# Did you know?

- Beyond being used for medical applications, X-rays triggered unprecedented euphoria

## MAGIC THEATER



<http://adammunich.com/a-brief-history-of-the-x-ray/>

## COIN OPERATED X-RAY MACHINES



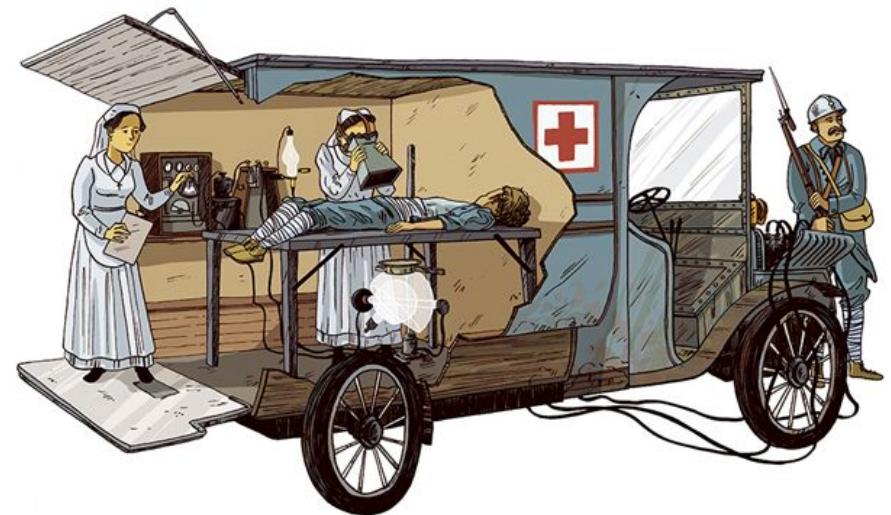
[http://www.underthepier.com/17\\_novelty\\_machines.htm](http://www.underthepier.com/17_novelty_machines.htm)

## Did you know?

- 1914-1918 (World War I): Marie Curie created mobile X-ray vehicles to assist battlefield surgeons



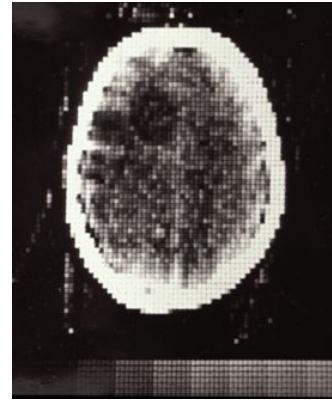
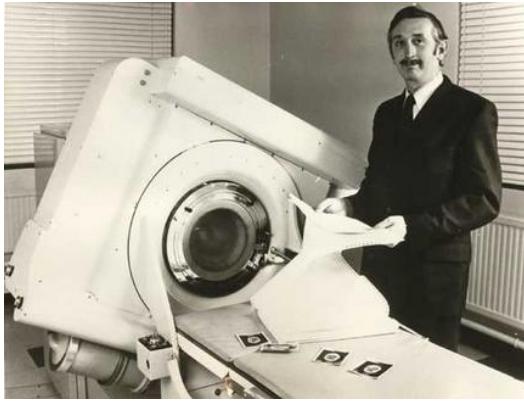
[https://en.wikipedia.org/wiki/Marie\\_Curie#World\\_War\\_I](https://en.wikipedia.org/wiki/Marie_Curie#World_War_I)



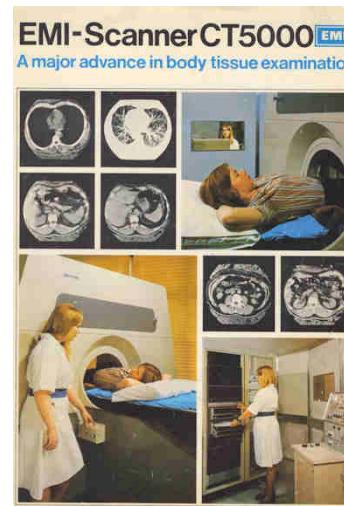
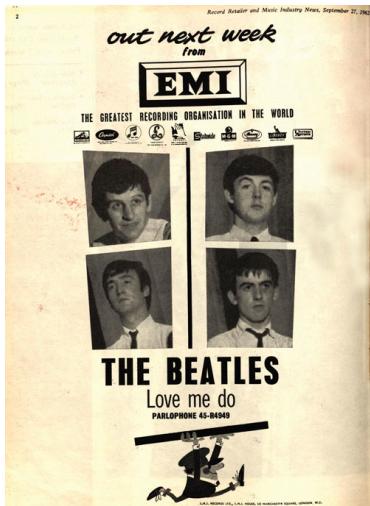
<http://www.carestream.com/blog/2014/11/13/radiology-first-world-war/>

# Did you know?

- 1979: Godfrey Newbold Hounsfield invented Computed Tomography



- CT scanner was “the greatest legacy” of the Beatles: the massive profits from their record sales enabled EMI to fund scientific research



See you at the Zeego Lab!