Accelerators in art and archaeology

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Outline

- Introduction
- Overview of scientific methods of examination and analysis of art works
- Ion beam analysis: physical principles, analytical capability and relevance to museum objects
- The IBA facility of the Louvre as an example
- Main applications
- ^{14}C dating with Accelerator Mass Spectrometry
- Conclusion and prospects

Scientific methods of examination

- *Visible light* : photography
  optical microscopy
- *Infrared* : reflectography
- *Ultraviolet :* fluorescence
- *Scanning electron microscope*
- *X-radiography, emissiography, betagraphy*

Scientific methods of analysis

- Techniques of elemental analysis
  - X-ray microanalysis coupled with SEM
  - X-ray fluorescence
  - Atomic emission spectrometry ICP-AES
  - **IBA techniques (PIXE, RBS, NRA, PIGE)**
- Techniques of structural and molecular analysis
  - X-ray diffraction
  - Gas chromatography GCMS
  - IR spectrometry
  - Raman spectrometry
- Dating techniques
  - **^{14}C radioactive counting and AMS**
  - **Thermoluminescence**

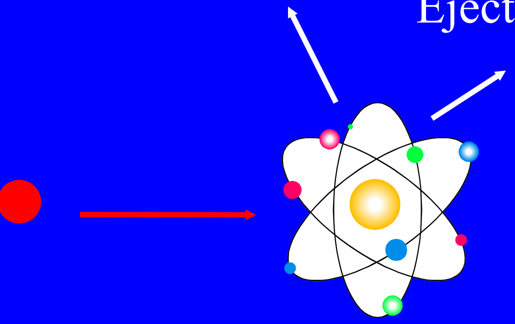
Physical principles of accelerator-based analytical techniques (IBA)

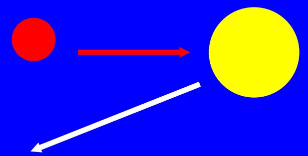
- Interaction of light ions p, d, α (energy ~MeV) with materials constituent atoms
- Energy of interaction product identifies the element (*qualitative analysis*)
- Signal intensity --> concentration (*quantitative analysis*)

PIXE RBS NRA

Emission of a characteristic X-ray

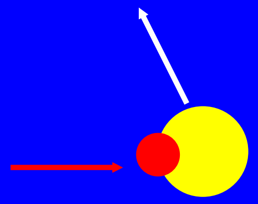
Ejection of an inner-shell electron





Backscattered ion

Secondary ion gamma ray



Specificity of IBA techniques

- quantitative
- multielemental including light elements
- **non-destructive**
- **in-situ analysis with external beam without sampling**
- high sensitivity (PIXE)
- possibility to combine several techniques
- concentration profiles (RBS, NRA)
- possibility of micro-beam for micro-mapping
- surface analysis (up to 15-20 µm)
- *no information on chemical state*
- *problems with insulators*

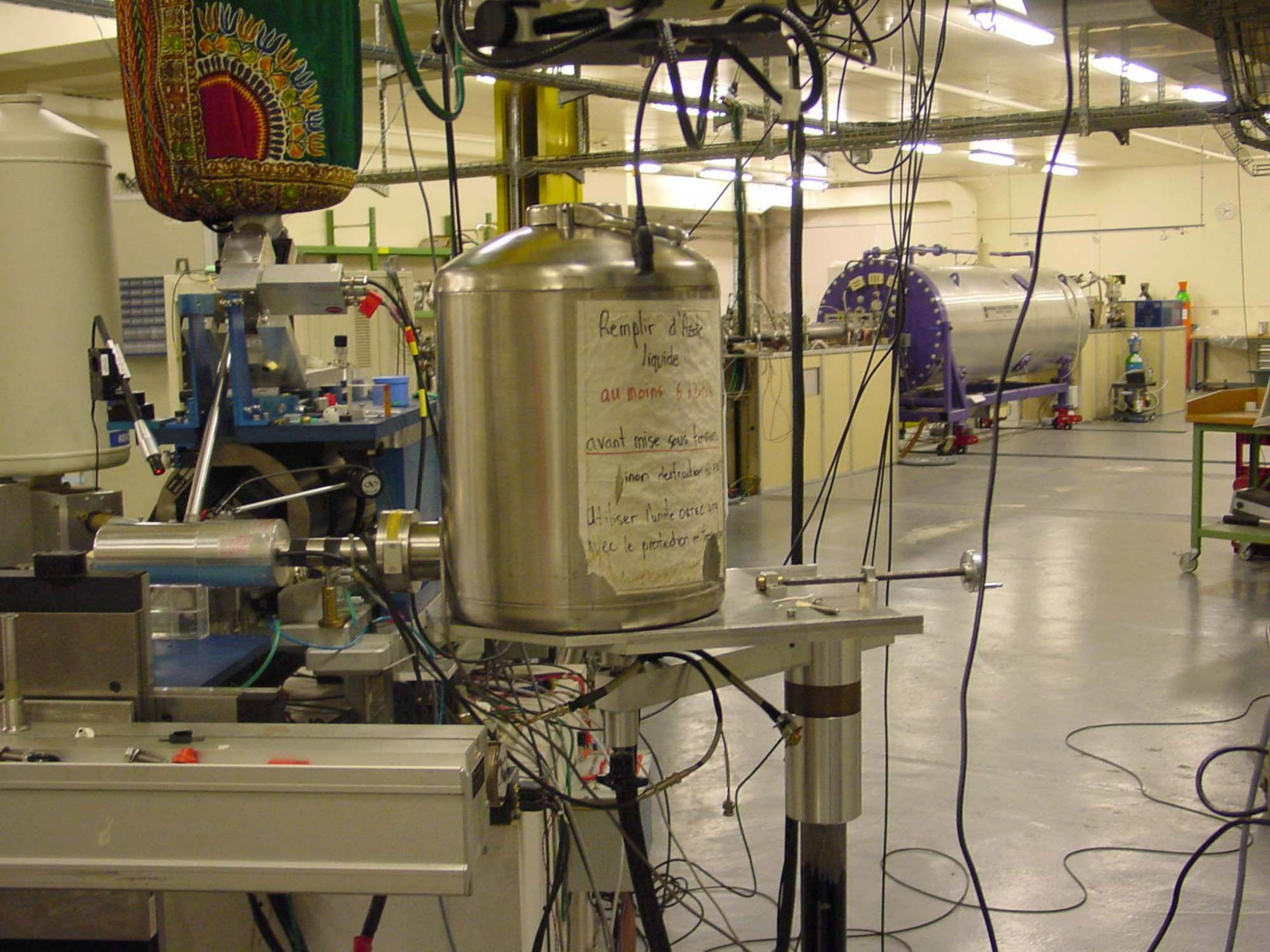
The IBA facility of the Louvre

- 2 MV tandem Pelletron 6SDH-2 NEC
- Working voltage 0.35-2.15 MV
- Ion sources (negative):
  - Alphatross radiofrequency (Rb)
  - Duoplasmatron
- Dielectric gas : SF_6 5 bars
- Stripper : N_2
- Available beams : p, d, ^{3}He, ^{4}He, ^{15}N, ^{16}O
- Radioprotection :

  deuteron beams allowed

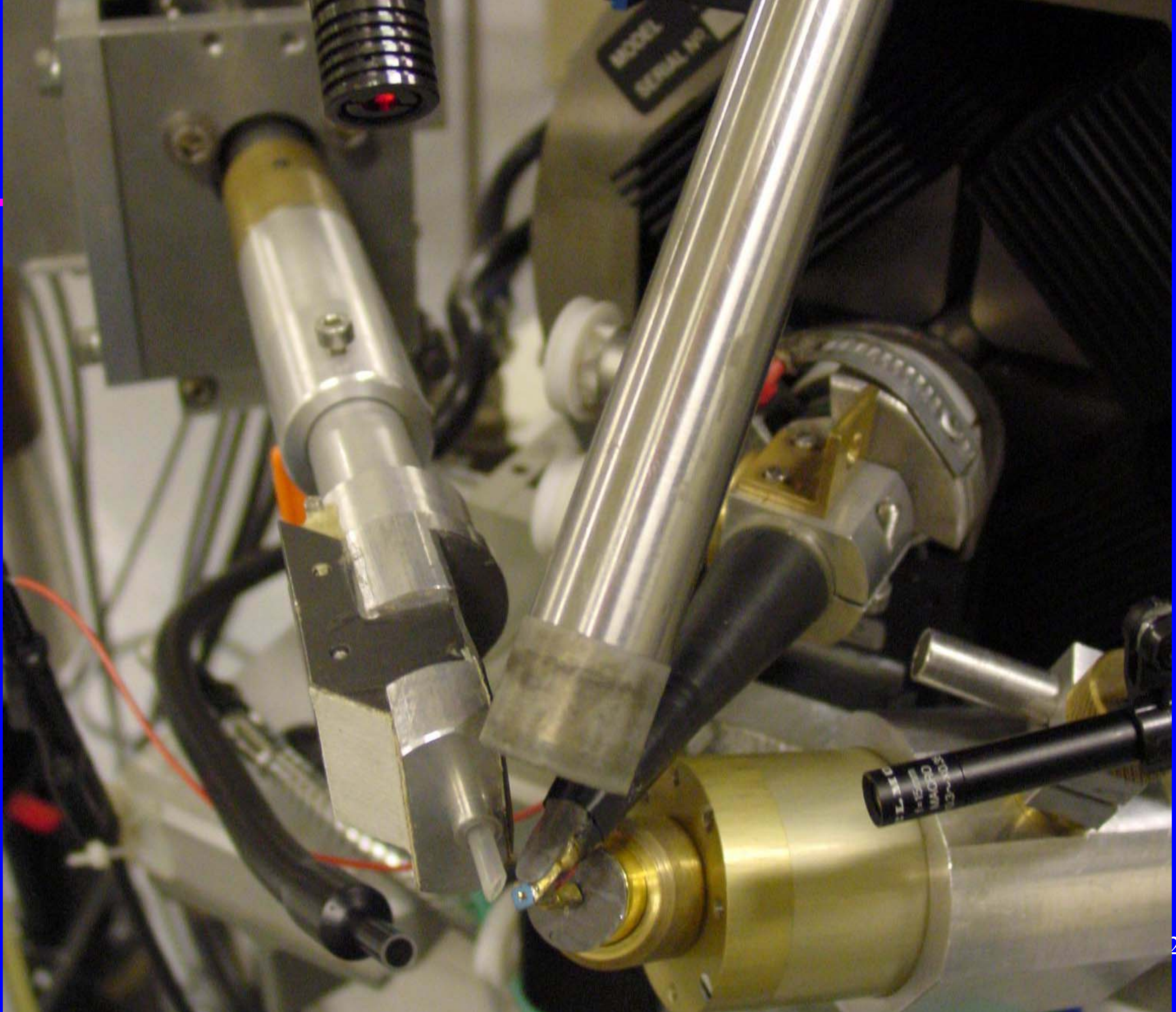
- Beam lines
  - Vacuum chamber
  - External beam (micro-beam)
  - PIXE-induced X-ray fluorescence (in progress)
- IBA techniques : PIXE, PIGE, RBS, NRA, (ERDA)
- Acquisition system
  - multiple detection (3 channels)
  - dead time correction
  - pile-up rejection
- Detectors : X Si(Li); γ HPGe, BGO; particles

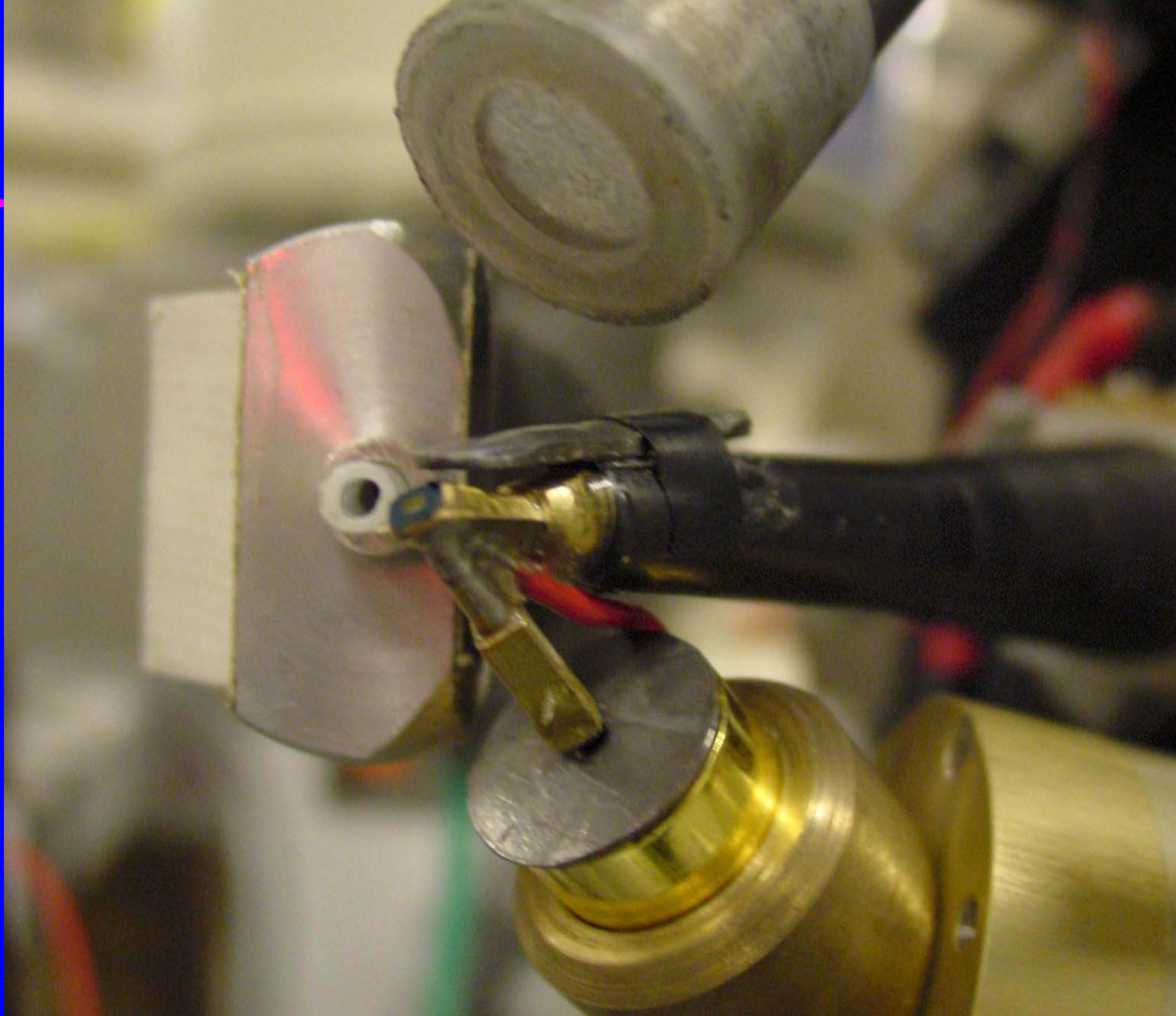

NATIONAL ELECTROSTATICS CORP.
DANGER

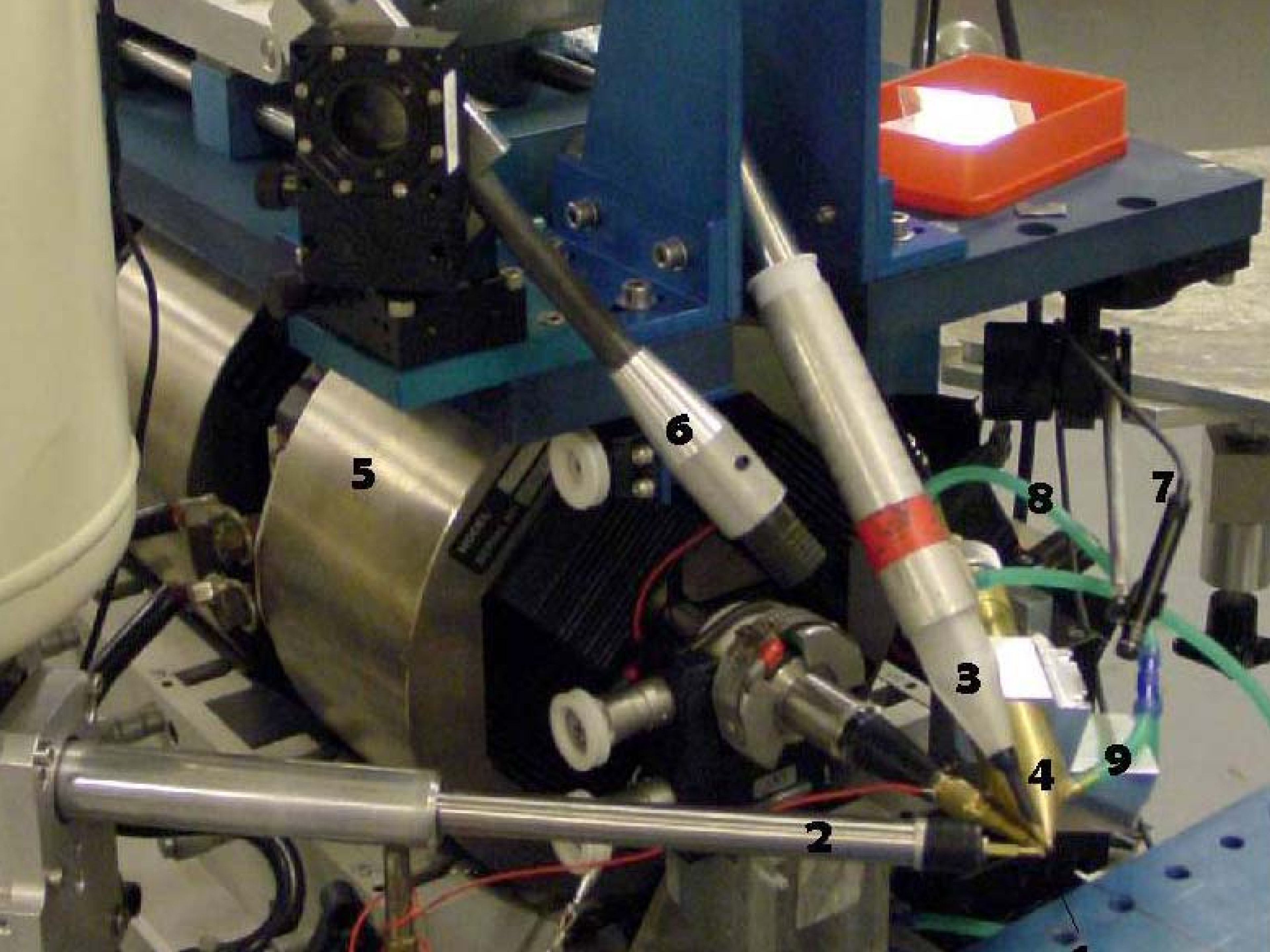

Remplir d'Azote
liquide
au moins
avant mise sous tension
sinon destruction
Utiliser l'unite ORTEC
avec le protection

Most useful experimental set-up : external beam

- in-situ measurements---> no sampling
- objects of large size or complex shape
- ease of handling and moving of objects
- no charging problem with insulators
- reduced thermal effects ---> no damage
- no dehydration problem
- possibility of small-sized beam 10 μm


MODEL
SERIAL NO




6
5
8
7
3
4
9
2

Ion beam analysis applied to materials of cultural heritage (1)

- Archaeometry (archaeological science)

Materials identification

➔ *PIXE analysis of major elements*

Materials provenance

(sources of raw materials and trade routes)

➔ *PIXE analysis of trace elements*

Artistic or fabrication technique

➔ *Spatial distribution required: lateral μPIXE, depth RBS*

Ion beam analysis applied to materials of cultural heritage (2)

- Conservation science

Assessment of state of conservation of museum objects

Study of alteration mechanisms with experimental materials submitted to accelerated ageing

➔ *depth profiling by RBS and NRA*

- Preventive conservation

Monitoring of museum environment

➔ *PIXE analysis of collected dust*

➔ *RBS analysis of monitors*

Materials identification

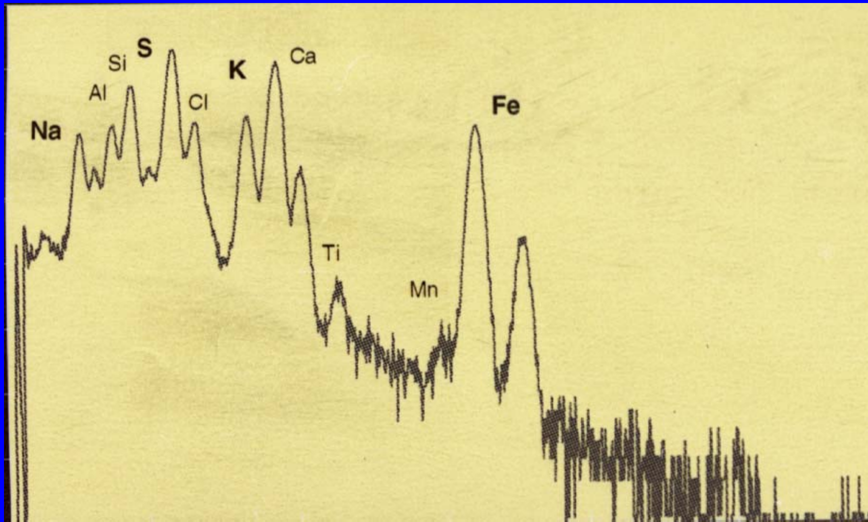
- Artistic or archaeological object
- Material of interest

- Renaissance drawings
- Antique jewels
- Antique statuette
- Antique papyrus
- Medieval miniatures
- Painted steles

- Metal points
- Gemstones
- Gemstones
- Inks and pigments
- Pigments
- Pigments

Materials identification by means of PIXE : nature of inks and pigments on manuscripts

- Micro-beam in PIXE mode with low beam current (50pA) well adapted :
  - very fragile material
  - need of good lateral resolution
  - easy quantitative measurements
  - easy discrimination between materials

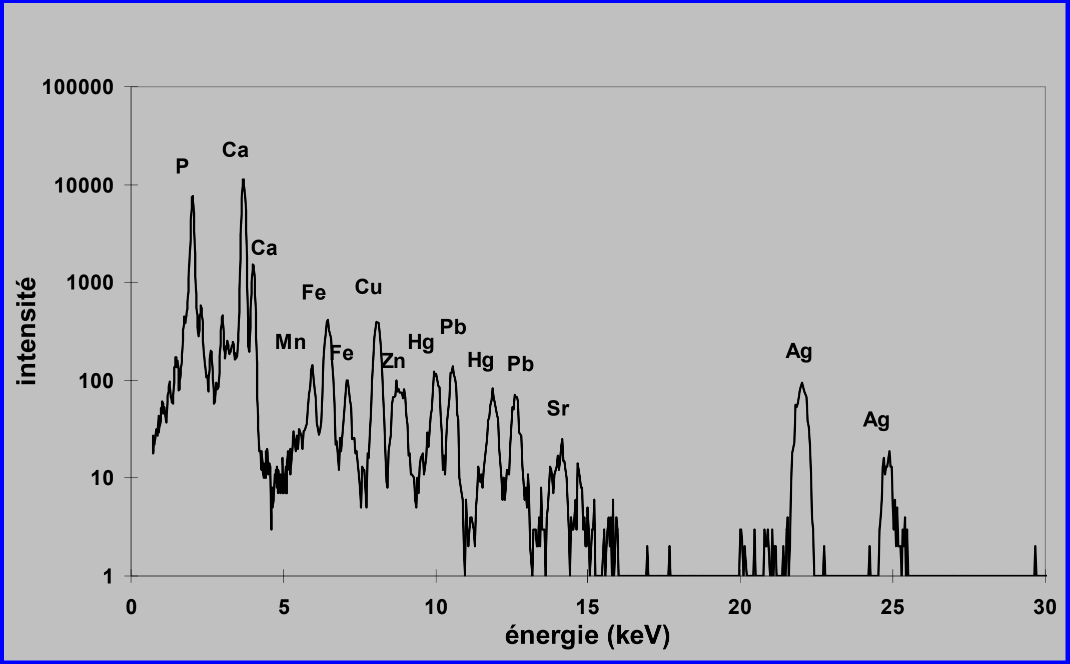


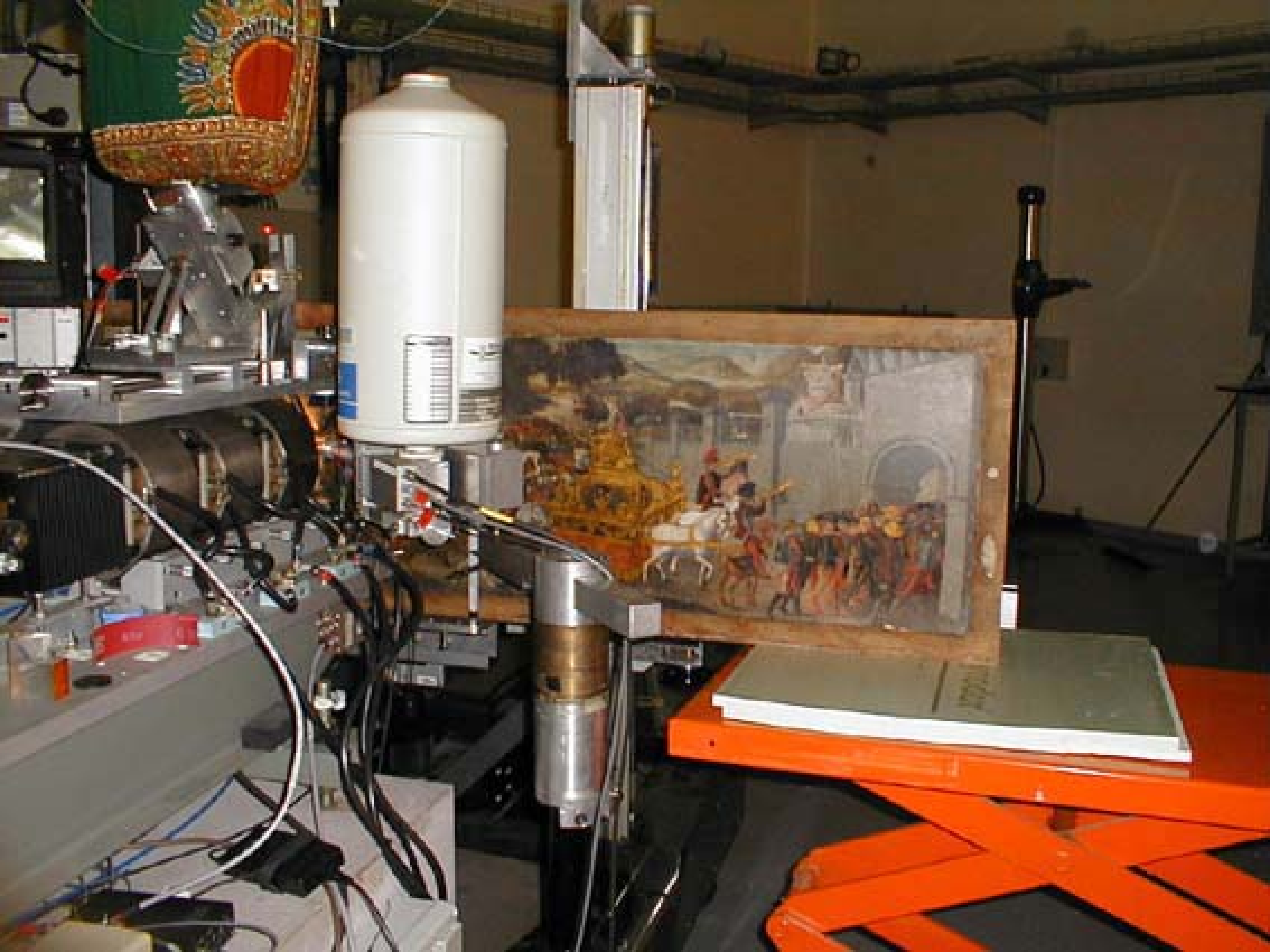
Drawing by Dürer

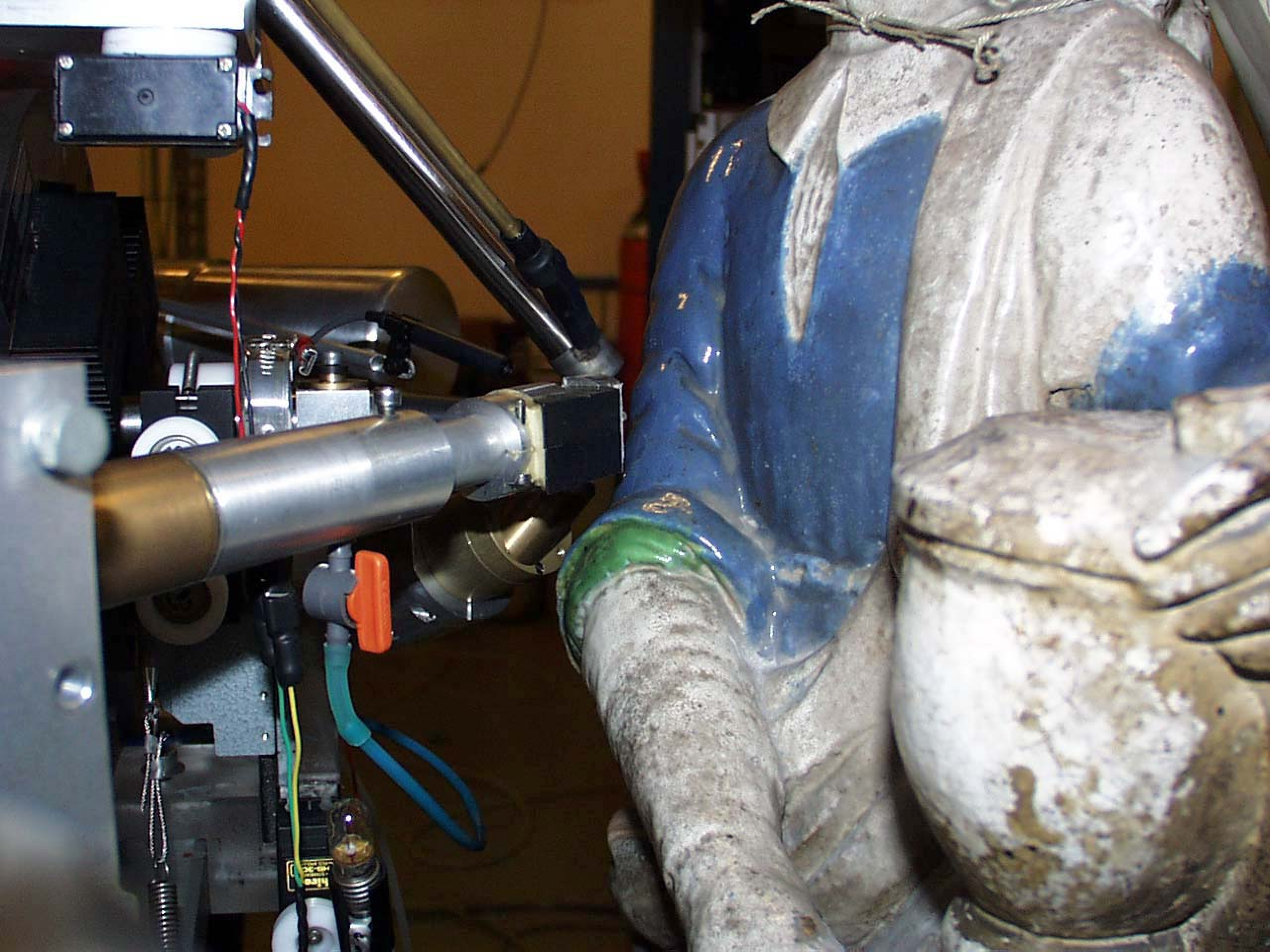
Drawing by Pisanello

Mark of metal point

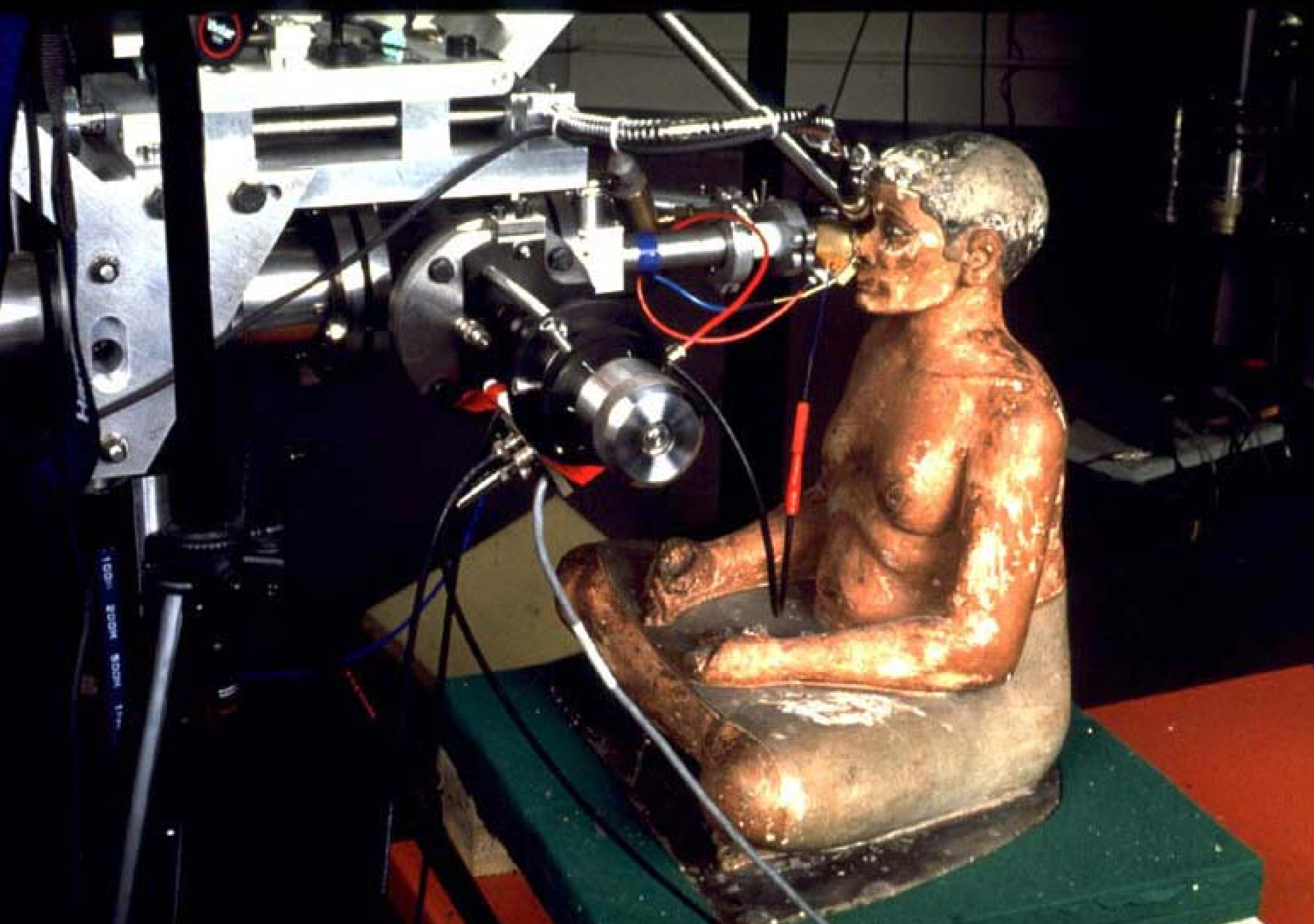
Drawing by Pisanello







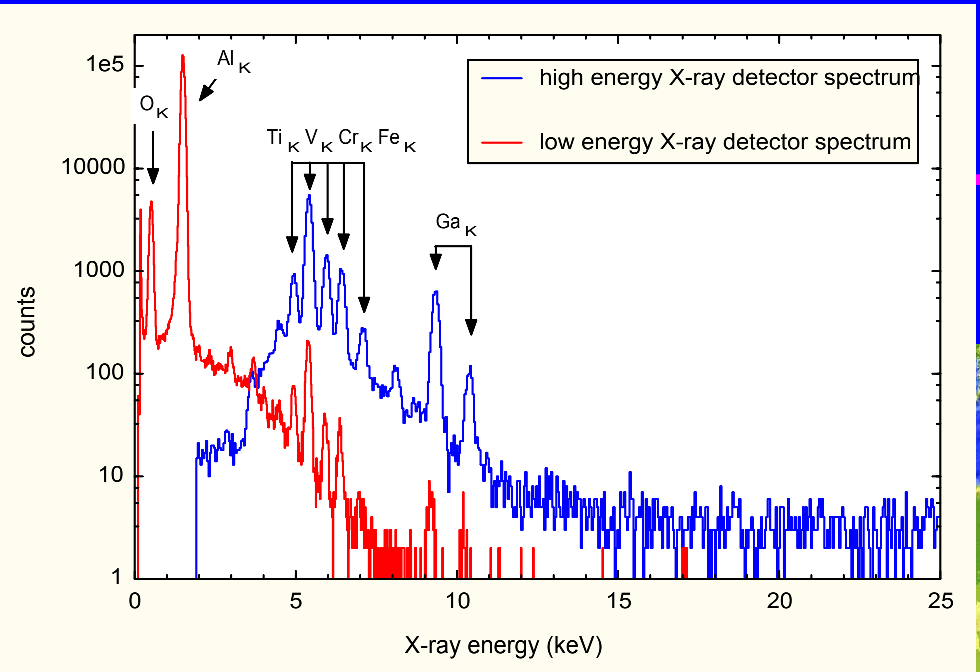
Egyptian scribe: nature of eye components

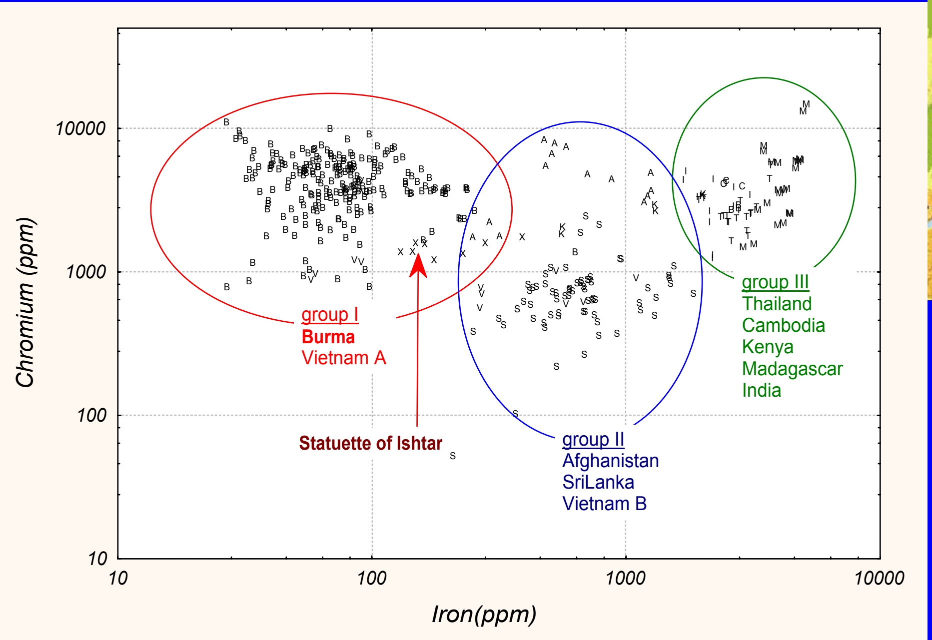


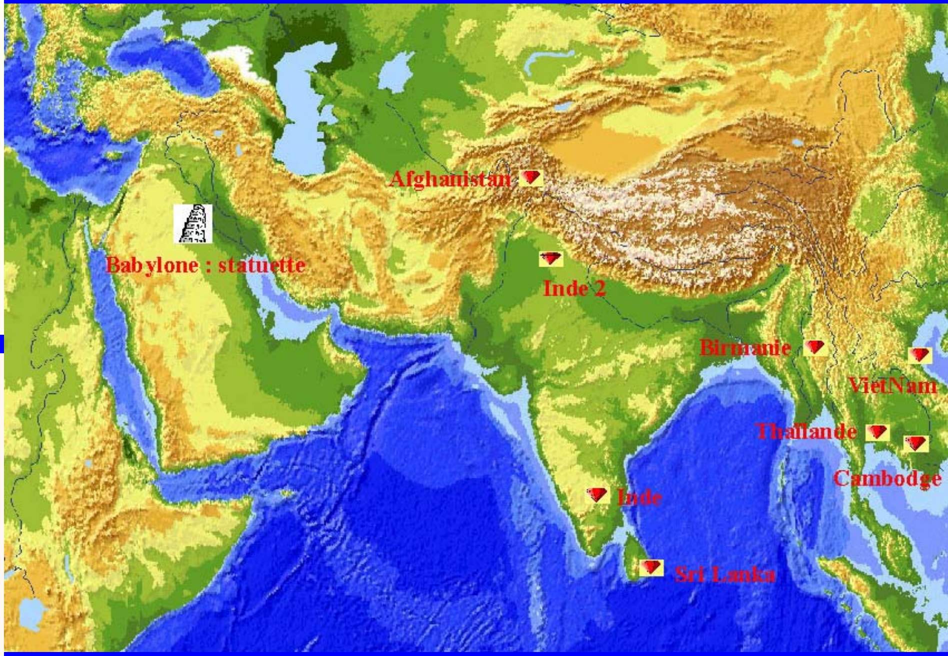
Provenance studies using PIXE analysis of trace elements

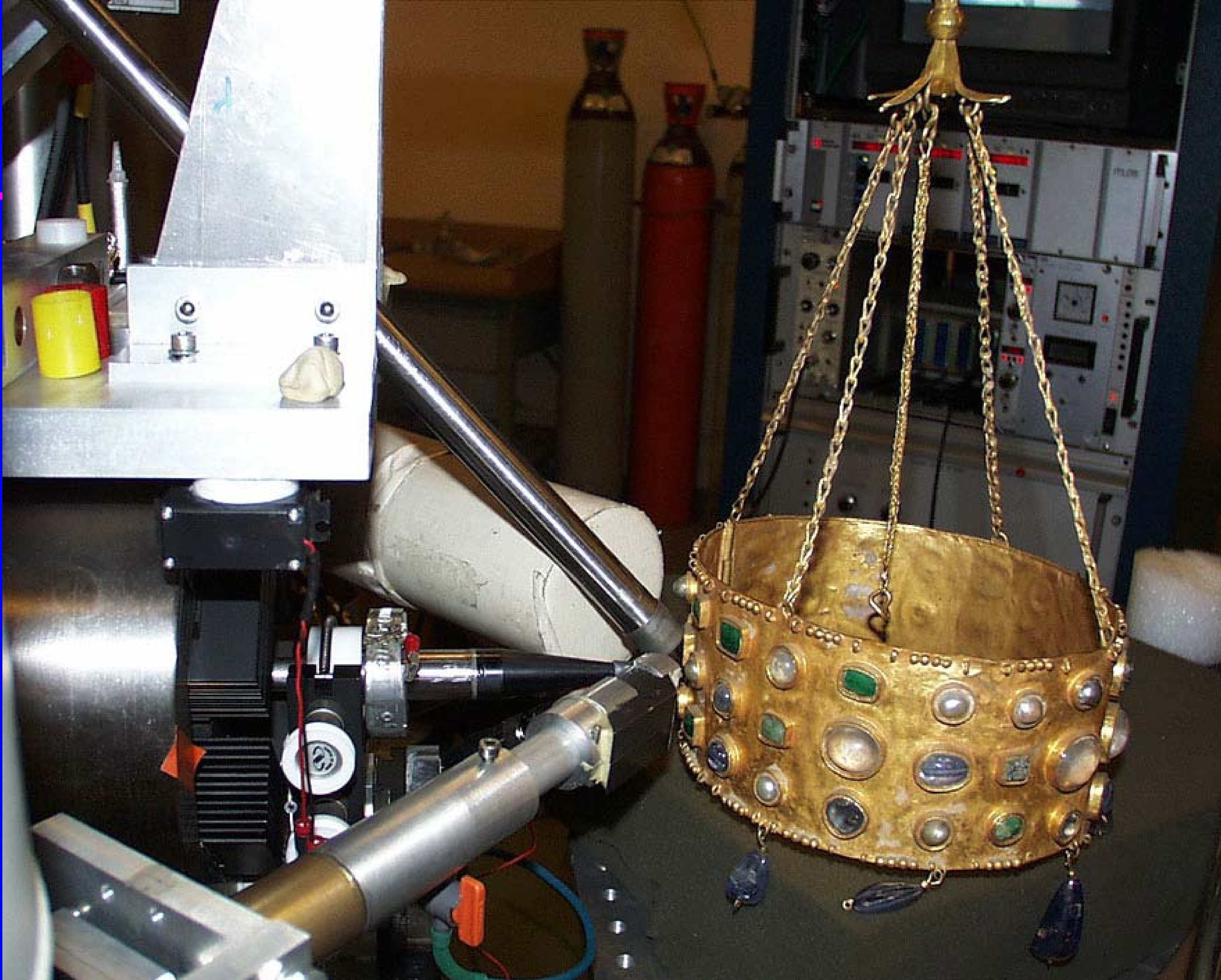
- Trace element content currently used as a fingerprint in archaeology
- Comparison with geological materials
- Statistical processing of data
- Fields of application
  - Stones: obsidian, flint
  - Gemstones
  - Ceramics

Provenance of statuette rubies

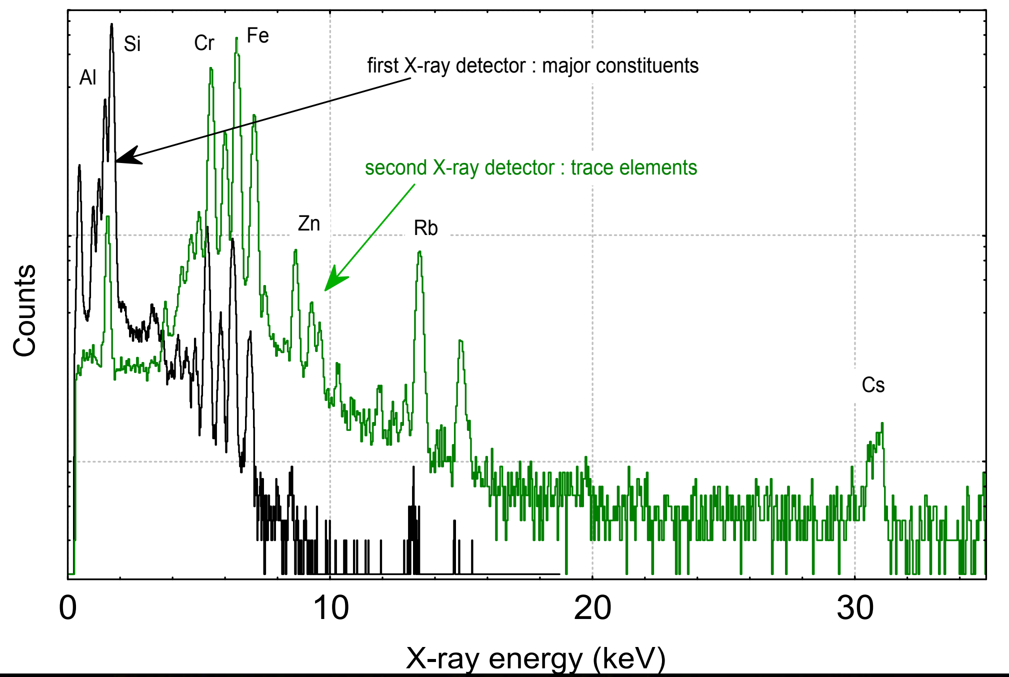


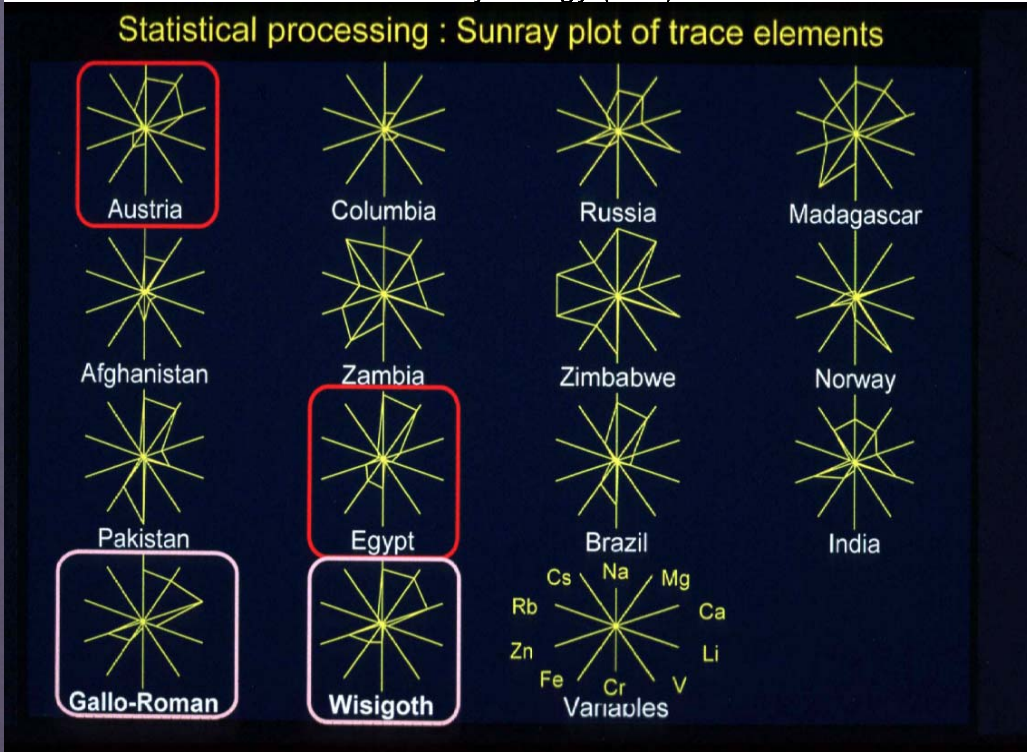


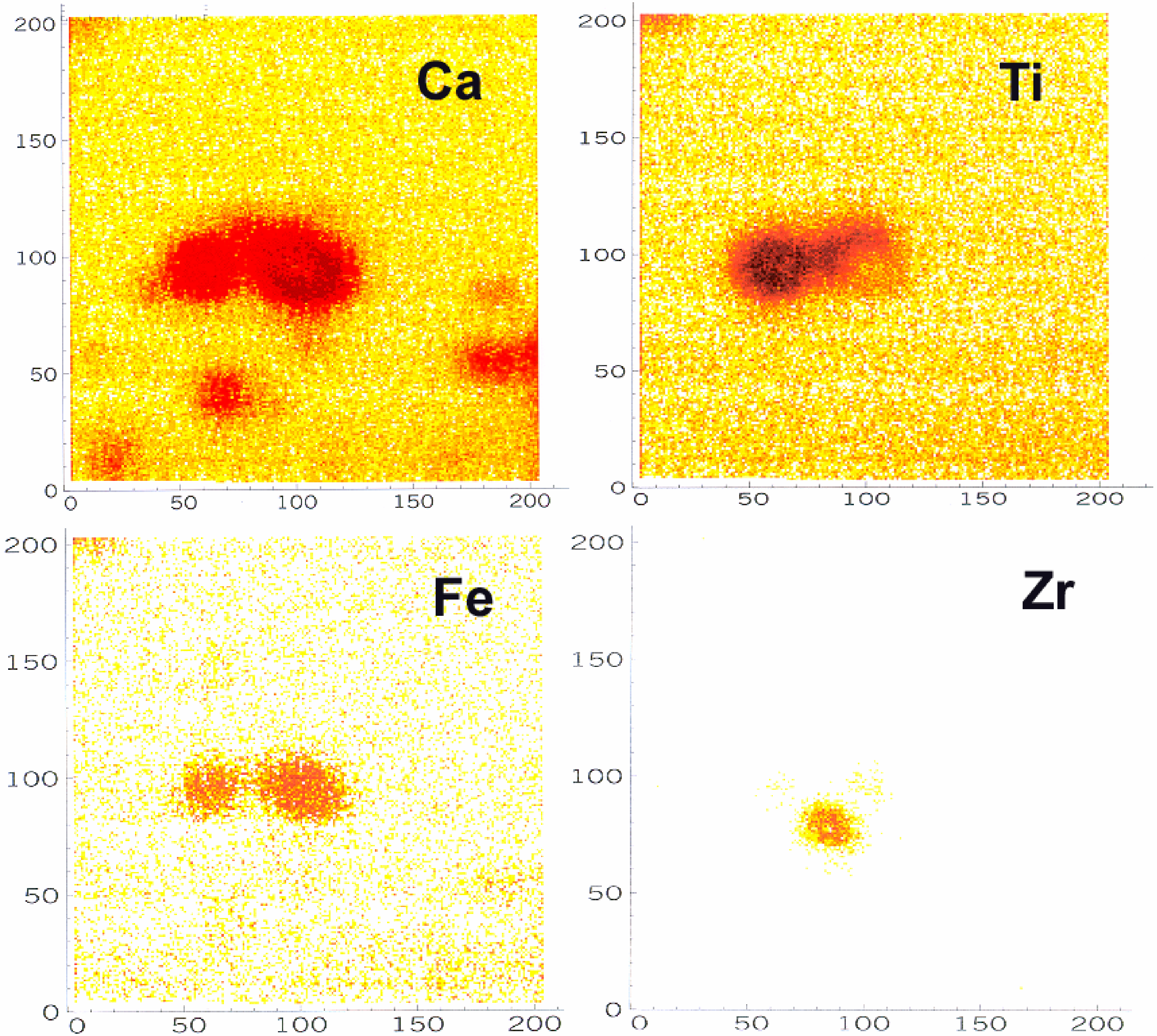




Merovingian emerald






Ca
Ti
Fe
Zr
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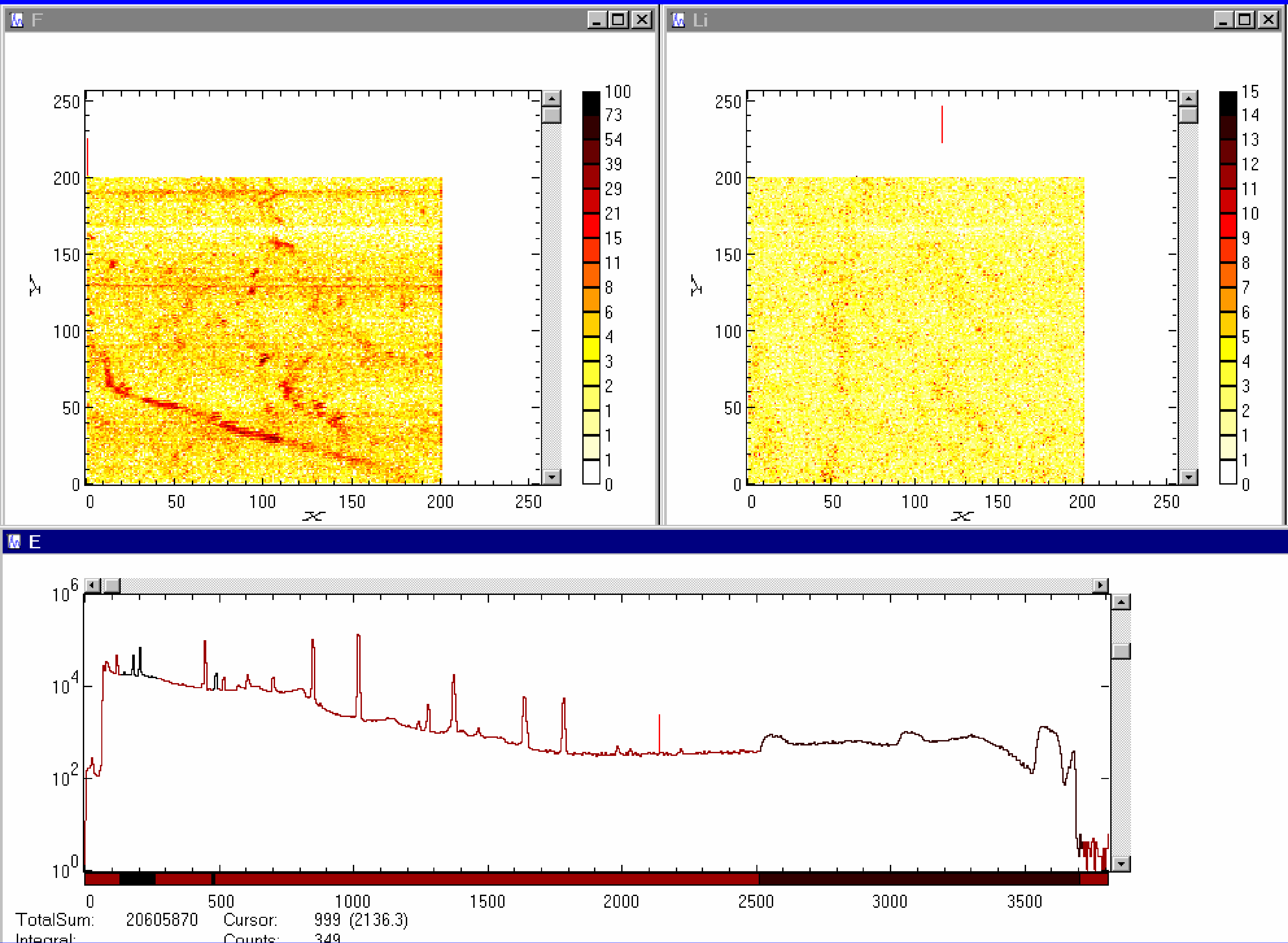
100
150
200


F
Li
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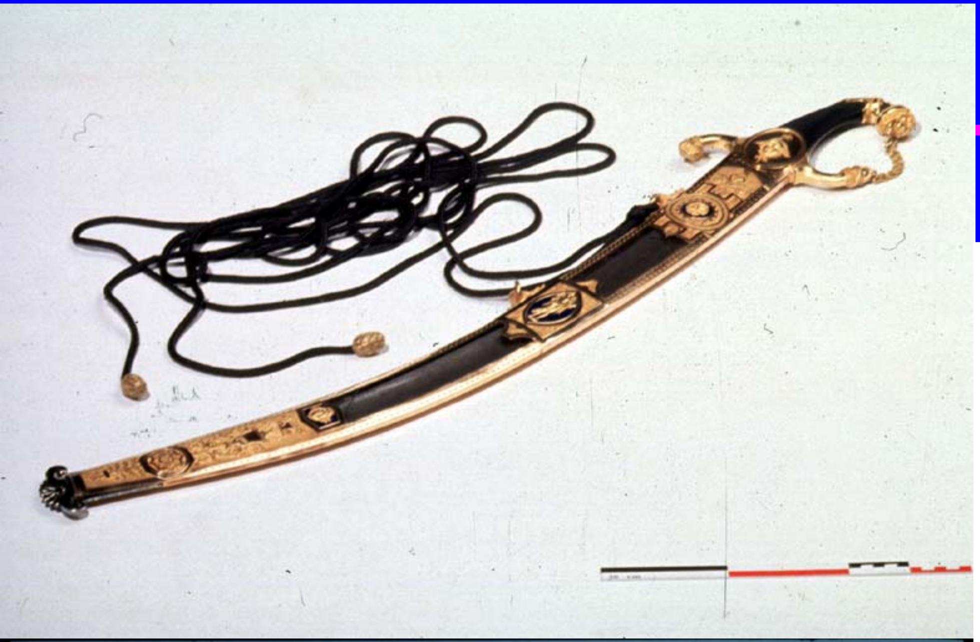
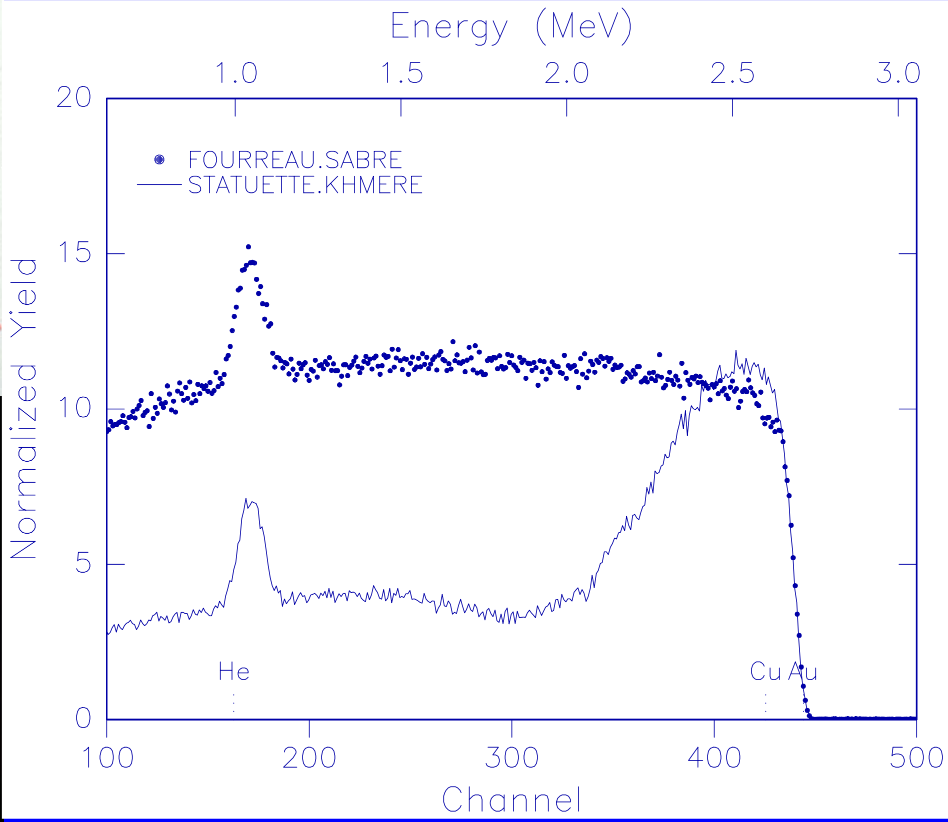
Surface analysis using RBS and NRA

- Structure of objects made of precious metals
- Patina on bronzes

Surface analysis using RBS and NRA

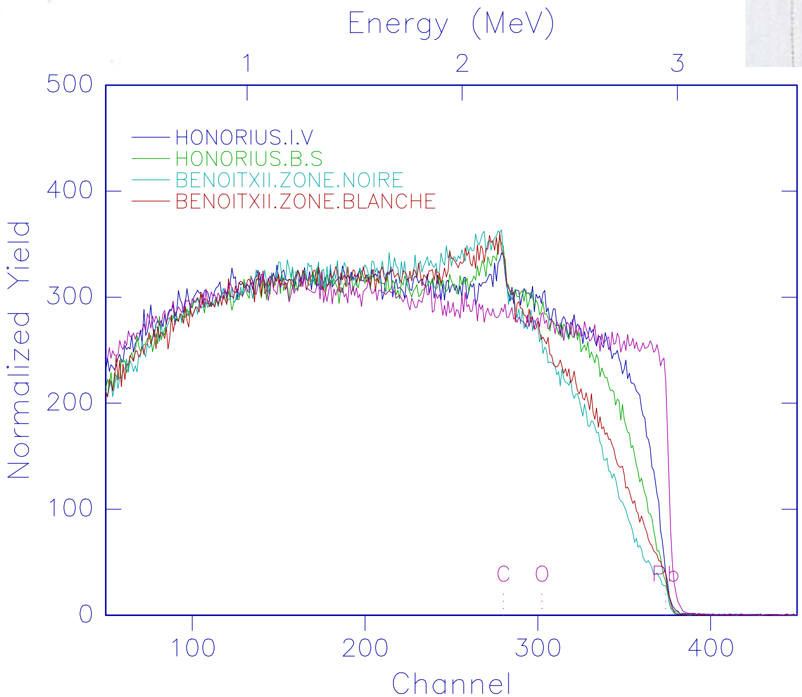




Applications in conservation science

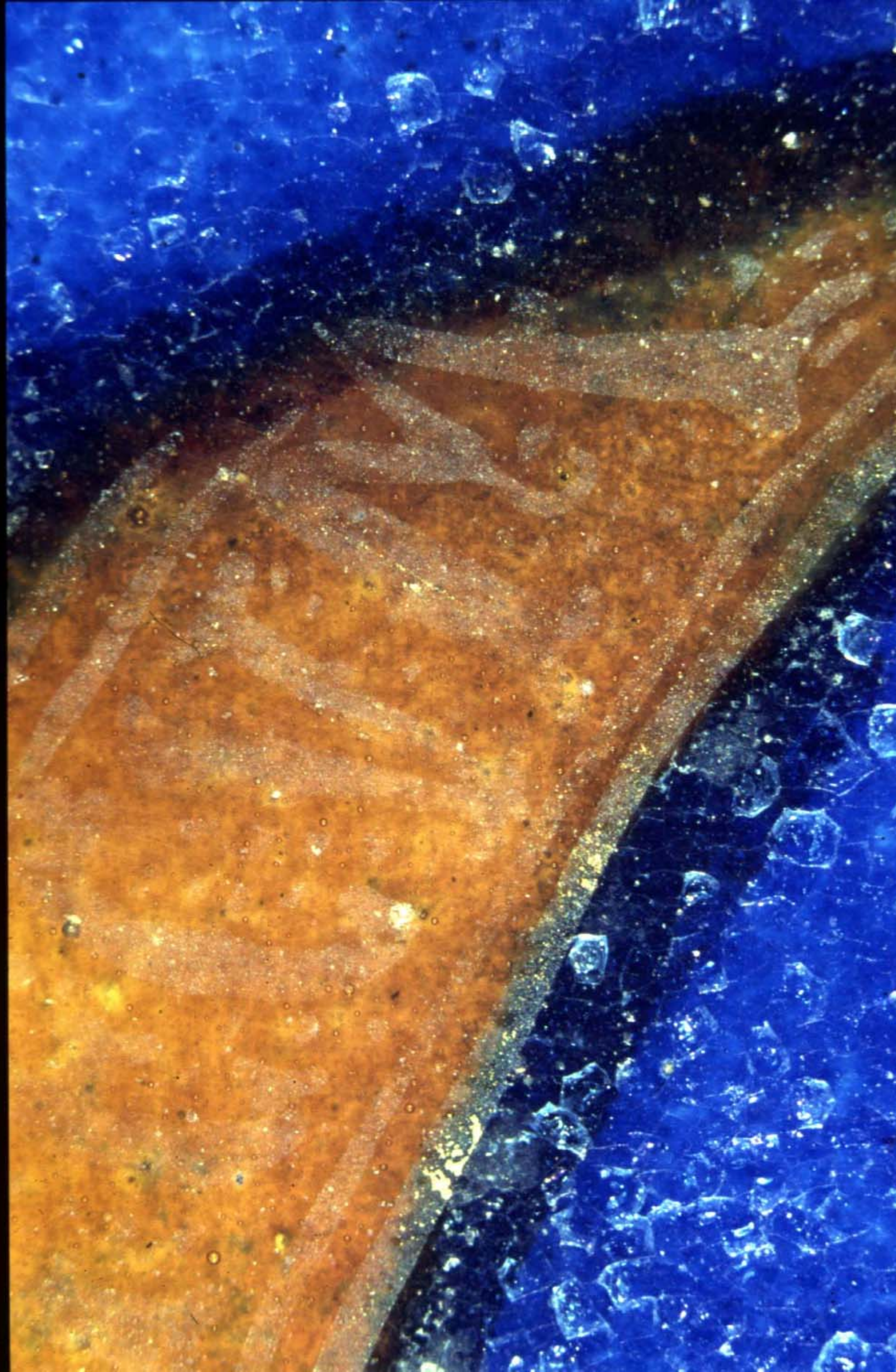
- corroded lead bullae from National Archives
- altered medieval enamels

Lead bullae



Energy (MeV)
1
2
3
500
400
300
200
100
0
Normalized Yield
HONORIUS.I.V
HONORIUS.B.S
BENOITXII.ZONE.NOIRE
BENOITXII.ZONE.BLANCHE
C
O
Pb
100
200
300
400
Channel

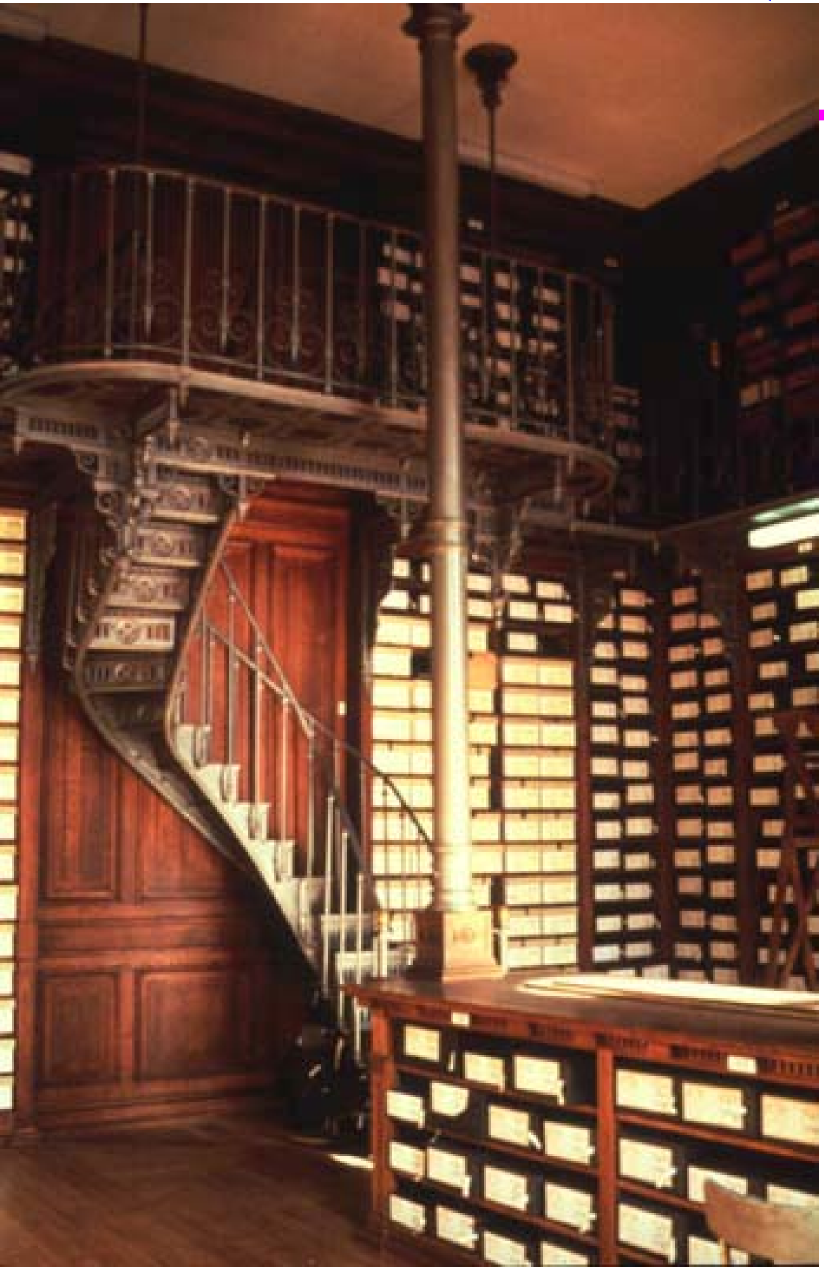

O ILLVSTRISSIMA ET EXCELLENTISSIMA
SEMPER VIRGO MARIA MATER
IHESV XPISTI

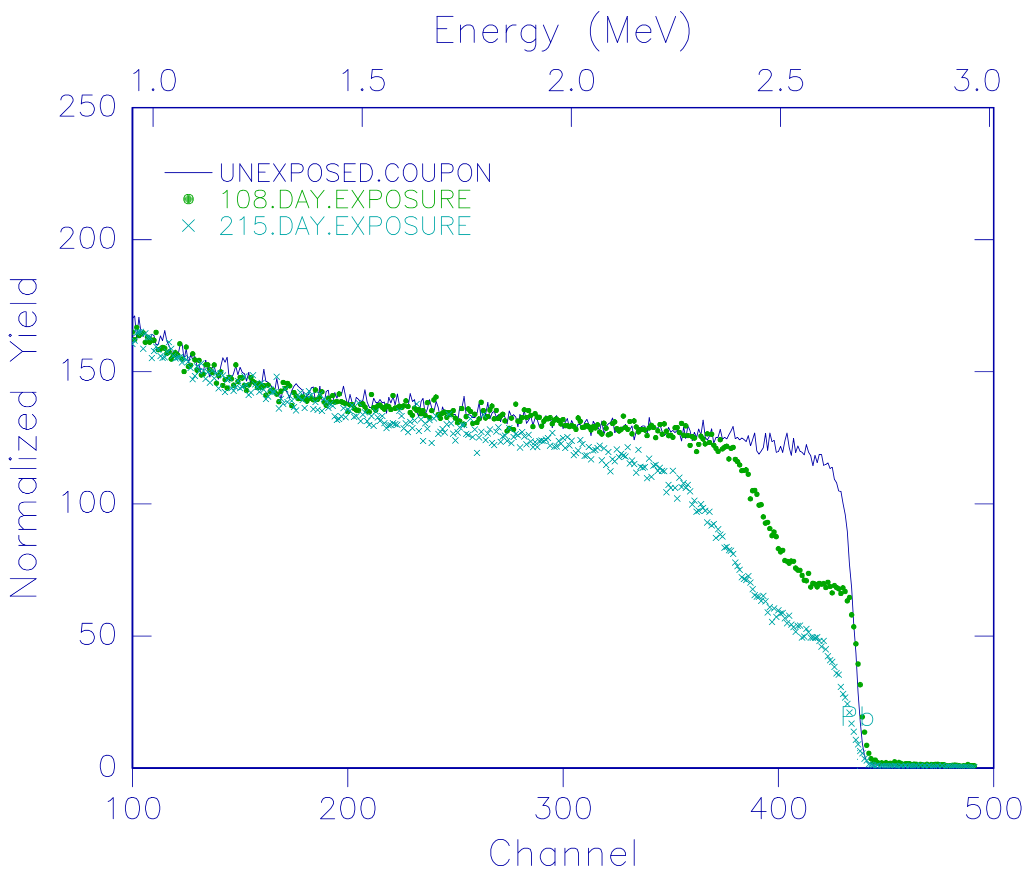


Application in preventive conservation

- Control of museum environment by sampling atmosphere components and by monitoring risk of corrosion

National Archives (seal department)

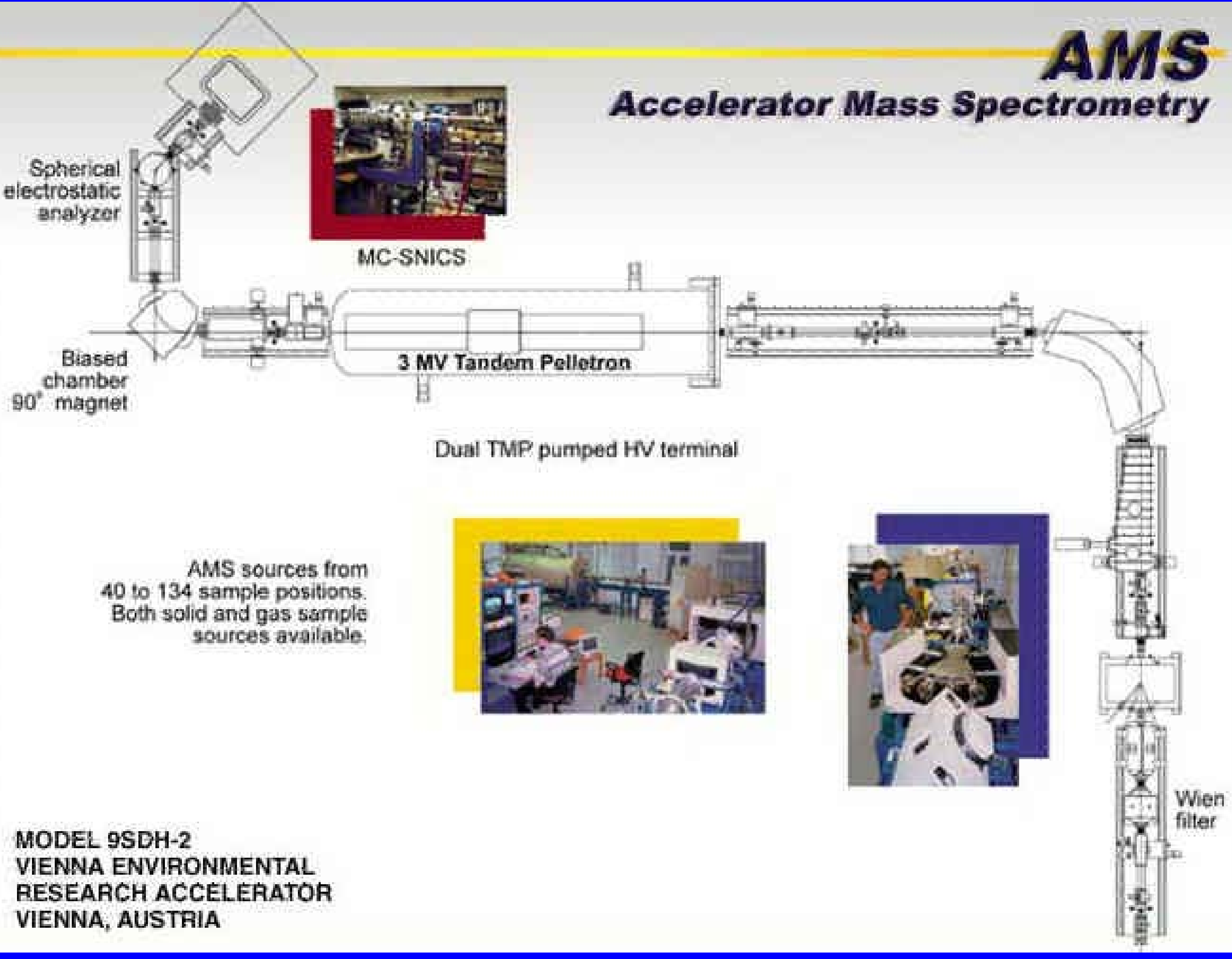




^{14}C dating with accelerator mass spectrometry (AMS)

- AMS applicable to cosmogenic nuclei ^{10}B, ^{14}C, ^{26}Al,..of extremely low isotopic abundance (10^{-15} to 10^{-12} for ^{14}C) and long half-life
- For ^{14}C direct measurement of amount of nuclei instead of radioactive counting → less material needed (1 mg vs 1 g) and reduced time of measurement
- C ions are accelerated up to 12 MeV to suppress isobaric molecular ions and use of nuclear detection systems (E-ΔE, TOF, SBD)

AMS
Accelerator Mass Spectrometry



AMS sources from 40 to 134 sample positions. Both solid and gas sample sources available.

MODEL 9SDH-2
VIENNA ENVIRONMENTAL RESEARCH ACCELERATOR
VIENNA, AUSTRIA

Future AMS facility for ^{14}C dating

Future AMS facility for ^{14}C dating

- 3 MV tandem Pelletron 9SDH-2 from NEC
- Two multicathode negative ion sources (134 and 40 samples)
- Sequential injection of ^{12}C, ^{13}C, ^{14}C
- Precision 0.3% on modern C
- Fully automatic
- Expected to be operational in early 2003
- About 4000 measurements per year (1500-2000 for archaeology)

Conclusion and prospects

- Usefulness of accelerator-based analytical techniques in the field of Art and Archaeology due to their performances and their non-destructive character
- Combination PIXE-PIGE mostly used
- Usefulness of external (micro-)beam
- Possibility of micro-mapping using the external micro-beam
- Use of complementary methods based on RBS and NRA for elemental depth-profiling
- Possibility of kinetic studies in real time with external beam
- ^{14}C dating with AMS increasingly used