X-ray Computed Tomography

16 November 2016

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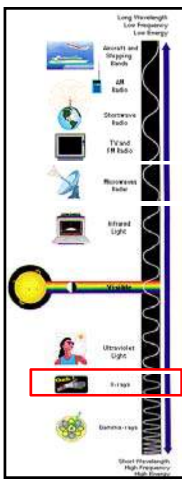
Getty Conservation Institute

Overview

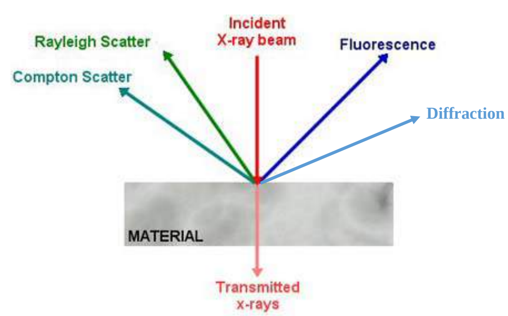
- Background on X-rays
- X-radiography: 2-D and 3-D objects
- Different types of Computed Tomography
- Medical CT example: JPGM Mummy
- Industrial CT example: GCI home-built scanner
- Tips and tricks
- Test objects and case studies



What are X-rays?

λ=248000 - 0.124keV **λ=10^{-5}- 100Å**

Interactions of X-rays with matter

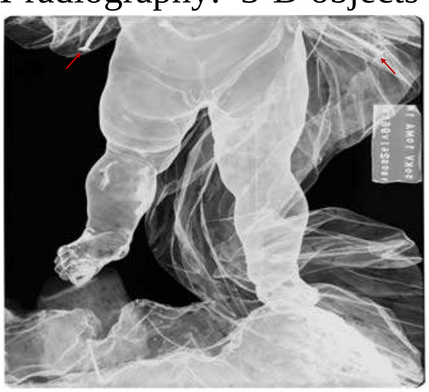


X-radiography: 2-D objects

X-radiography: 2-D objects

An Old Man In Military Costume
78.PB.246
J. Paul Getty Museum

X-radiography: 3-D objects

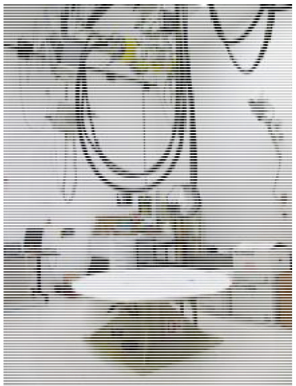


Christ Child
96.SD.18
J. Paul Getty Museum

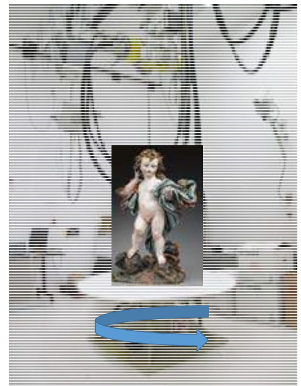
X-radiography: 3-D objects

Christ Child
96.SD.18
J. Paul Getty Museum

X-radiography: 3-D objects



X-radiography: 3-D objects



X-radiography: 3-D objects

- Quick way to see object at different angles
- Composite of X-radiographies stitched together to create video
- Difficult to see the different areas of object – cannot slice to specific level of interest

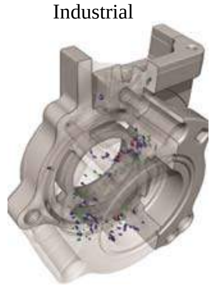
What is CT?

Combines a series of X-ray images taken from different angles and uses computer processing to create cross-sectional images

Medical

http://www.radiologyinfo.org

Industrial



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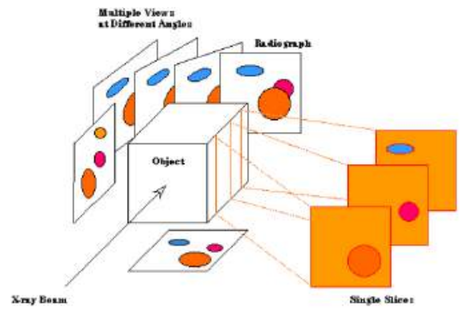

Courtesy of Dan Schneberk, Lawrence Livermore National Laboratory

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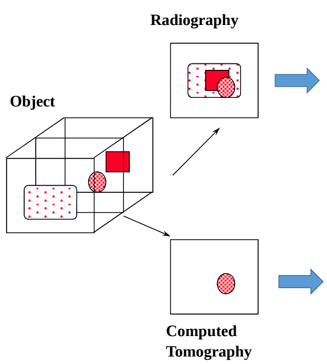

Courtesy of Dan Schneberk, Lawrence Livermore National Laboratory

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What is CT?

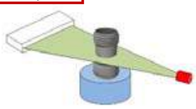
Medical

- Detector and source rotate around object
- Optimized for the human body
  - Objects with similar materials and dimensions work best
- Lower X-ray power: max 160 kVp

What is CT?

Industrial

Line-beam system



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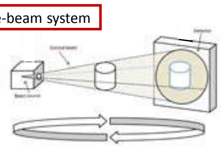
Cone-beam system



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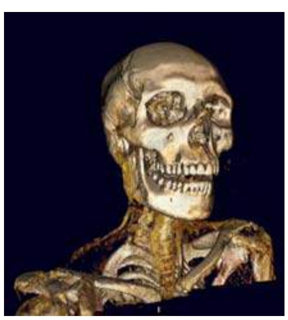
- Line scanners: first generation of industrial CT scanners
  - X-ray beam is collimated to create a line and then translated across the object
- Cone-beam scanners
  - Object rotates
  - Cone of X-rays produce 2D images which are then processed to create a 3D volume rendering of the external and internal geometries of the object
- Higher X-ray power
  - Penetrate metals

Mummies!!

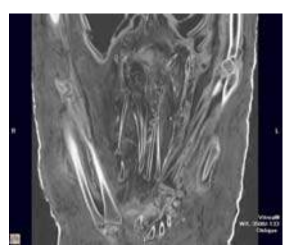
1st c. AD
Roman Egyptian red shroud mummy

91.AP.6
J. Paul Getty Museum

CT at UCLA Medical Center

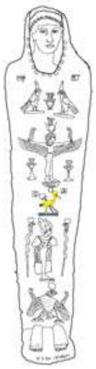


CT at UCLA Medical Center



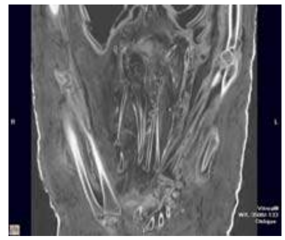
- Different slices allows for different views of object
  - Longitudinal slice
  - Transverse slice
  - Oblique slice

- Higher resolution compared to X-radiography


91.AP.6
J.Paul Getty Museum

CT at UCLA Medical Center



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  - Oblique slice

- Higher resolution compared to X-radiography

GCI home-built CT scanner

Motivation

- High resolution (< 100 microns)
- Compatible for large range of objects
- Have enough power to penetrate bronze
- Inexpensive

Requirements:
- Detector system
- X-ray source
- Rotation system

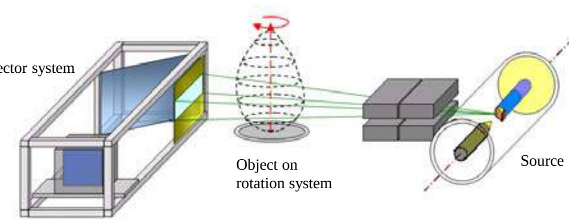
First iteration in 2004

Franco Casali group
University of Bologna,
Dept. of Physics

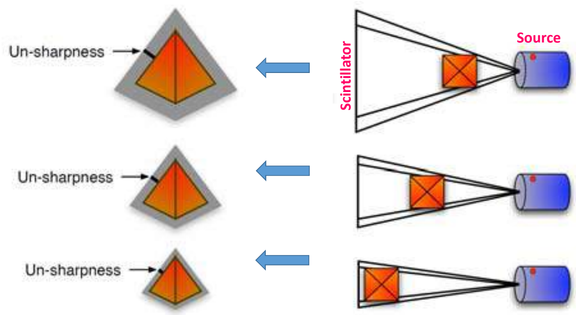
Cone-beam based CT scanner

Pros
- **Reduced scanning time**
- **Utilize non-specialized digital devices for detector system**
  - **CCD**
  - **CMOS**
  - **Flat panels**

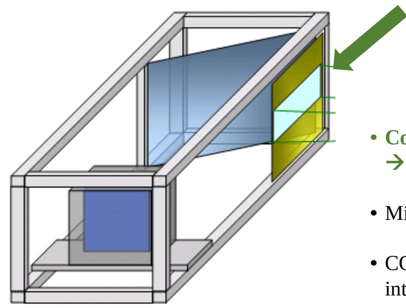
Cons
- **Sensitive to diffuse radiation → lower resolution**



Sharpness, Magnification



Detector box

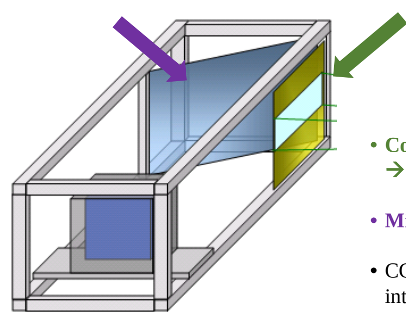


- **Converter Screen → Scintillator plate**
- Mirror
- CCD camera with interchangeable lens

Detector box: Scintillator plate

- Hamamatsu structured Cesium Iodide screen
- 1 mm CsI (Tl) thickness on 1mm Al substrate
- Imaging area: 44 x 44 cm^2

Detector box

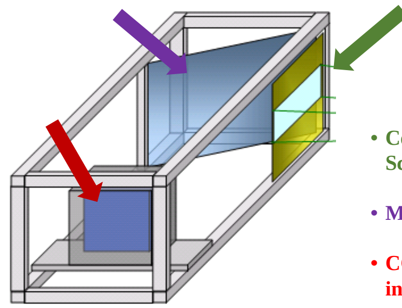


- **Converter Screen → Scintillator plate**
- **Mirror**
- CCD camera with interchangeable lens

Detector box

- First Surface Al mirror
- Avoid direct X-ray beam to the CCD camera

Detector box

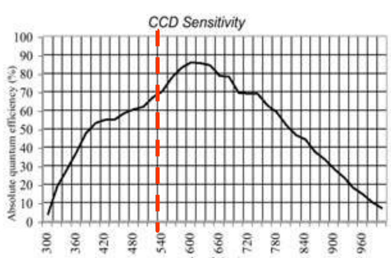


- **Converter Screen → Scintillator plate**
- **Mirror**
- **CCD camera with interchangeable lens**

Detector box: Camera

Kodak Apogee U32
(Astronomy Grade)

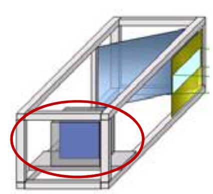
- 2184 x 1472 array
- 6.8 x 6.8 micron pixels
- 2 A/D Converters:
  - 12-bit speed 10 MHz
  - 16 bit speed 1 MHz
- Internal memory: 32MB
- PC interface: USB 2.0

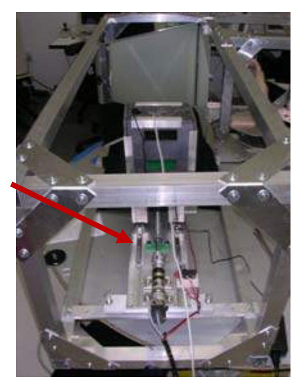


Lens

- Large field of view (Nikon 28mm / f 1.4)
- Small field of view (Nikon 50mm /f 1.2)
- Very small field of view (Nikon 128mm / macro)

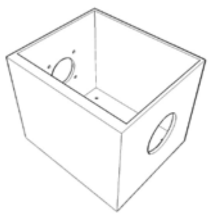
Camera: Focusing

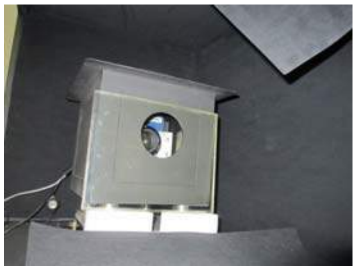




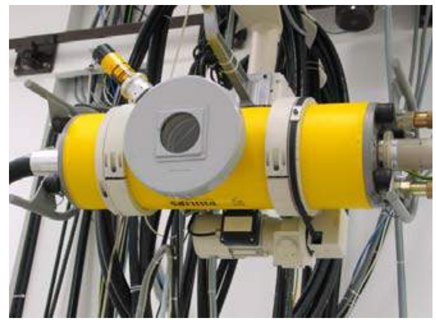
- Motorized 60 cm axis
- Detector setup mounted on optical table

Camera: Lead box housing



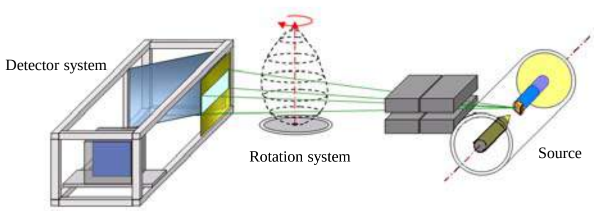


X-ray source

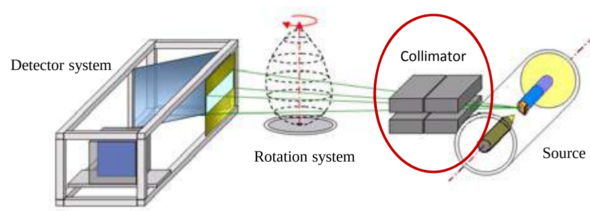


450 kVp X-ray tube

CT scanner schematic

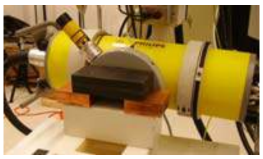


CT scanner schematic

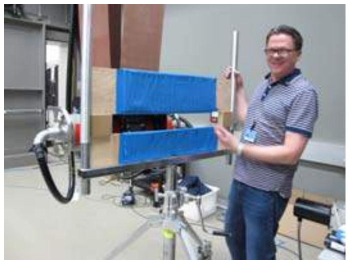


Collimator

Purpose:
Reduction of unwanted scatter radiation



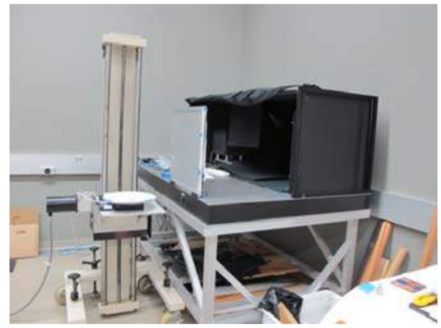
Lead bricks



Lead sheets: adjustable slit width

Rotation stage

- Motorized stage
  - Stepper motor with high precision
- Sturdy frame
  - Stable for larger, heavy objects
  - Move object in vertical direction
- Scintillator proximity to object important factor in resolution
- Collimator slit images on portion of scintillator plate

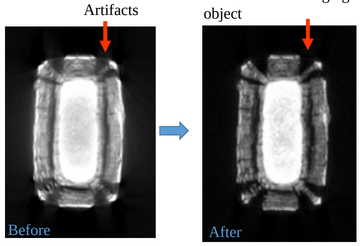


Artifacts due to X-ray attenuation and interaction with material

Geological sample: Limestone with sodium sulfate

Artifacts

More accurate imaging of object

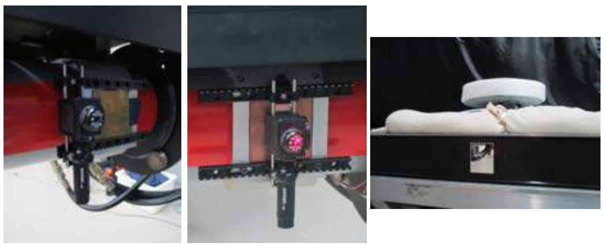


Correction with beam filtering and software post-processing

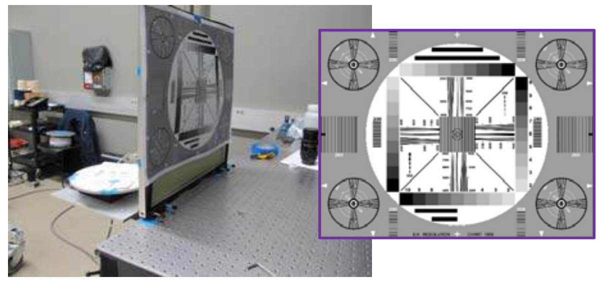
Tips and tricks

- Alignment of X-ray beam to object and table
- Focusing (camera)
- Alignment with object to camera

Tips and tricks: Beam alignment with object and table

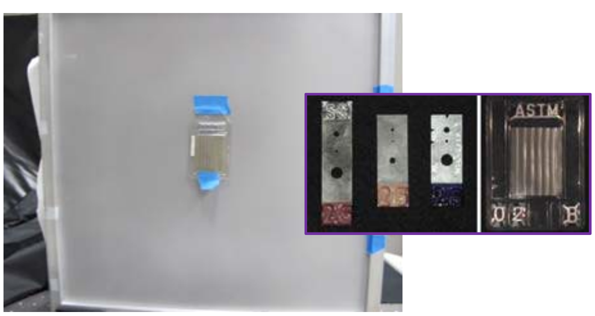


Tips and tricks: Camera focusing



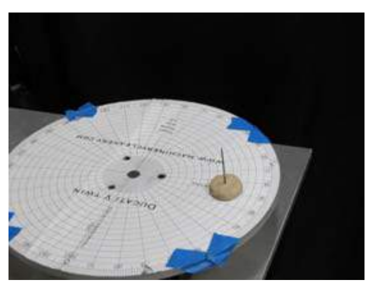
Rough camera focusing

Tips and tricks: Camera focusing



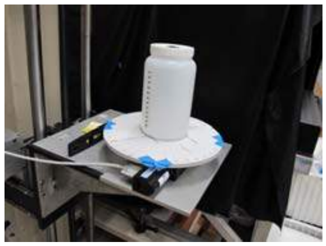
Resolution target used to refine image quality with X-ray beams (image quality indicators, IQIs)

Tips and tricks: Aligning object

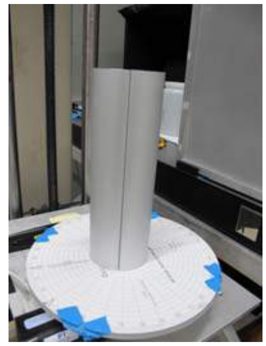


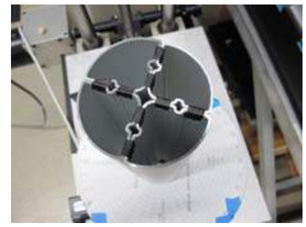
Aligning stage to camera

Tips and tricks: Aligning object



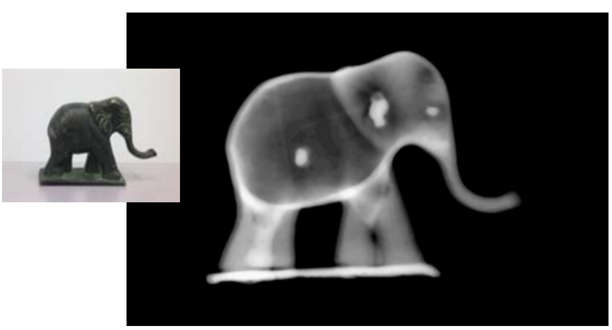
Tips and tricks: Aligning object



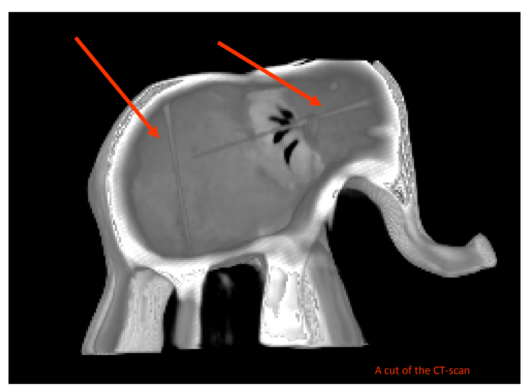


Final standard object: cylinder
easiest geometry for optimization

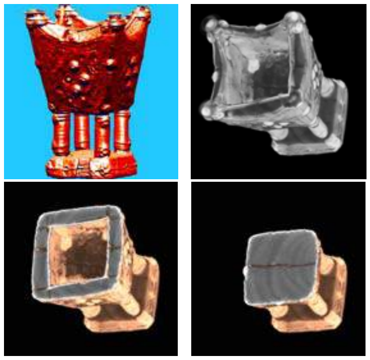
Test Object #1: Elephant



Test Object #1: Elephant

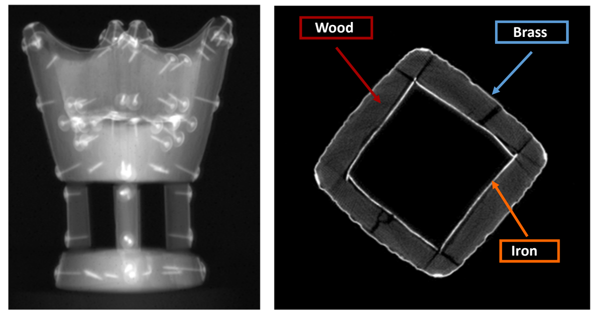


Test Object #2: Iranian incense burner



Slices

Test Object #2: Iranian incense burner



Test Object #3: Jumping horse (wood; metal armature and pins)

Case Study: JPGM Eros

- 1st c. AD Roman
- 67 inches tall
- Copper alloy

96.AB.53
J.Paul Getty Museum

Case Study: JPGM Eros

- 1st c. AD Roman
- 67 inches tall
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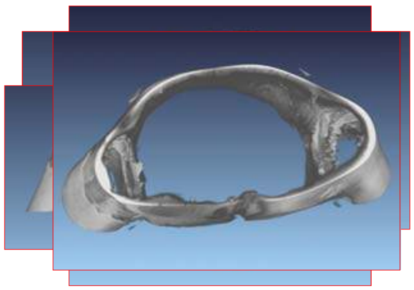
96.AB.53
J.Paul Getty Museum



Bettuzzi, M., Casali, F., et al. (2015). "Computed tomography of a medium size Roman bronze statue of Cupid", Applied Physics A 118 (4): 1161-1169

Case Study: JPGM Eros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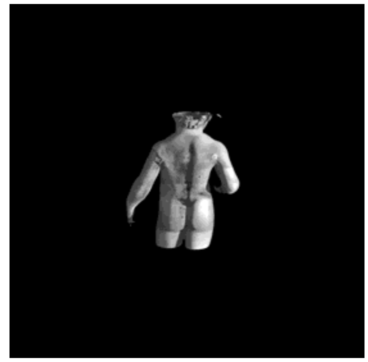

Case Study: JPGM Eros


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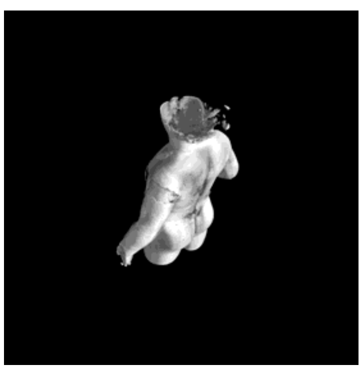
J.Paul Getty Museum



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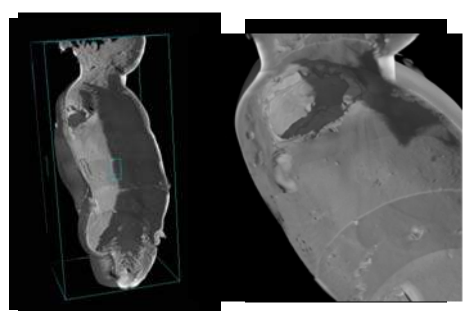
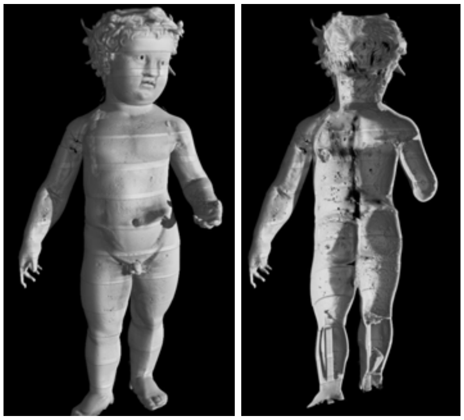
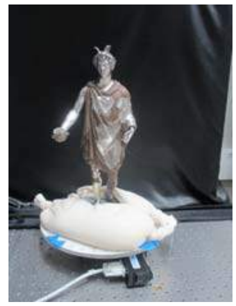




Case Study: Roman Silver Treasures (Bibiliothèque nationale de France)

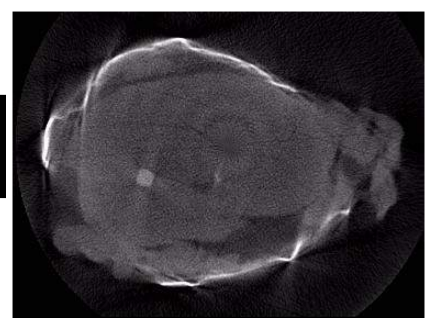


56.2

56.7

Case Study: Mercury statuette

Case Study: Mercury statuette



Case Study: Repoussé Skyphos

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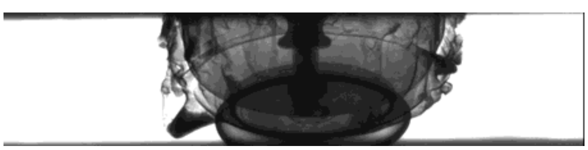

Conclusions

Why do you want to do it?
What is it good for?
What is it not good for?

Partnership with medical, industry or academia with computer science capabilities and resources