Materials science for the cultural heritage

Gilberto Artioli

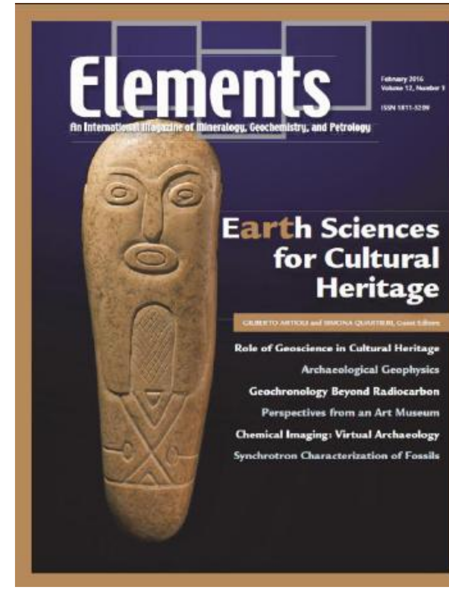
Dip. Geoscienze UNIPD
CIRCe Center for Cement Materials

Rovereto - Dec 2018

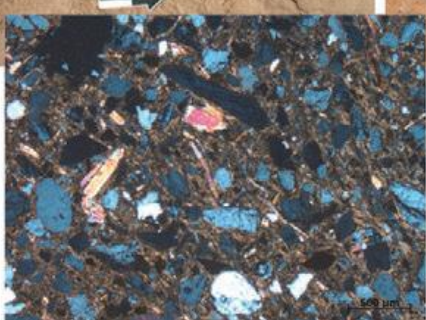
Remote / Large scale survey

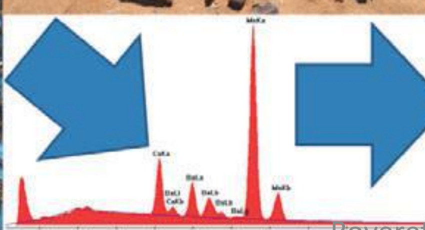
Field / Site survey

Excavation / Stratigraphy

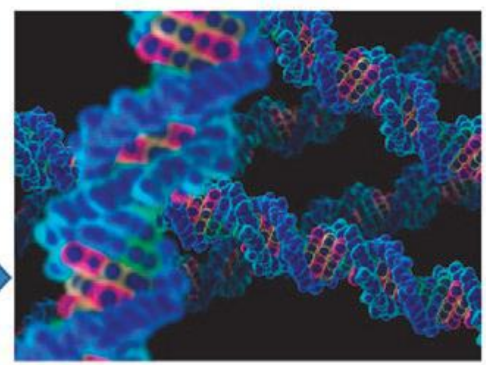


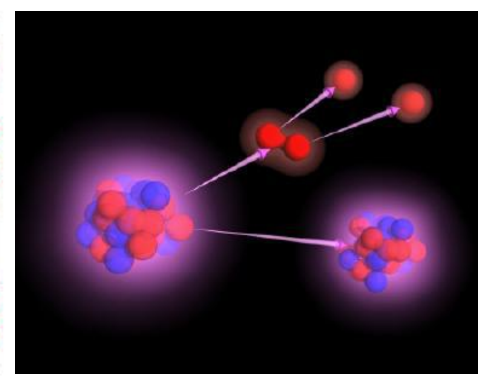
Nature of materials





Laboratory analyses





Molecular archaeology

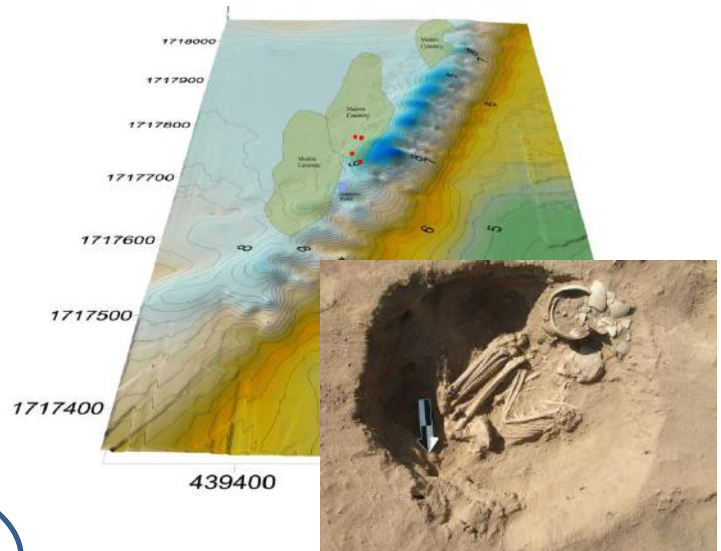
Geologi
Sedimentologi
Geomorfologi

Archeologi

Metereologi
Paleoclimatologi

Biologi
Microbiologi

Mineralogisti
Petrografi



Botanici
Palinologi

Chimici

Fisici

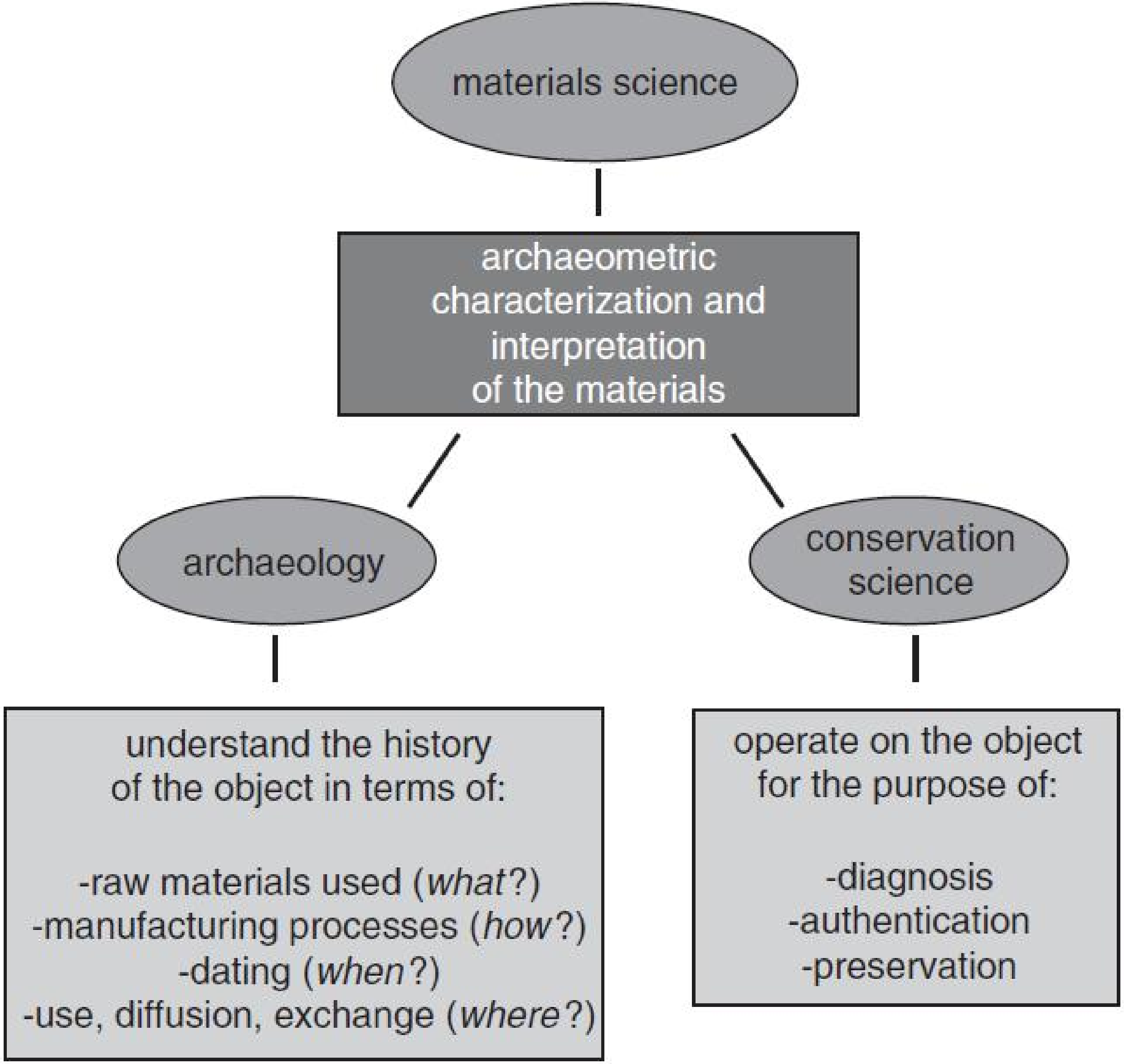
Medici forensi
Antropologi
Zoologi

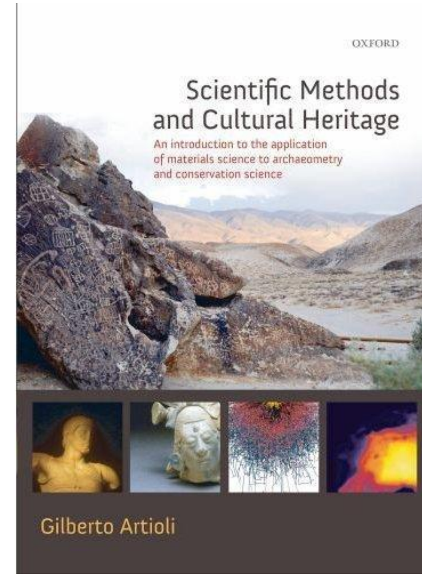
Complex problems require multidisciniplinary/multitechniques answers

Tangible cultural heritage

Archaeometry
Archaeology
Conservation science
Materials science
…

Intangible values


materials science
archaeometric characterization and interpretation of the materials
archaeology
conservation science
understand the history of the object in terms of:
-raw materials used (*what*?)
-manufacturing processes (*how*?)
-dating (*when*?)
-use, diffusion, exchange (*where*?)
operate on the object for the purpose of:
-diagnosis
-authentication
-preservation

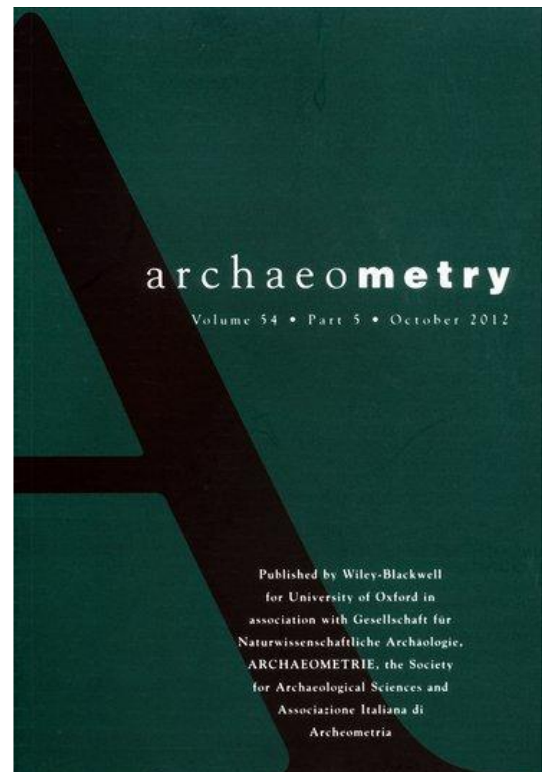

OXFORD
Scientific Methods and Cultural Heritage
An introduction to the application of materials science to archaeometry and conservation science
Gilberto Artioli

Archeometria
=
Scienza dei materiali nello studio dei beni culturali
(beni culturali = archeologia – storia dell’arte)

- *Capire il passato*

- *Interpretare le relazioni fra ambiente, risorse, ed evoluzione culturale/sociale*

- *Analizzare i materiali per mostrare l’invisibile…..*

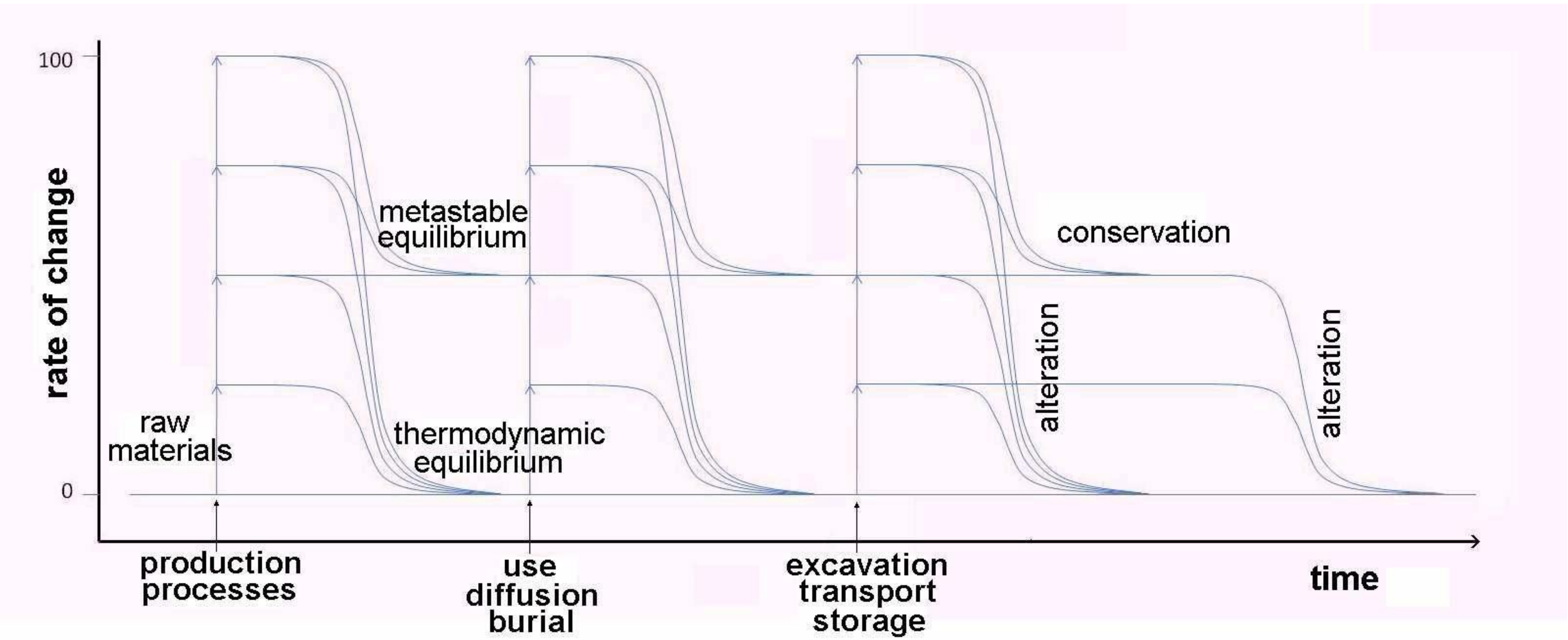


The Encyclopedia of Archaeological Sciences

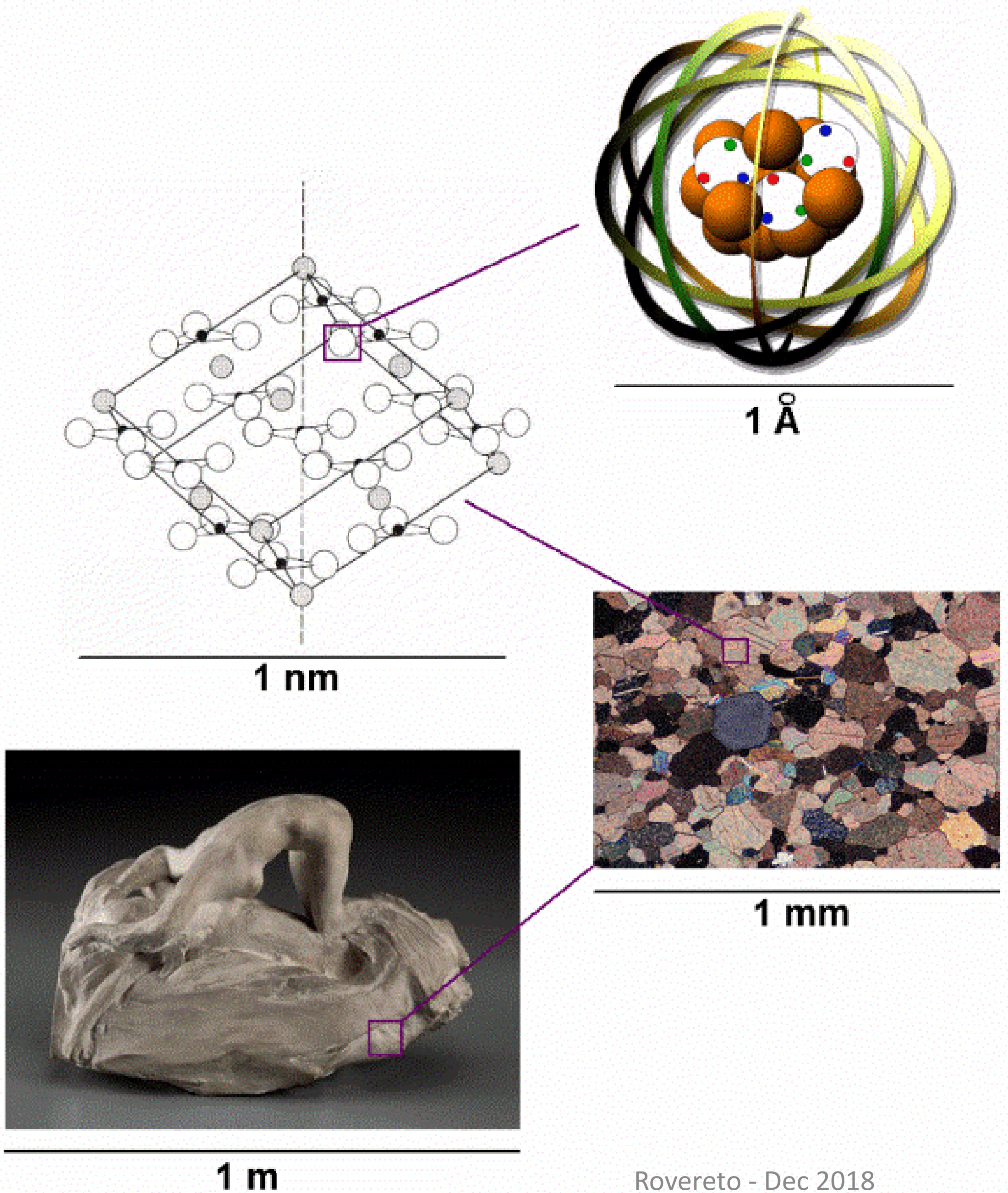
Sandra L. López Varela

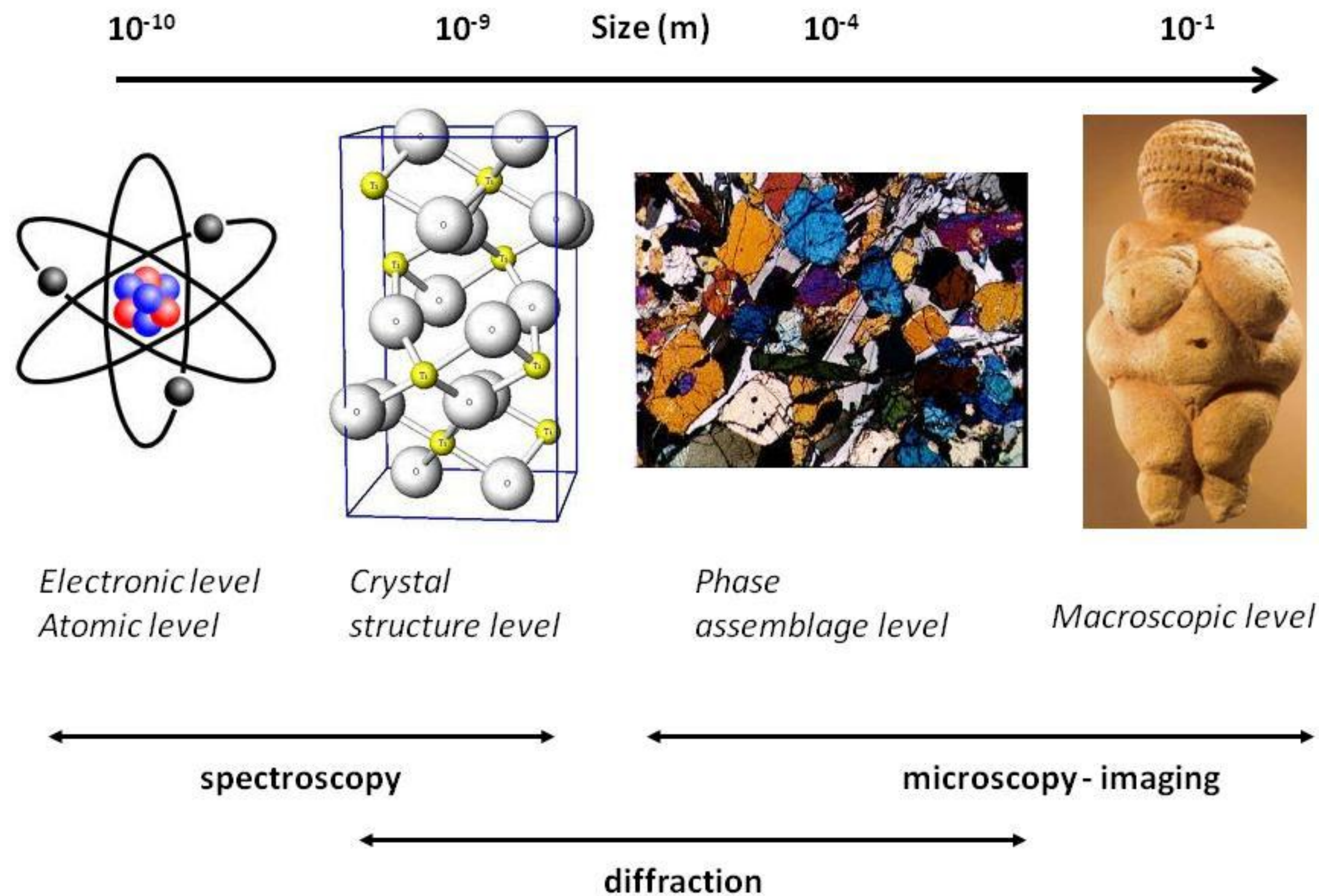
ISBN: 978-0-470-67461-1

Oct 2018, Wiley-Blackwell

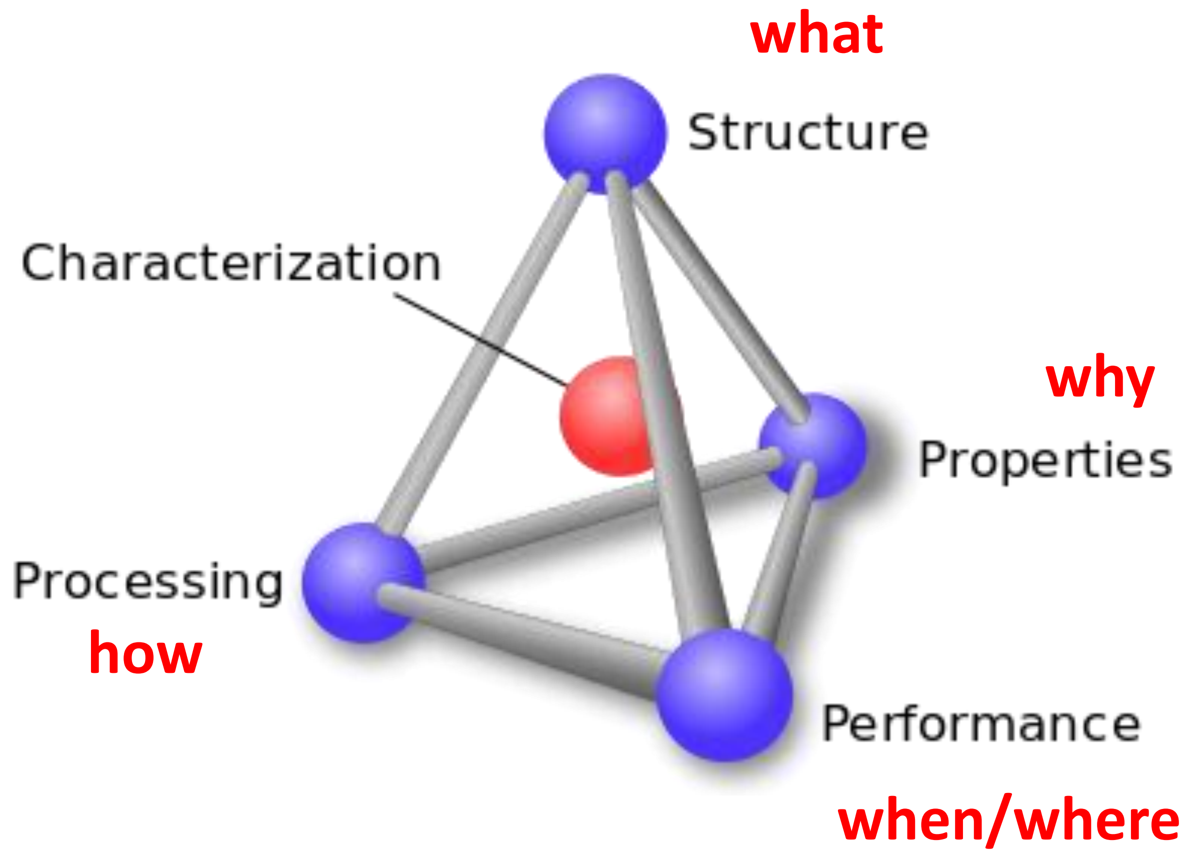


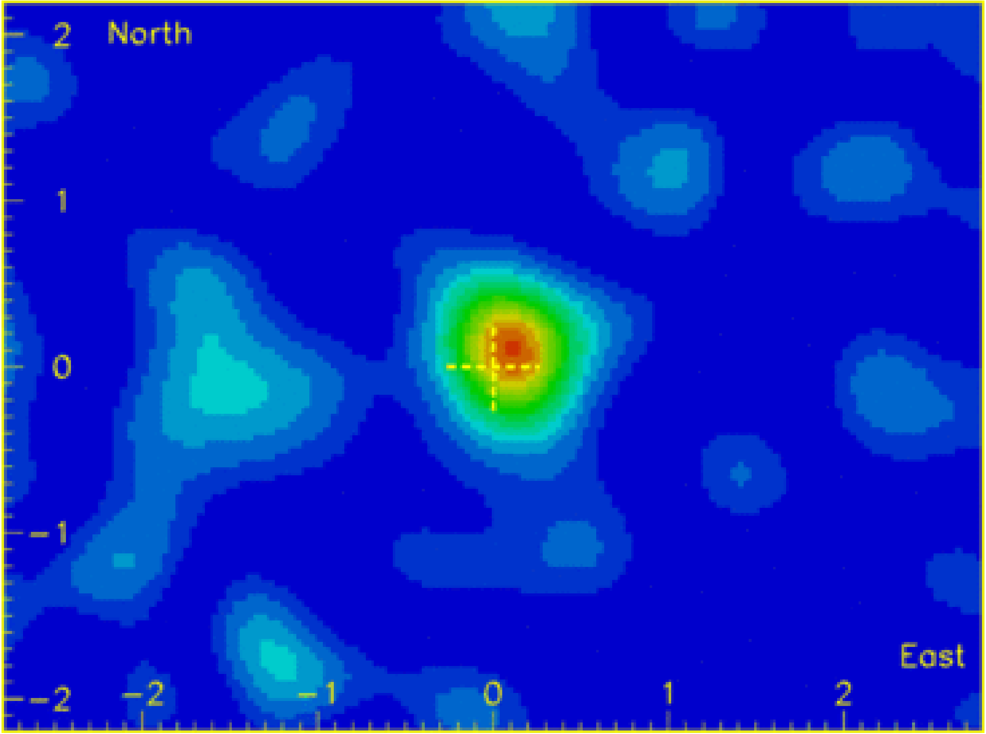
ARTIOLI G., ANGELINI I.: Mineralogy and archaeometry: fatal attraction. Eur. J. Miner. 23, 849-855, 2011.


1 Å
1 nm
1 mm
1 m



10^{-10}
10^{-9}
Size (m)
10^{-4}
10^{-1}
Electronic level
Atomic level
Crystal
structure level
Phase
assemblage level
Macroscopic level
spectroscopy
microscopy - imaging
diffraction


what
Structure
Characterization
why
Properties
Processing
how
Performance
when/where



An image of the shadow of the Moon in muons as produced by the 700m subterranean Soudan 2 detector in the Soudan Mine in Minnesota. The shadow is the result of approximately 120 muons missing from a total of 33 million detected in Soudan 2 over its 10 years of operation. The cross denotes the actual location of the Moon. The shadow of the Moon is slightly offset from this location because cosmic rays are electrically charged particles and were slightly deflected by the Earth's magnetic field on their journey to the upper atmosphere. The shadow is produced due to the shielding effect the Moon has on galactic and cosmic rays, which stream in from all directions. The cosmic rays normally strike atoms high in the upper atmosphere, producing showers of muons and other short lived particles.

Published Online: 17 August 2015

Feasibility study of archaeological structures scanning by muon tomography

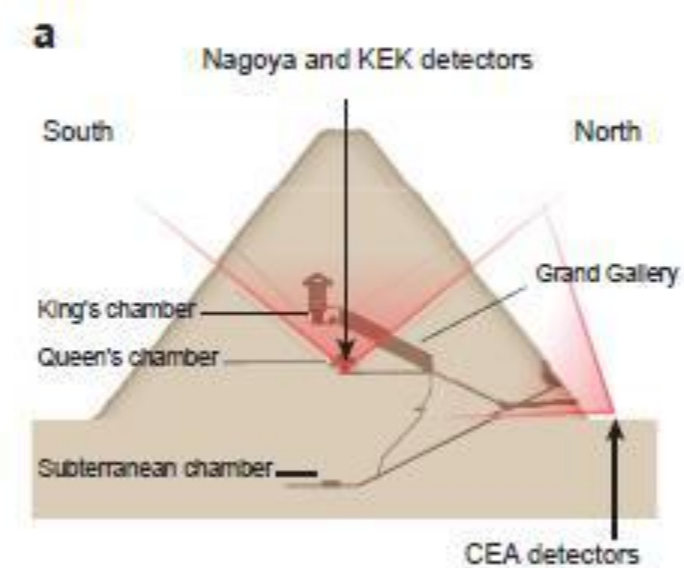
AIP Conference Proceedings **1672**, 140004 (2015); https://doi.org/10.1063/1.4928020

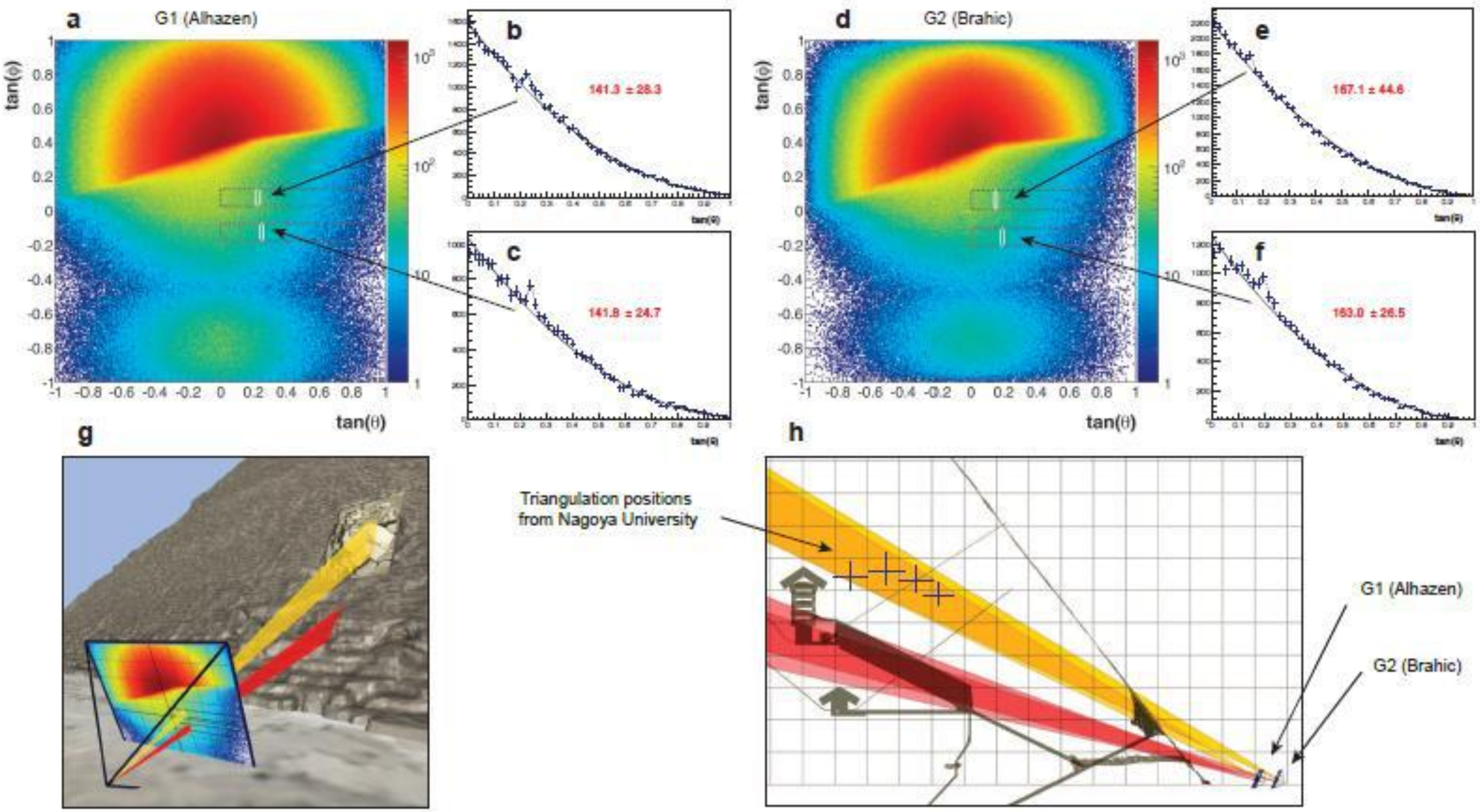
H. Gómez*, C. Carloganu†, D. Gibert**, J. Marteau‡, V. Niess†, S. Katsanevas*, *and* A. Tonazzo*

Discovery of a big void in Khufu's Pyramid by observation of cosmic-ray muons

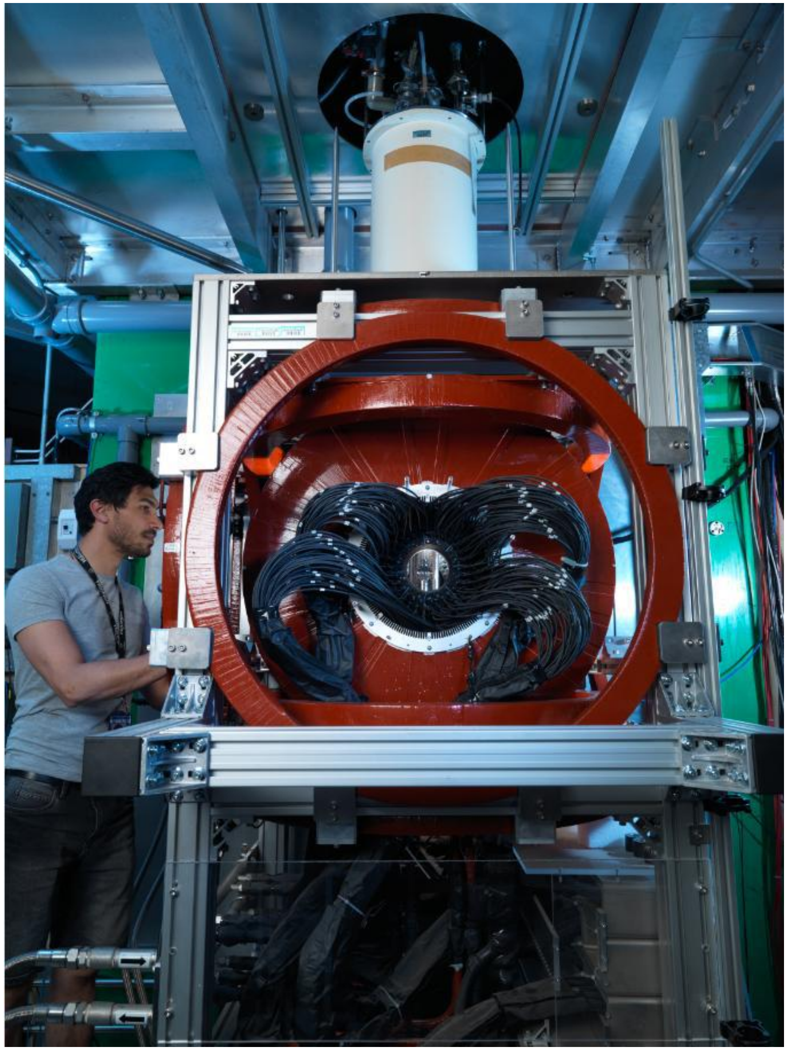
Kunihiro Morishima[1], Mitsuaki Kuno[1], Akira Nishio[1], Nobuko Kitagawa[1], Yuta Manabe[1], Masaki Moto[1] — Fumihiko Takasaki[2], Hirofumi Fujii[2], Kotaro Satoh[2], Hideyo Kodama[2], Kohei Hayashi[2], Shigeru Odaka[2] — Sébastien Procureur[3], David Attié[3], Simon Bouteille[3], Denis Calvet[3], Christopher Filosa[3], Patrick Magnier[3], Irakli Mandjavidze[3], Marc Riallot[3] — Benoit Marini[5], Pierre Gable[7], Yoshikatsu Date[8], Makiko Sugiura[9], Yasser Elshayeb[4], Tamer Elnady[10], Mustapha Ezzy[4], Emmanuel Guerriero[7], Vincent Steiger[5], Nicolas Serikoff[5], Jean-Baptiste Mouret[11], Bernard Charlès[6], Hany Helal[4,5], Mehdi Tayoubi[5,6]

Nature **volume 552**, pages 386–390
(21 December 2017)



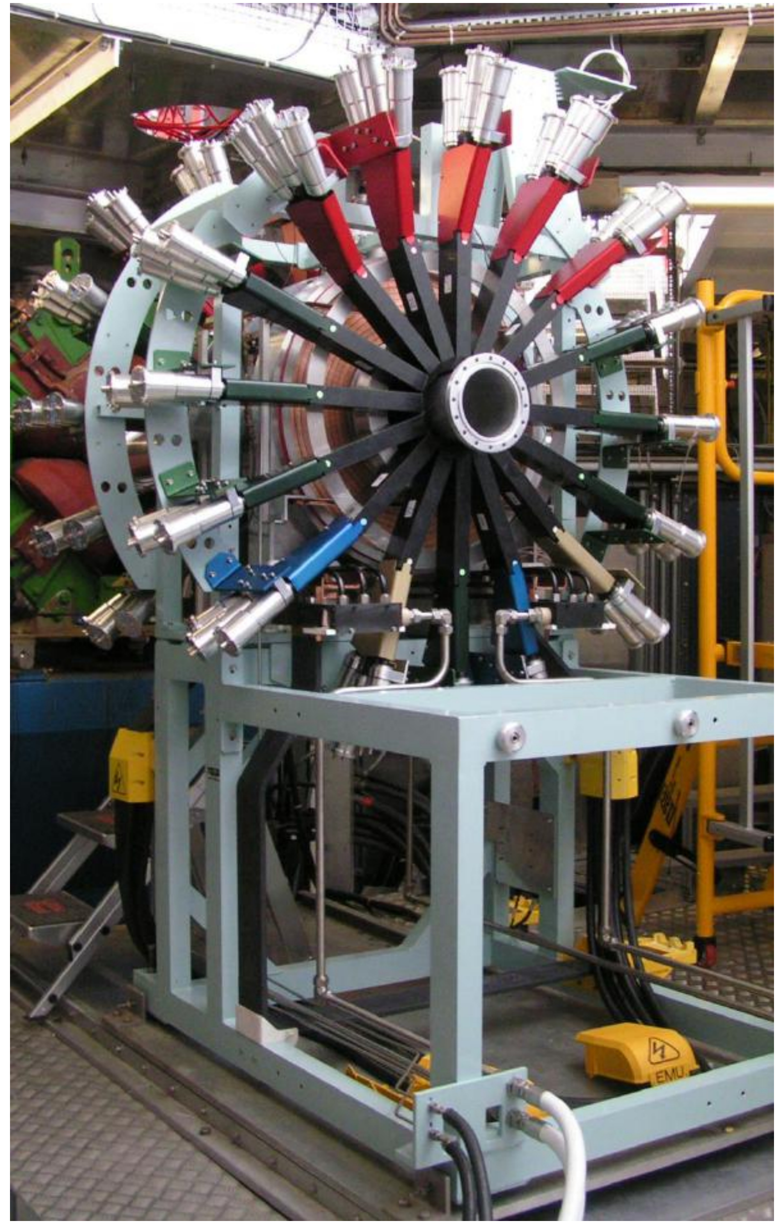


a
G1 (Alhazen)
tan(φ)
tan(θ)
b
141.3 ± 28.3
c
141.8 ± 24.7
d
G2 (Brahic)
e
167.1 ± 44.6
f
163.0 ± 26.5
g
h
Triangulation positions
from Nagoya University
G1 (Alhazen)
G2 (Brahic)



CHRONUS

ISIS is the world's most intense source of pulsed muons for condensed matter research



EMU

Probing beneath the surface without a scratch — Bulk non-destructive elemental analysis using negative muons☆

A.D. Hillier [a,*], D.McK. Paul [b], K

Microchemical Journal 125 (2016) 203-

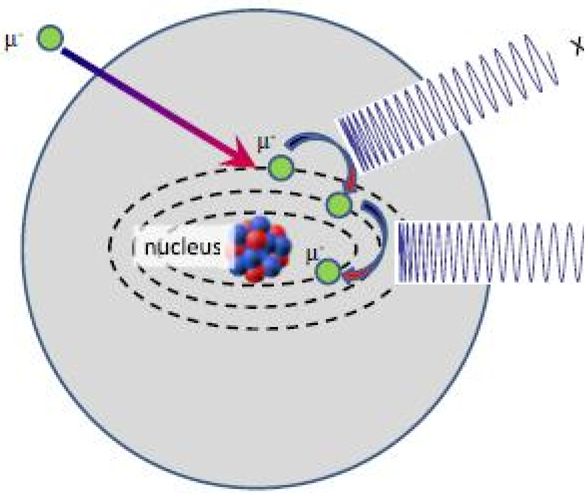


Fig. 1. A schematic diagram which shows the μ-capture and X-ra

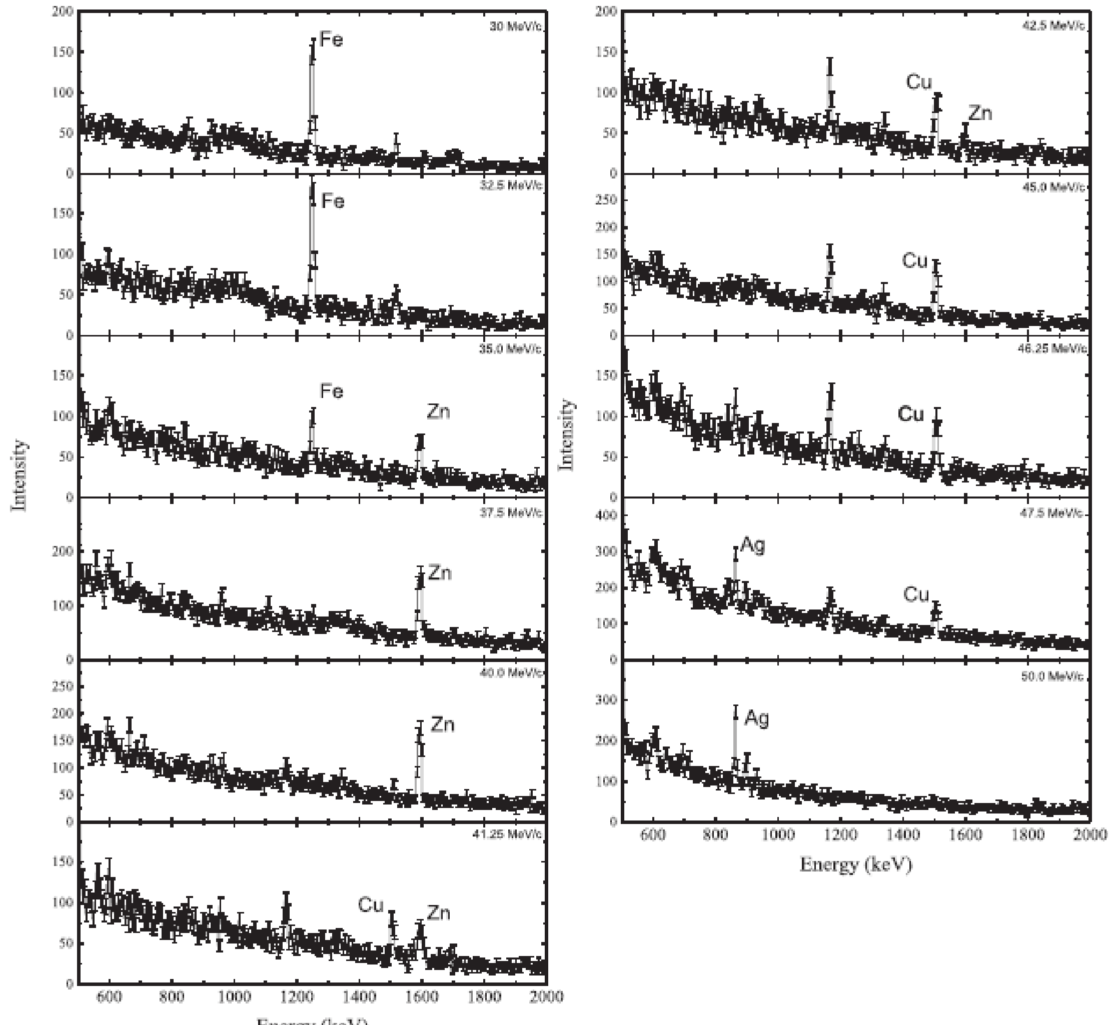


Fig. 6. This figure shows the momentum dependence of the X-ray emission. The lowest momentum shows just the Fe X-ray peaks and the highest shows just the Ag X-ray peaks, with Zn and Cu at intermediate muon momentum. This data is from one detector only.

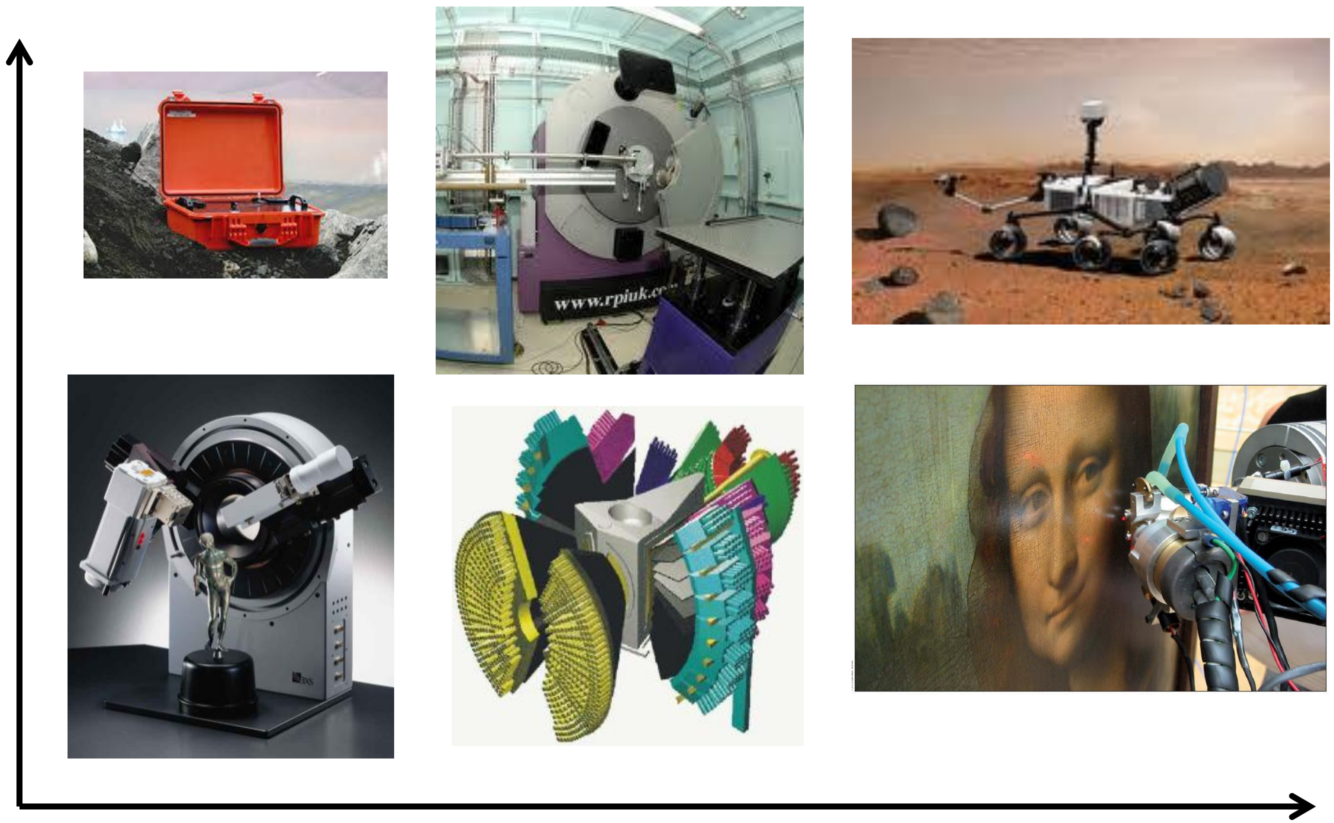
Table 2.9. Indicative limits of detection of elements for the most used chemical analysis techniques

Technique	Detectable elements (Z)	Detection limits (ppm) [10 000 ppm = 1%]
SEM-EDS	normal 11–92 (windowless 6–92)	1000–5000
EPMA(WDS)	11–92	100–1000
XRF	11–92	10–100
PIXE	11–92	1–100
NAA	9–83	0.00001–0.1 (see Fig. 3.a.1)
PGAA	1–92	1–100 (see Fig. 3.a.2)
ICP-OES	1–92	0.001–0.1
LIBS	1–92	1–30
AAS	11–92	1–10
MS	1–92 (including isotopes)	0.001–0.01

non invasive

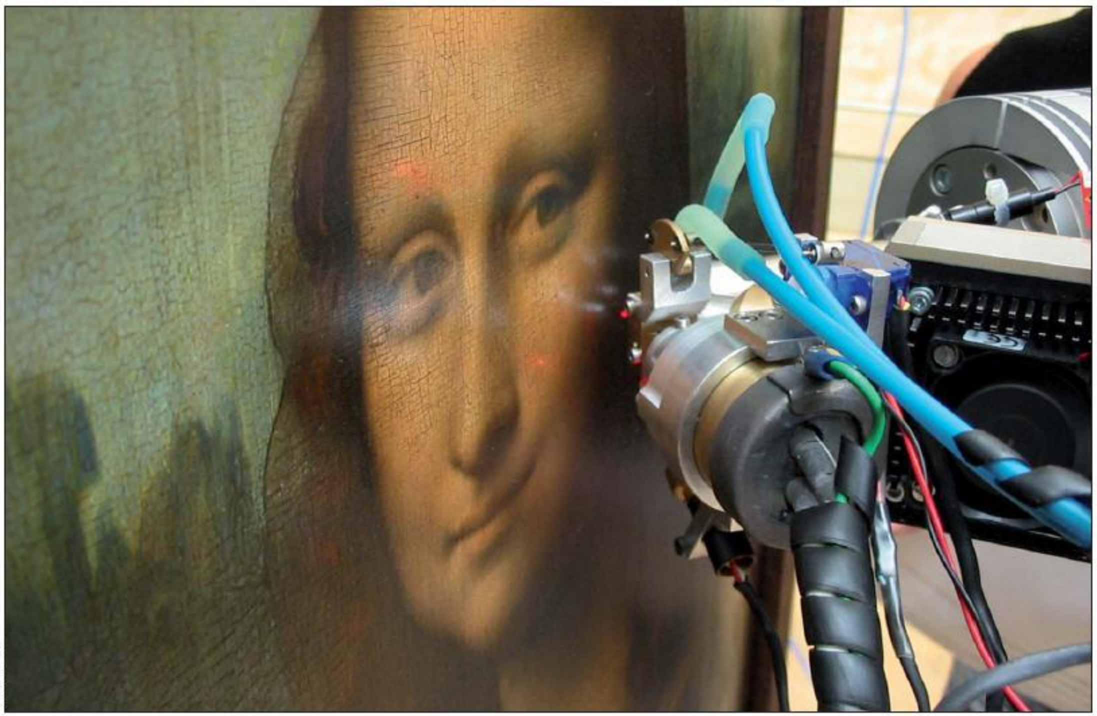
micro-invasive

invasive



time / manpower / cost

INVASIVE vs NON-INVASIVE (SAMPLING)




20

Present trends:

- **Portable instruments**
- **Non invasive measurements**

CNRS-LC2RMF within EU-ARTECH

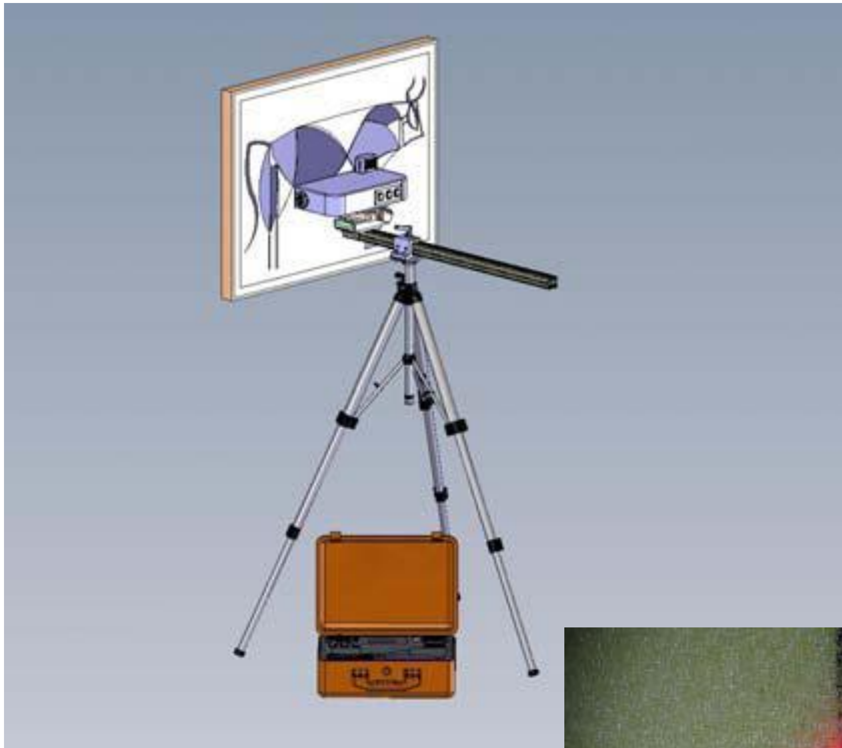
INXITU @ www.inxitu.com/html/Duetto.html

Non-standard instrumentation require:

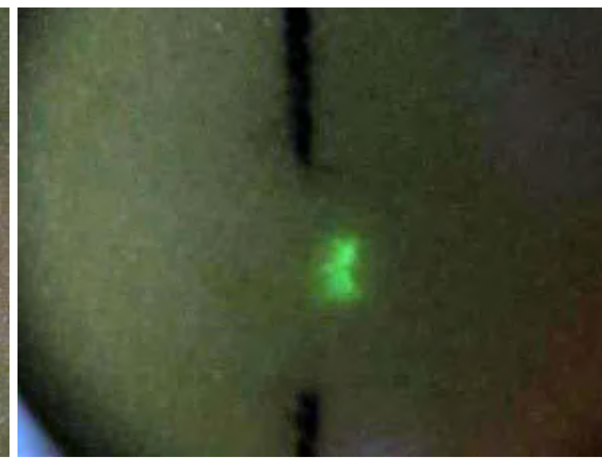
- Optimized measurement protocols
- Careful calibration
- Appropriate interpretation of the results
- Comparison with standard measurements

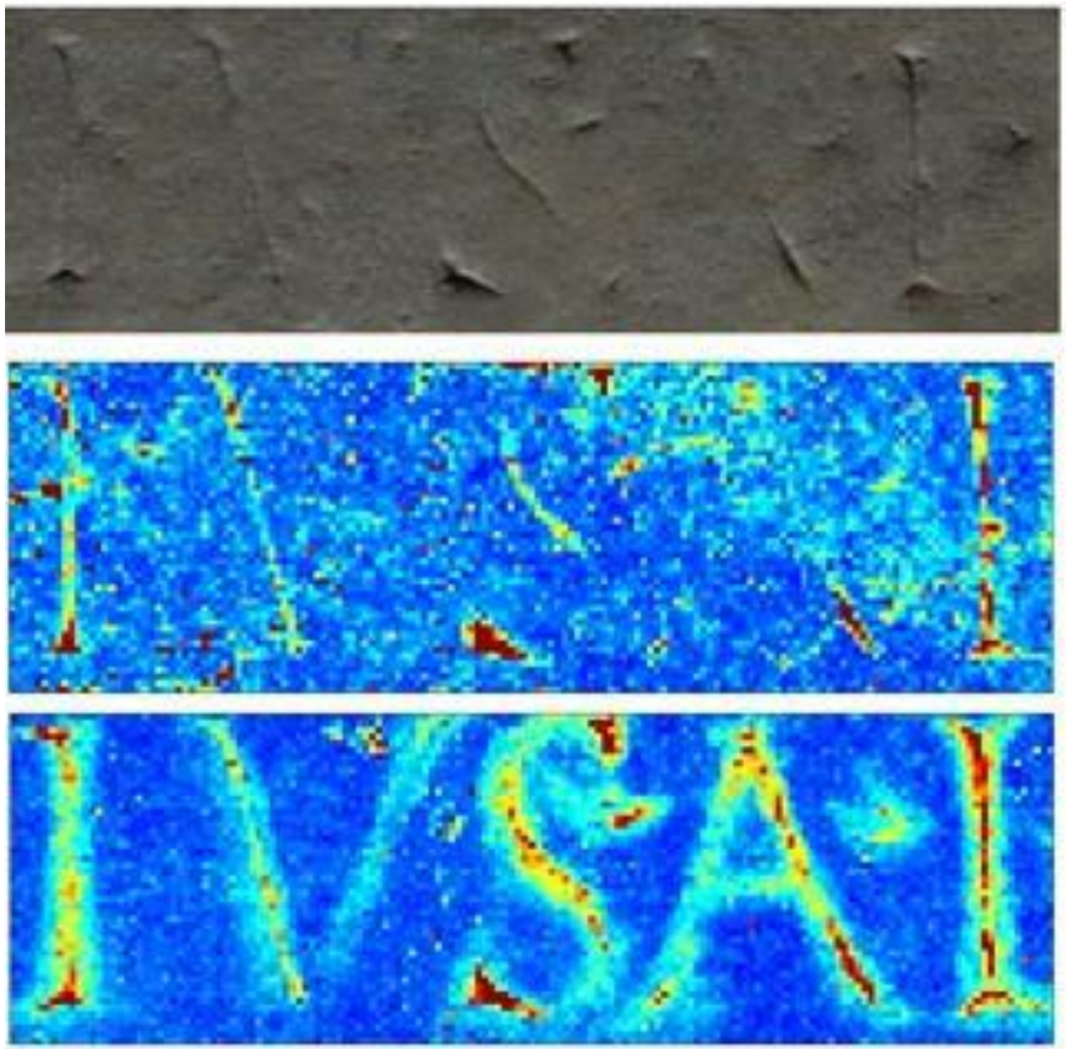

Duetta

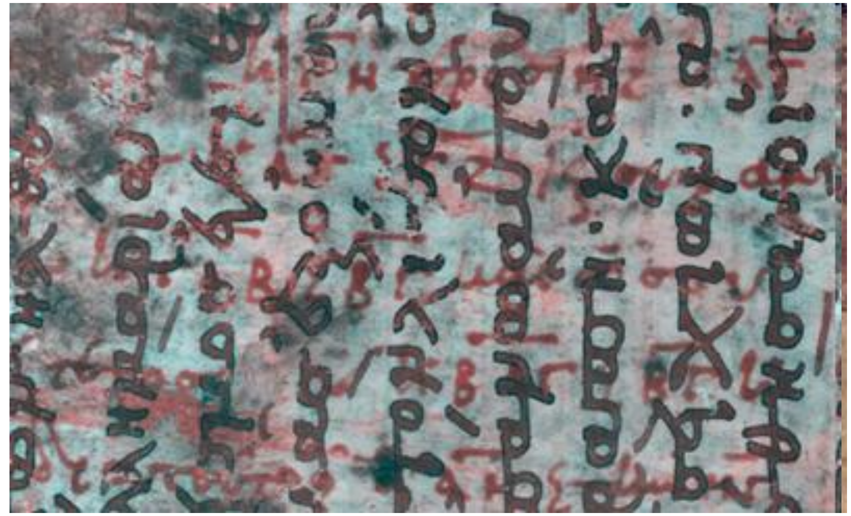

CAUTION
X-RAYS PRODUCED WHEN ENERGIZED

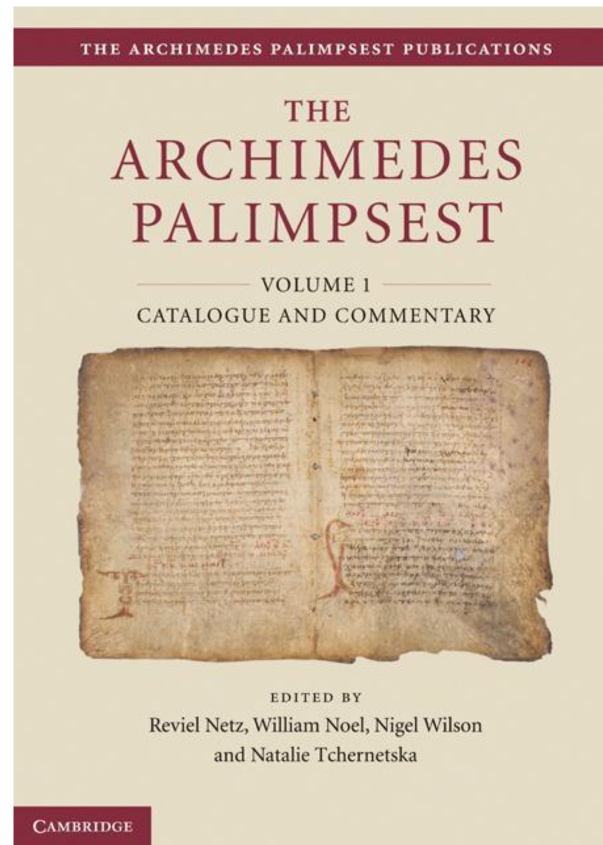



iTU








THE ARCHIMEDES PALIMPSEST PUBLICATIONS
THE ARCHIMEDES PALIMPSEST
VOLUME 1
CATALOGUE AND COMMENTARY
EDITED BY
Reviel Netz, William Noel, Nigel Wilson and Natalie Tchernetska
CAMBRIDGE

Cucci, C., Delaney, J.K. and Picollo, M., 2016. Reflectance hyperspectral imaging for investigation of works of art: old master paintings and illuminated manuscripts. Accounts of chemical research, 49(10), pp.2070-2079.

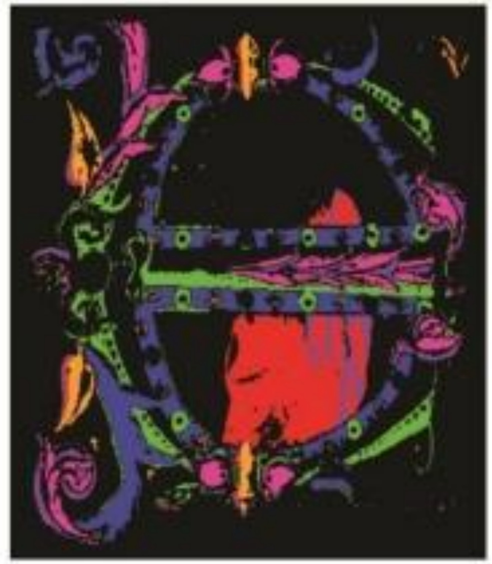
Delaney, J.K., Thoury, M., Zeibel, J.G., Ricciardi, P., Morales, K.M. and Dooley, K.A., 2016. Visible and infrared imaging spectroscopy of paintings and improved reflectography. Heritage Science, 4(1), p.6.

Conover, D.M., Delaney, J.K. and Loew, M.H., 2013, May. Accurate accommodation of scan-mirror distortion in the registration of hyperspectral image cubes. In Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XIX (Vol. 8743, p. 87431S). International Society for Optics and Photonics.

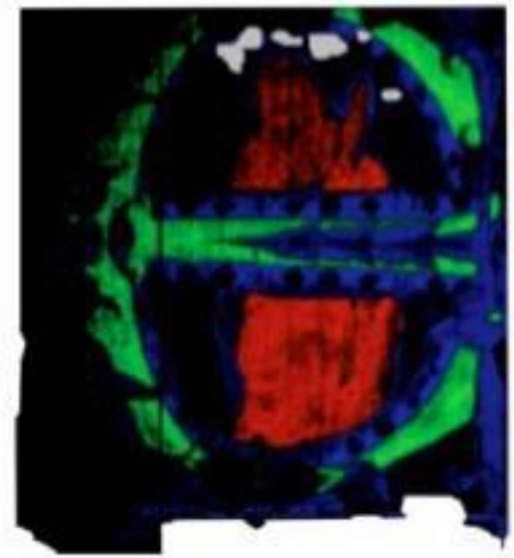
Delaney, J.K., Zeibel, J.G., Thoury, M., Littleton, R., Morales, K.M., Palmer, M. and de la Rie, E.R., 2009, July. Visible and infrared reflectance imaging spectroscopy of paintings: pigment mapping and improved infrared reflectography. In O3A: Optics for Arts, Architecture, and Archaeology II (Vol. 7391, p. 739103). International Society for Optics and Photonics.

Lorenzo Monaco, *Praying Prophet*, 1410/1413, miniature on vellum, National Gallery of Art

Praying Prophet



Pigment Map

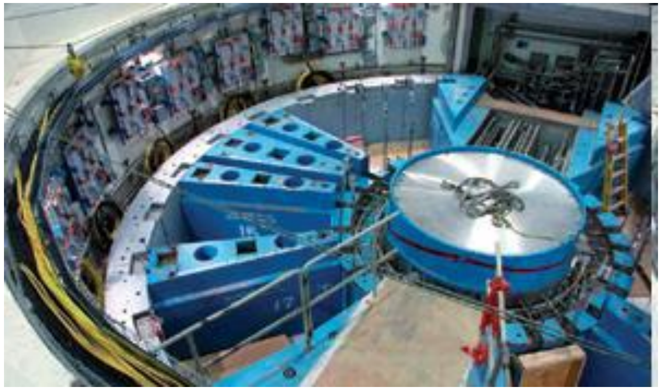


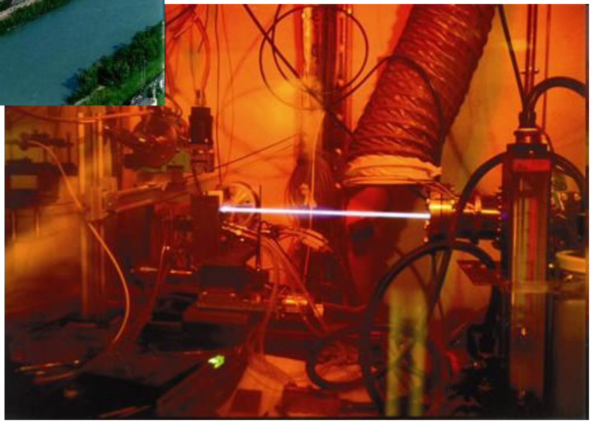
Paint Binder Map

The center map represents the pigments used by the artist and their location within the illumination. An organic yellow dye was mixed with azurite to obtain the green portion of the initial. Blue areas were painted using two grades of ultramarine blue. The orange leaves were painted with red lead and the pink leaves with an insect-derived red dye. The red robe of the prophet was painted using vermilion and a red dye-based glaze. The paint binder map unexpectedly shows the figure of the prophet painted using a fat-containing binder, most likely egg yolk (represented in red) in contrast to the decorative letter where a protein-based binder and/or gum arabic was used (seen in green and red).

Thermal / pulsed neutrons

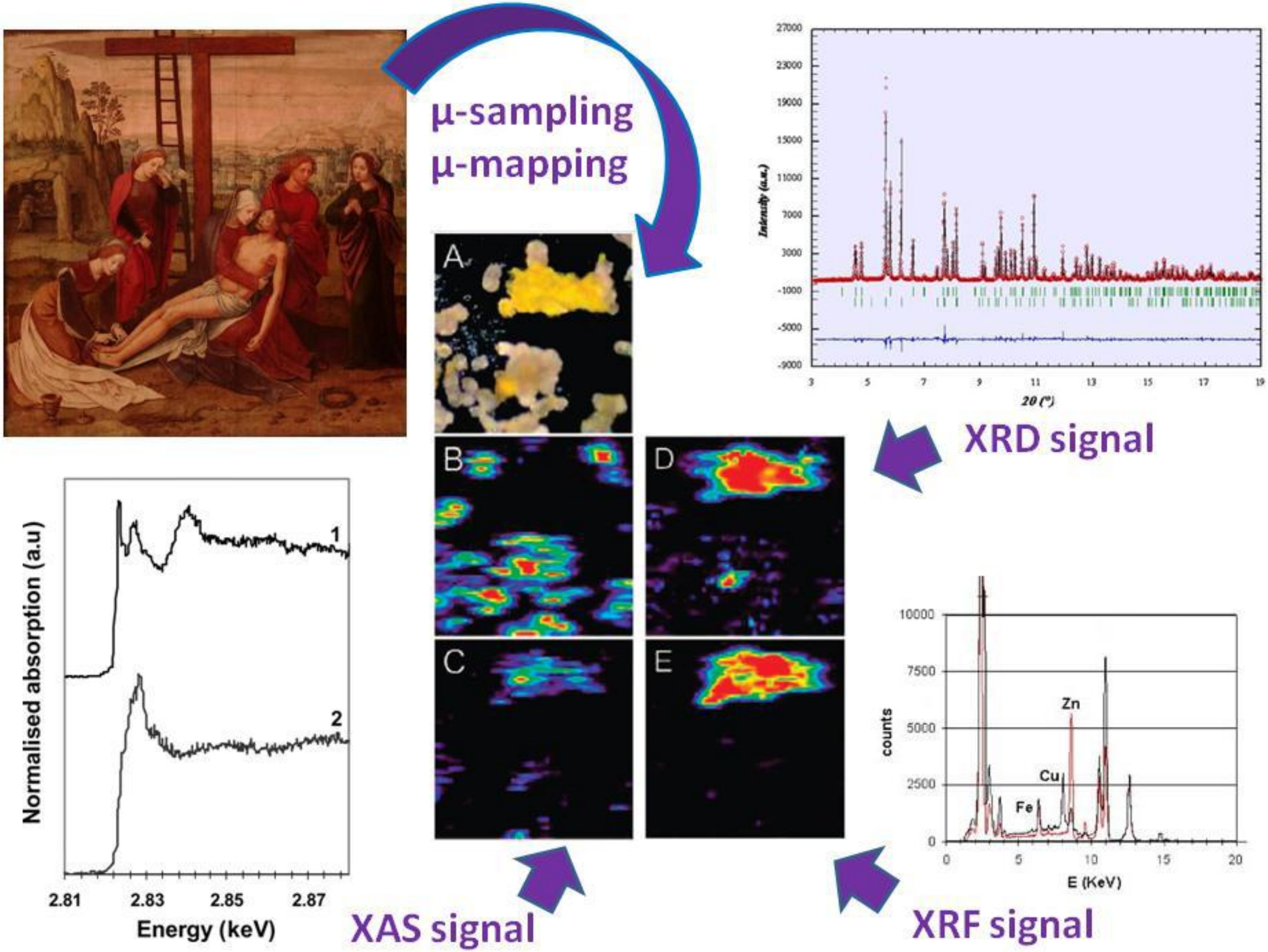
Penetrating beams
Large objects
Low spatial resolution
Time of Flight mode



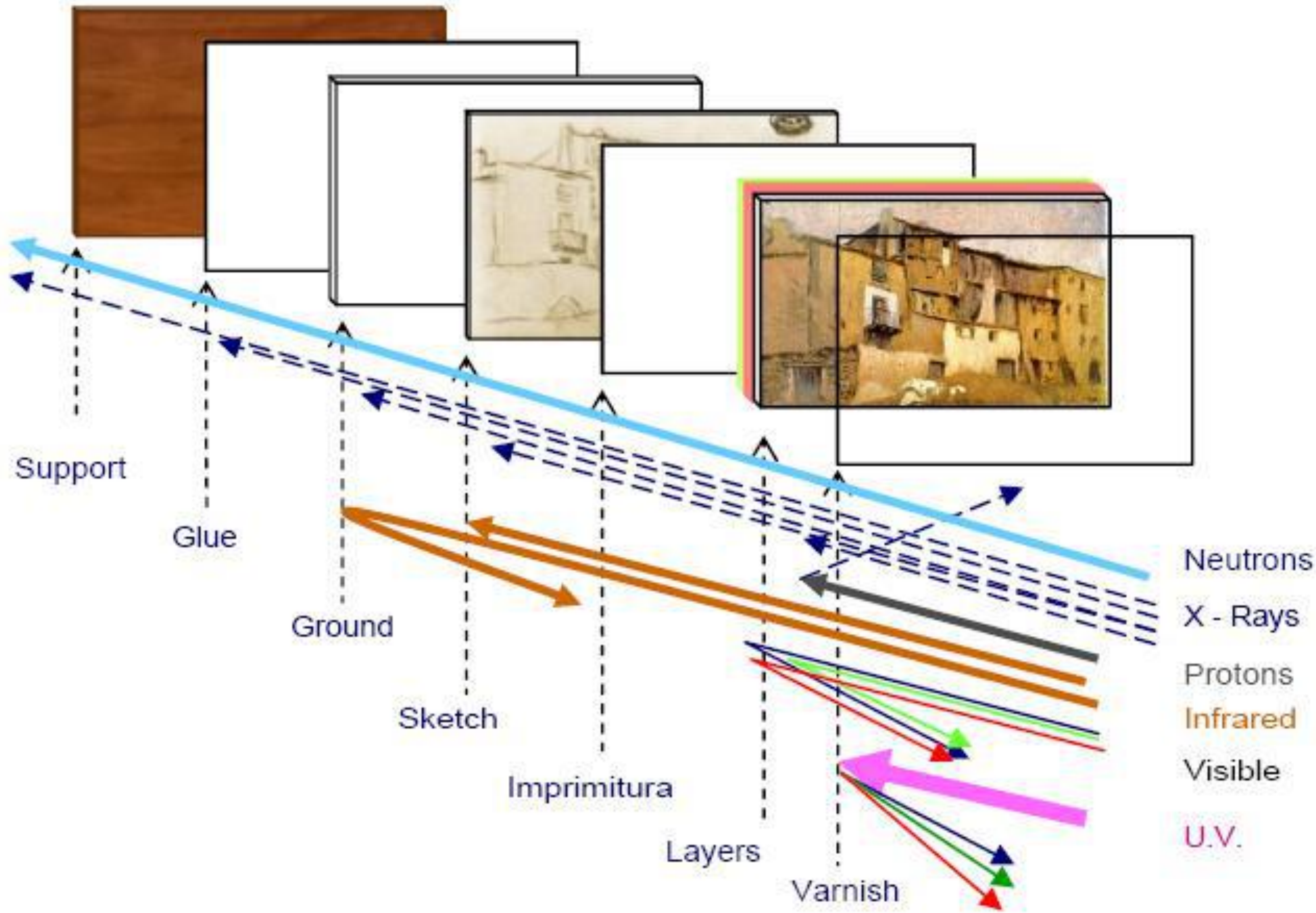


Synchrotron
X-rays

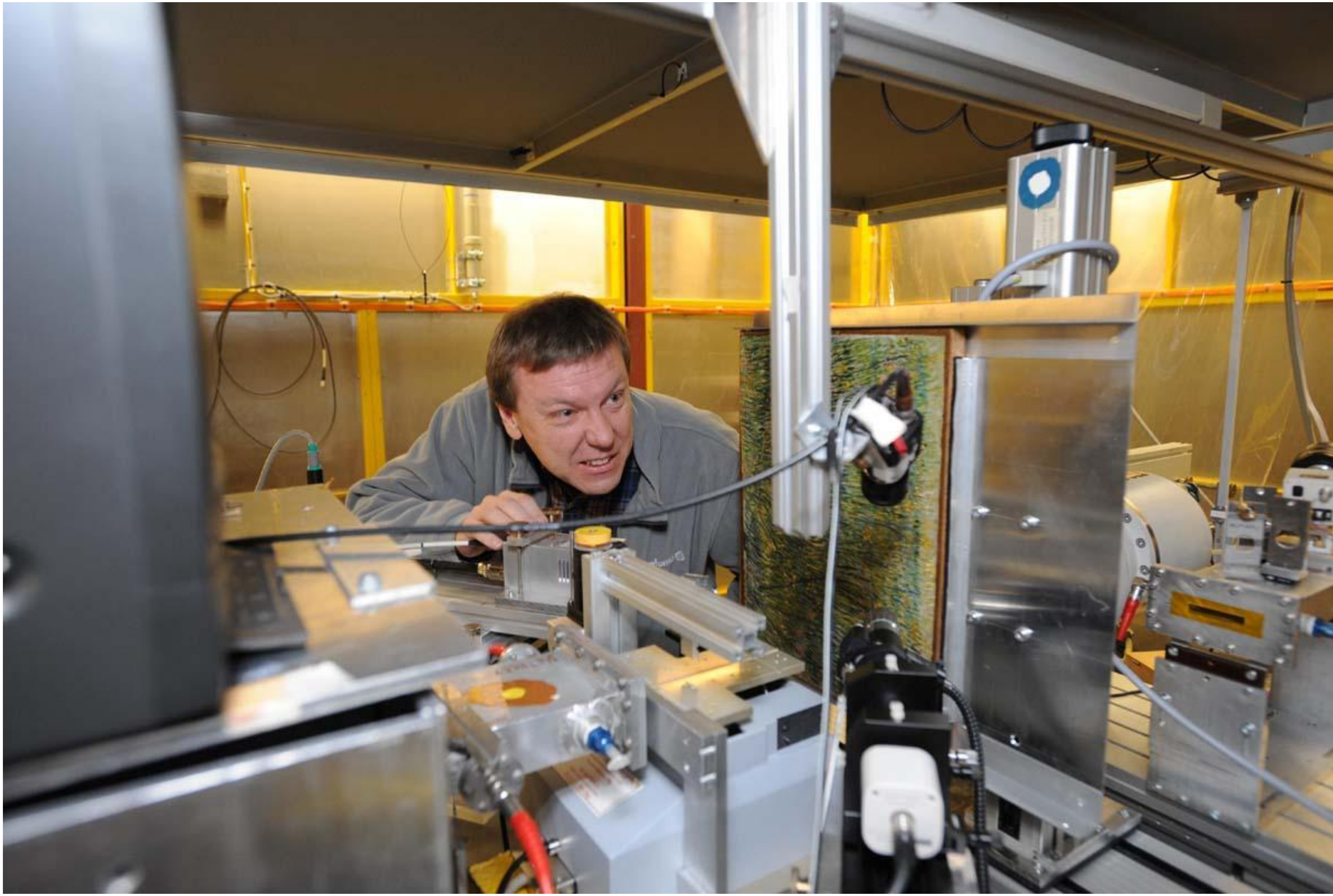
Microbeams
High spatial resolution
Small samples



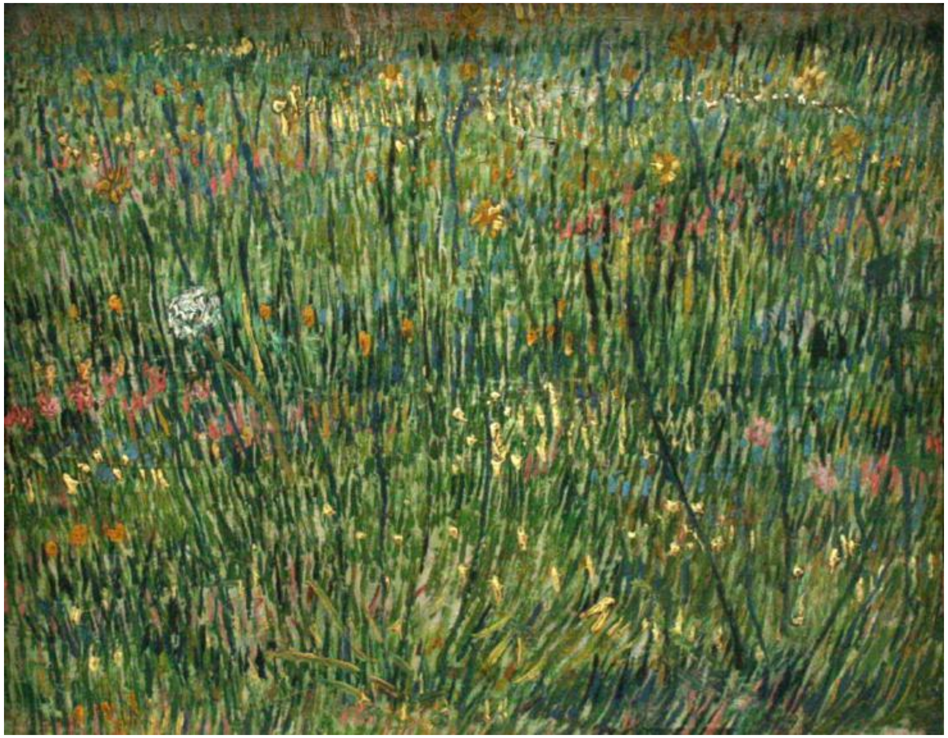
μ-sampling
μ-mapping
A
B
C
D
E
XRD signal
XAS signal
XRF signal
Normalised absorption (a.u)
Energy (keV)
2.81
2.83
2.85
2.87
1
2
Intensity (a.u.)
2θ (°)
counts
E (KeV)
Zn
Cu
Fe

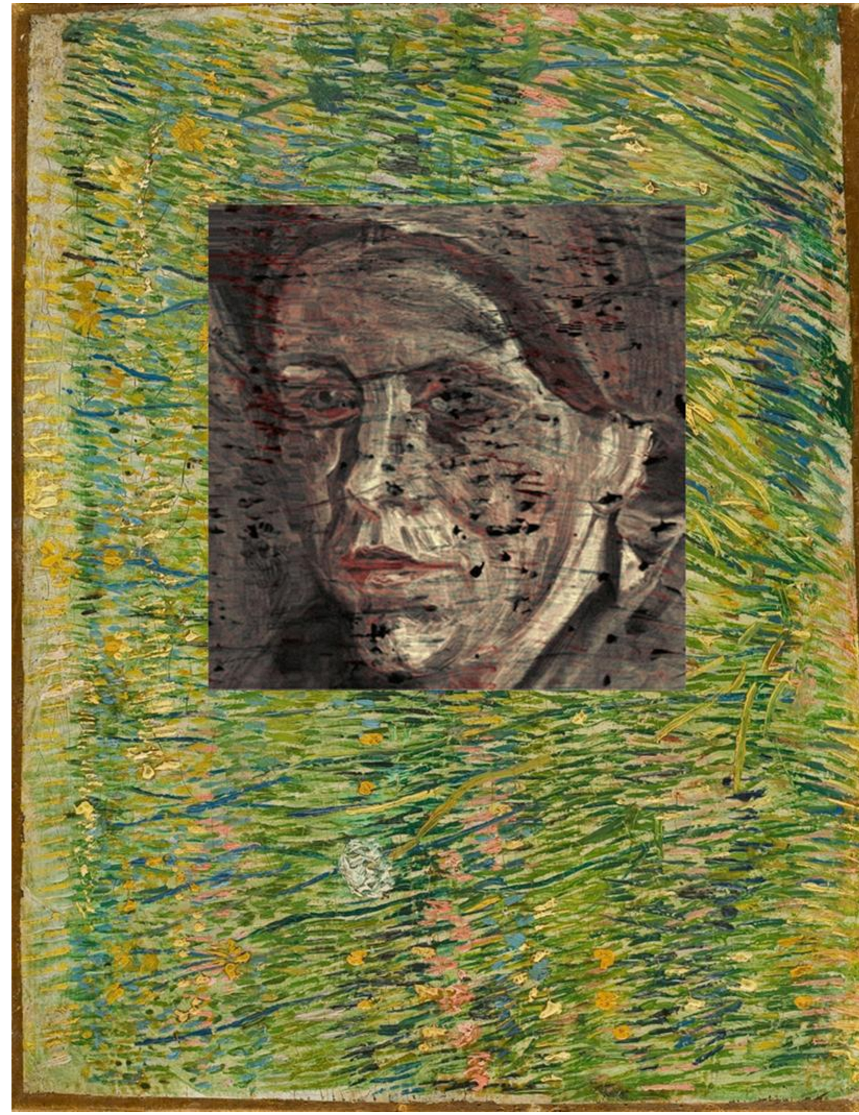


Nuclear Physics A 752 (2005) 659c–674c



http://www.vangogh.ua.ac.be/





Art Gallery of New South Wales

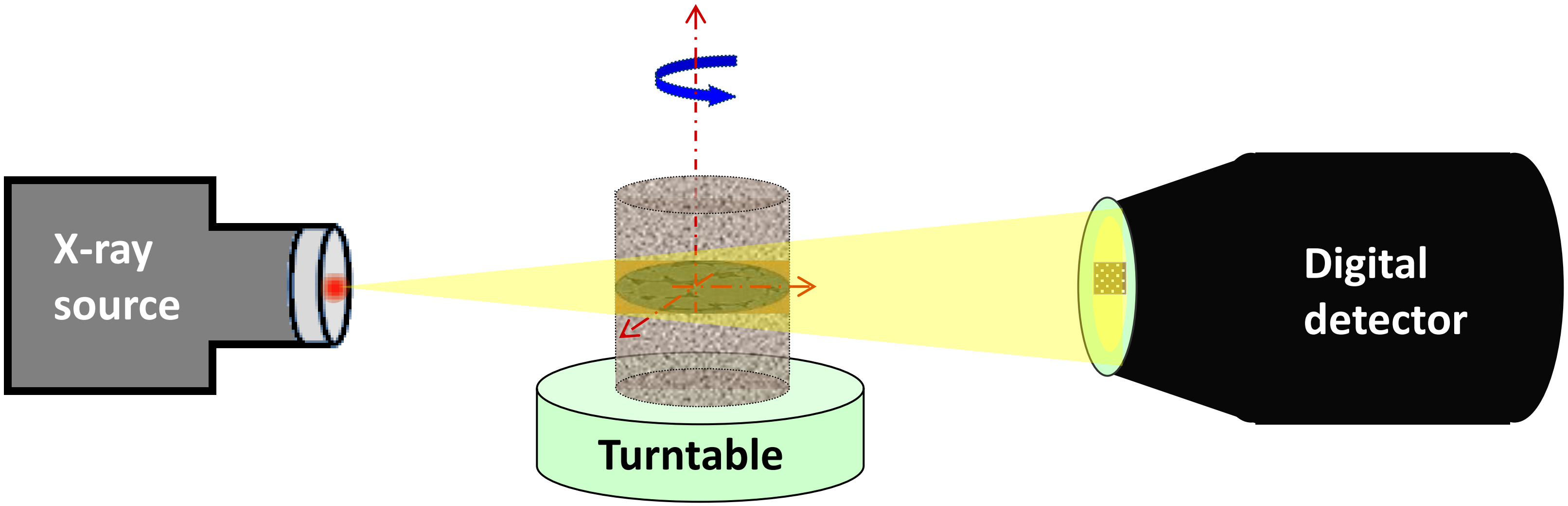
Paul Gauguin
Nafea Faa Ipoipo – 1892
~ US$ 300 M

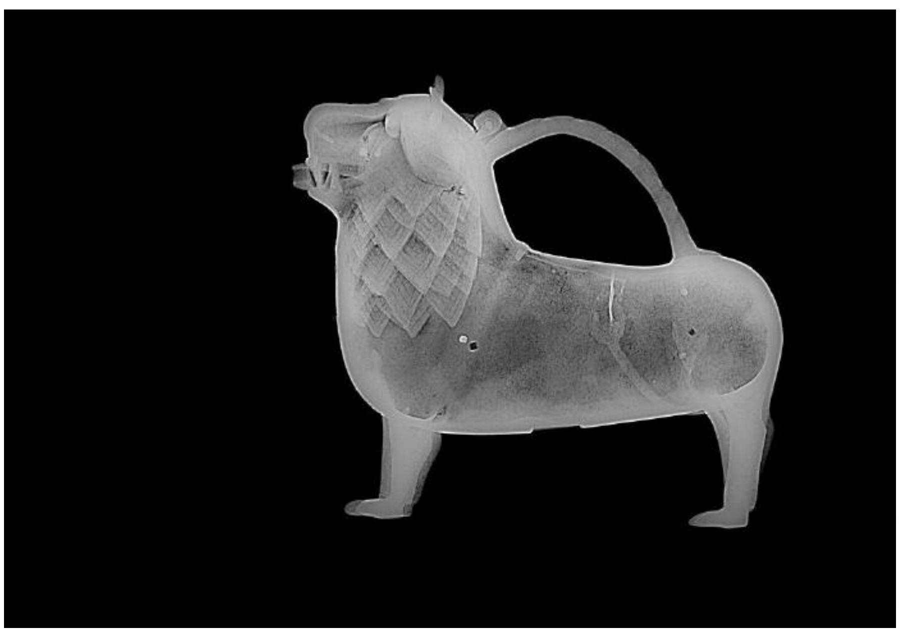
Willem de Kooning
Interchange – 1955
~ US$ 300 M

Paul Cézanne
The card players – 1892
~ US$ 272 M

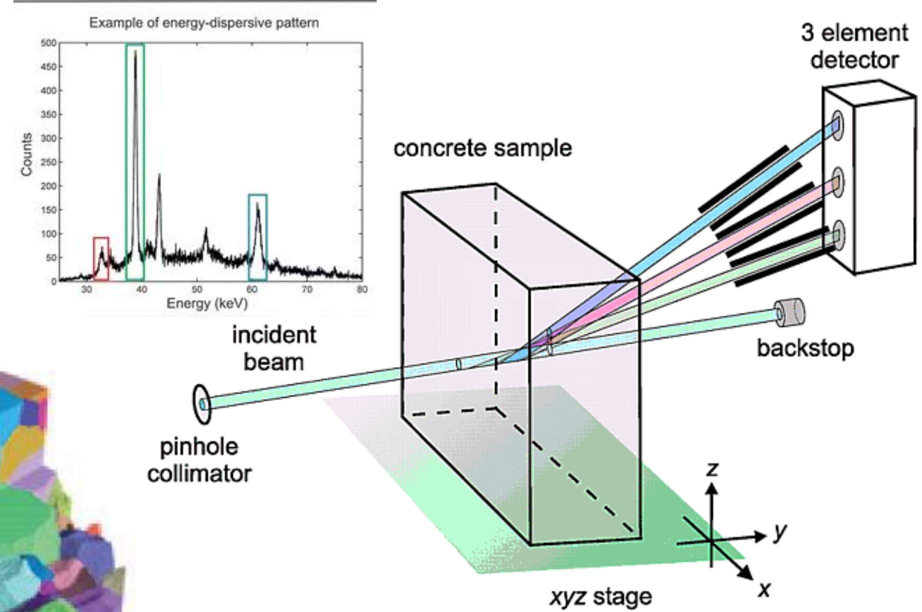
Mark Rotko
No. 6 (Violet, Green and Red)
1951
~ US$ 186 M

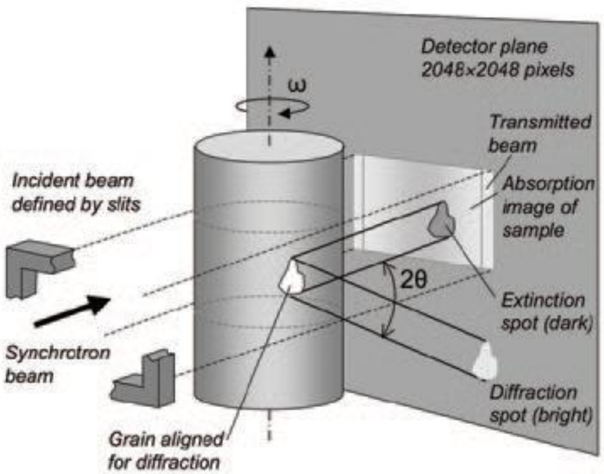
Jackson Pollock
Number 17A - 1948
~ US$ 200 M

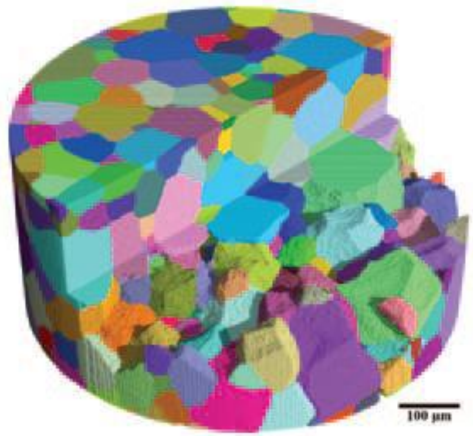

X-ray
source
Turntable
Digital
detector



tomographic energy dispersive diffraction imaging (TEDDI)



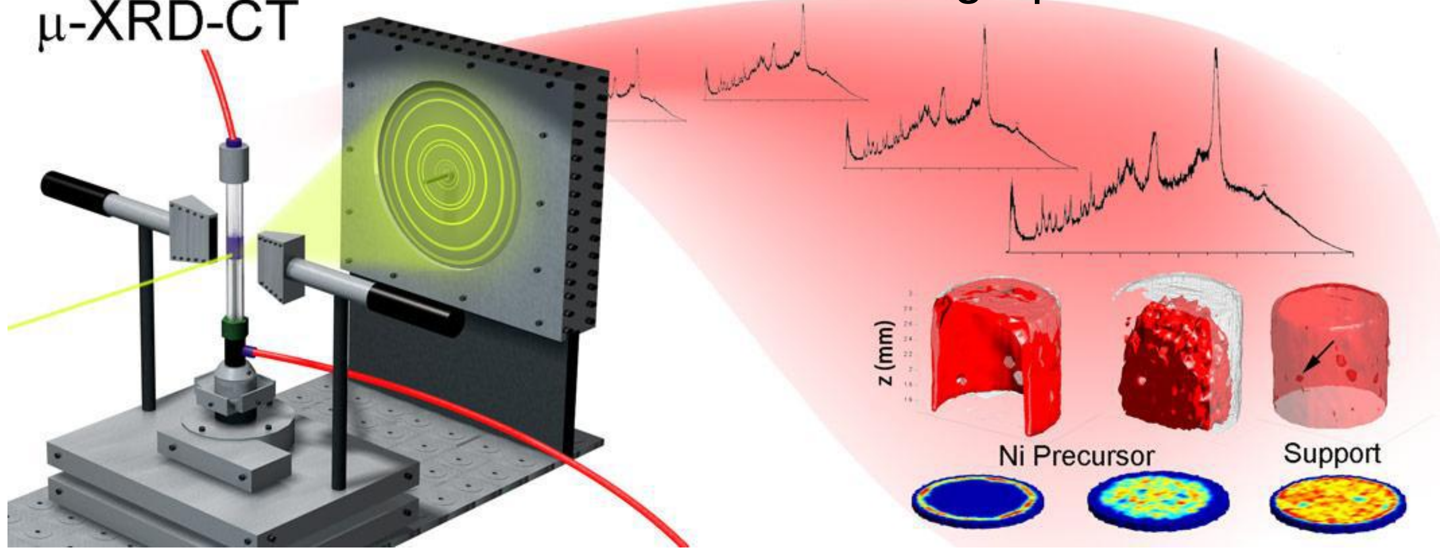


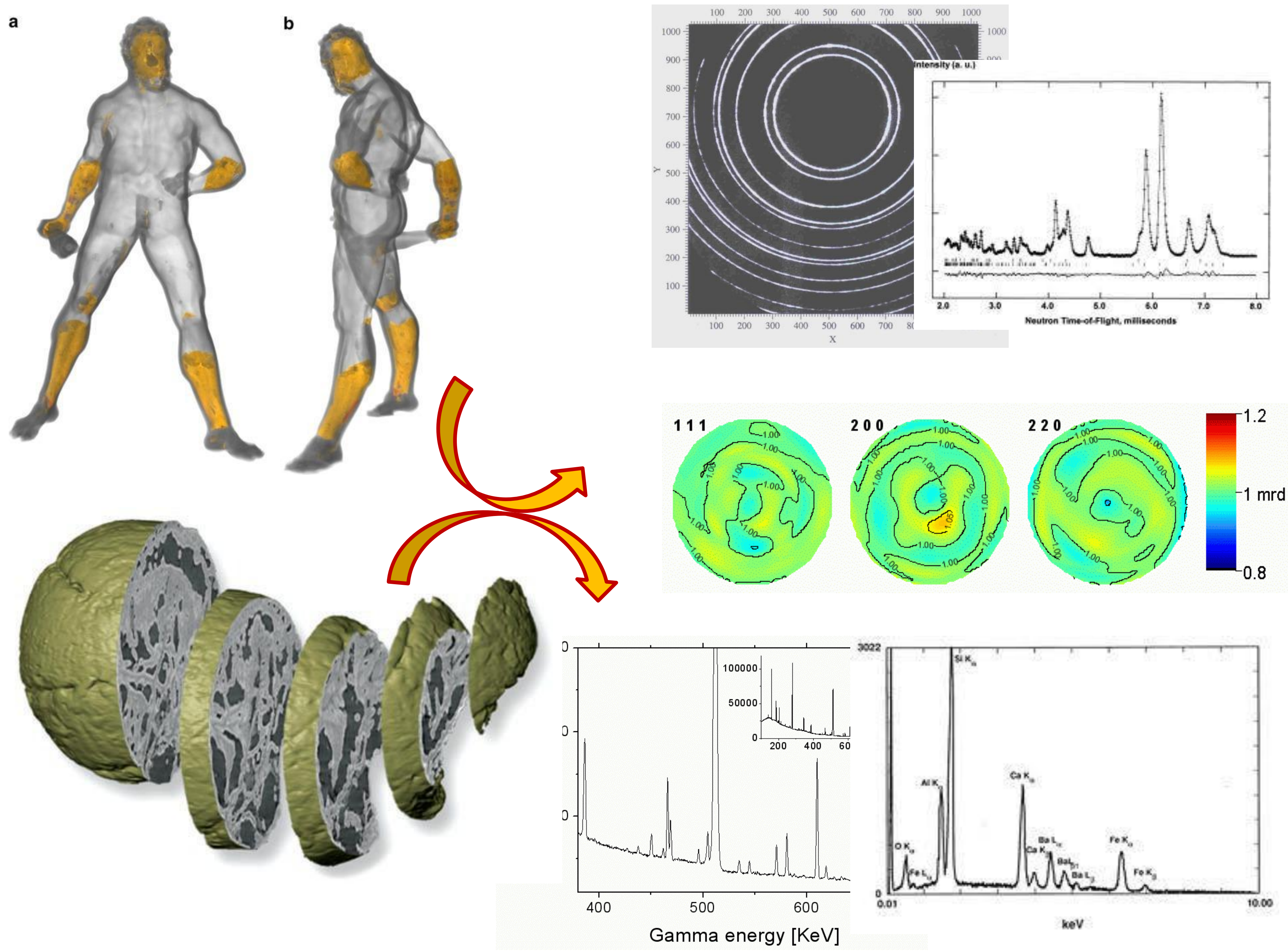


Pencil beam tomographic scan

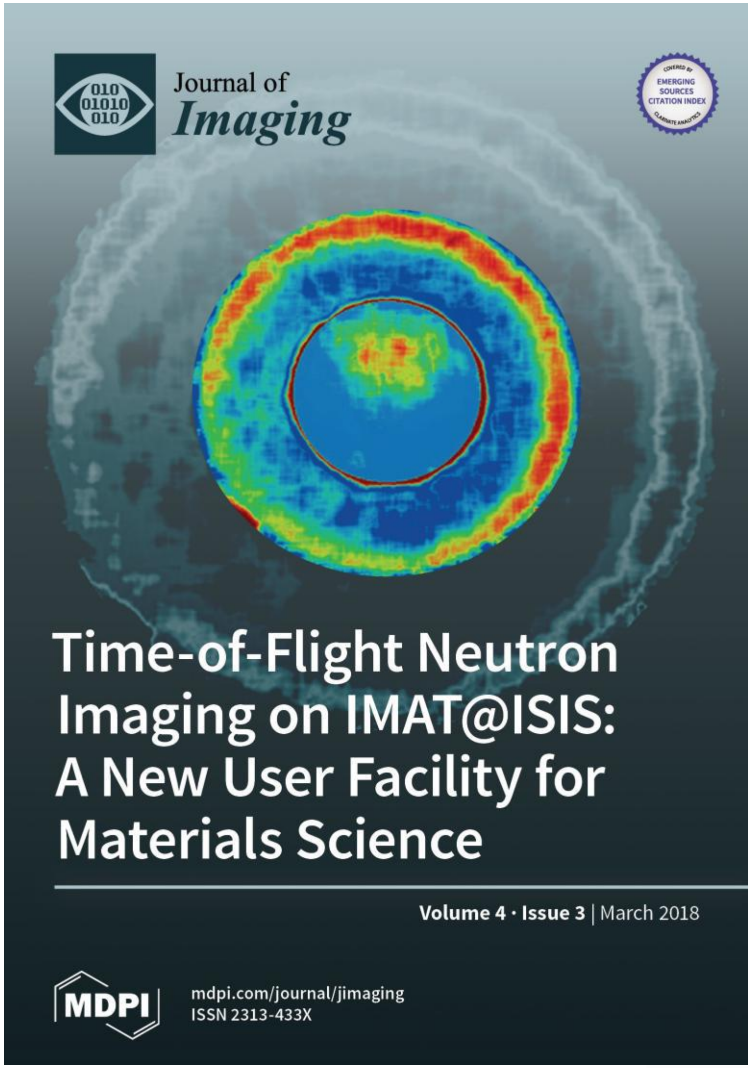
Ray tracing (grain-index)

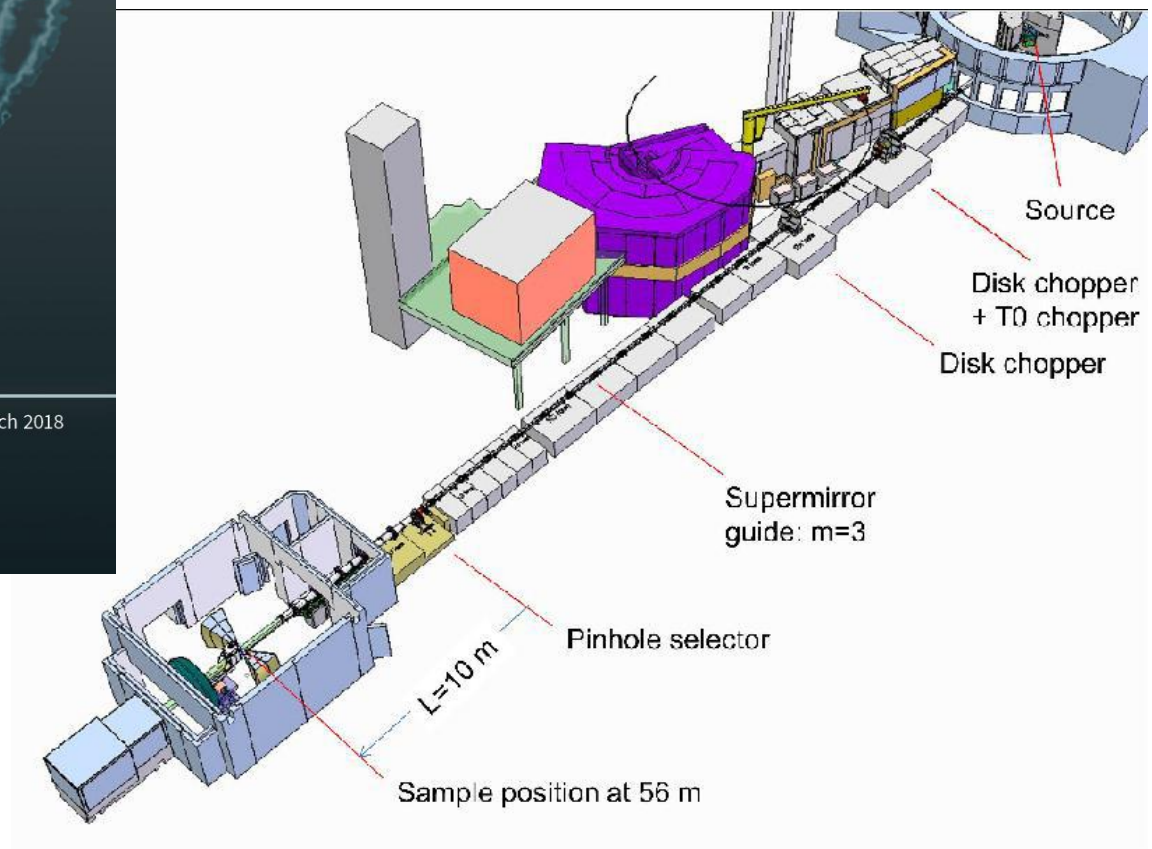
μ-XRD-CT



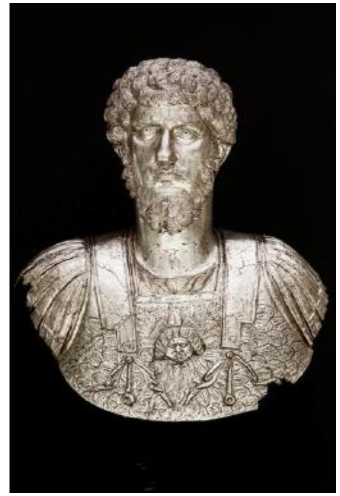


a
b
Intensity (a. u.)
Neutron Time-of-Flight, milliseconds
X
Y
1 1 1
2 0 0
2 2 0
1.2
1 mrd
0.8
Gamma energy [KeV]
keV
Si K_α
Al K_α
Ca K_α
Fe K_α
O K_α


Journal of
Imaging
Time-of-Flight Neutron Imaging on IMAT@ISIS: A New User Facility for Materials Science
Volume 4 · Issue 3 | March 2018
MDPI
mdpi.com/journal/jimaging
ISSN 2313-433X


Source
Disk chopper
+ T0 chopper
Disk chopper
Supermirror
guide: m=3
Pinhole selector
L=10 m
Sample position at 56 m

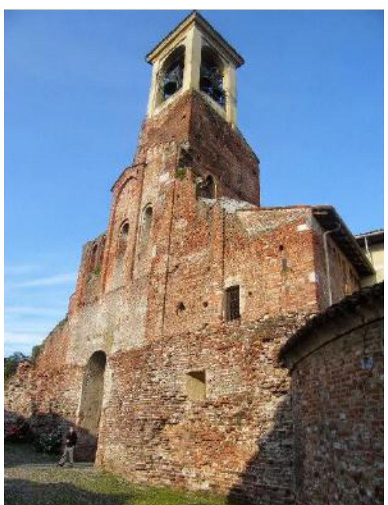
Ancient metallurgy

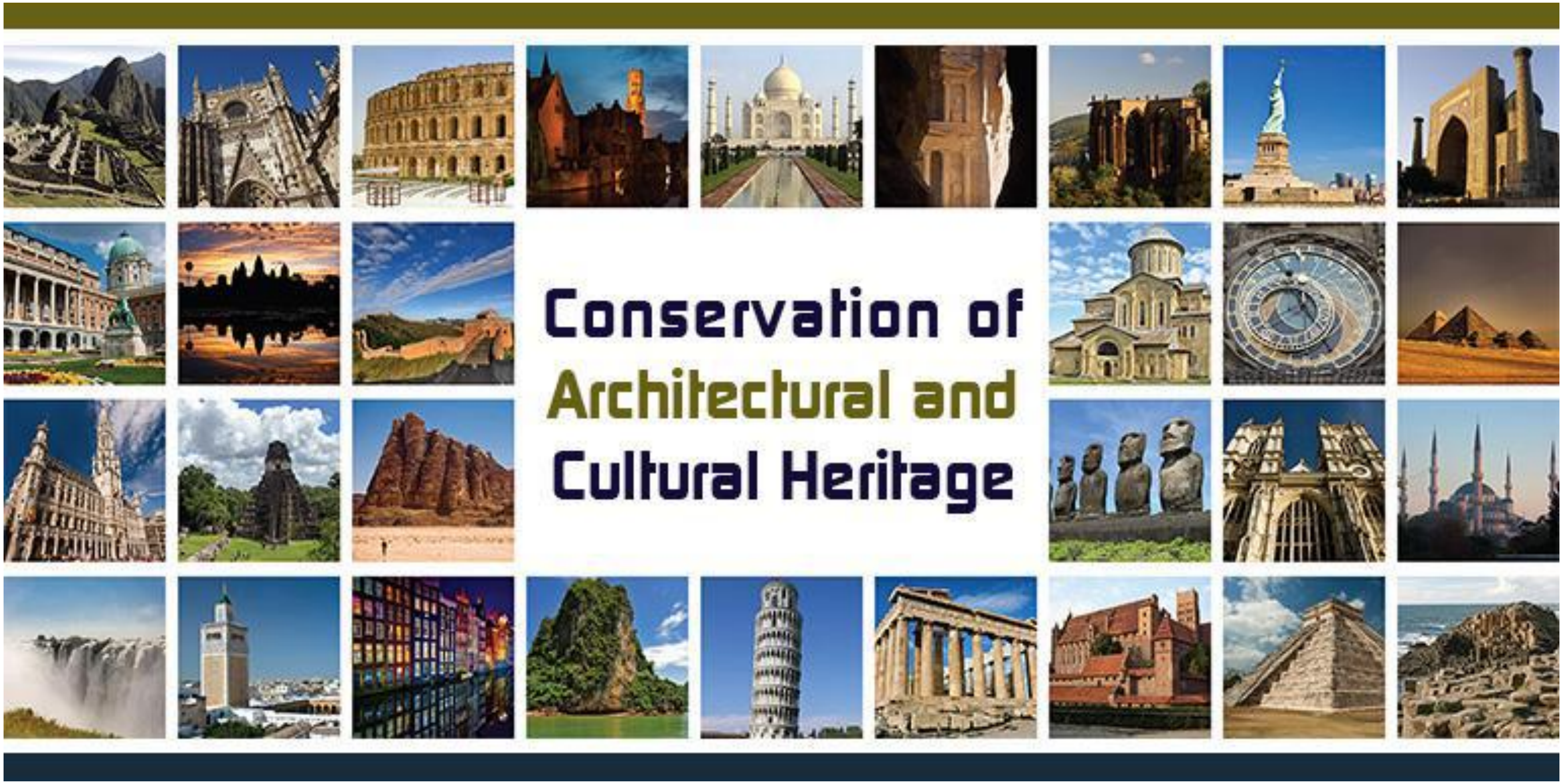


materials

Ancient glass

Building materials





Rovereto - Dec 2018

Archaeometry of built heritage

		purpose
Materials science	Lithics Structural ceramics Binders	Provenance/trade Structural state/preservation Identification of previous interventions Dating
Structural engineering	Mechanical tests/ Stabilization/ Reinforcement	Structural survey and modeling Preservation Resilience/earthquake risk reduction
Geophysics	Survey	Investigation of structures and geological surroundings
Architecture		Architectural interpretation Urban setting Valorization/fruition/display
Archaeology		Interpretation Building history/stages

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Assessment of degradation

Formulation and optimization of binders for buildings and conservation

Characterization of ancient binders

Mortar ^{14}C dating

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http://circe.dicea.unipd.it/