The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

2455-2

Workshop on Portable X-ray Analytical Instruments for Cultural Heritage

29 April - 3 May, 2013

Realization of an instrument for X-ray radiography and tomography dedicated to objects of historical and artistic interest within the neu_ART regional project

Alessandro Re

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Joint ICTP-TWAS Workshop on Portable X-ray Analytical Instruments for Cultural Heritage

Trieste, 29 April – 3 May 2013

Realization of an instrument for X-ray radiography and tomography dedicated to objects of historical and artistic interest within the neu_ART regional project

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neu_ART project (2010-2013) funded by: REGIONE PIEMONTE

INFN Istituto Nazionale di Fisica Nucleare

Centro Conservazione e Restauro La Venaria Reale

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La Venaria Reale

Centro Conservazione e Restauro
La Venaria Reale

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Objectives of the neu_ART project

1. *Development and construction of a X-ray scanner to perform digital radiographies of paintings (canvas and wooden panels up to 3 x 2.5 m^2)*

2. *Development and construction of a X-ray tomography apparatus to analyze large objects (up to 2 m wide and 2.5 m high)*

   in collaboration with Bologna University (F. Casali, M.P Morigi, M. Bettuzzi)

3. *Development and construction of an apparatus to perform K-edge radiographies*

   in collaboration with Ferrara University (F. Petrucci e M. Gambaccini)

4. *Feasibility study to use compact fusion neutron source (D-D; D-T) to perform neutron radiographies and tomographies*

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Project and design of a custom CT scanner

Evaluation of dimensions of artworks restored at CCR

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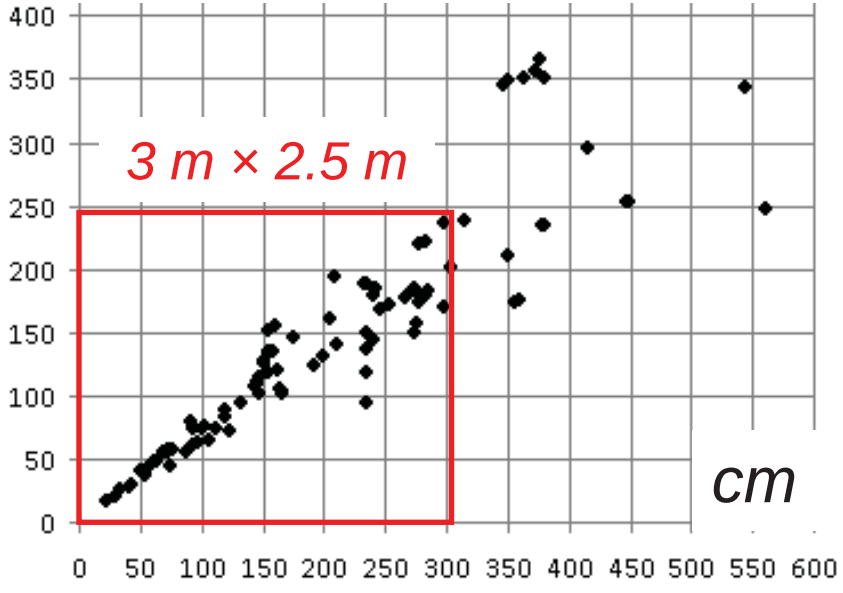
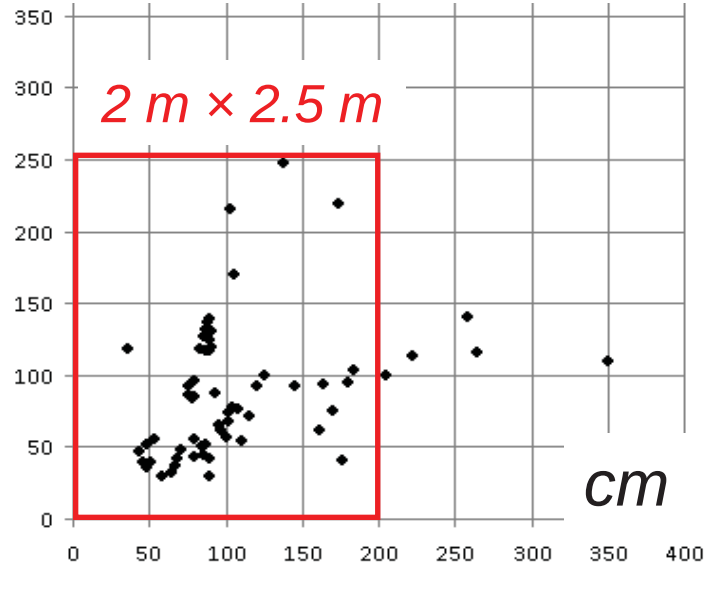
La Venaria Reale

Painted canvas and wooden panel



Wooden statues and furniture



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The shielded area

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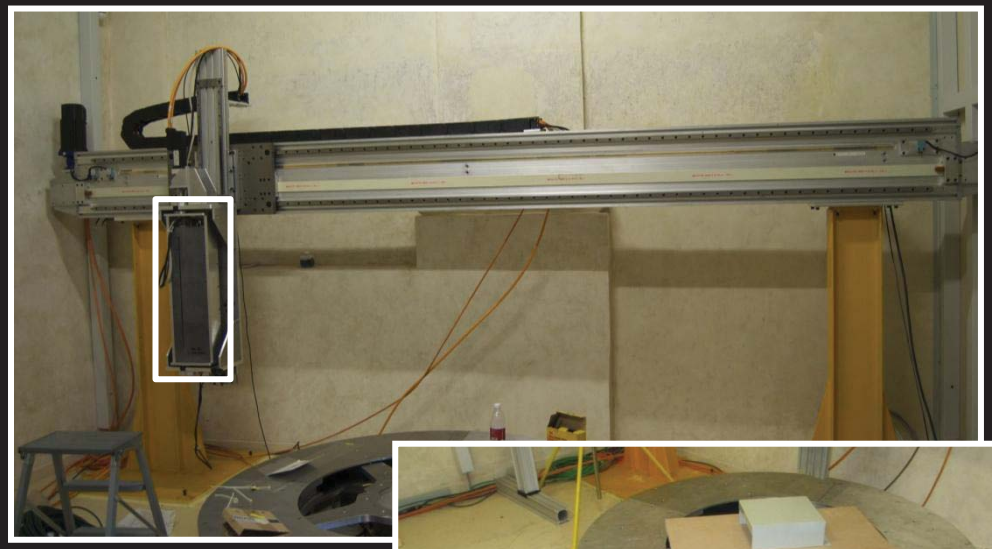
The scanner

- horizontal axis to move the X-ray detector
- X-ray linear detector
- vertical axis to move the X-ray source



- Rotary stage (160 cm diameter)

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X-ray source and detector

X-ray source

General Electric

Eresco 42MF4

Tube voltage: 5 - 200 kV

Tube current: 0.5 - 10 mA

Max power: 900 W

Focal spot size: 3 mm

Cone beam: 60^{o} (h) x 40^{o} (v)

Anode: tungsten

Window: Beryllium (0.8 mm)

X-ray Line Sensor Camera

Hamamatsu

C9750-20TCN

Pixel size: 200 x 200 μm^2

Pixel number: 2560

Sensitive area: 512 x 0.2 mm^2

Scintillator: Gd

Max scan speed: 20 m/min

Output: 12 bit (4096 grey levels)

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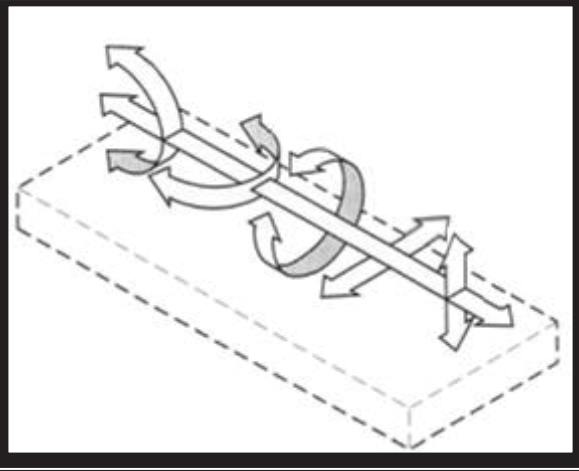
Characterization of the scanner

Motorized mechanical system with high precision

350 cm (horizontal) x 200 cm (vertical)

Deviation lower than pixel dimension (200 μm)



Dynamic Calibrator Agilent Technologies 5529A

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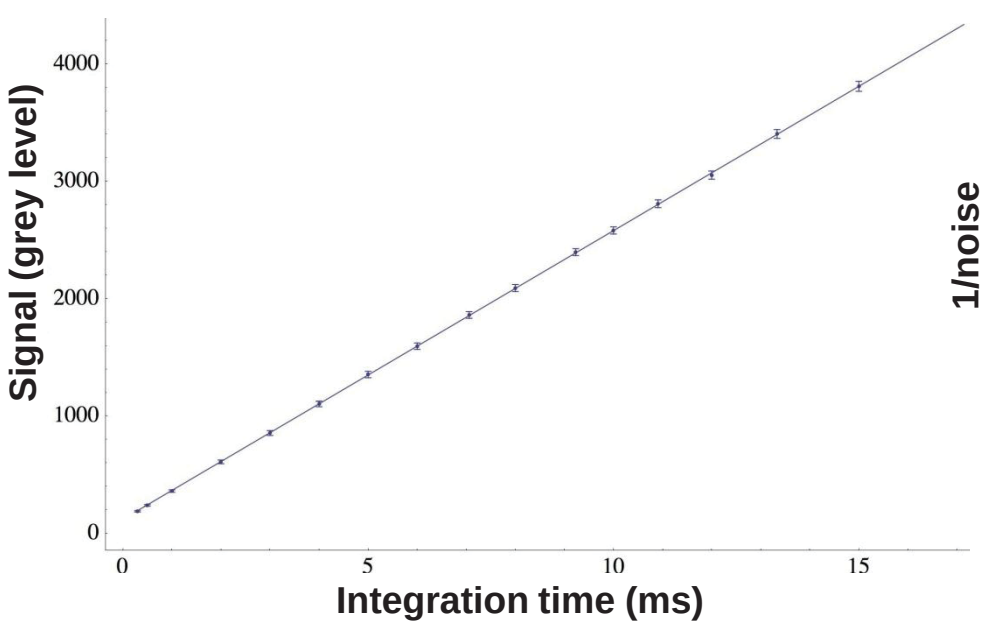
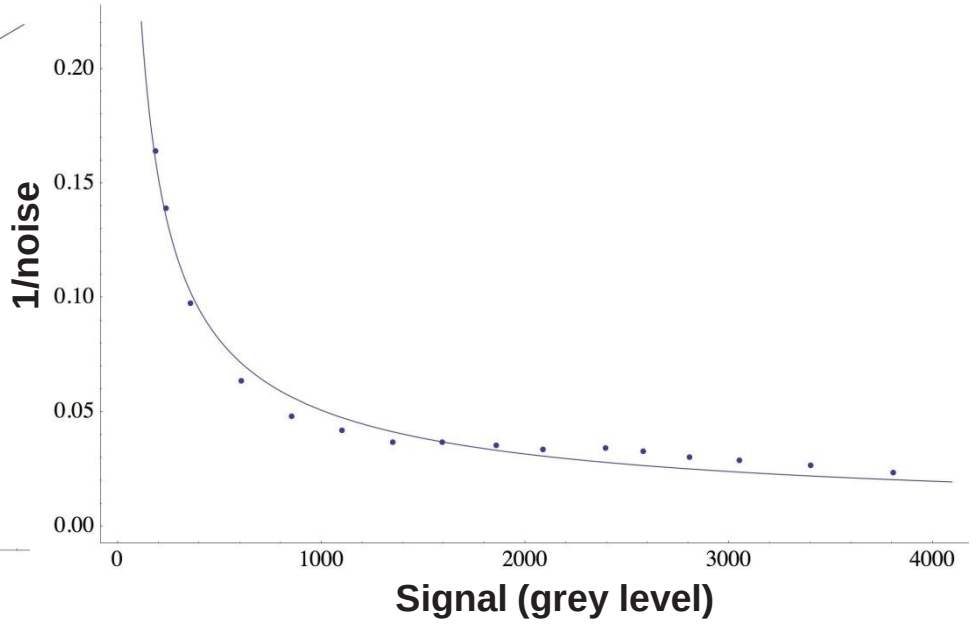
Characterization of the scanner

Dynamic range





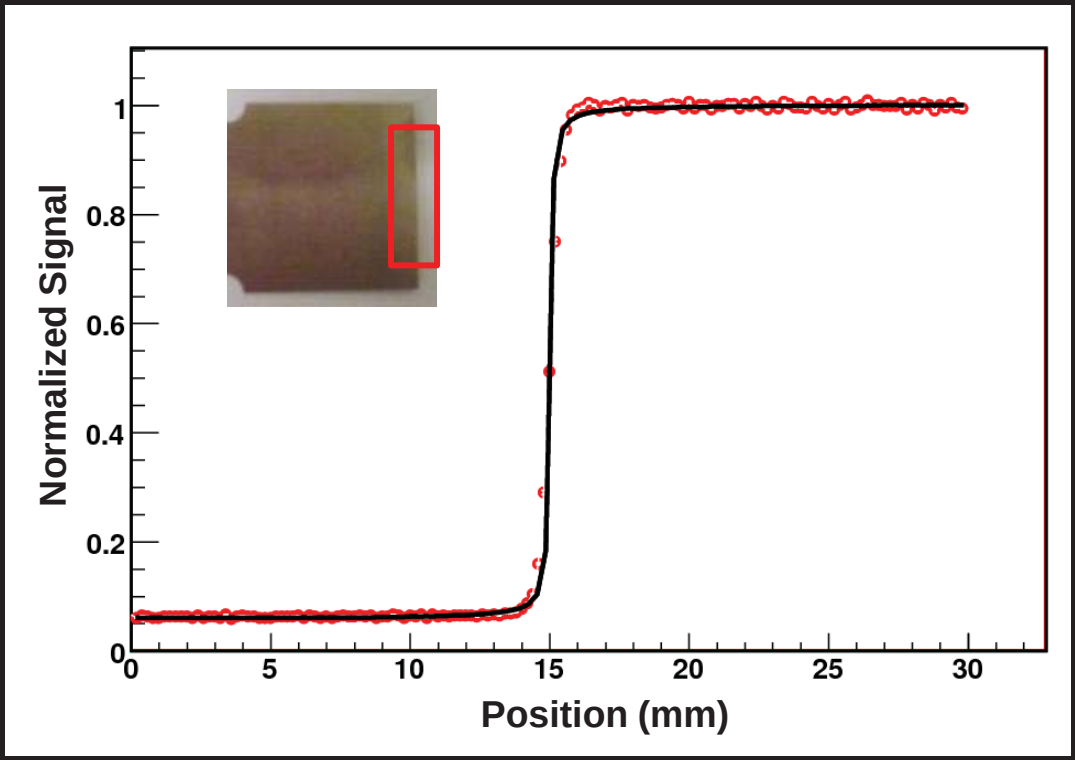
Effective grey levels: (172 ± 12)

Effective dynamic range: (44.8 ± 0.9) dB

Procedure from: Bettuzzi et al (2007), Proceedings of SPIE Vol 6616, doi: 10.1117/12.726165

Characterization of the scanner

Spatial resolution



Sharp-edge

MTF from Edge Spread Function

10% MTF:
(2,5 ± 0,1) lp/mm

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Standard image correction

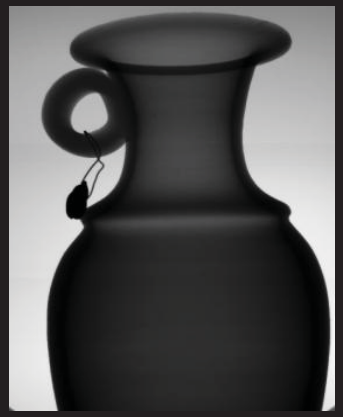
To take into account:

- characteristic of the detector (different response of each pixel and dark current)
- inhomogeneity of the beam (cone)

Corrected radiography

=

Raw radiography



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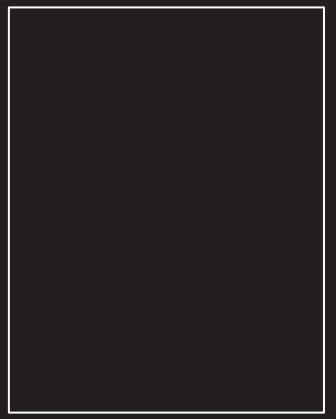
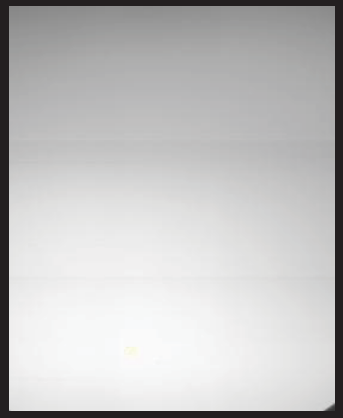
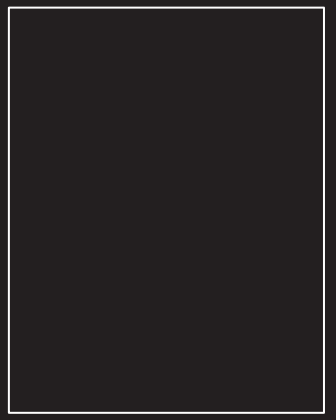
Dark image





White image

−



Dark image

Portraits of the Savoy Family

From the Racconigi Castle (CN) – Italy

"FILIPPO II DI SAVOIA" (1443 – 1497)

Dimensions: 200 cm x 110 cm

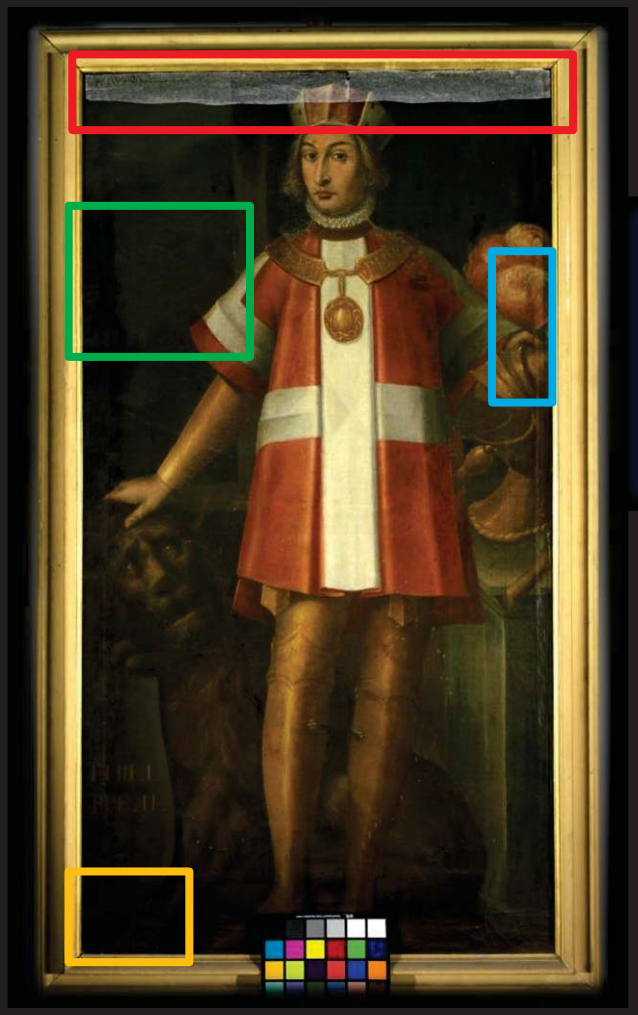
Radiographic parameters	
X-ray tube voltage	90 kV
X-ray tube current	10 mA
Scanning speed	1 m/min
Object-Detector Distance	20 cm
Source-Detector Distance	294.3 cm
Source-Object Distance	274.5 cm
Magnification	1.07 ×
Penumbra	≈ 0.2 mm
# of radiographic scan	5

Digital radiography

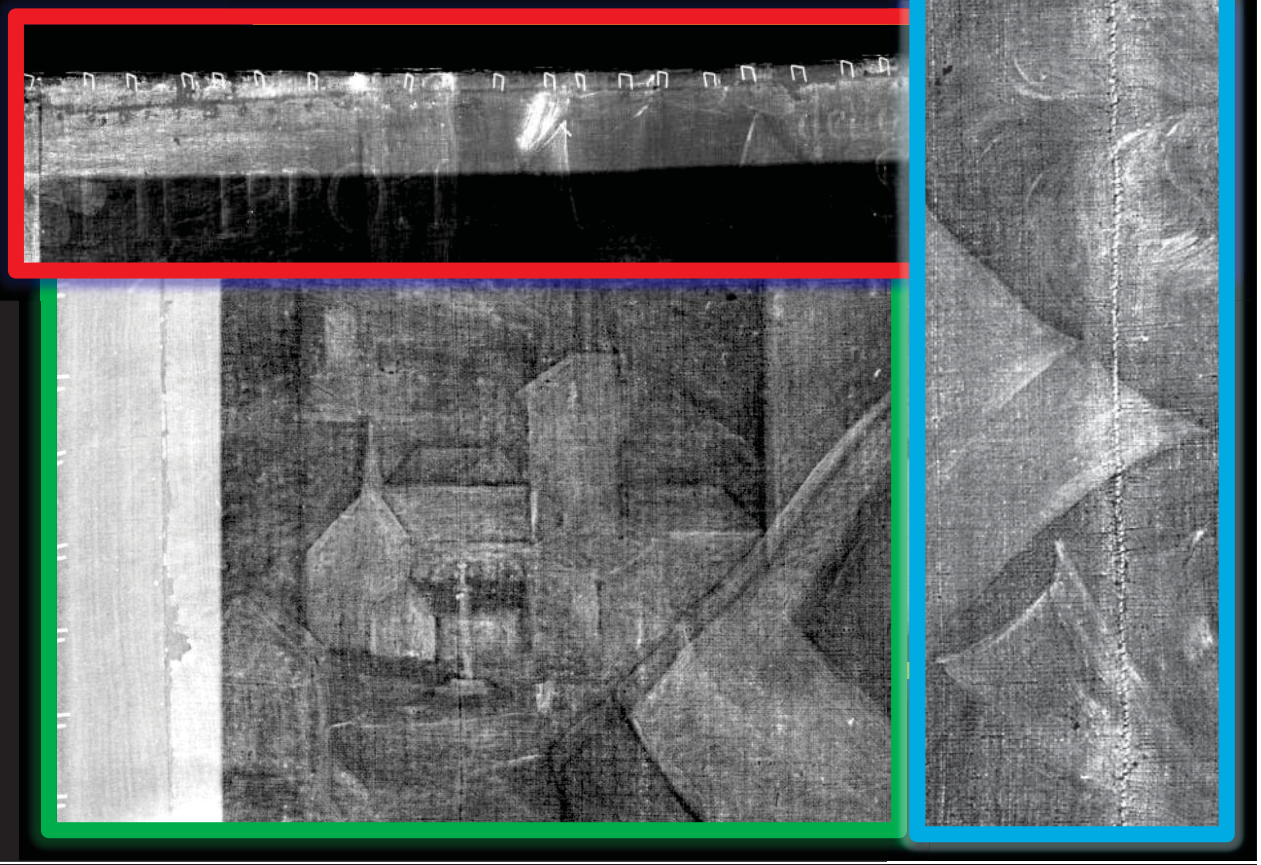
Portraits of the Savoy Family

From the Racconigi Castle (CN) – Italy

"FILIPPO II DI SAVOIA" (1443 – 1497)



inscription - underpainting - seam



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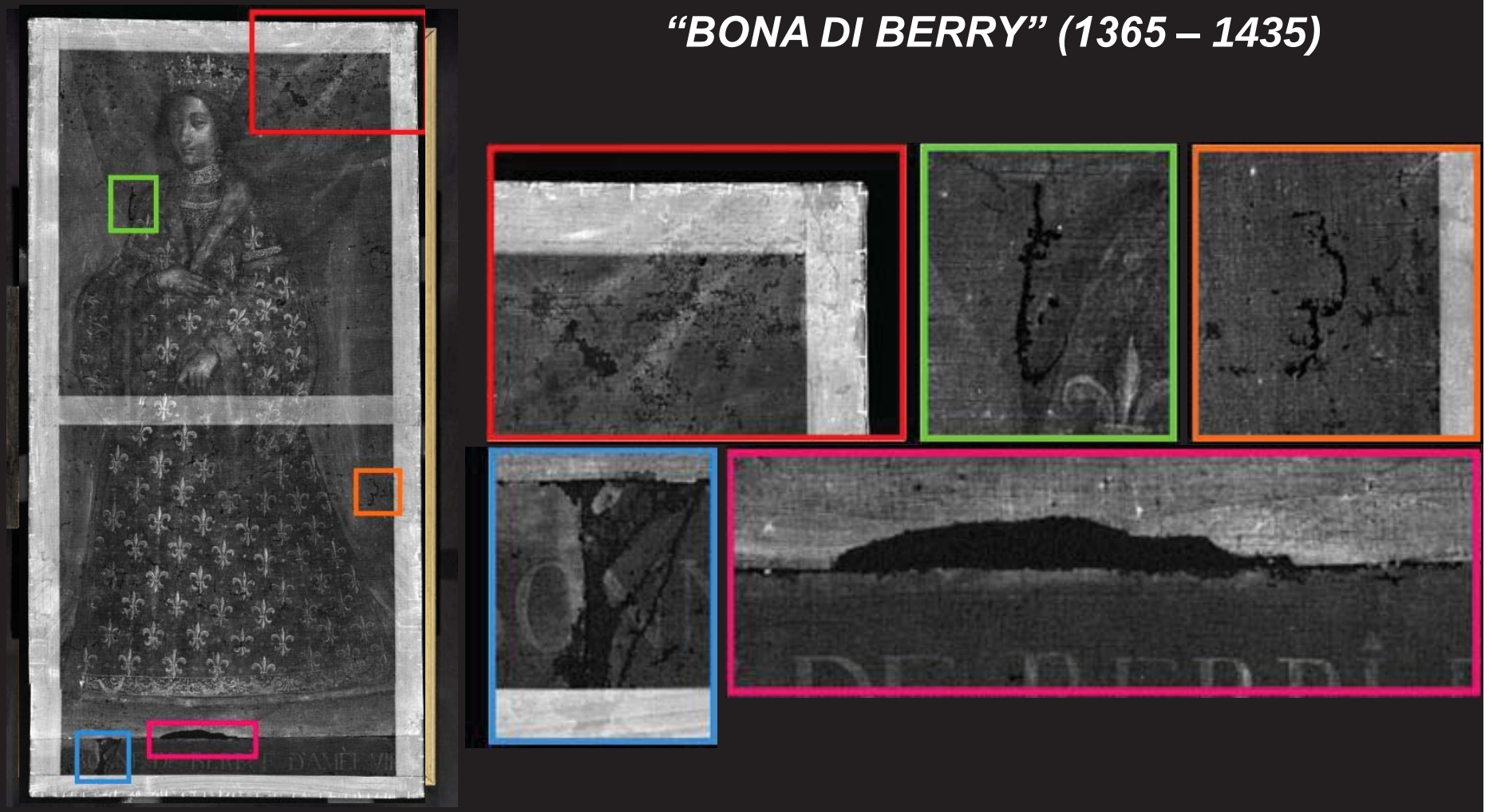
Portraits of the Savoy Family

From the Racconigi Castle (CN) – Italy

"BONA DI BERRY" (1365 – 1435)



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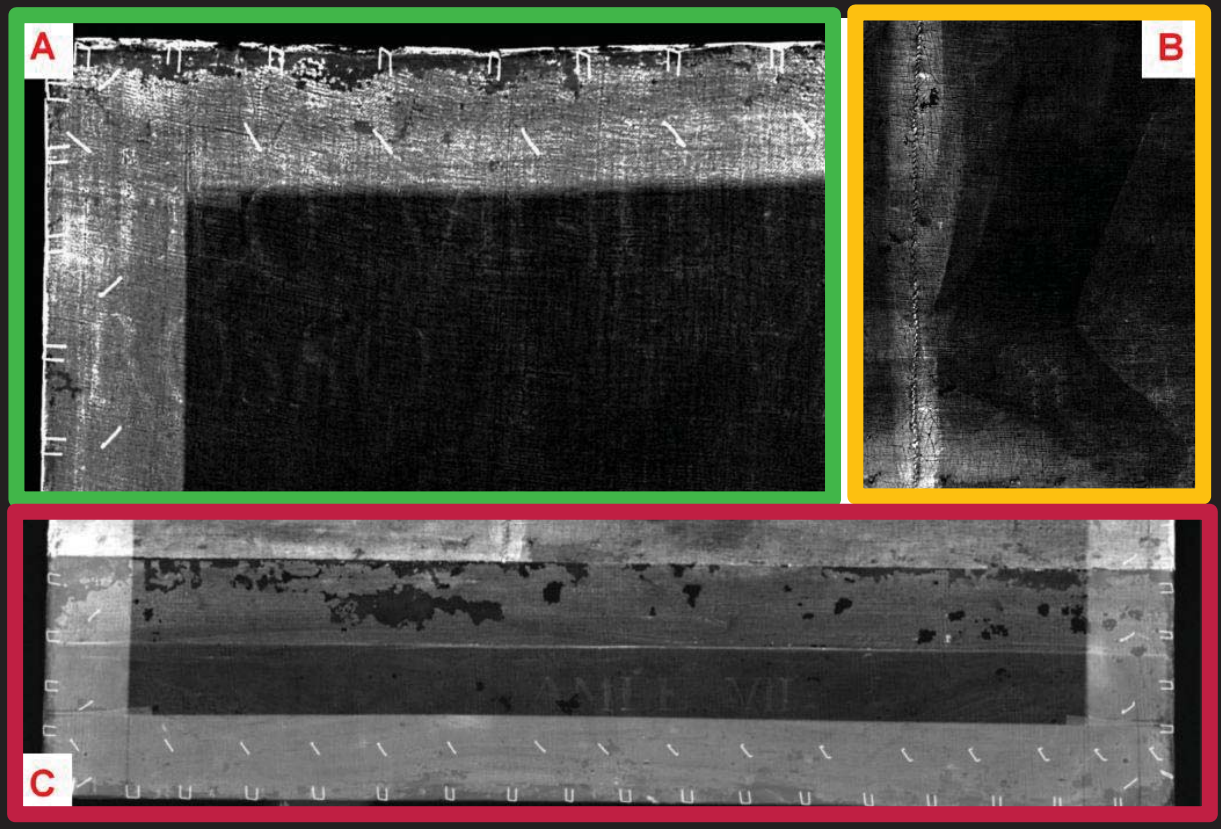
Digital radiography

Portraits of the Savoy Family

From the Racconigi Castle (CN) – Italy

"AMEDEO VII" (1360 – 1391)



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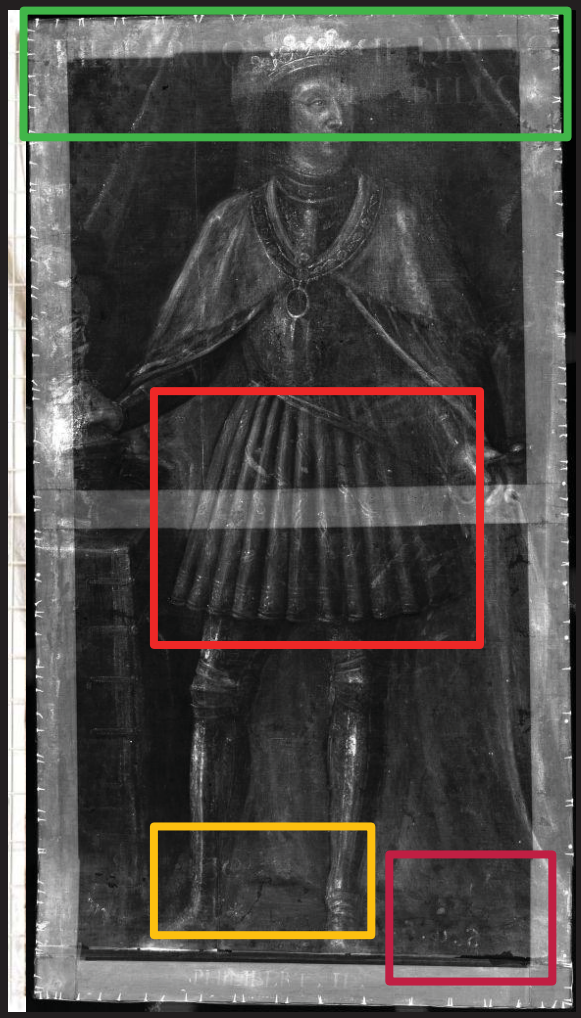
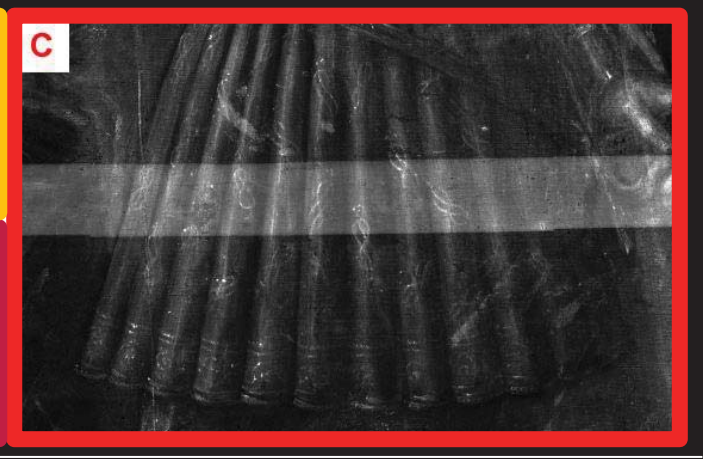
Portraits of the Savoy Family

From the Racconigi Castle (CN) – Italy

"FILIBERTO II" (1480 - 1504)





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Fake Etruscan "Bronzes"

Soprintendenza per i Beni Archeologici del Piemonte e del Museo Antichità Egizie

Bronze thickness:

from 2 to 10 mm

Operative conditions:

200 kV - 4,5 mA - 0,5 m/min

Lantern

Mirror

Statue

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Fake Etruscan "Bronzes"

Mirror

- **Increased readability**
- **State of conservation, critical points**

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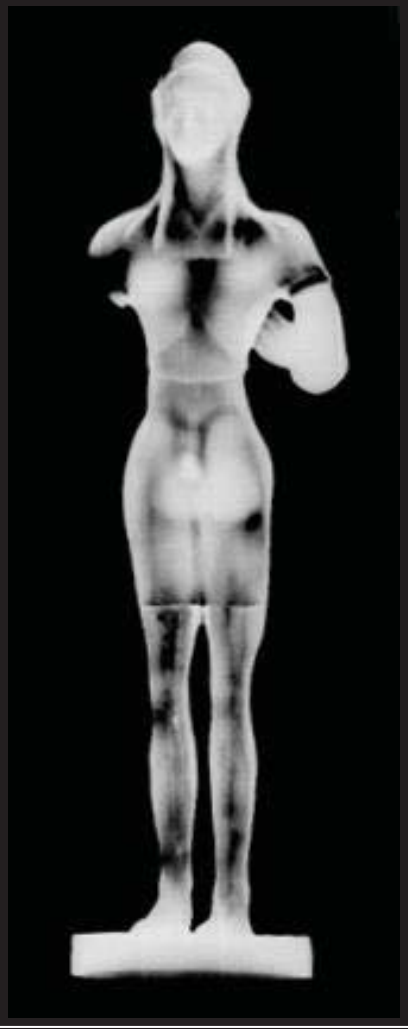
Fake Etruscan "Bronzes"

Statue: executive technique, state of conservation, critical points



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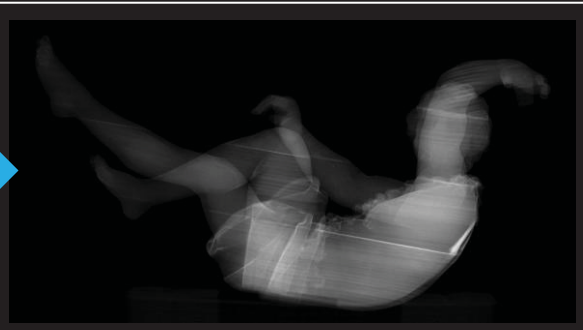
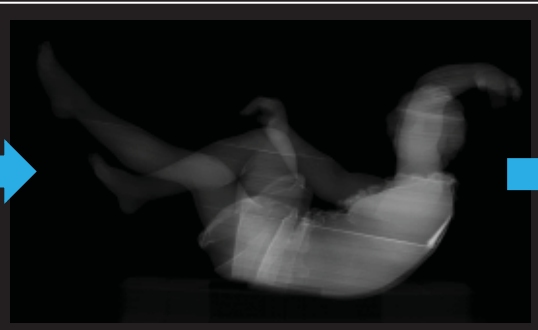
Computed tomography

CT reconstruction

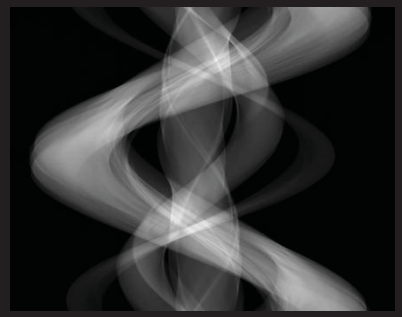
Raw radiograph



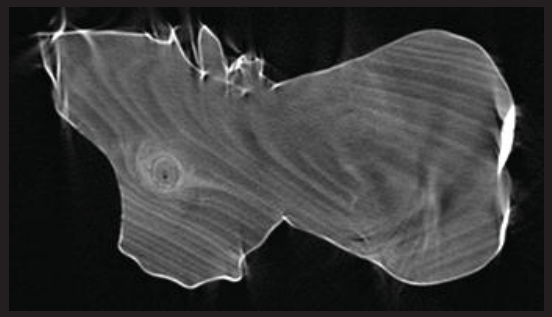
Corrected radiograph
(open beam and dark correction)



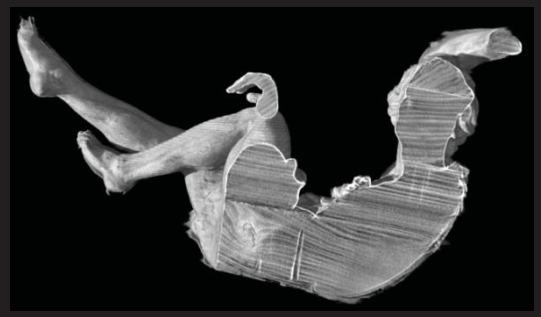
Sequence



Sinogram



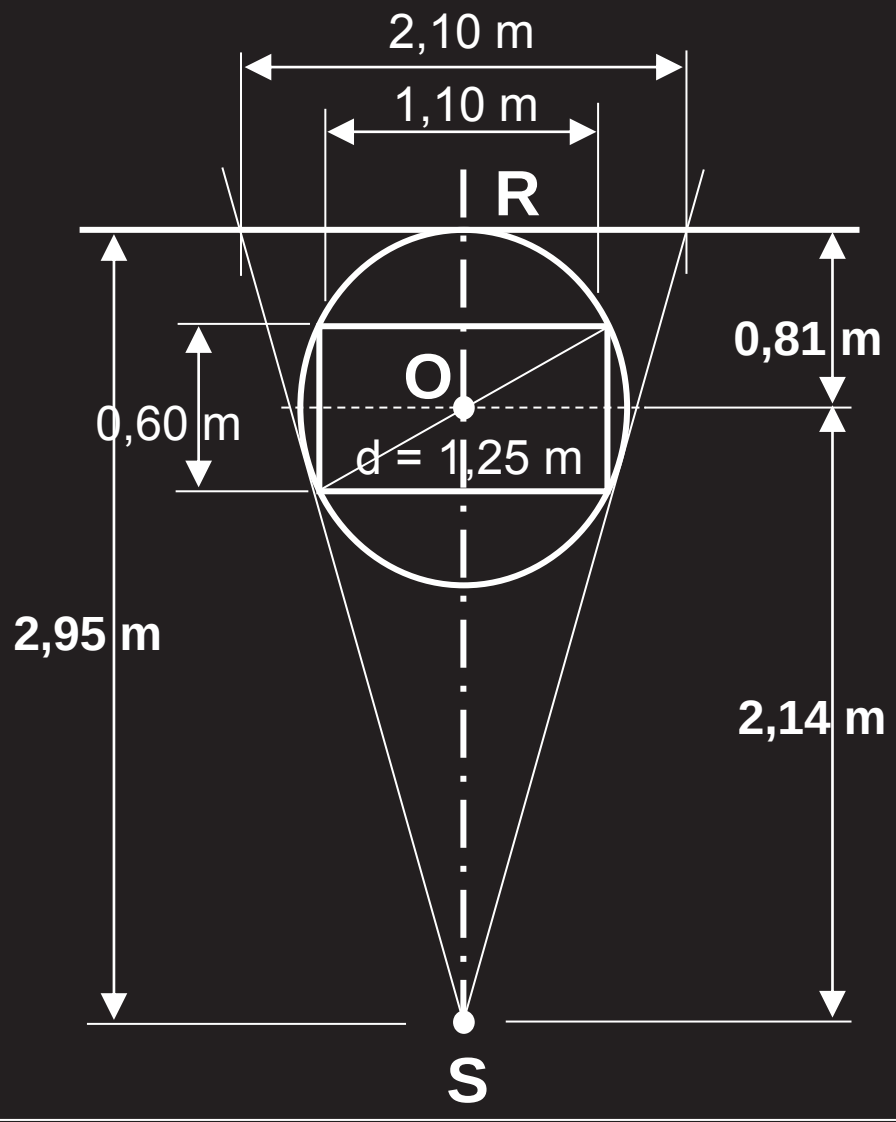
CT horizontal section



CT 3D rendering

CT reconstruction performed with a non-commercial software-utility developed by Dan Schneberk of Lawrence Livermore National Laboratory (USA), fan beam geometry and filtered back-projection algorithm

Acquisition parameters



Fan-beam geometry

- Distances:
  - Source-Detector: 2,95 m
  - Source-Object: 2,14 m
  - Object-Detector: 0,81 m
- Pixel size: 0,8 mm
- Magnification: 1,38 x
- Voxel size: 0,58 mm

X-ray beam

- Tube voltage: 180 kV
- Current: 5 mA
- Focal spot size: 3 mm
- Scan speed: 5 m/min

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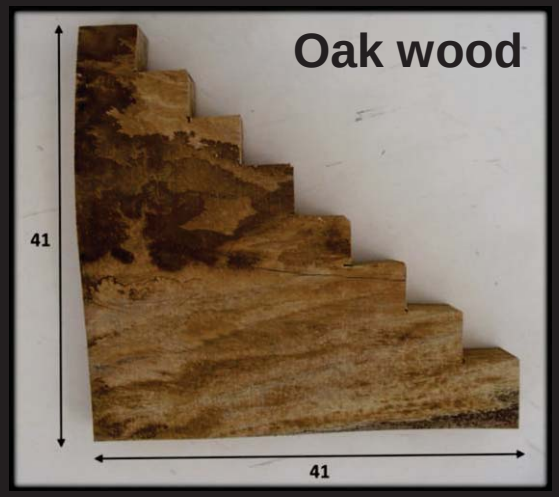
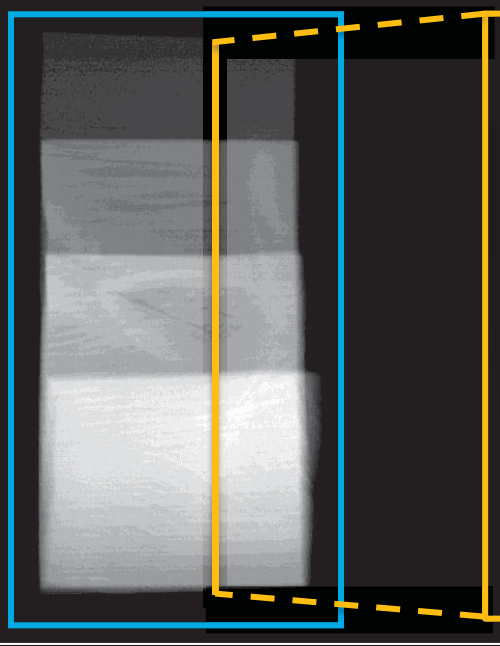
Test on some pieces of wood

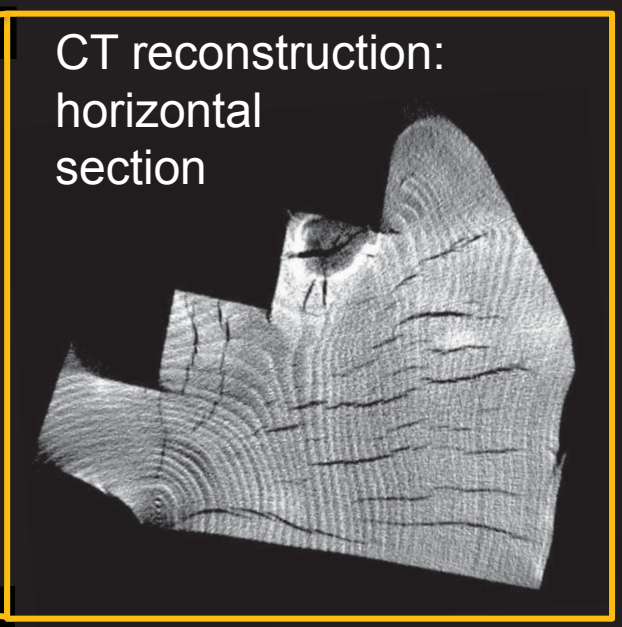
Sample prepared by the wooden artworks laboratory of the CCR "La Venaria Reale"

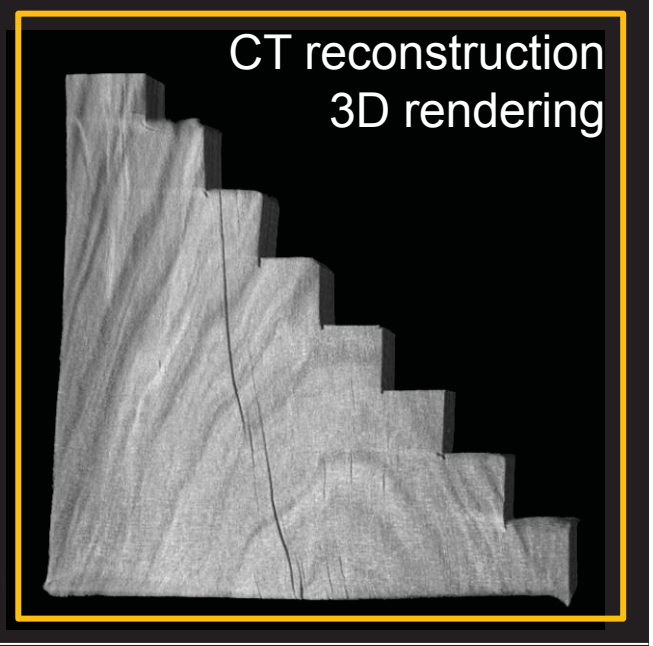
Centro Conservazione e Restauro La Venaria Reale



Radiograph







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Computed tomography

Earth block with hidden objects

From an archaeological excavation near L'Aquila (Italy)

Soprintendenza per i Beni Archeologici dell'Abruzzo

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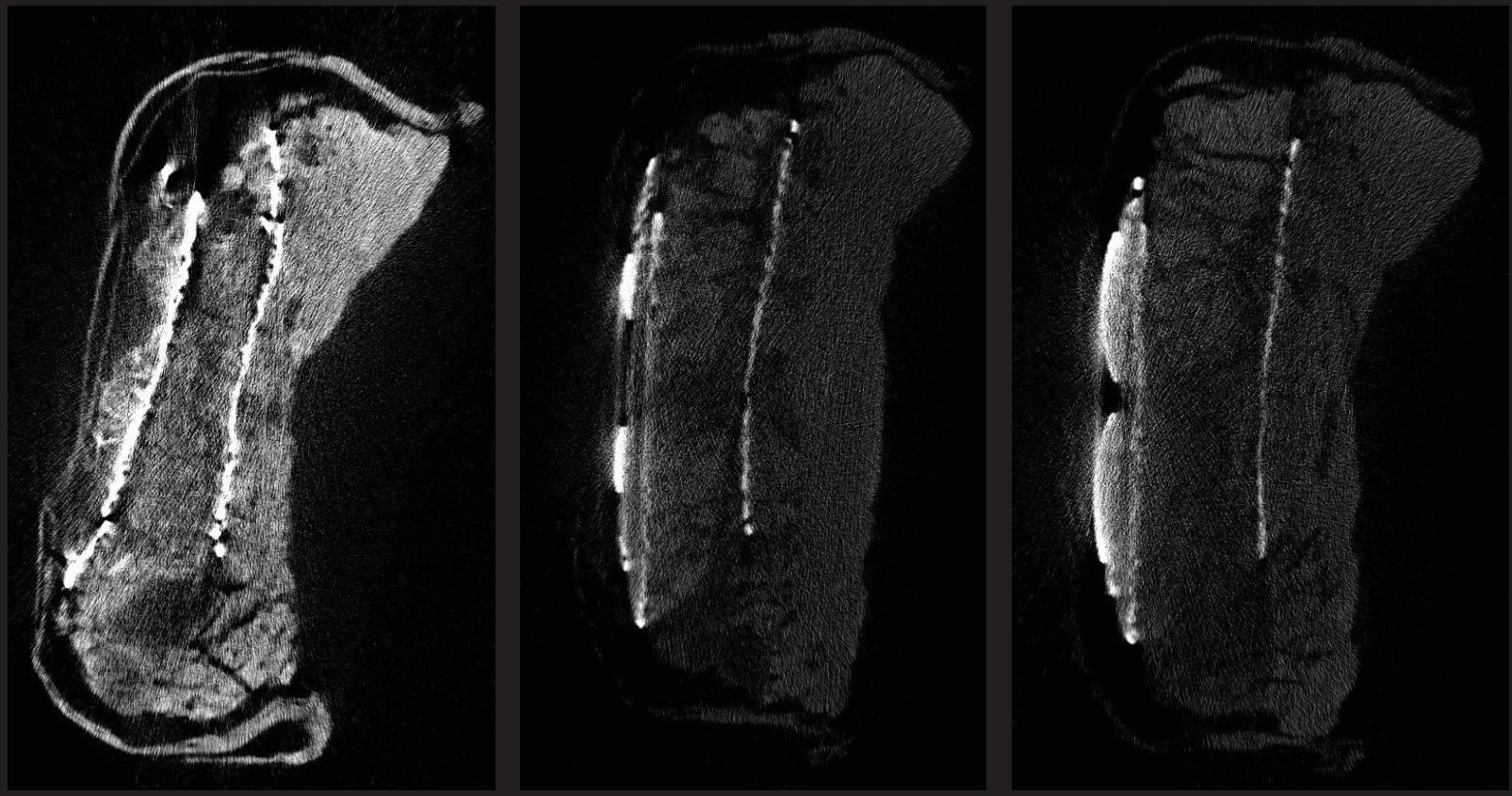
Earth block with hidden objects



CT reconstruction: horizontal sections

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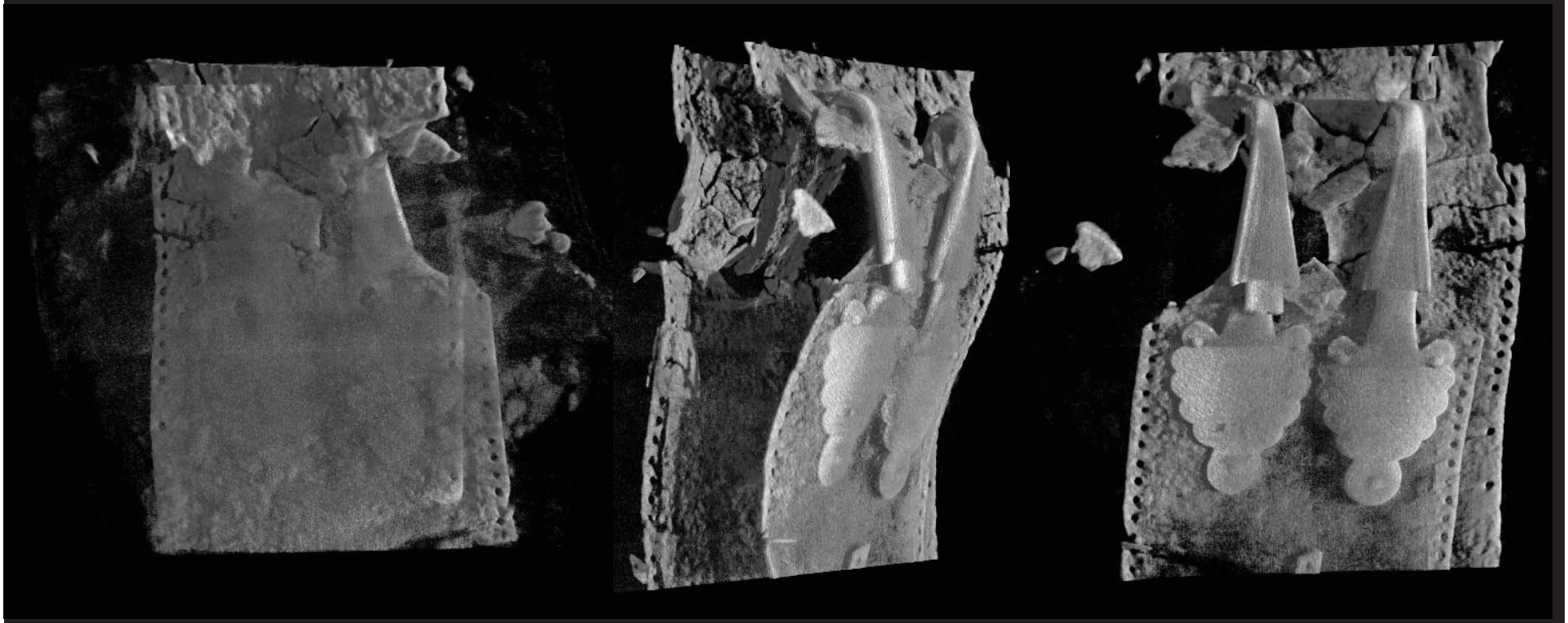
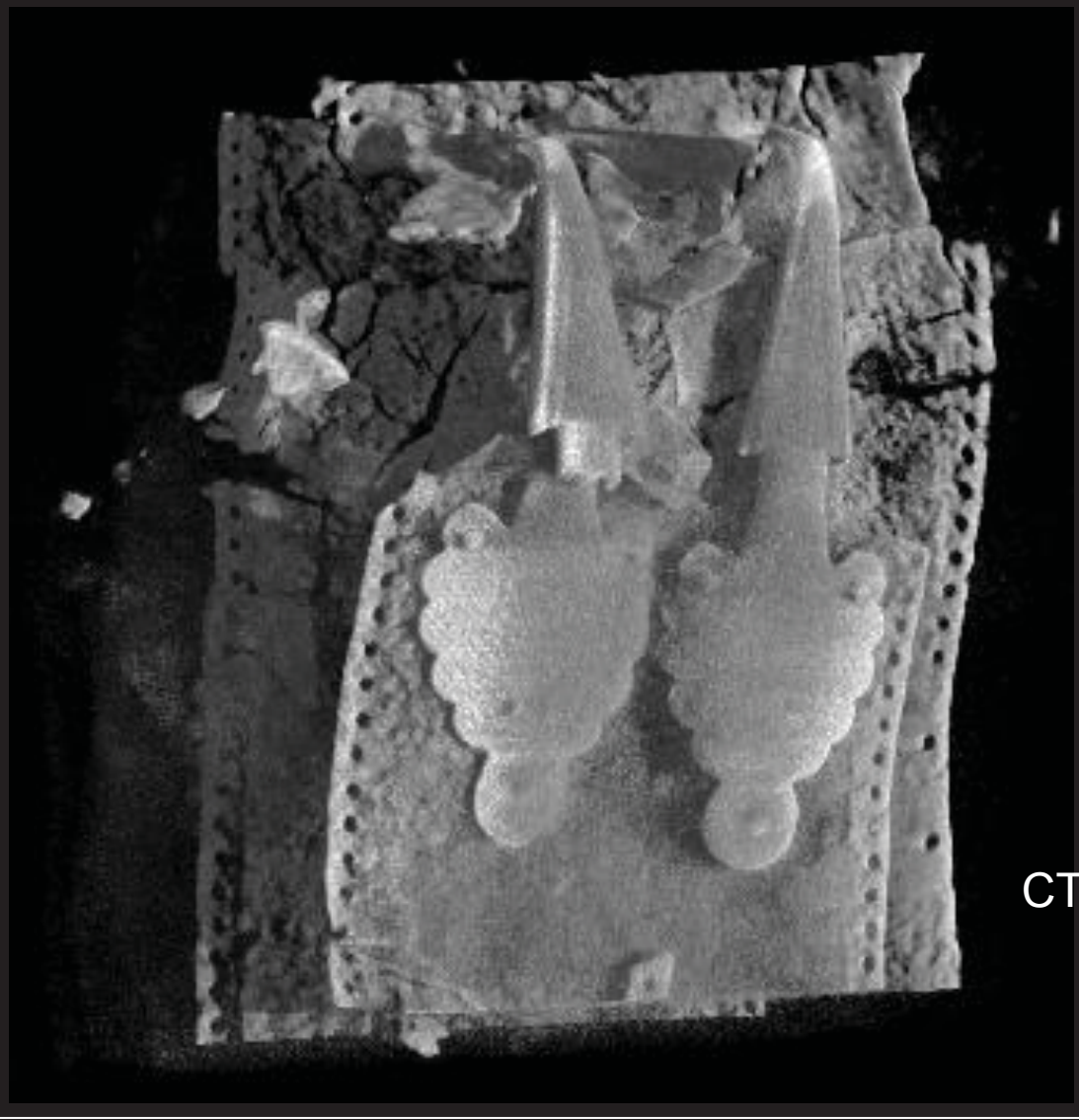
Earth block with hidden objects



CT reconstruction: 3D rendering

Earth block with hidden objects



CT reconstruction:
3D rendering

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Computed tomography

Wooden decorative column

From the "Etruscan Room", Racconigi Castle (CN) – Italy

Wooden column decorated with wooden inlays (XIX century)

Dimensions: 143 cm high; diameter: 35 cm

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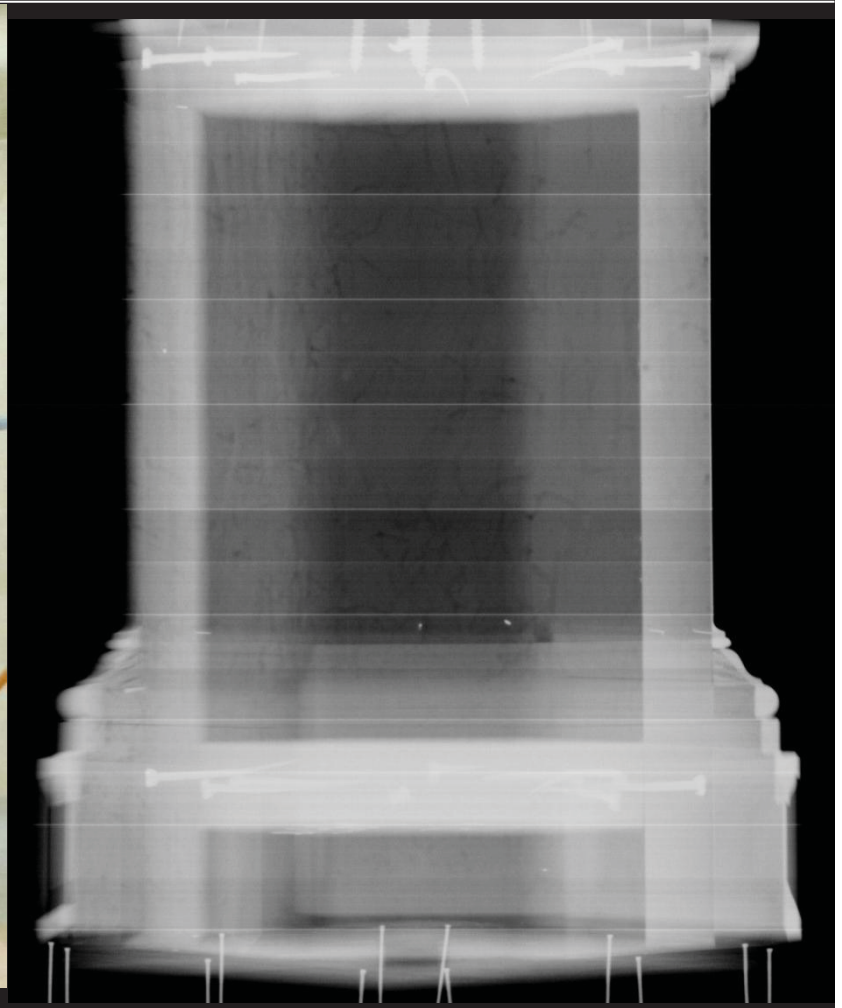
Computed tomography

Wooden decorative column



The plinth is empty

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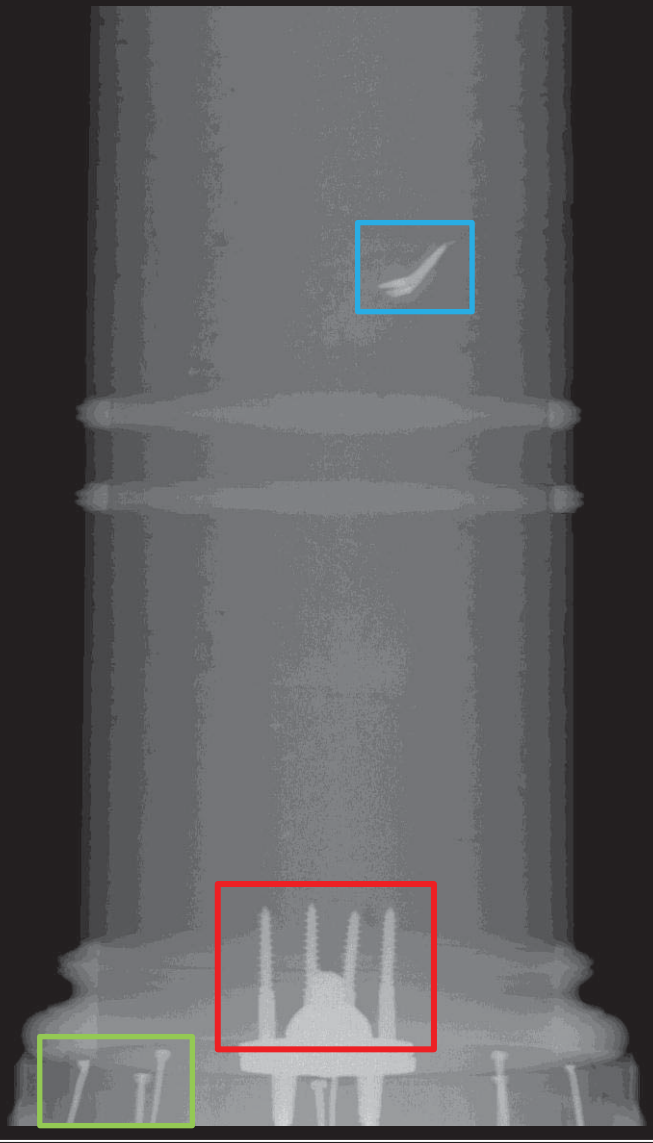
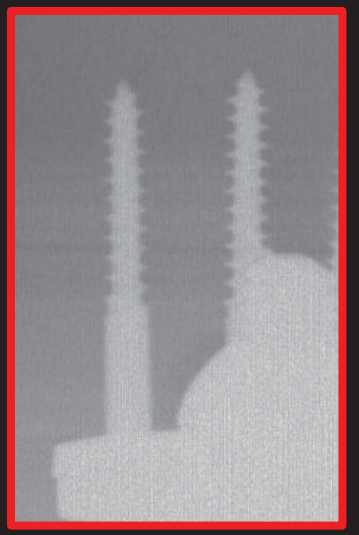
Computed tomography

Wooden decorative column



A nail in the main body of the column (not visible from outside)

Original nails



Modern screws

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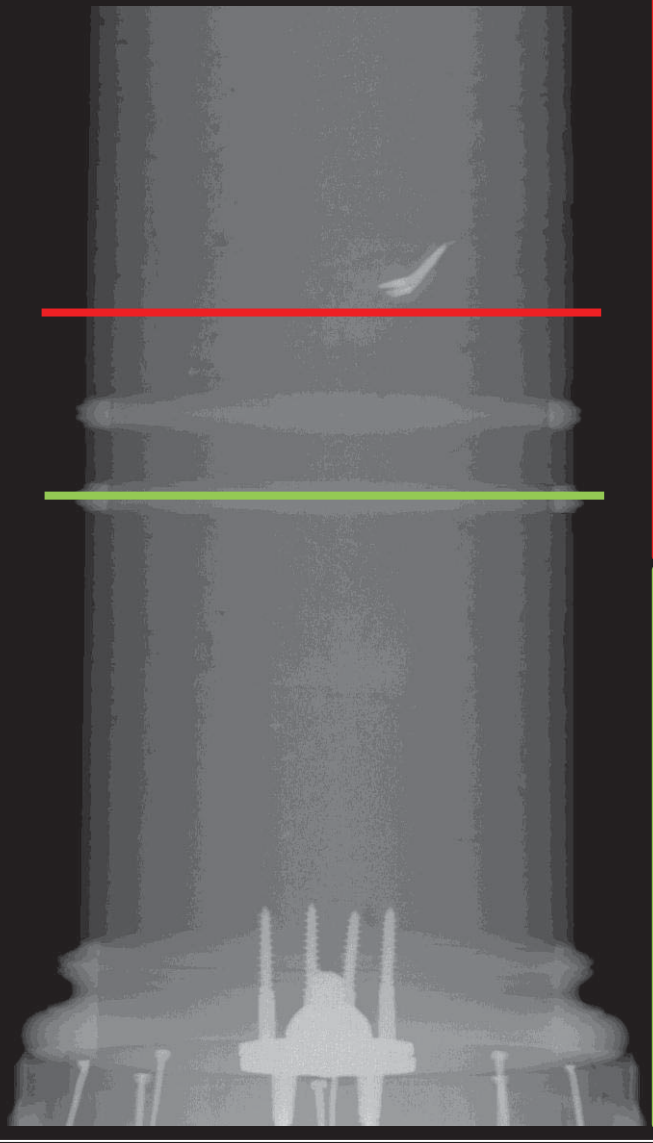
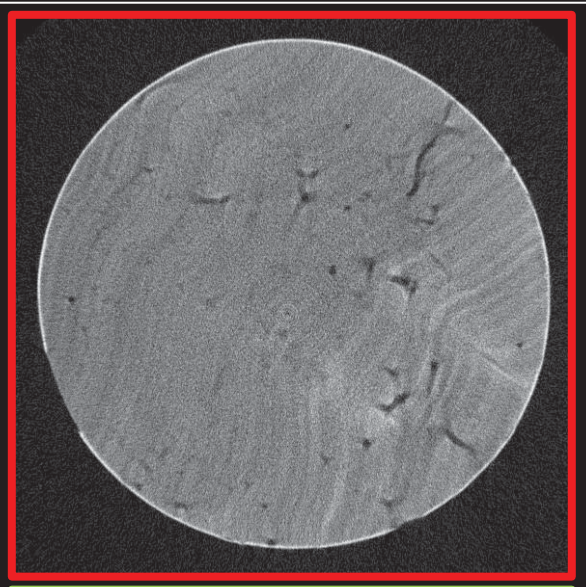
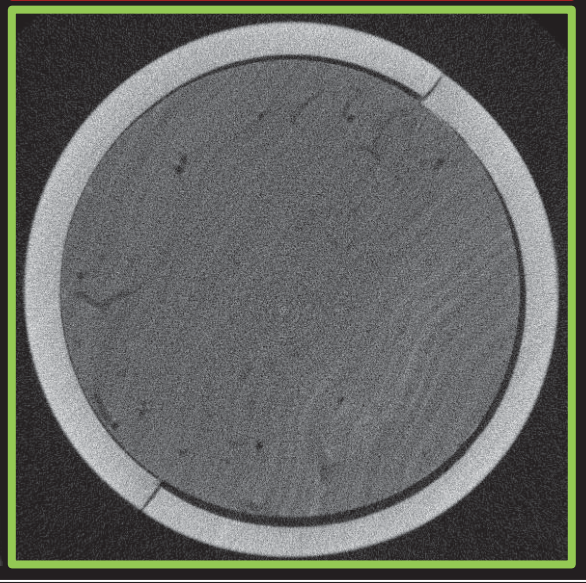
Computed tomography

Wooden decorative column





Holes of xylo-phagous insects



Decorative ring divided in two part and made in a different kind of wood

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Computed tomography

"Doppio Corpo" by Pietro Piffetti

- *Pietro Piffetti: one of the most famous European cabinetmakers of XVIII century (Savoy court)*
- *"Doppio corpo": part of the collections of Quirinale Palace in Rome*
- *Made of exotic woods, polychrome ivories, nacre, tortoiseshell*
- *Dimensions: 312 × 128 × 62 cm^3*

Why a tomography?

- Building technique
- Conservative conditions
- Previous interventions

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Computed tomography

"Doppio Corpo" by Pietro Piffetti

- Size: 129 x 59 x 312 cm^3
- Horizontal sections: 13
- Radiographs/sections: 720
- Total radiographs: 9360
- Resolution: 10500x2560 $pixel^2$
- Pixel size: 200 µm
- Scanned area: 2.1 x 0.5 m^2
- Output: 12 bit
- Image size: 51,3 MB
- Disk space: 437 GB
- Mean time for a section: 10 hours
- Total time: 5,6 days

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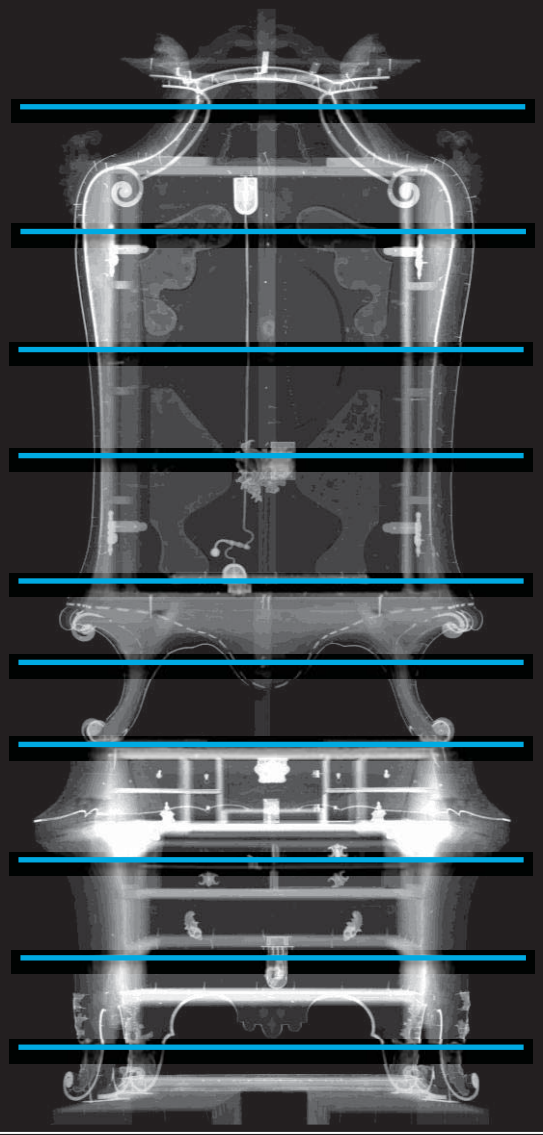
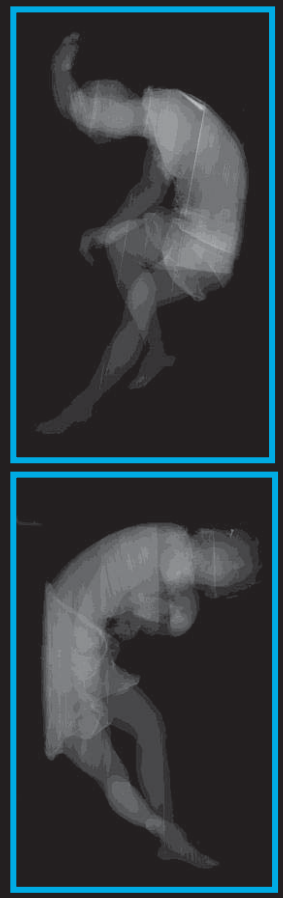
Computed tomography

"Doppio Corpo" by Pietro Piffetti





Radiographs of the
13 horizontal sections

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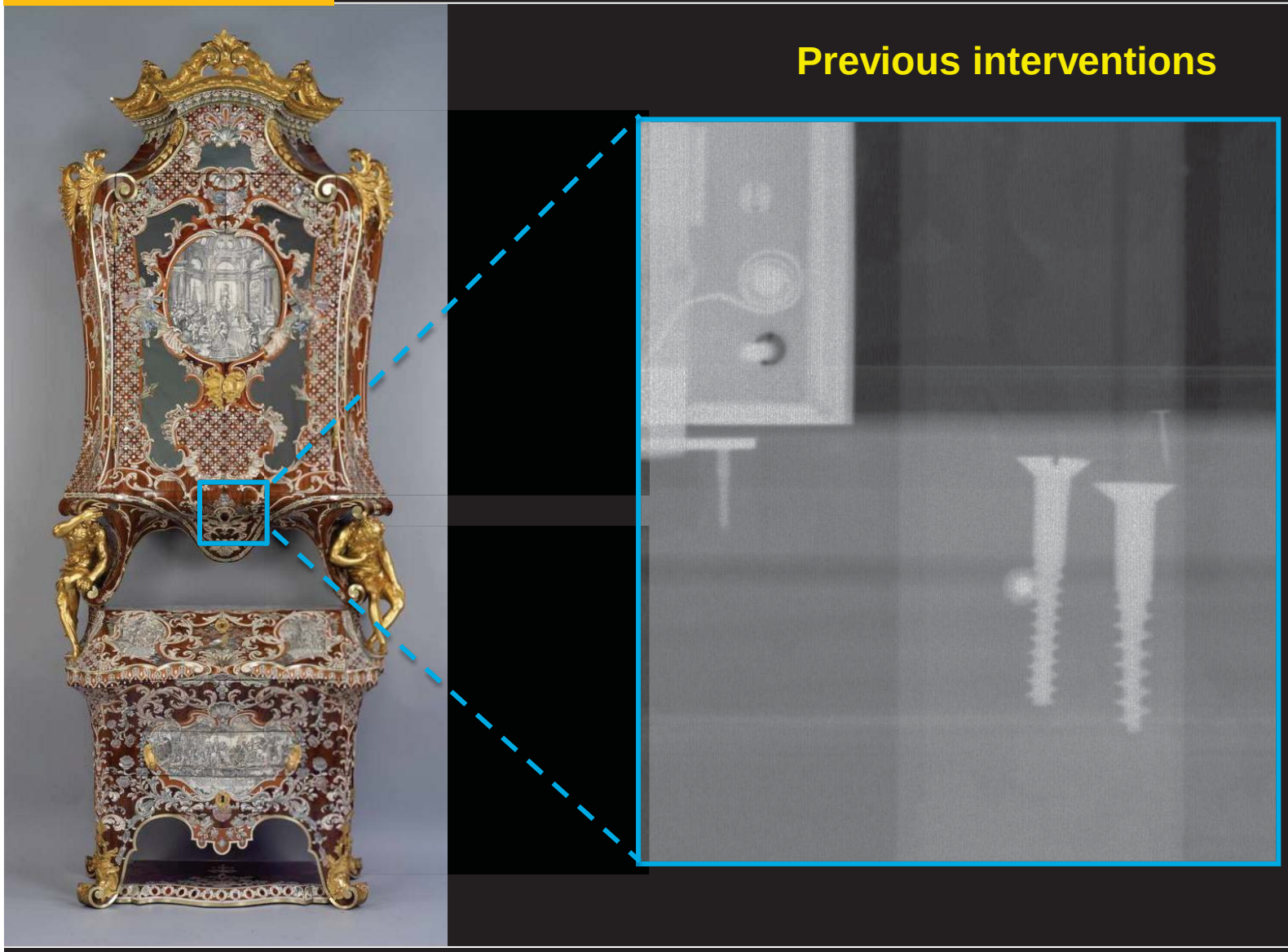
Computed tomography

“Doppio Corpo” by Pietro Piffetti



Previous interventions

Radiograph:

screws are different and more recent than the ones employed by Pietro Piffetti in other artworks

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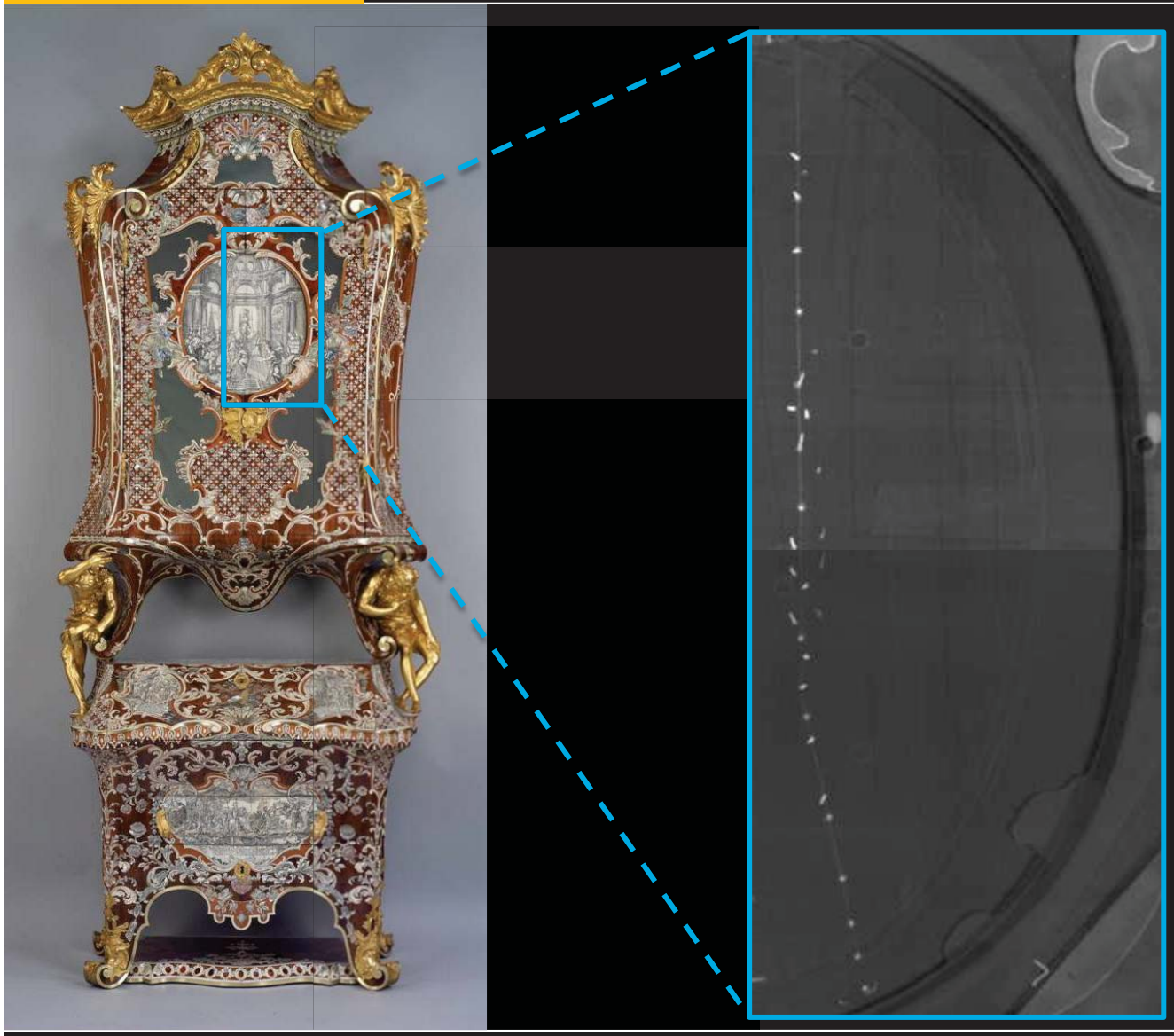
Computed tomography

“Doppio Corpo” by Pietro Piffetti



Previous interventions

Radiograph:

row of small nails (not visible either from the outside or from the inside) to repair a longitudinal fractures of the wood behind the ivory plate in the door, to fix a crevice

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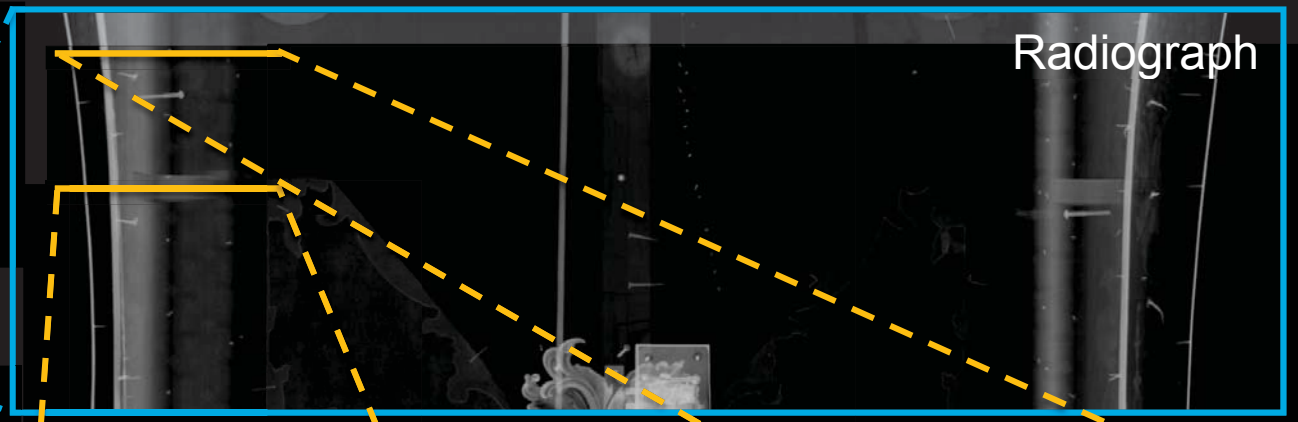
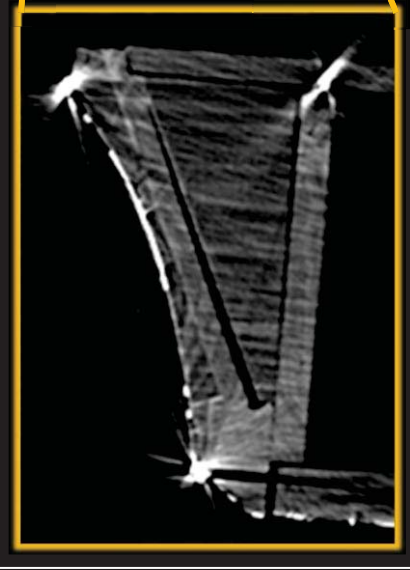
Computed tomography

"Doppio Corpo" by Pietro Piffetti

Building technique





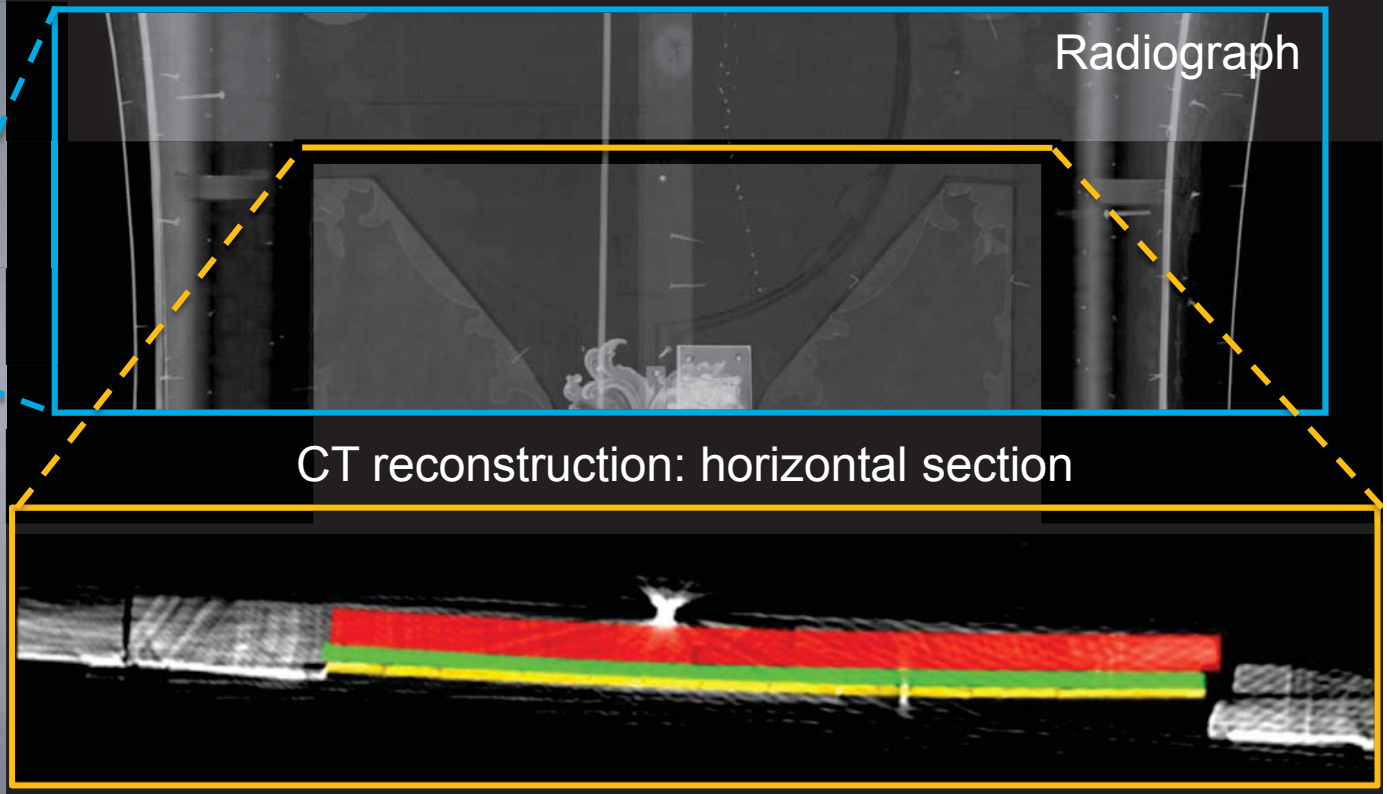
CT reconstruction: horizontal section

three triangular spacers in the external side

Computed tomography

"Doppio Corpo" by Pietro Piffetti

Building technique



Layer 1: ivory veneer (half cm thick)

Layer 2: thin wooden layer (one cm thick)

Layer 3: wooden support

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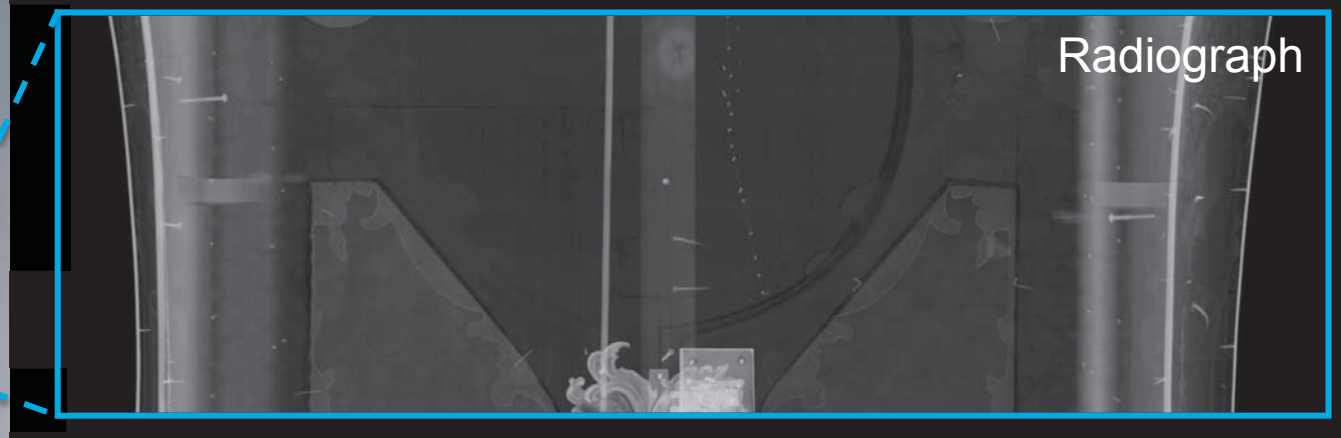
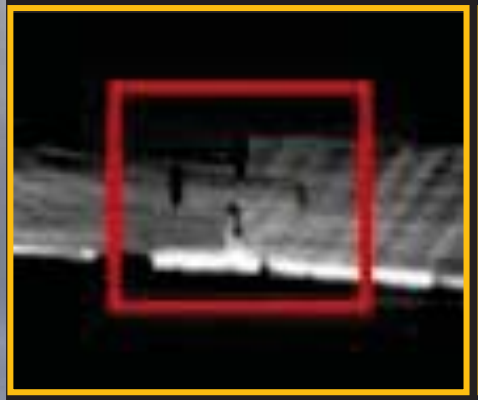
Computed tomography

"Doppio Corpo" by Pietro Piffetti

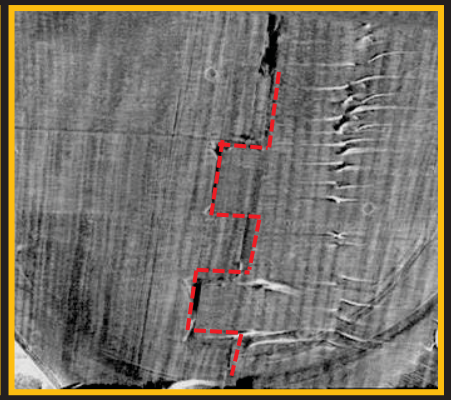
Building technique



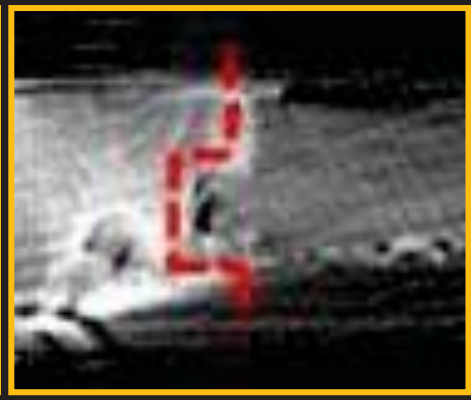
CT reconstruction:
different kinds of joints



tonguings



cogs



cog and groove

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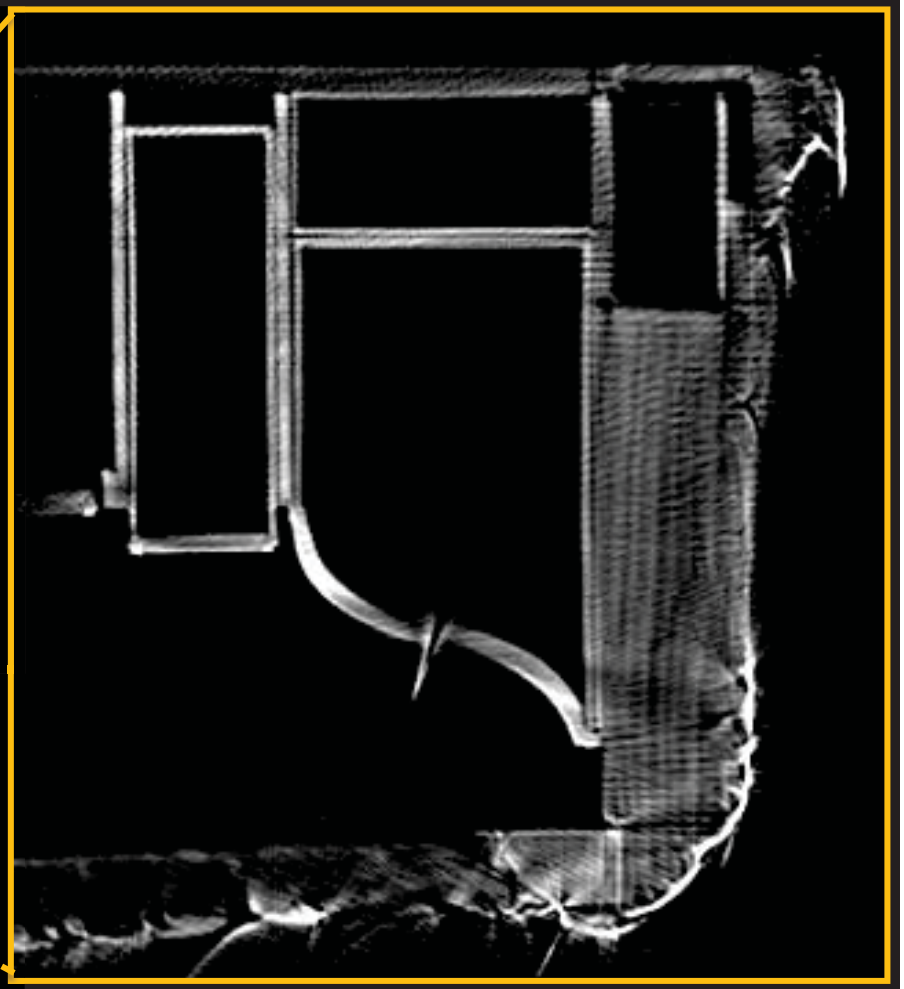
Computed tomography

"Doppio Corpo" by Pietro Piffetti

Building technique

CT reconstruction: horizontal section

secret drawers and openings



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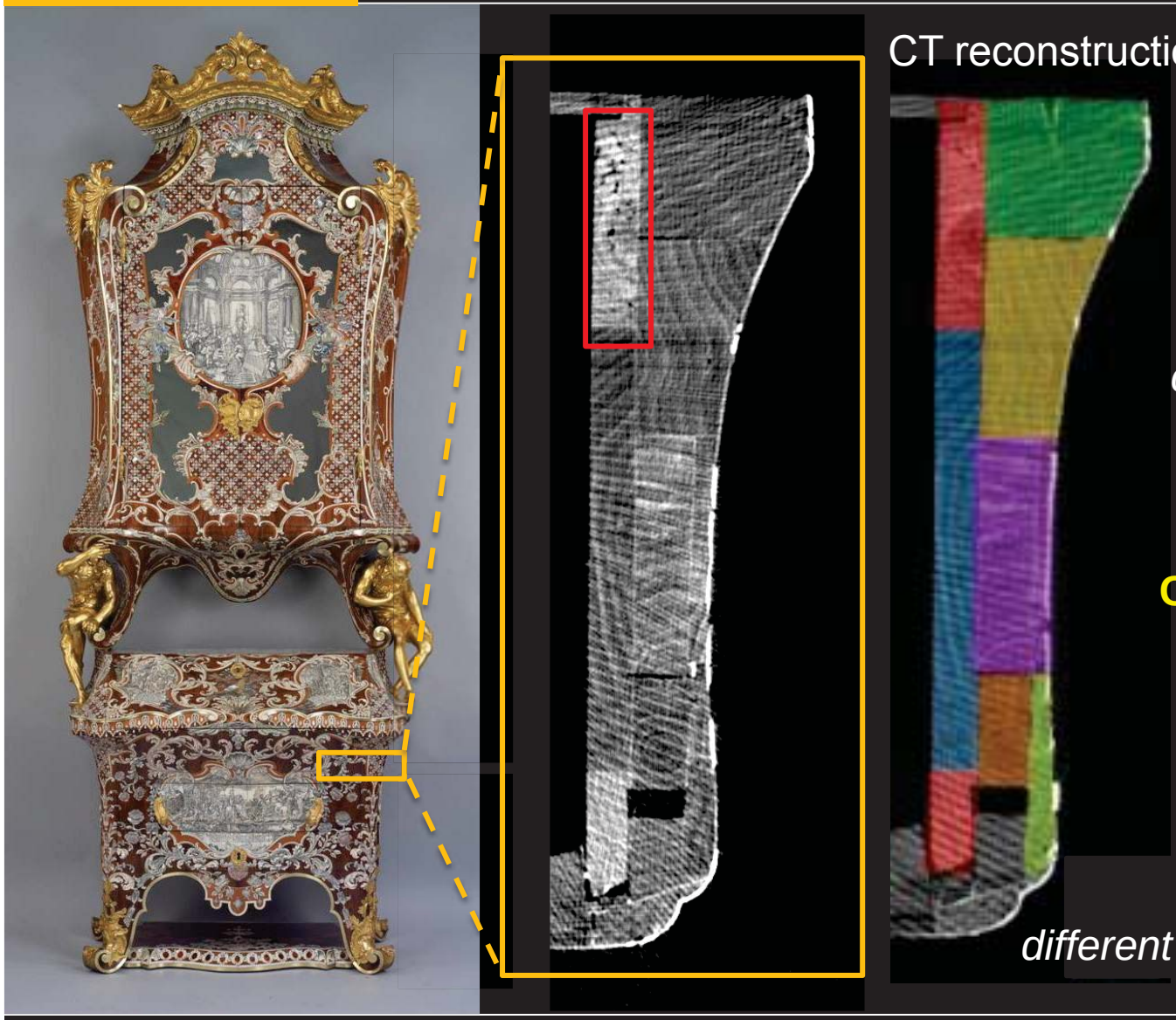
Computed tomography

"Doppio Corpo" by Pietro Piffetti



CT reconstruction: horizontal section

Building technique

cavity and brighter blocks (probably walnut wood)

Conservative conditions

holes of xylophagous insects

different wooden blocks highlighted

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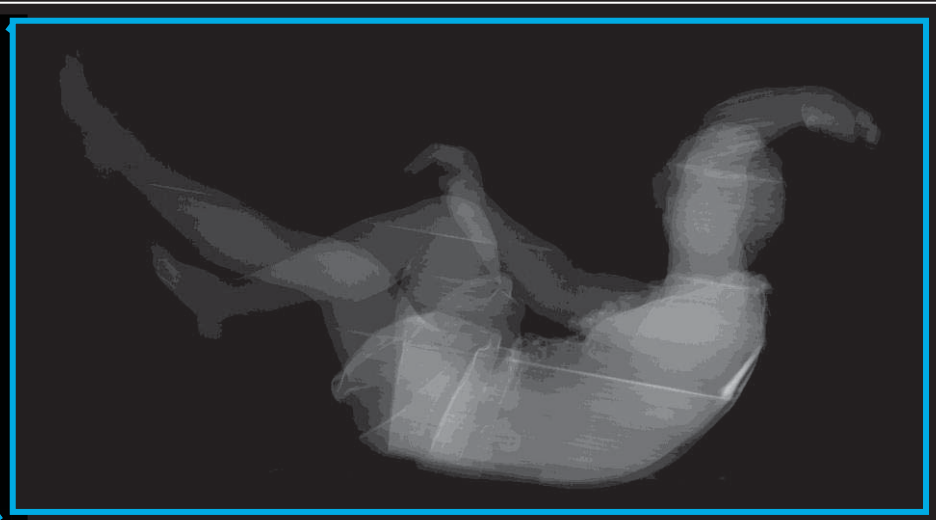
Computed tomography

"Doppio Corpo" by Pietro Piffetti



Radiograph

Building technique

CT reconstruction: 3D rendering

composed by many parts pasted together

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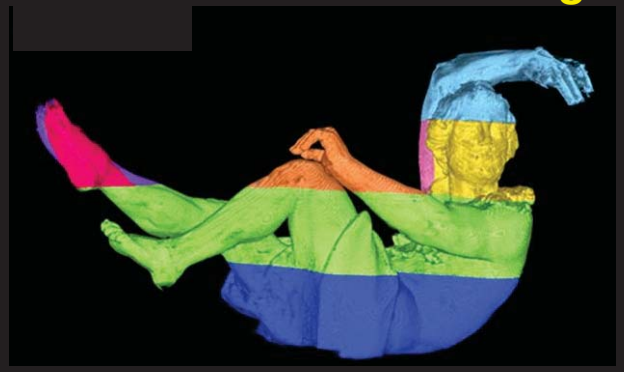
Computed tomography

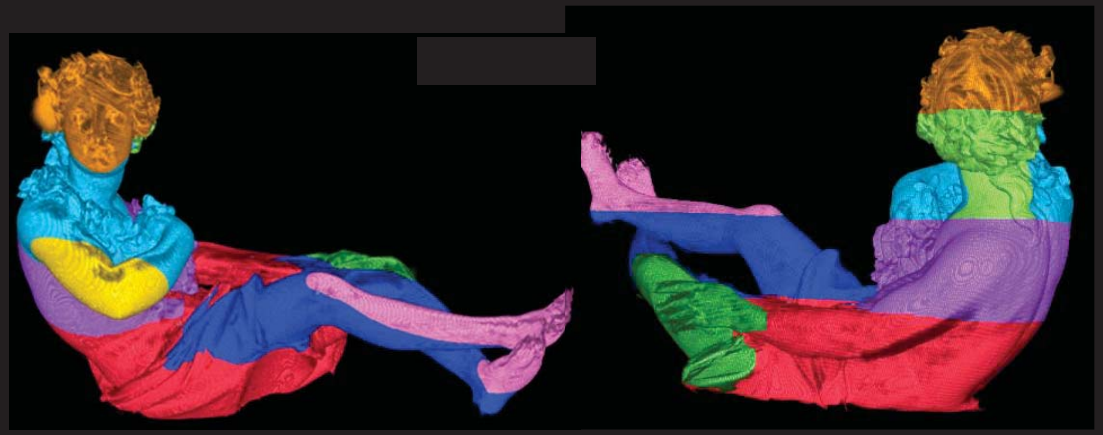
"Doppio Corpo" by Pietro Piffetti

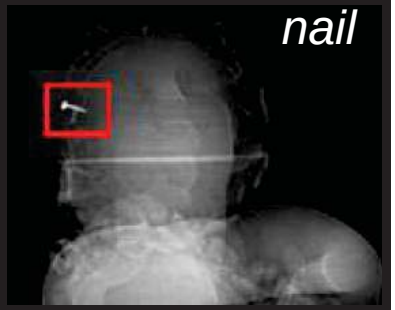
Building technique



CT reconstruction: 3D rendering

different wooden blocks highlighted





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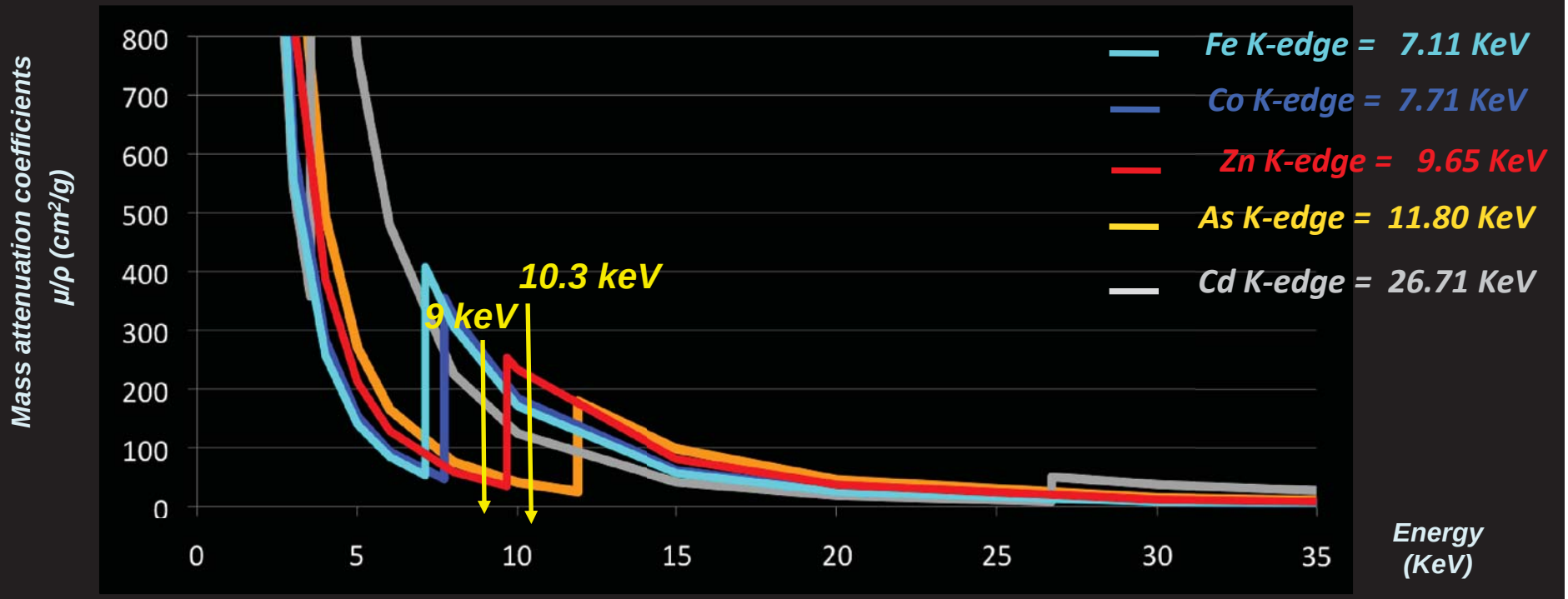
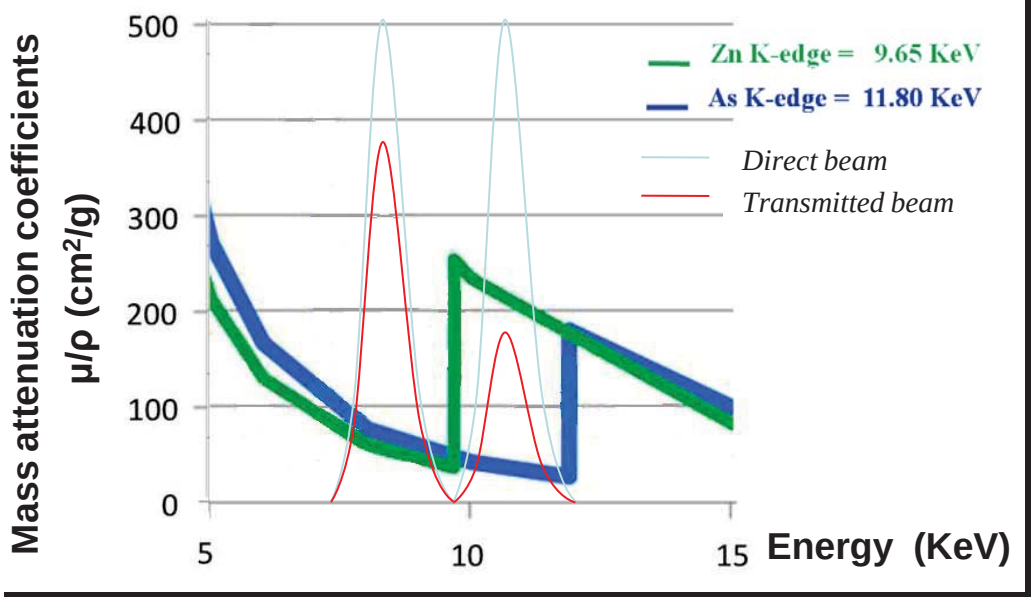
Description of the method

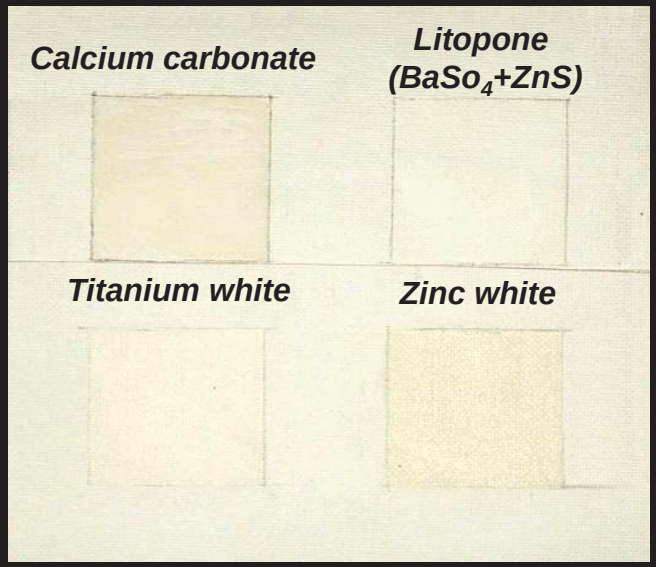
Takes advantage of the sharp rise of X-ray absorption coefficient of the investigated element

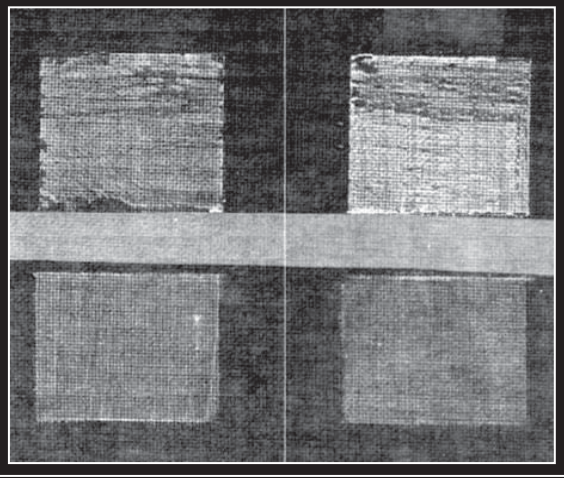


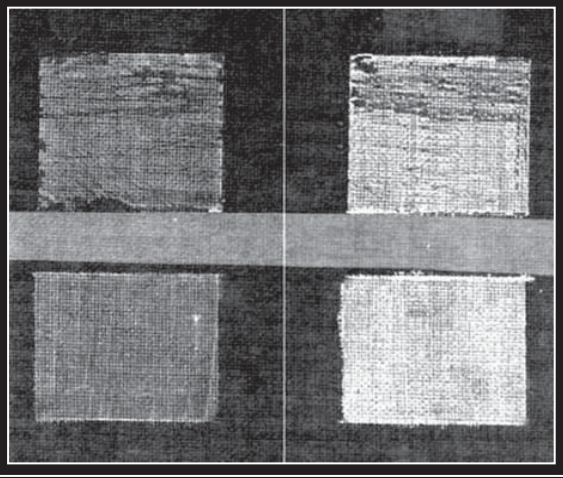
Two monochromatic images, with energy braketing K-edge, are acquired. With an algorithm processing an elemental mapping is obtained.

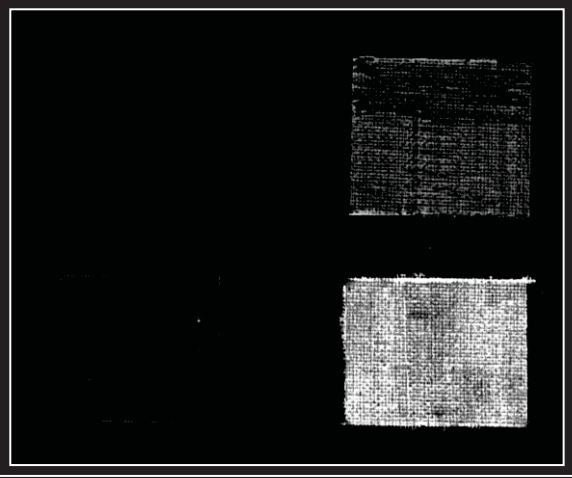
Description of the method











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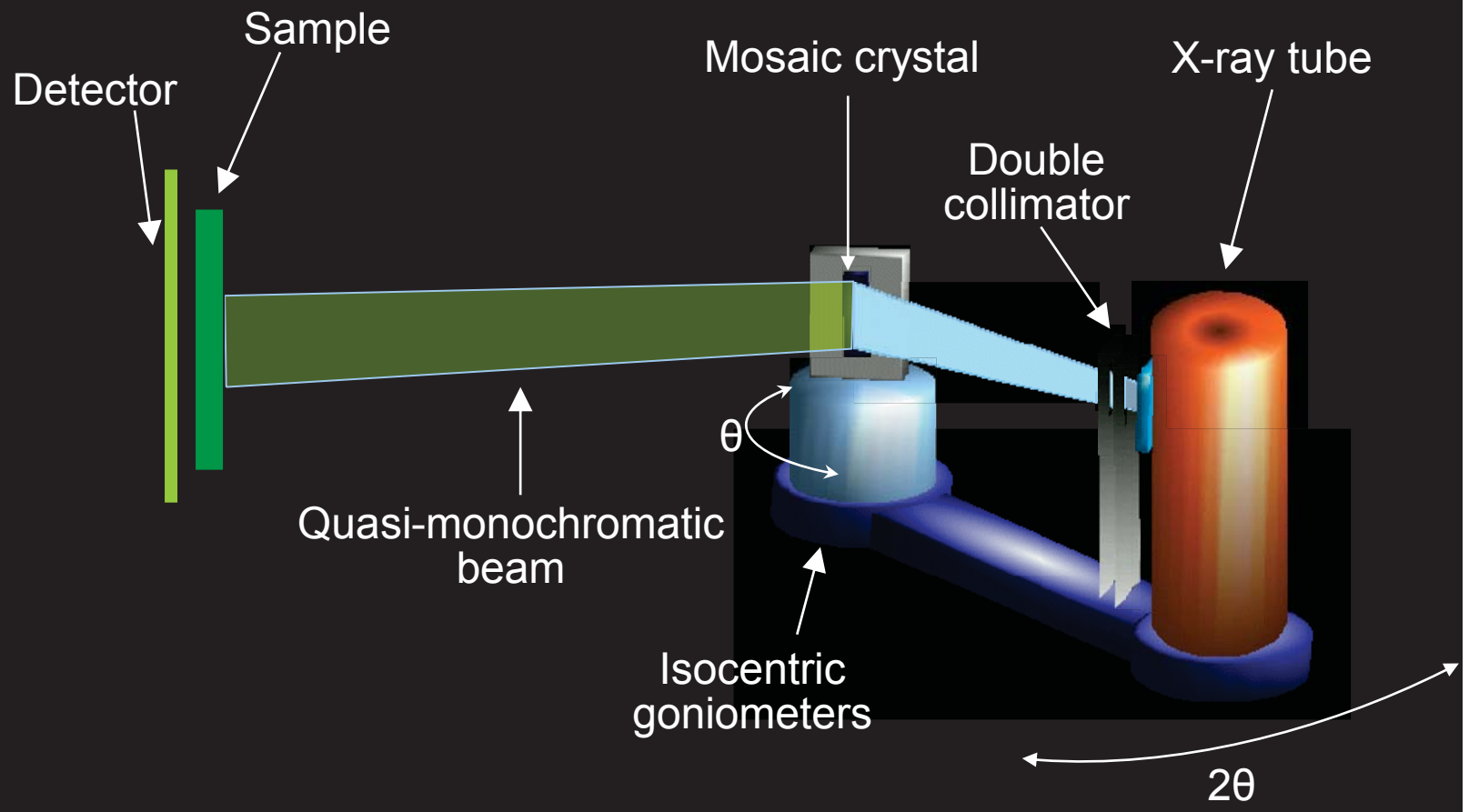
Experimental setup



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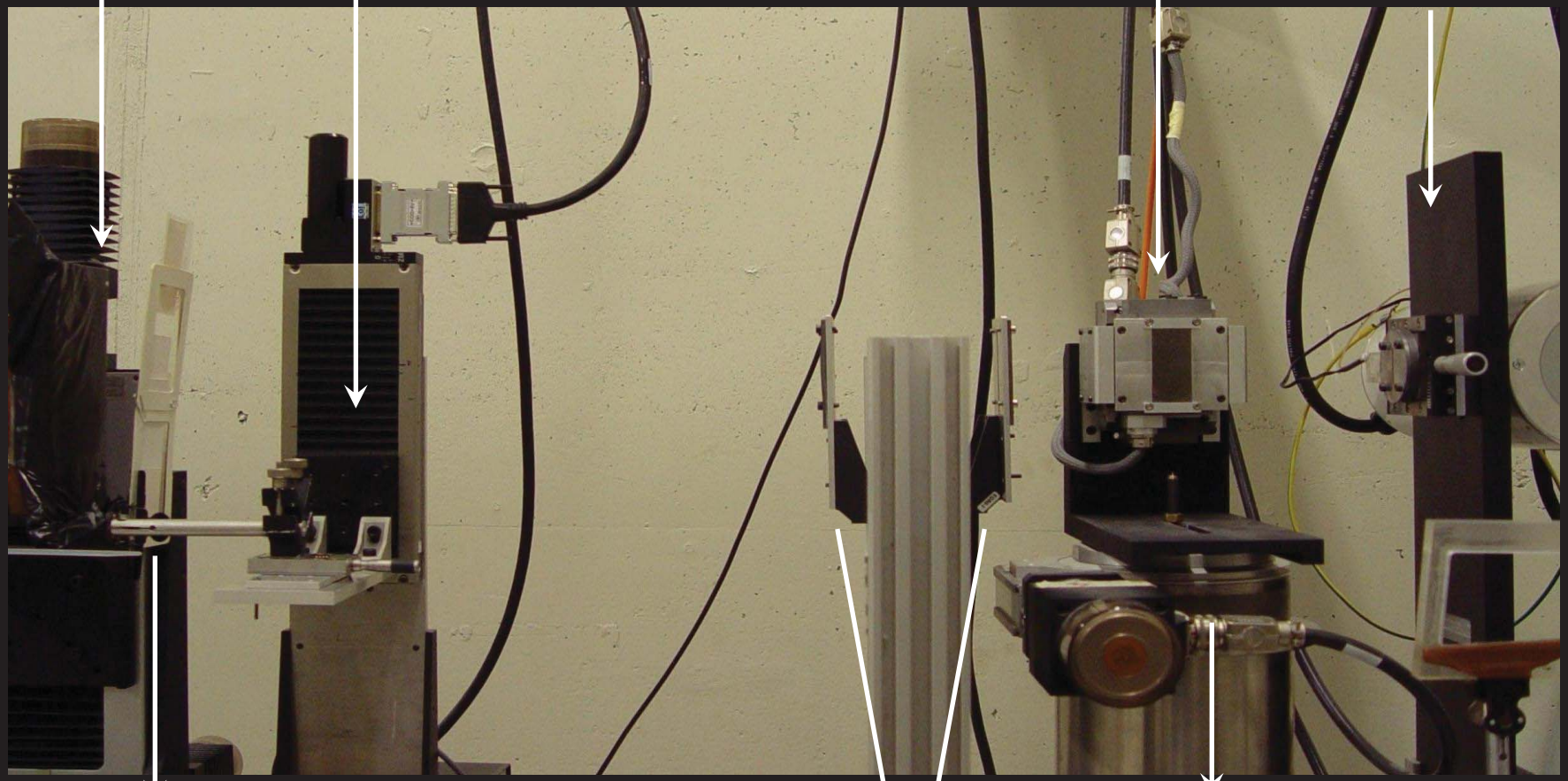
Experimental setup



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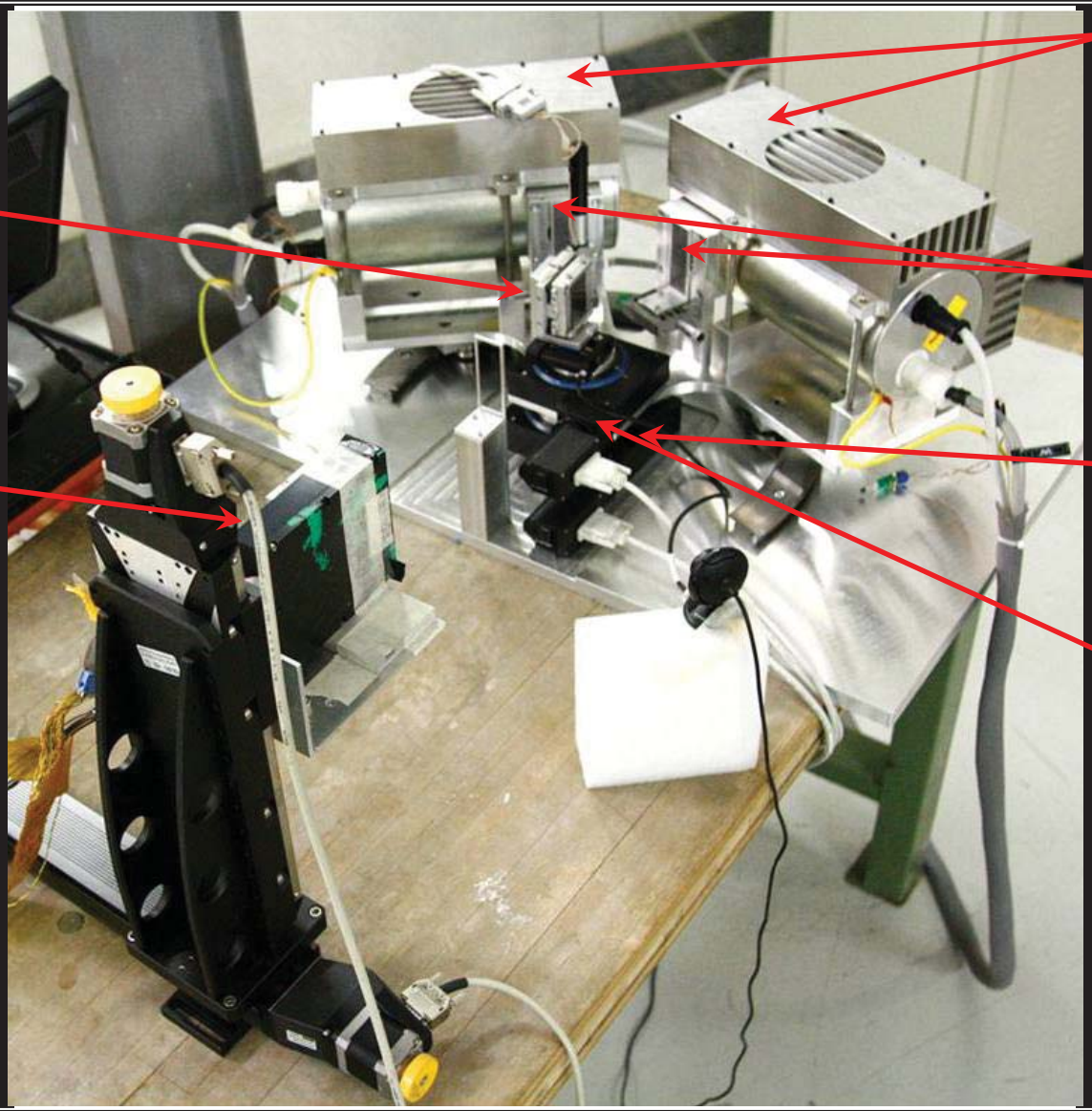
Experimental setup



X-ray tubes Metaltronica (Mo and W)

Collimators

Goniometer for the X-ray tube

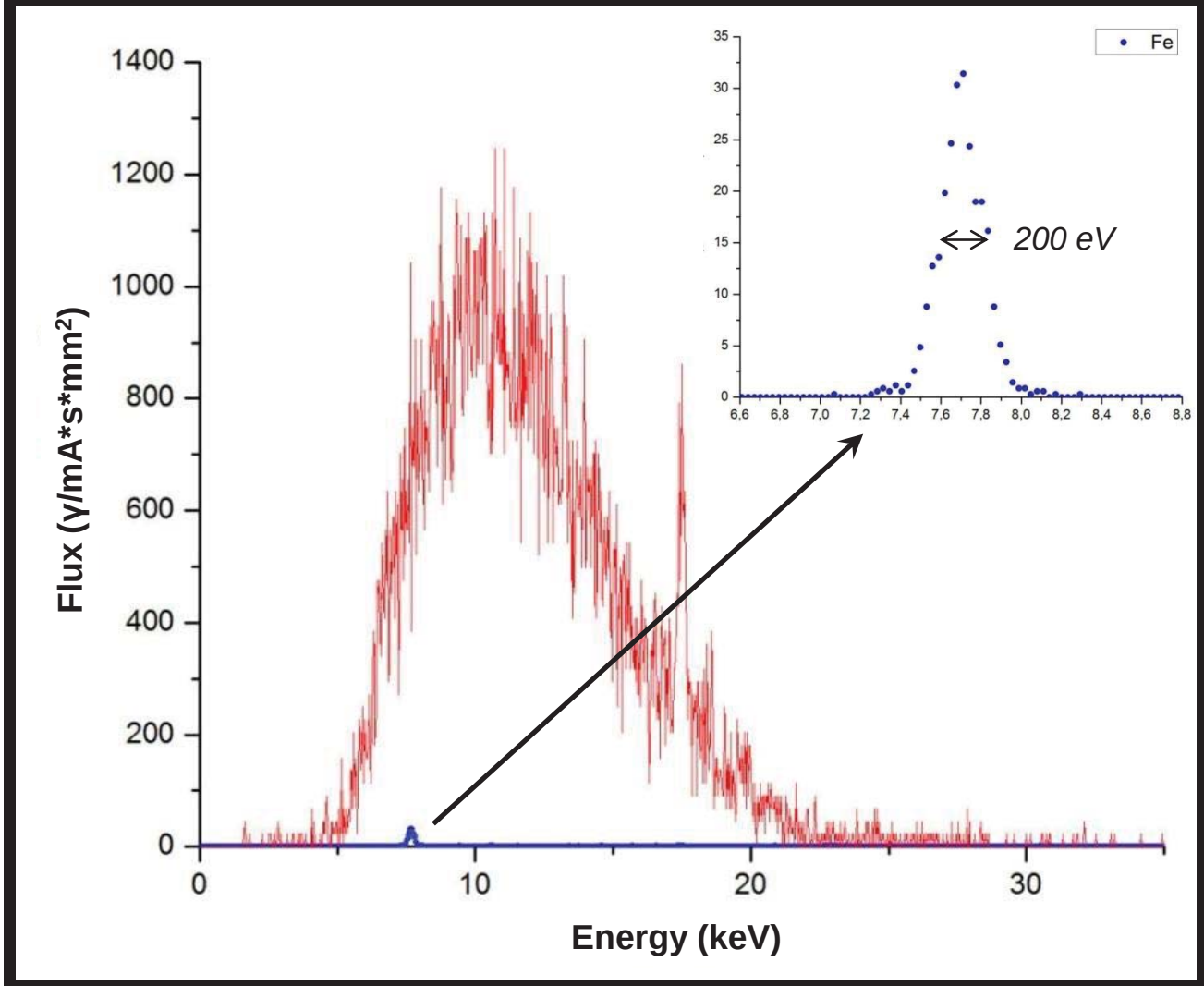
Goniometer for the crystal

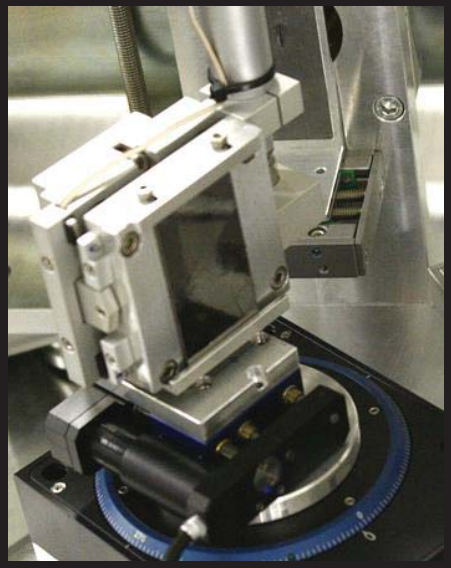
Mosaic crystal (graphite)

SSD detector

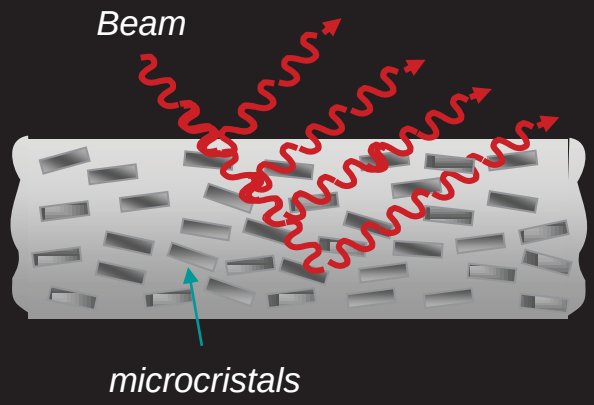
Amptek Si-PIN XR-100CR

Experimental setup





Grafite d = 3.365 Å

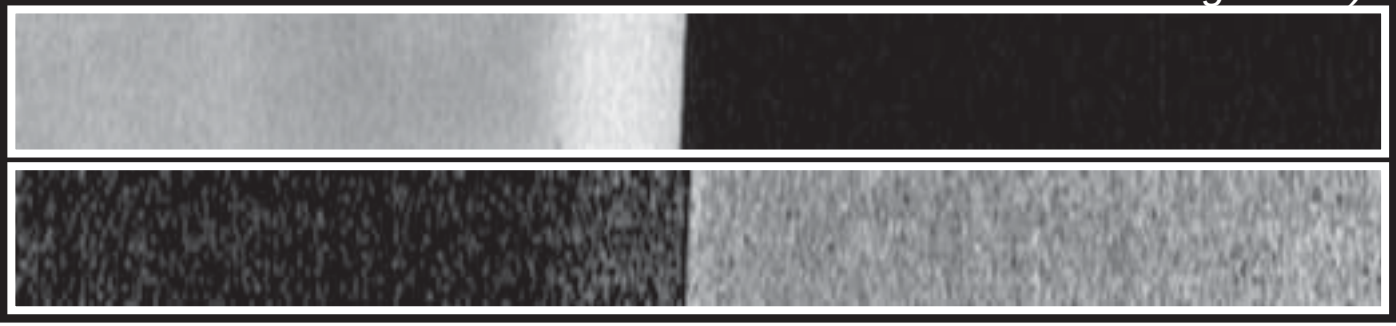


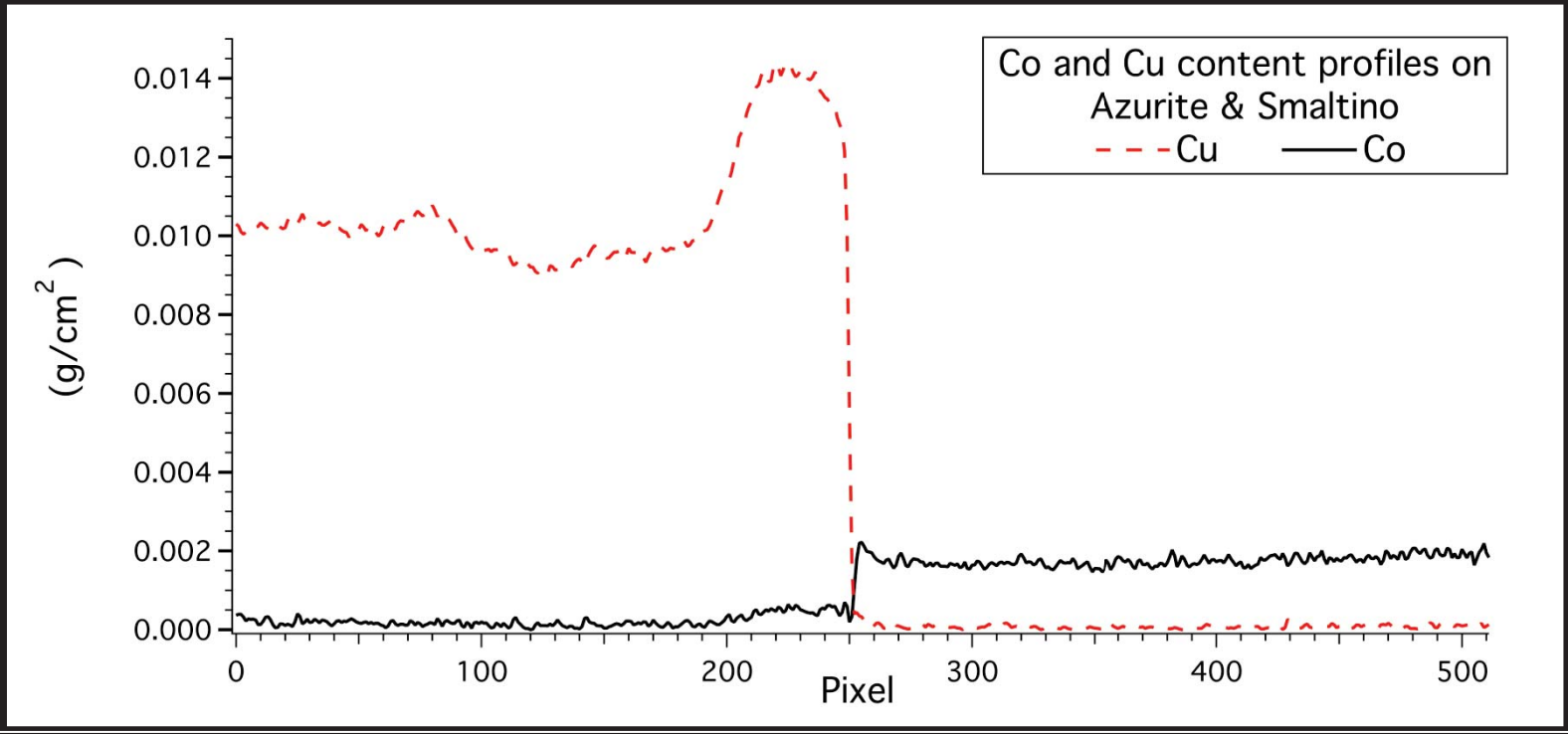
Test on canvas #1

Azurite ($2CuCO_3 \cdot Cu(OH)_2$) *Smaltino* *(potassium glass containing cobalt)*

Cu imaging
K-edge: 8.97 keV

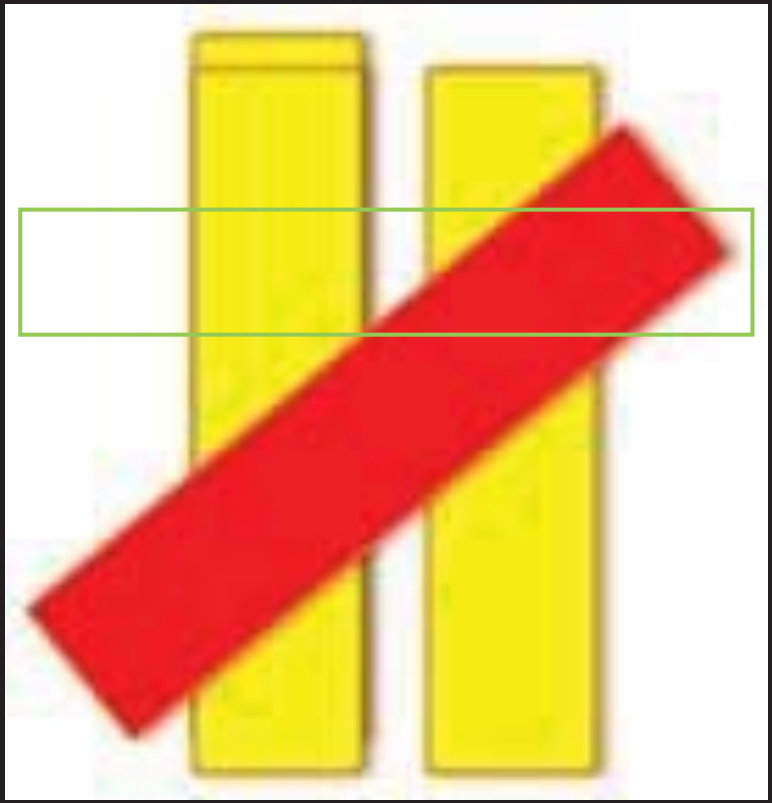
Co imaging
K-edge: 7.7 keV



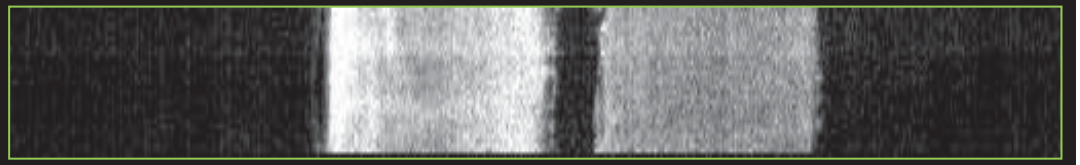


Test on canvas #2

Single Cadmium Red (CdS) pigment layer (diagonal)
on a double (on the left) and single (on the right)
Naples Yellow ($Pb_2Sb_2O_7$) layers pigments (vertical)



Sb imaging (K-edge: 30.49 keV)



Cd imaging (K-edge: 26.71 keV)

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Acknowledgements

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Thanks for your attention!

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