School on Synchrotron Light Sources and their Applications
13-24 January 2025

Li-Hill, 2019, Grenoble

Synchrotron multi-modal micro-analyses for cultural heritage: Application to the study of inks composition in Egyptian papyri

Presentation and tutorial on the use of PyMca software

Marine Cotte

[1] ESRF (Synchrotron Européen),
71 avenue des martyrs, 38000 Grenoble (France)

[2] Laboratoire d'Archéologie Moléculaire et Structurale,
CNRS UMR 8220, Sorbonne Universités, Univ Paris 06, 4 place Jussieu
75005, Paris (France)

THE EUROPEAN SYNCHROTRON RADIATION FACILITY, GRENOBLE, FRANCE

19 PARTNER COUNTRIES

13 Member States:

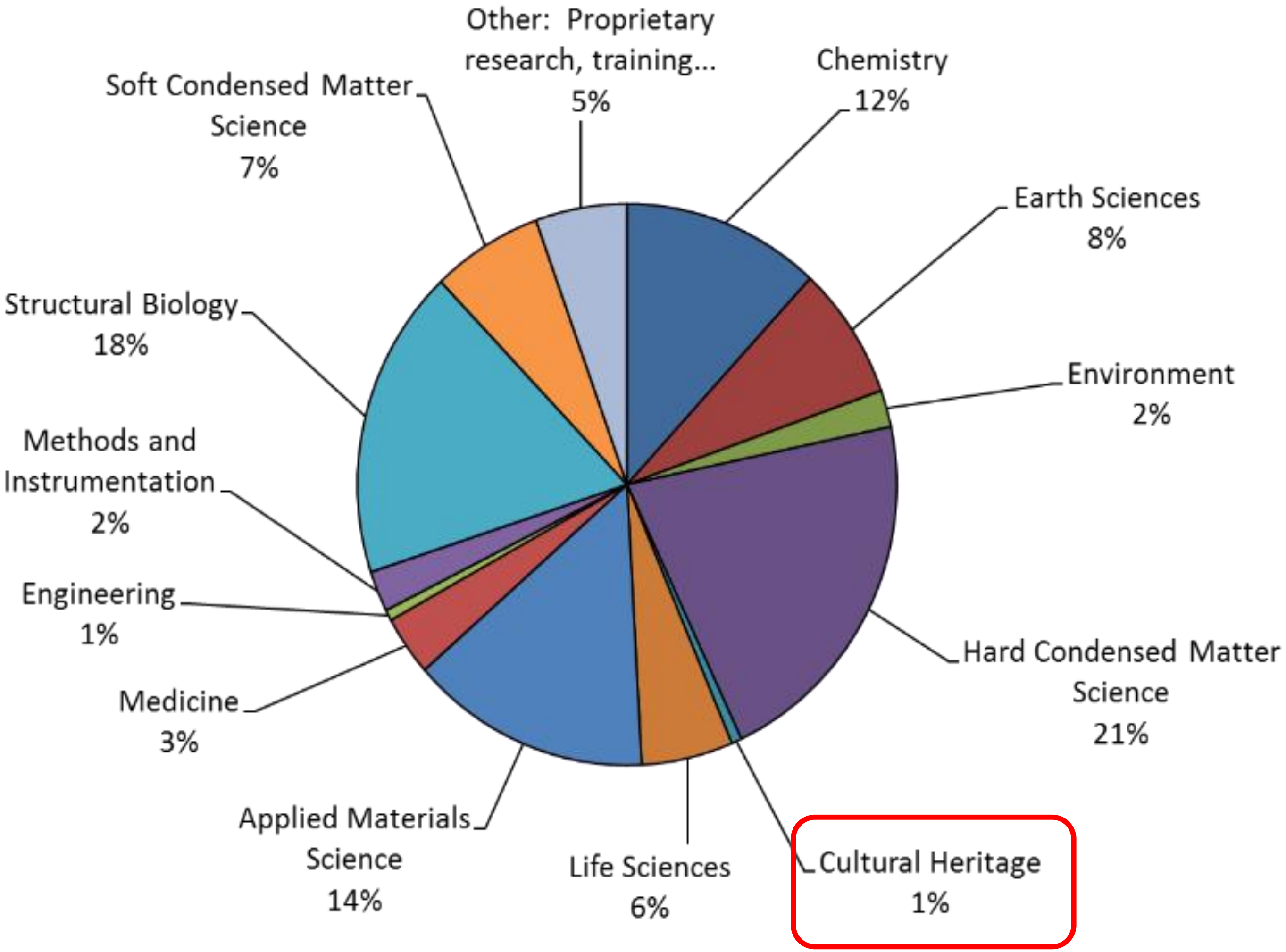
France	27.5 %
Germany	24.0 %
Italy	13.2 %
United Kingdom	10.5 %
Russia	6.0 %
Benesync (Belgium, The Netherlands)	5.8 %
Nordsync (Denmark, Finland, Norway, Sweden)	5.0 %
Spain	4.0 %
Switzerland	4.0 %

6 Scientific Associate Countries:

Israel	1.75 %
Austria	1.75 %
Poland	1.0 %
Portugal	1.0 %
Czech Republic	0.6%
South Africa	0.30 %

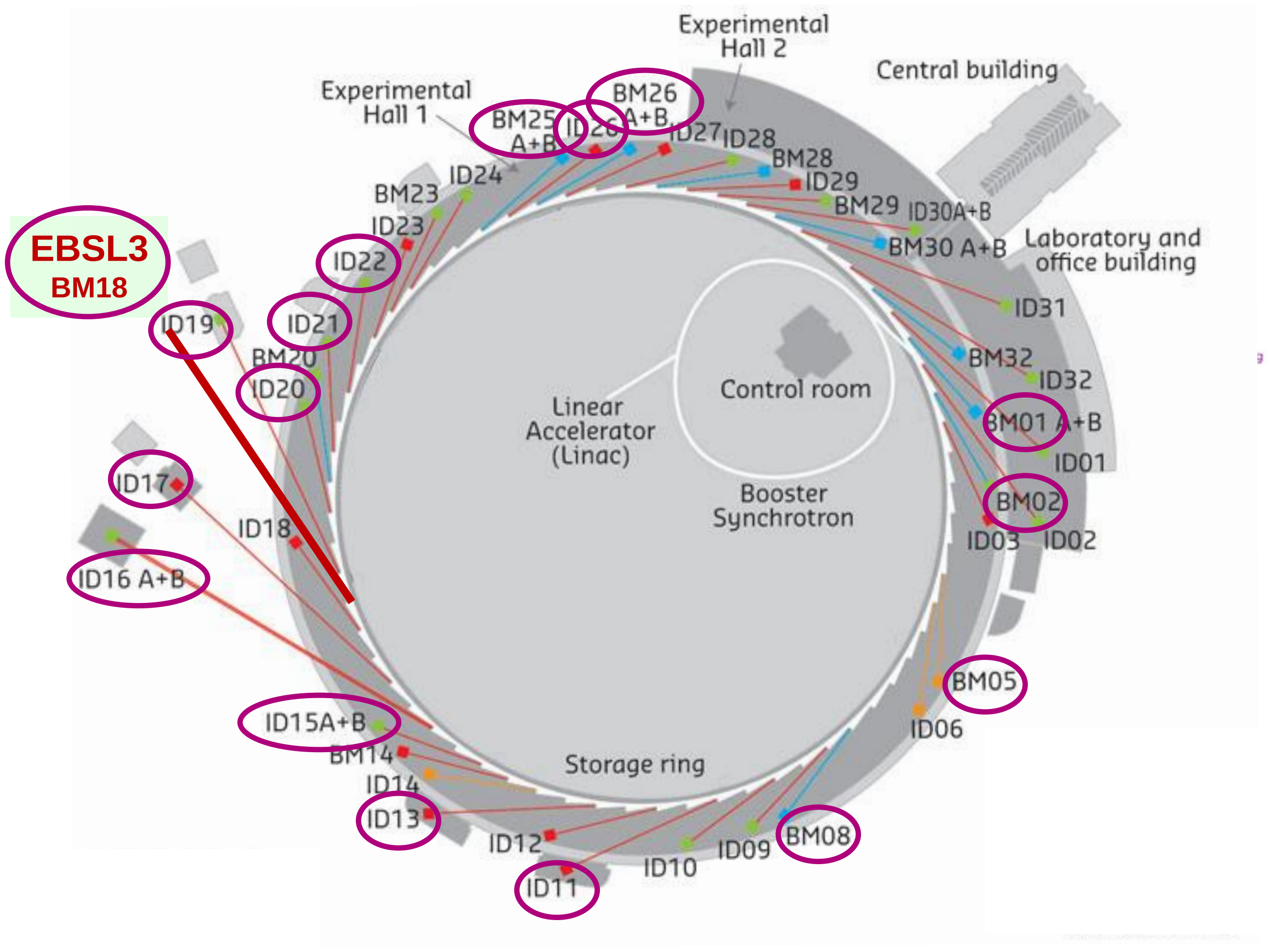
NATURAL AND CULTURAL HERITAGE AT THE ESRF

Distribution of shifts (8hrs) delivered on beamlines during the scheduling year 2018, by scientific area



THE CULTURAL HERITAGE COMMUNITY AT THE ESRF

Heritage studies via user program



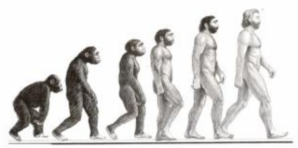
THE MAIN OBJECTIVES OF SYNCHROTRON ANALYSES OF ANCIENT MATERIALS

Non-manufactured objects: evolution of Life.

Natural processes involved at all time scales:

- days-months (e.g. embryonic development),

- months-years (e.g. growth from child to adult),
- centuries-millenia (e.g. species domestication),
- 1M-1B years (life evolution)



Manufactured objects: evolution of technologies.

Physical and chemical processes during and after creation:

- Creation of artworks : evolution of technologies in space and time, choice and combination of materials, formulations. Authentication

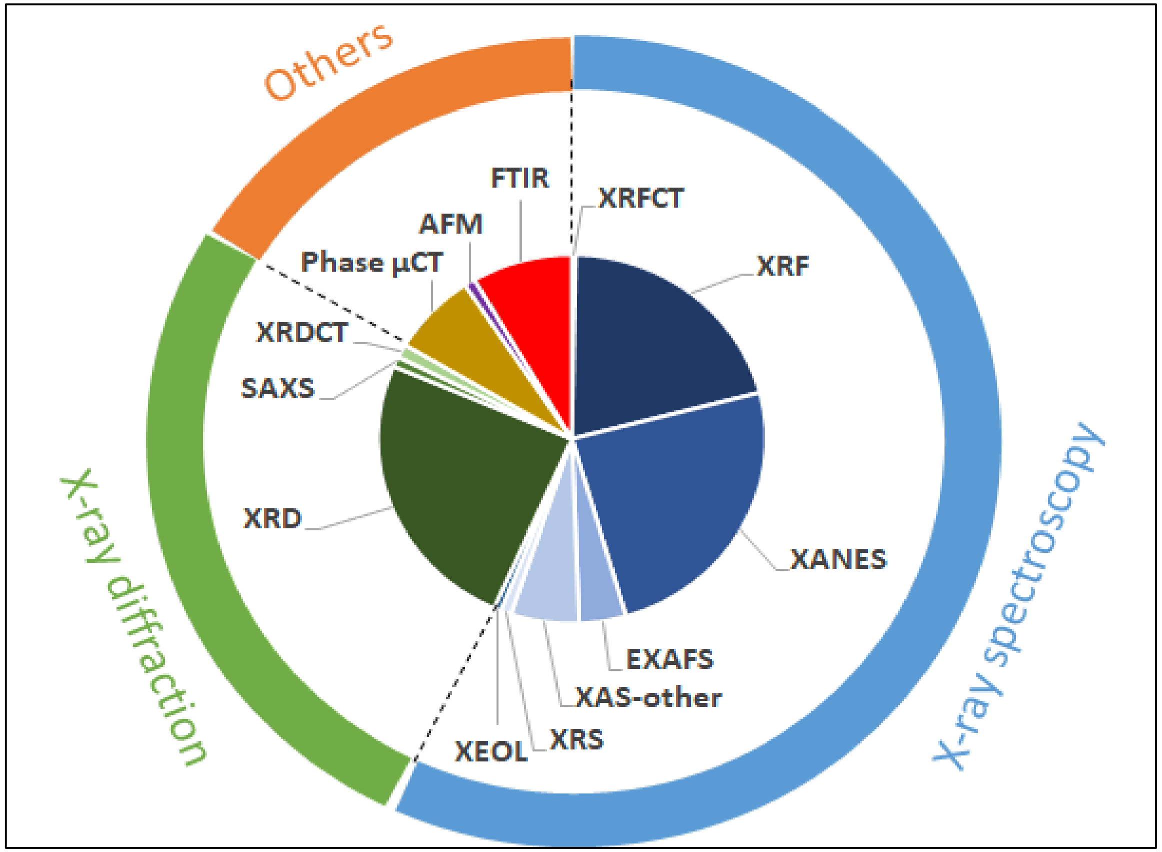
- Degradation, preservation, conservation

Structure, morphology

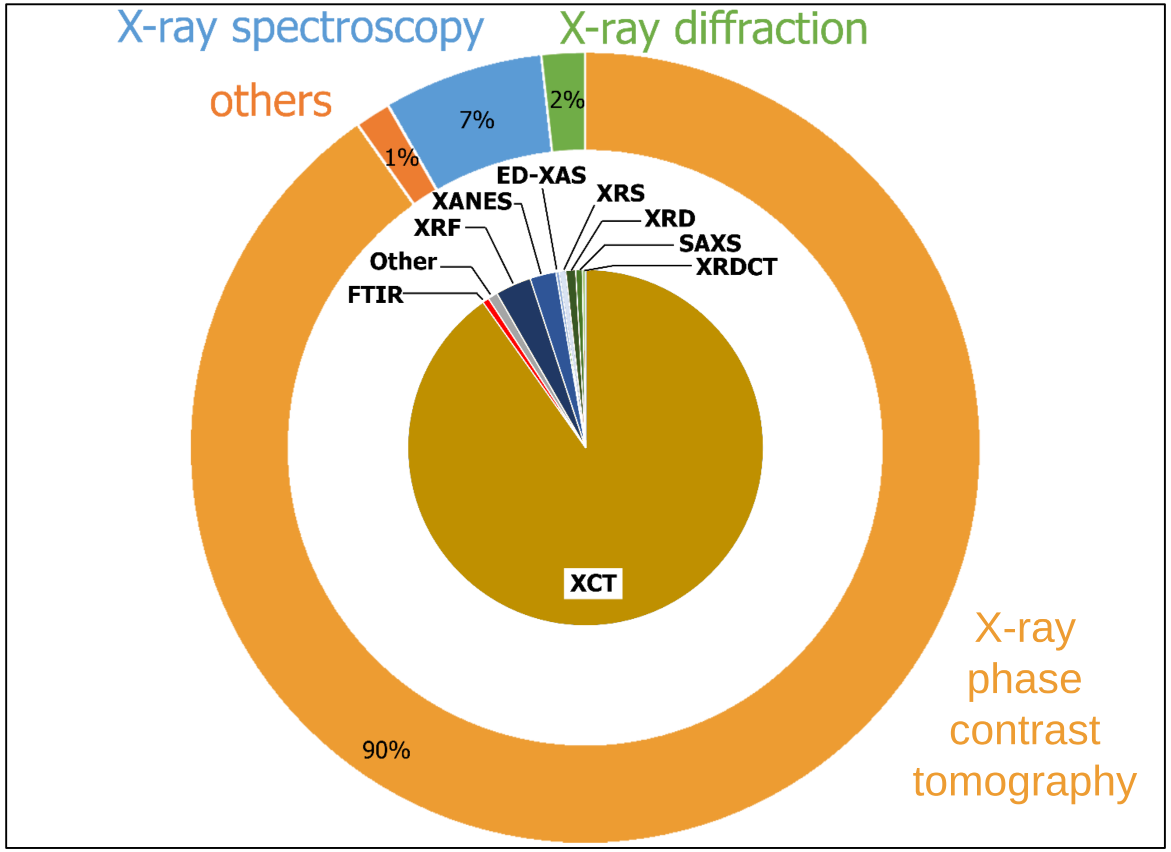
Chemistry

NATURAL AND CULTURAL HERITAGE AT THE ESRF

Cultural Heritage



Natural Heritage



SOME ARTEFACTS ANALYZED AT THE ESRF IN 2016-2023 (NOT EXHAUSTIVE)

Inks on Papyri
Carlsberg Collection,
Copenhagen, Christiansen
Herculaneum, Brun

Cimabue's *Maestà of Santa Maria dei Servi*
(1280–1285),
L. Monico,
Perugia

Ming porcelains
Beijing Archaeological
Institute (15th-16th C.),
Ph. Sciau,
Toulouse

Ultramarine pigment in *Girl with a Pearl Earing*,
Mauritshuis, (1665),
A. Gambardella,
Amsterdam

Van Gogh's *Sunflowers*
van Gogh Museum,
(1888-1889),
L. Monico,
Perugia, Antwerp

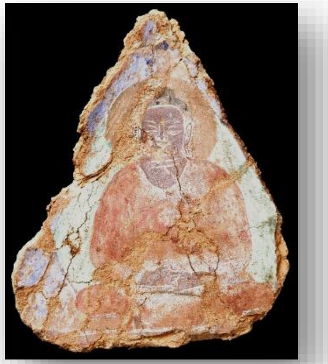
Munch's *Scream*,
Munch Museum
(1910),
L. Monico,
Perugia

Rodin's modelling clay
Rodin museum
(1908-1913),
J. Langlois,
Paris

Miro's *Femme dans la rue*
(1973),
M. Ghirardello,
Milano

Antiquity → **Today**

Hellenistic Egyptian Blue
Kos, (1st C. BCE)
A. Kostomistopoulo,
Oslo



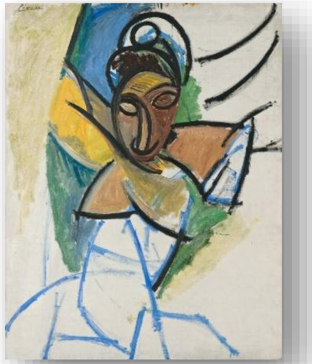
Bamiyan Buddhist paintings
Afghanistan, (6th-9th C.)
Y. Taniguchi,
Tokyo

Leonardo da Vinci's *last Supper*
Santa Maria Delle Grazie
(1495-1498)
M. Cotte,
ESRF

Rembrandt's *Night watch*
Rijksmuseum
(1642),
V. Gonzalez,
Delft

Caspar David Friedrich's *Wanderer above the Sea of Fog*
Hamburger Kunsthalle,
(1818),
I. Reiche, Paris

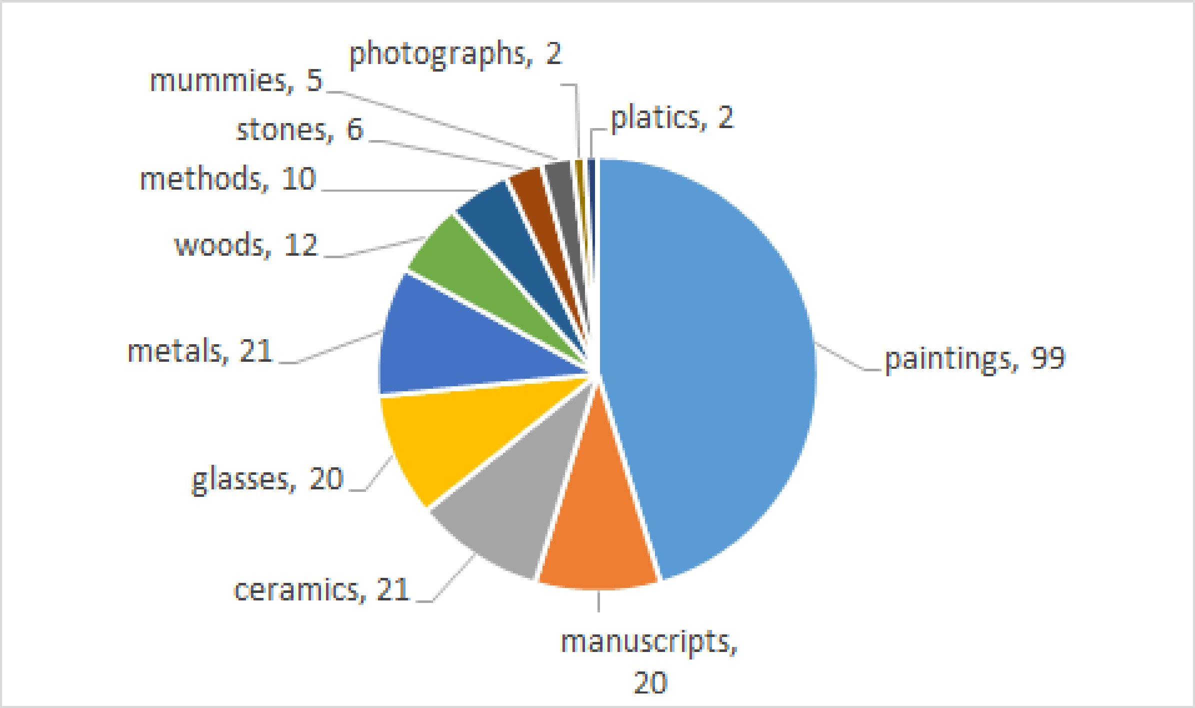
Porcelains, Sèvres manufacture
End 19th Beg. 20th C.
L. Verger,
Paris

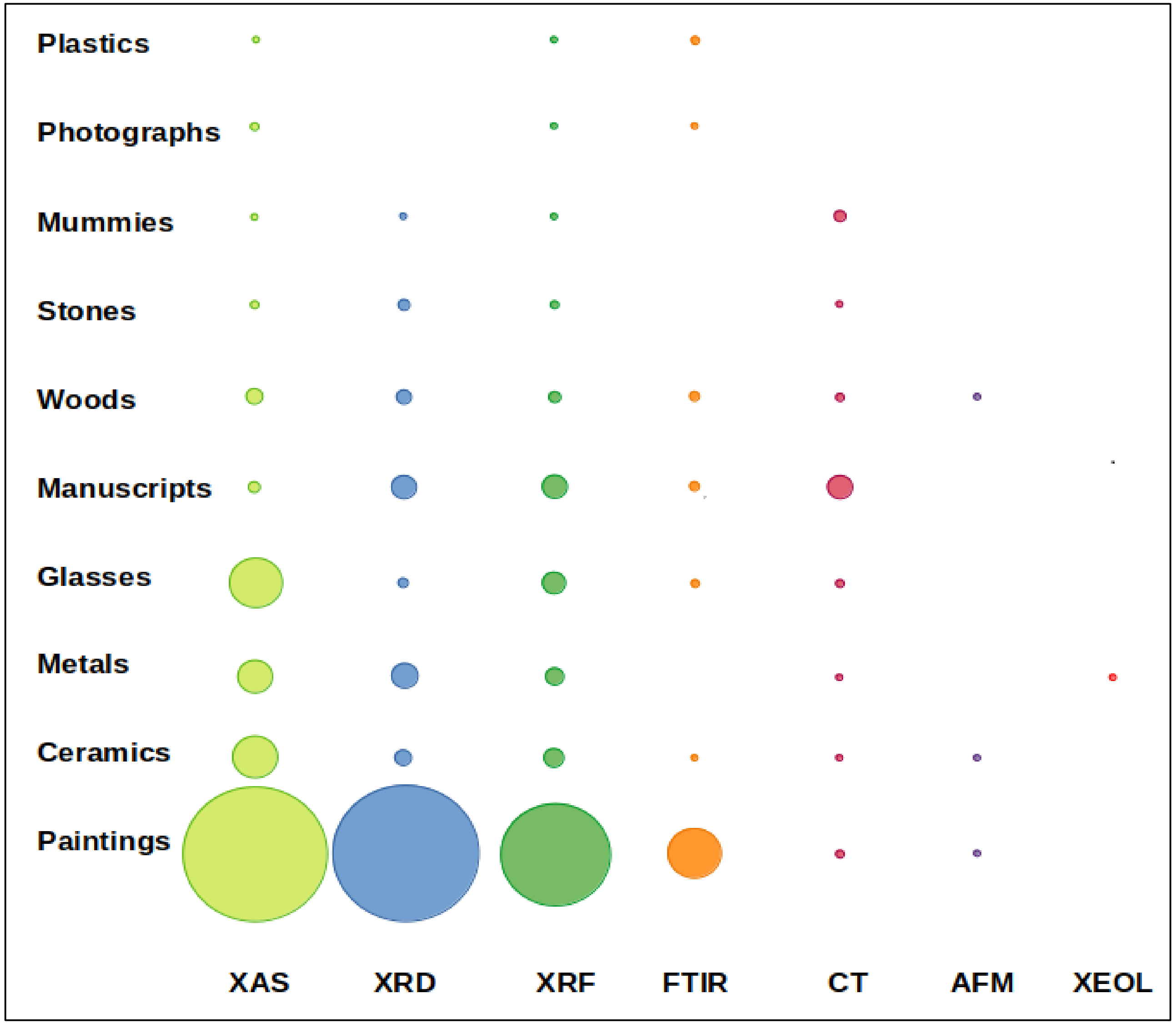


Picasso's *Femmes*
Foundation Beyeler,
(1907),
M. Ghirardello,
Milano

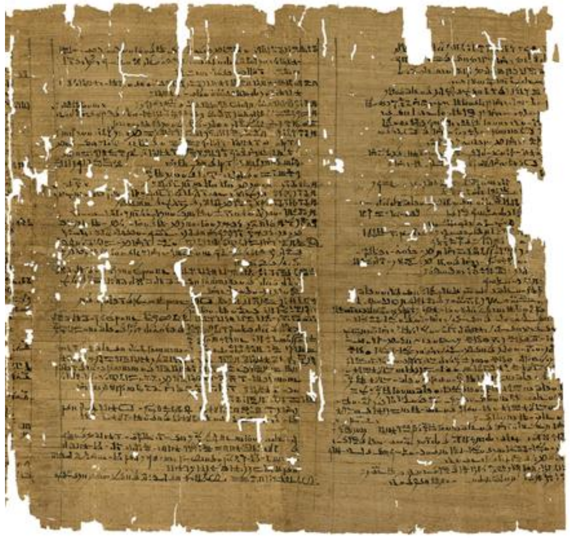
Ducos du Hauron early color photographs,
1870's, M. Cotte,
ESRF

WHICH TECHNIQUES TO STUDY WHICH MATERIALS?





Revealing nature of ancient Egyptian inks



In collaboration with Thomas Christiansen[1], Poul Erik Lindelof [2], Kell Mortensen[2], Kim Ryholt[1], Sine Larsen[3]

1- Department of Cross-Cultural and Regional Studies (ToRS), Section of Egyptology, University of Copenhagen, Karen Blixens Plads 8, 2300 Copenhagen S, Denmark
2- Niels Bohr Institute (NBI), University of Copenhagen, Universitetsparken 5, 2100 Copenhagen Ø, Denmark
3- Department of Chemistry, University of Copenhagen, Universitetsparken 5, 2100 Copenhagen Ø, Denmark

Papyrus from the P. Carlsberg collection, University of Copenhagen
Tebtunis temple library, 1st - 3rd century CE
Pathyris, late 2nd and early 1st century BCE

THE TWO MAIN PUBLICATIONS

RESEARCH ARTICLE | ANTHROPOLOGY |

Insights into the composition of ancient Egyptian red and black inks on papyri achieved by synchrotron-based microanalyses

PNAS

Thomas Christiansen, Marine Cotte, Wout de Nolf, +10, and Sine Larsen Authors Info & Affiliations

Edited by Katherine Faber, California Institute of Technology, Pasadena, and accepted by Editorial Board Member Tobin J. Marks September 21, 2020 (received for review March 10, 2020)

October 26, 2020 | 117 (45) 27825-27835 | https://doi.org/10.1073/pnas.2004534117

SCIENTIFIC REPORTS

OPEN

The nature of ancient Egyptian copper-containing carbon inks is revealed by synchrotron radiation based X-ray microscopy

Received: 31 August 2017
Accepted: 31 October 2017
Published online: 10 November 2017

Thomas Christiansen[1,7], Marine Cotte[2,3], René Loredo-Portales[4], Poul Erik Lindelof[5], Kell Mortensen[5], Kim Ryholt[1] & Sine Larsen[6]

SCiEnTiFiC REPORTS | 7: 15346 | DOI:10.1038/s41598-017-15652-7

2- INK COMPOSITION IN EGYPTIAN PAPYRI

WORKS LED BY

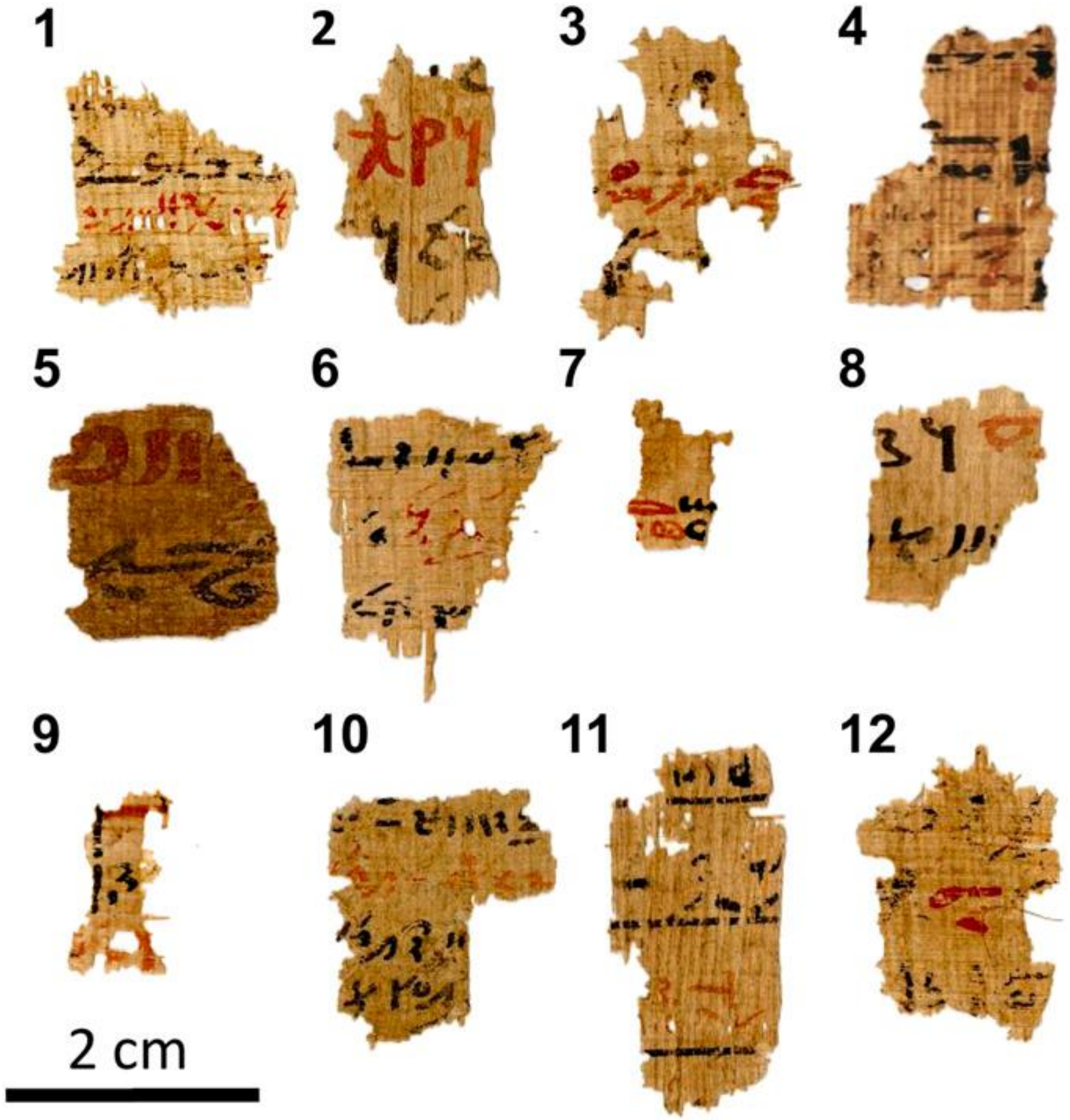
Thomas Christiansen, Sine Larsen,
University of Copenhagen

SAMPLES

12 fragments of papyri from the Carlsberg Collection (Tebtunis temple library, 1st-3rd C. CE), with both red and black inks

QUESTIONS

Which are the components present in inks? A unique recipe? Iron and lead identified with laboratory techniques. Which compounds?

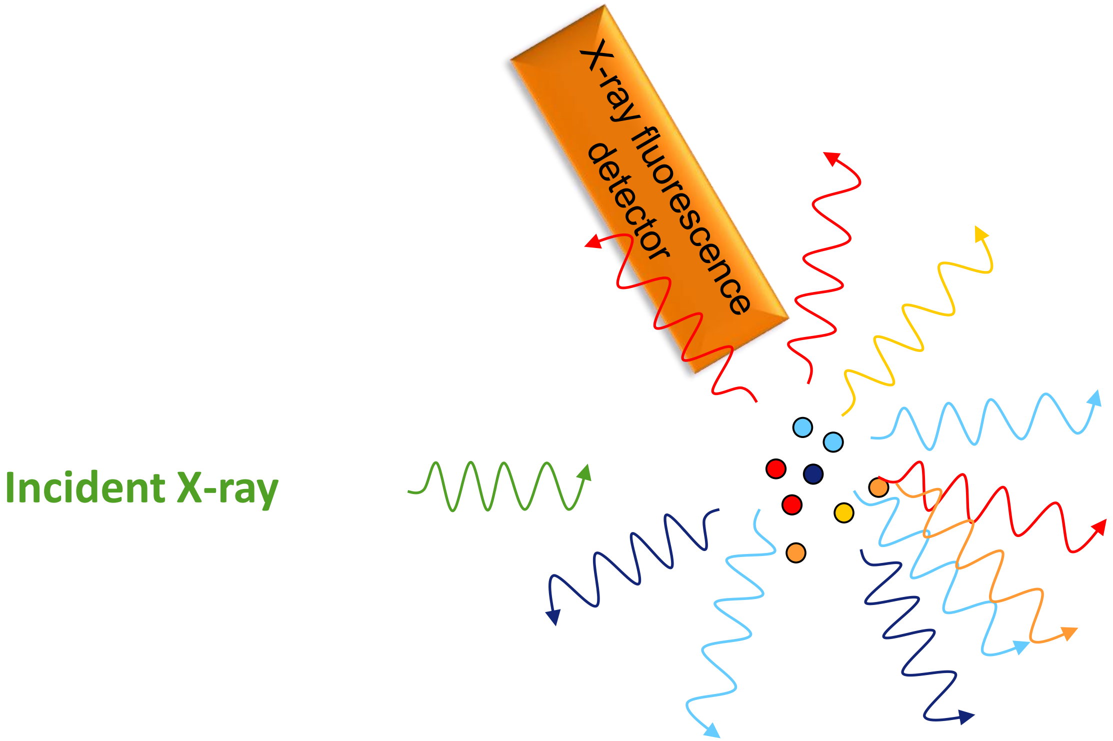


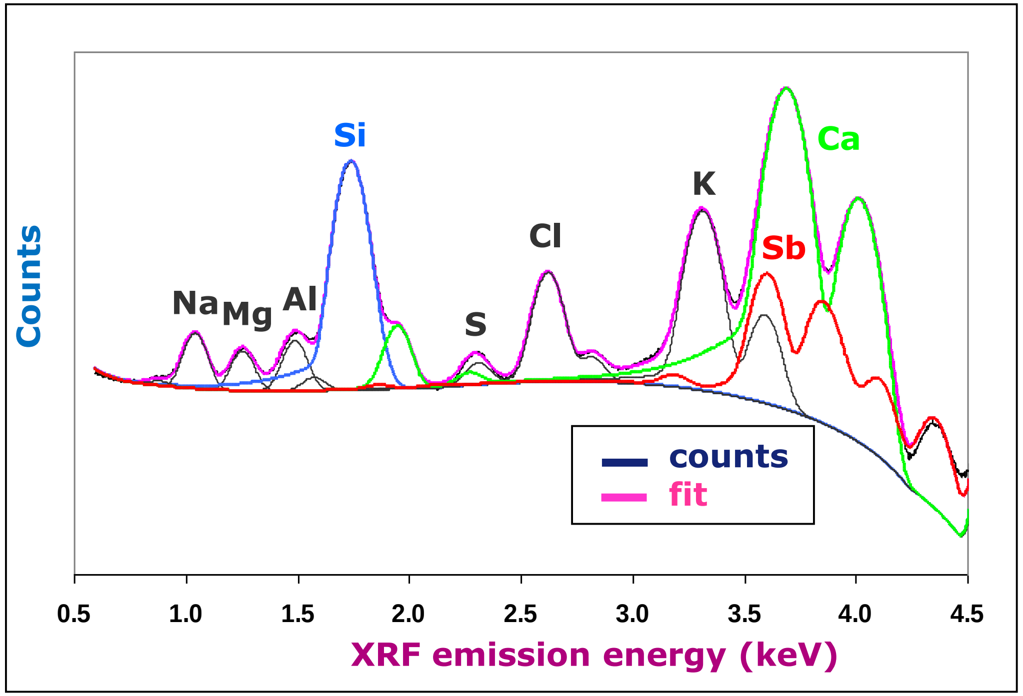
Part 1: how to obtain element maps?

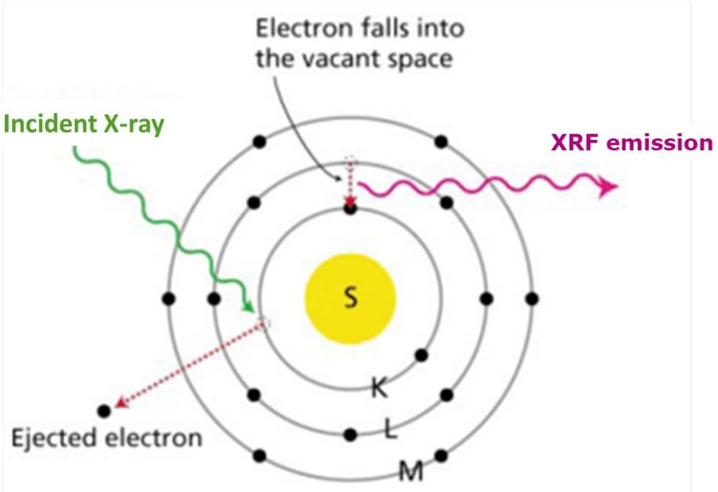
X-RAY FLUORESCENCE (XRF)

To determine elemental composition

X-RAY FLUORESCENCE SPECTROSCOPY





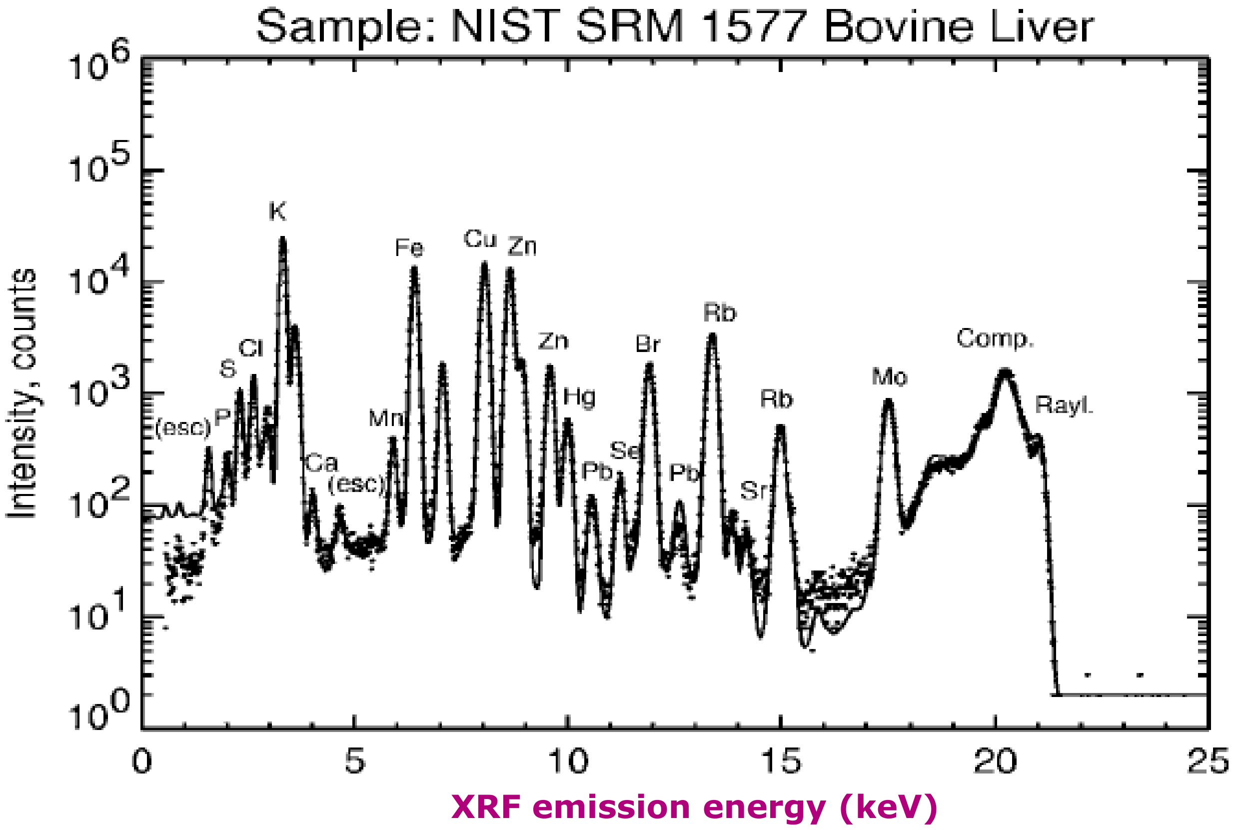


=> identification of elemental composition

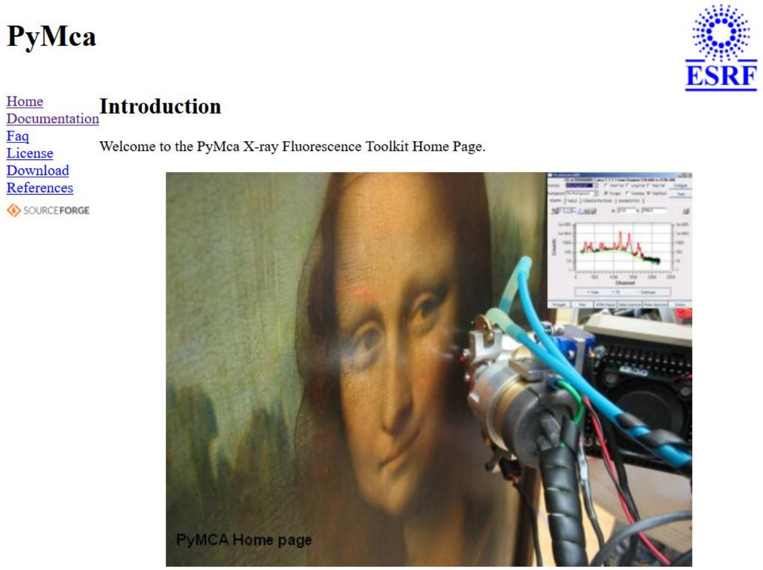
X-RAY FLUORESCENCE: ELEMENTAL IDENTIFICATION

X-ray fluorescence emission energies (eV)

Element	$K\alpha_1$	$K\alpha_2$	$K\beta_1$	$L\alpha_1$	$L\alpha_2$	$L\beta_1$	$L\beta_2$	$L\gamma_1$	$M\alpha_1$
3 Li	54.3								
4 Be	108.50								
5 B	183.3								
6 C	277								
7 N	392.4								
8 O	524.9								
9 F	676.8								
10 Ne	848.6	848.6							
11 Na	1,040.98	1,040.98	1,071.1						
12 Mg	1,253.60	1,253.60	1,302.2						
13 A1	1,486.70	1,486.27	1,557.45						
14 Si	1,739.98	1,739.38	1,835.94						
15 P	2,013.7	2,012.7	2,139.1						
16 S	2,307.84	2,306.64	2,464.04						
17 C1	2,622.39	2,620.78	2,815.6						
18 Ar	2,957.70	2,955.63	3,190.5						
19 K	3,313.8	3,311.1	3,589.6						
20 Ca	3,691.68	3,688.09	4,012.7	341.3	341.3	344.9			
21 Sc	4,090.6	4,086.1	4,460.5	395.4	395.4	399.6			
22 Ti	4,510.84	4,504.86	4,931.81	452.2	452.2	458.4			
23 V	4,952.20	4,944.64	5,427.29	511.3	511.3	519.2			
24 Cr	5,414.72	5,405.509	5,946.71	572.8	572.8	582.8			
25 Mn	5,898.75	5,887.65	6,490.45	637.4	637.4	648.8			
26 Fe	6,403.84	6,390.84	7,057.98	705.0	705.0	718.5			
27 Co	6,930.32	6,915.30	7,649.43	776.2	776.2	791.4			
28 Ni	7,478.15	7,460.89	8,264.66	851.5	851.5	868.8			
29 Cu	8,047.78	8,027.83	8,905.29	929.7	929.7	949.8			
30 Zn	8,638.86	8,615.78	9,572.0	1,011.7	1,011.7	1,034.7			
31 Ga	9,251.74	9,224.82	10,264.2	1,097.92	1,097.92	1,124.8			
32 Ge	9,886.42	9,855.32	10,982.1	1,188.00	1,188.00	1,218.5			
33 As	10,543.72	10,507.99	11,726.2	1,282.0	1,282.0	1,317.0			
34 Se	11,222.4	11,181.4	12,495.9	1,379.10	1,379.10	1,419.23			
35 Br	11,924.2	11,877.6	13,291.4	1,480.43	1,480.43	1,525.90			
36 Kr	12,649	12,598	14,112	1,586.0	1,586.0	1,636.6			
37 Rb	13,395.3	13,335.8	14,961.3	1,694.13	1,692.56	1,752.17			
38 Sr	14,165	14,097.9	15,835.7	1,806.56	1,804.74	1,871.72			
39 Y	14,958.4	14,882.9	16,737.8	1,922.56	1,920.47	1,995.84			
40 Zr	15,775.1	15,690.9	17,667.8	2,042.36	2,039.9	2,124.4	2,219.4	2,302.7	
41 Nb	16,615.1	16,521.0	18,622.5	2,165.89	2,163.0	2,257.4	2,367.0	2,461.8	
42 Mo	17,479.34	17,374.3	19,608.3	2,293.16	2,289.85	2,394.81	2,518.3	2,623.5	
43 Tc	18,367.1	18,250.8	20,619	2,424	2,420	2,538	2,674	2,792	
44 Ru	19,279.2	19,150.4	21,656.8	2,558.55	2,554.31	2,683.23	2,836.0	2,964.5	
45 Rh	20,216.1	20,073.7	22,723.6	2,696.74	2,692.05	2,834.41	3,001.3	3,143.8	
46 Pd	21,177.1	21,020.1	23,818.7	2,838.61	2,833.29	2,990.22	3,171.79	3,328.7	
47 Ag	22,162.92	21,990.3	24,942.4	2,984.31	2,978.21	3,150.94	3,347.81	3,519.59	
48 Cd	23,173.6	22,984.1	26,095.5	3,133.73	3,126.91	3,316.57	3,528.12	3,716.86	
49 In	24,209.7	24,002.0	27,275.9	3,286.94	3,279.29	3,487.21	3,713.81	3,920.81	
50 Sn	25,271.3	25,044.0	28,486.0	3,443.98	3,435.42	3,662.80	3,904.86	4,131.12	
51 Sb	26,359.1	26,110.8	29,725.6	3,604.72	3,595.32	3,843.57	4,100.78	4,347.79	
52 Te	27,472.3	27,201.7	30,995.7	3,769.33	3,758.8	4,029.58	4,301.7	4,570.9	
53 I	28,612.0	28,317.2	32,294.7	3,937.65	3,926.04	4,220.72	4,507.5	4,800.9	
54 Xe	29,779	29,458	33,624	4,109.9	—	—	—	—	
55 Cs	30,972.8	30,625.1	34,986.9	4,286.5	4,272.2	4,619.8	4,935.9	5,280.4	
56 Ba	32,193.6	31,817.1	36,378.2	4,466.26	4,450.90	4,827.53	5,156.5	5,531.1	
57 La	33,441.8	33,034.1	37,801.0	4,650.97	4,634.23	5,042.1	5,383.5	5,788.5	833
58 Ce	34,719.7	34,278.9	39,257.3	4,840.2	4,823.0	5,262.2	5,613.4	6,052	883
59 Pr	36,026.3	35,550.2	40,748.2	5,033.7	5,013.5	5,488.9	5,850	6,322.1	929



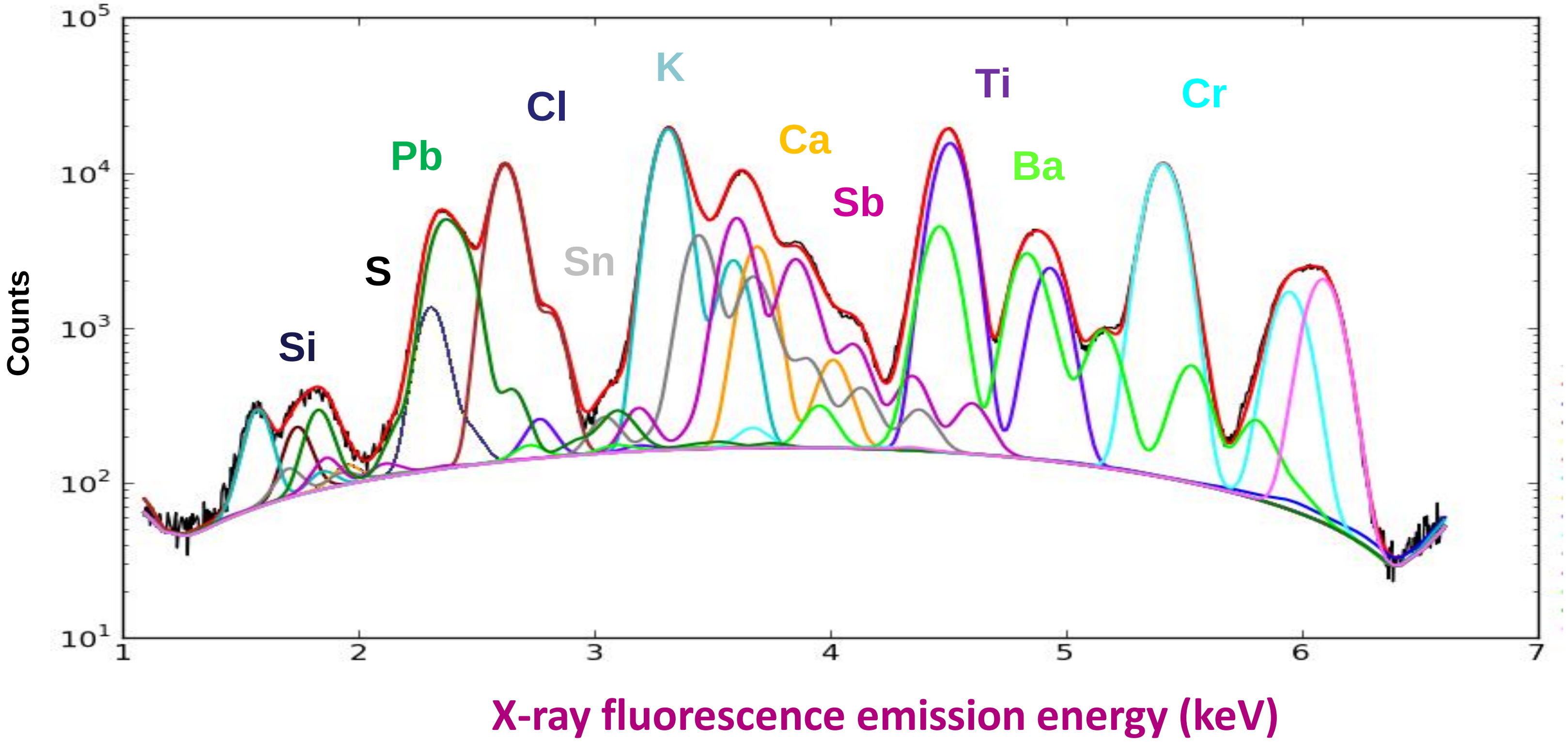
FIT OF XRF SPECTRA : PYMCA



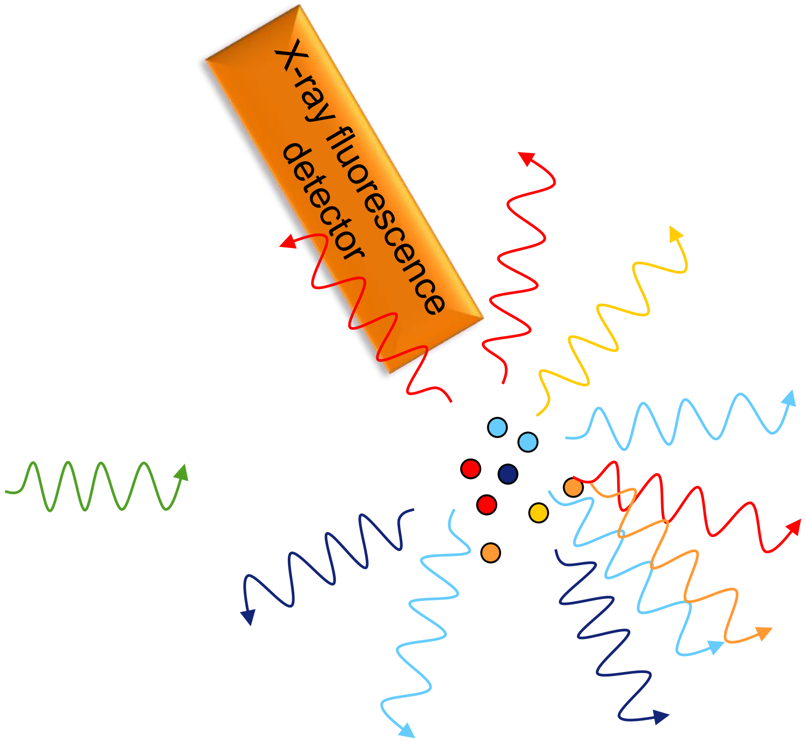
http://pymca.sourceforge.net/

Principles:

- fit with constraints on the fitting parameters (detector characteristics, detection geometry, matrix composition, excitation energy, etc.)
- complete emission line series (i.e., M, L or K series)

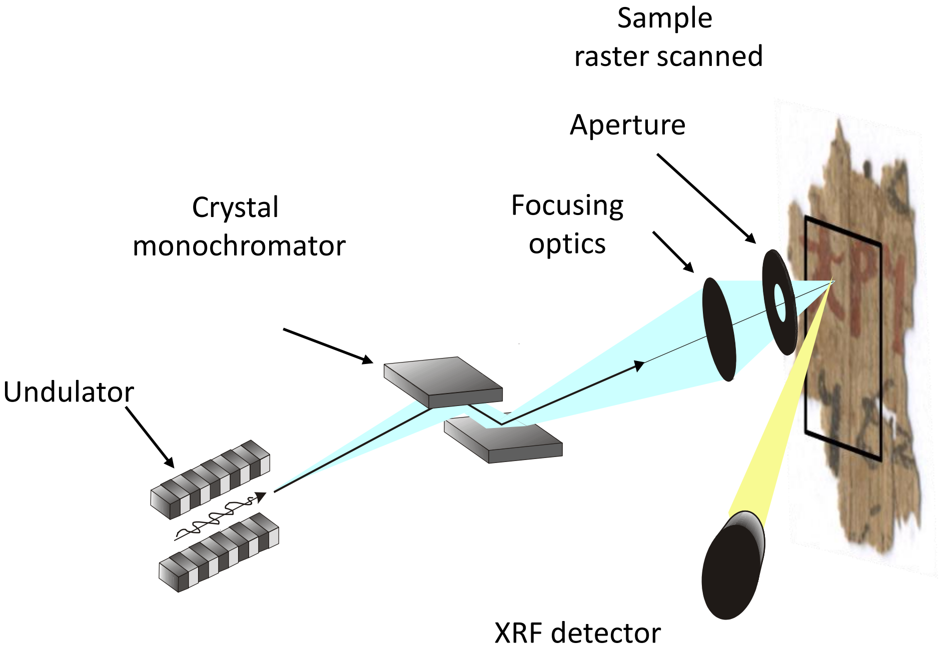


ADVANTAGES OF SYNCHROTRON SOURCES FOR XRF MAPPING

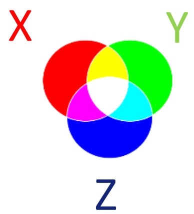


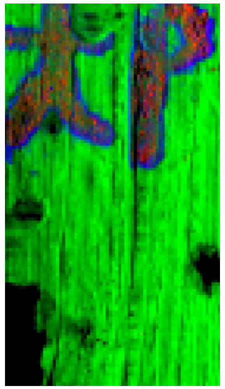
Incident X-ray

1- Flux = speed
2- Beam size
3- Beam energy (ies)

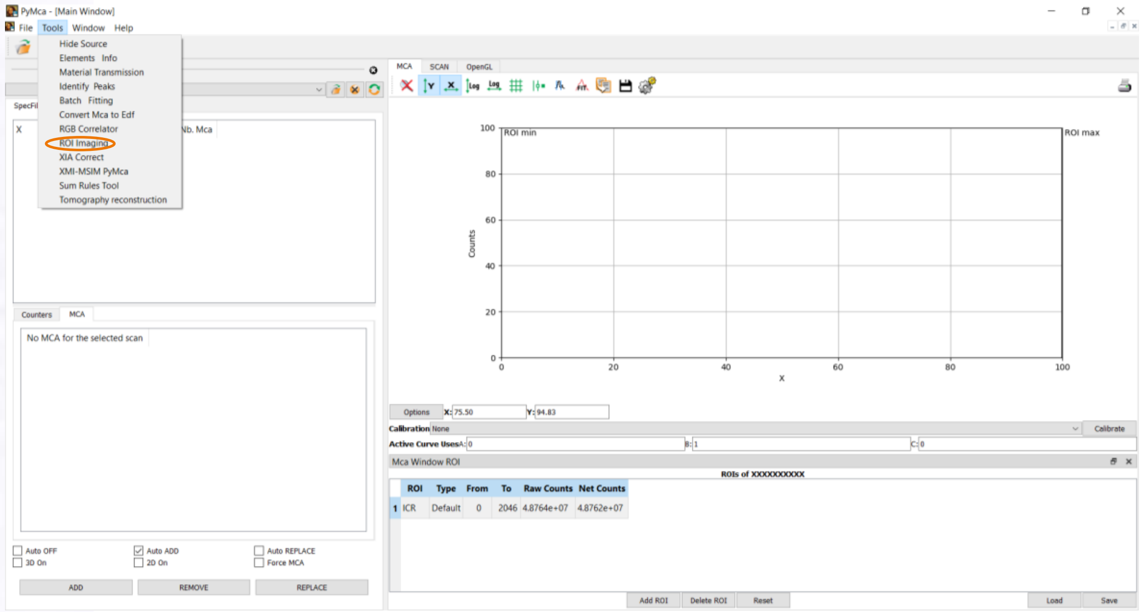


Elemental mapping





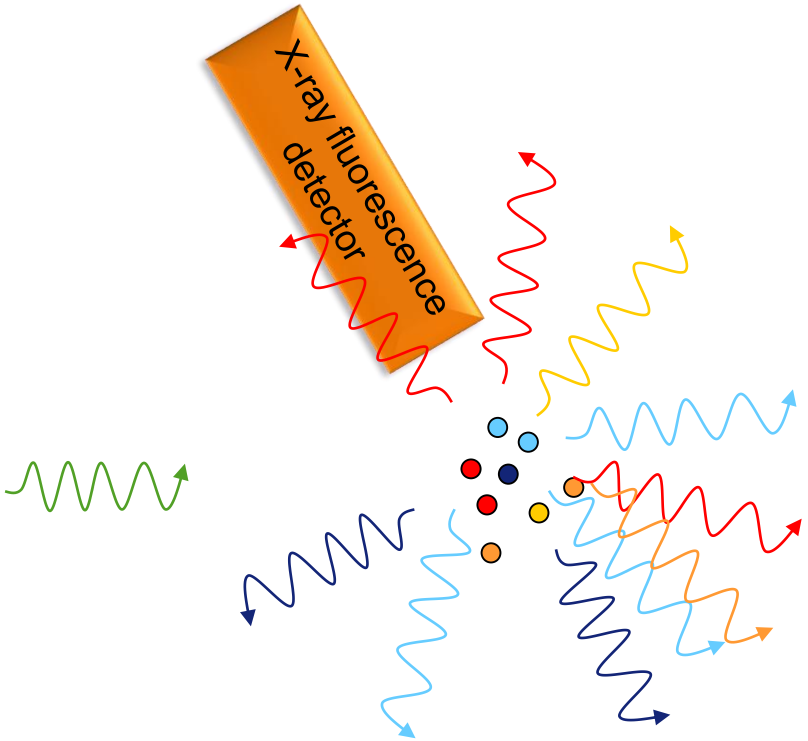
DEMO 1: MACRO-XRF MAPPING



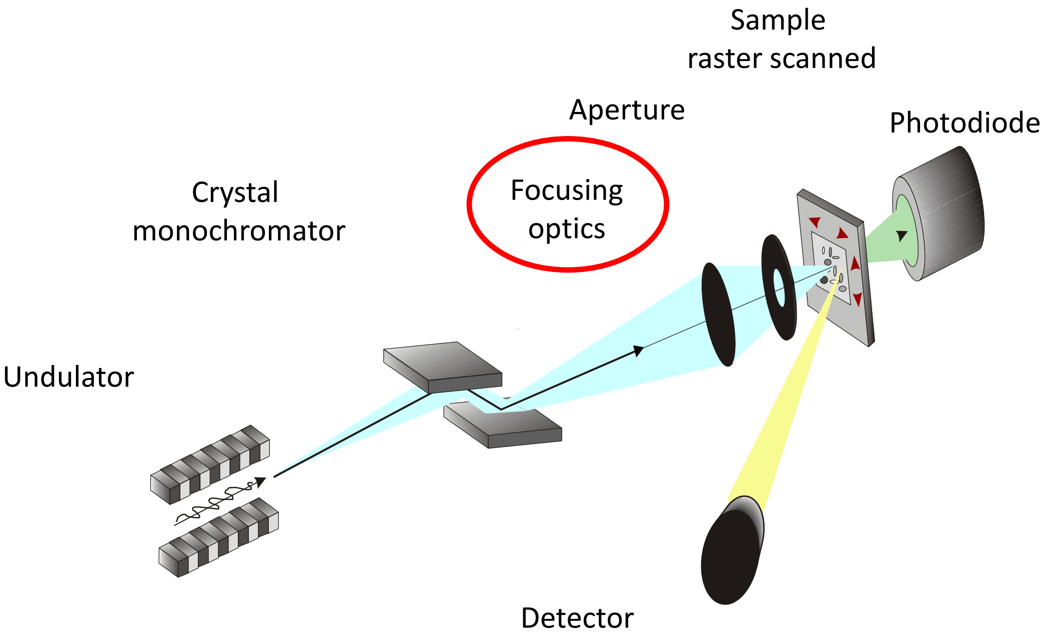
Sample9 unfocused Cl map1
124*69 steps of 100µm

- Open the .edf files in sample9_Cl_unfocussed (select one file; PyMca opens all)

ADVANTAGES OF SYNCHROTRON SOURCES FOR XRF



Incident X-ray

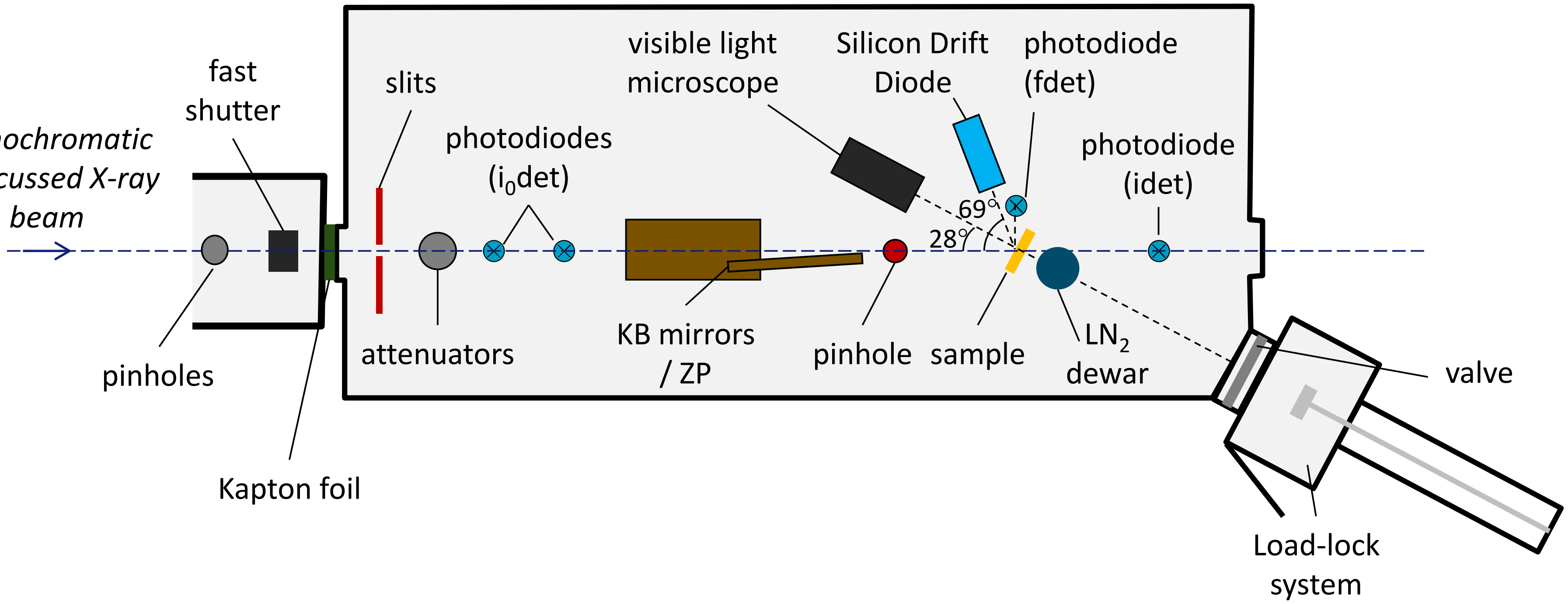


1- Flux = speed

2- Beam size

3- Beam energy (ies)

THE ID21 SCANNING X-RAY MICRO-SPECTROSCOPY END-STATION



Beam focussed with Kirkpatrick Baez mirrors (or Zone plates)

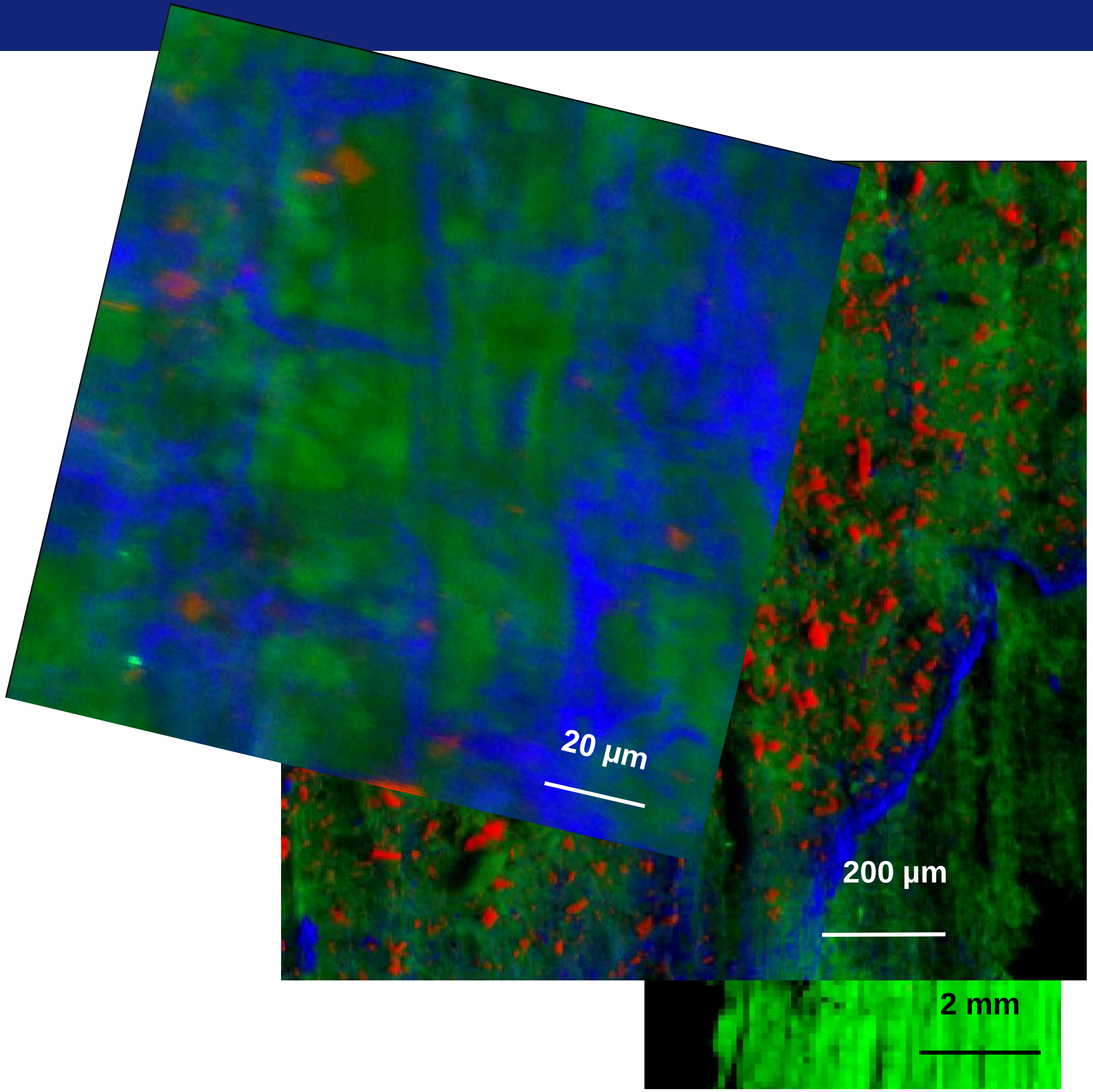
Beam size: 0.3µm ver. × 0.7µm hor.

Flux 10^{10} ph/s

Energy range: 2.0-11keV

Macro and µXRF mapping at ID21

Egypt, 1st-2nd CE,
P. Carlsberg 89



Beam size 0.3×0.7µm²
Pixel size 0.5×0.5µm²

Beam size 0.3×0.7µm²
Pixel size 4×4µm²

Beam size ∅ 100µm
Pixel size 100×100µm²

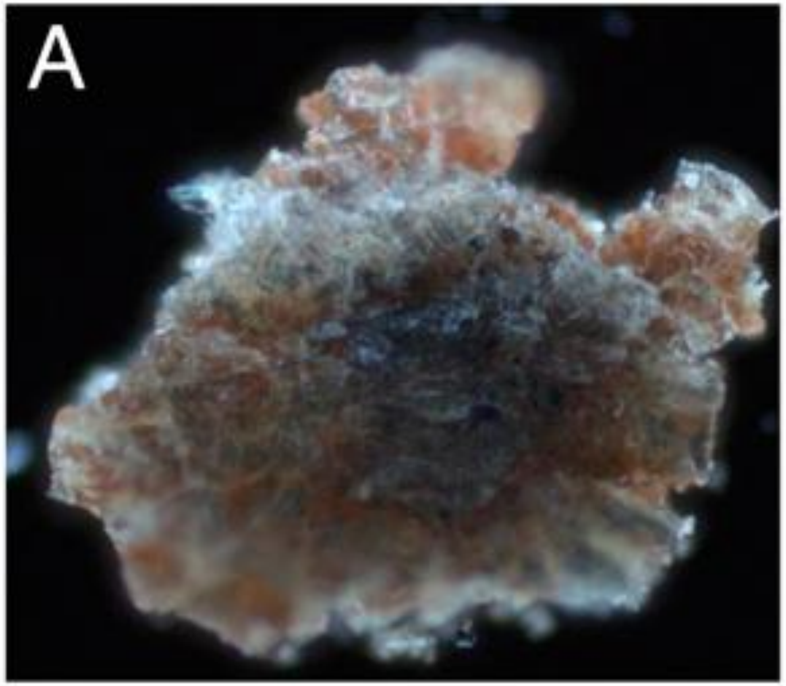
At the ESRF, beamlines offer beam size from ~1mm² down to 30×30nm²

T. Christiansen, M. Cotte, R. Loredo-Portales, P. E. Lindelof, K. Mortensen, K. Ryholt and S. Larsen, "**The nature of ancient Egyptian copper-containing carbon inks is revealed by synchrotron radiation based X-ray microscopy**", ***Scientific Reports, 7, 15346 (2017).***

Part 2: how to obtain identification and location on organic compounds (binder)?

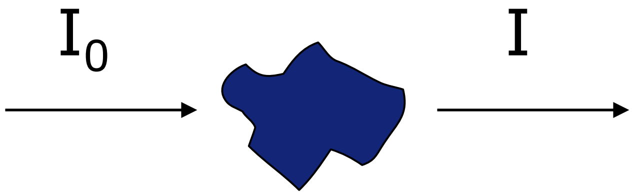
Towards the identification of lead compounds

How to identify organic molecular groups?

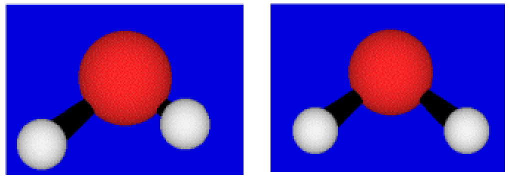


µFTIR map on a fragment of ink

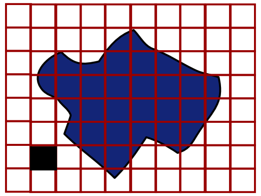
Infrared spectro-microscopy

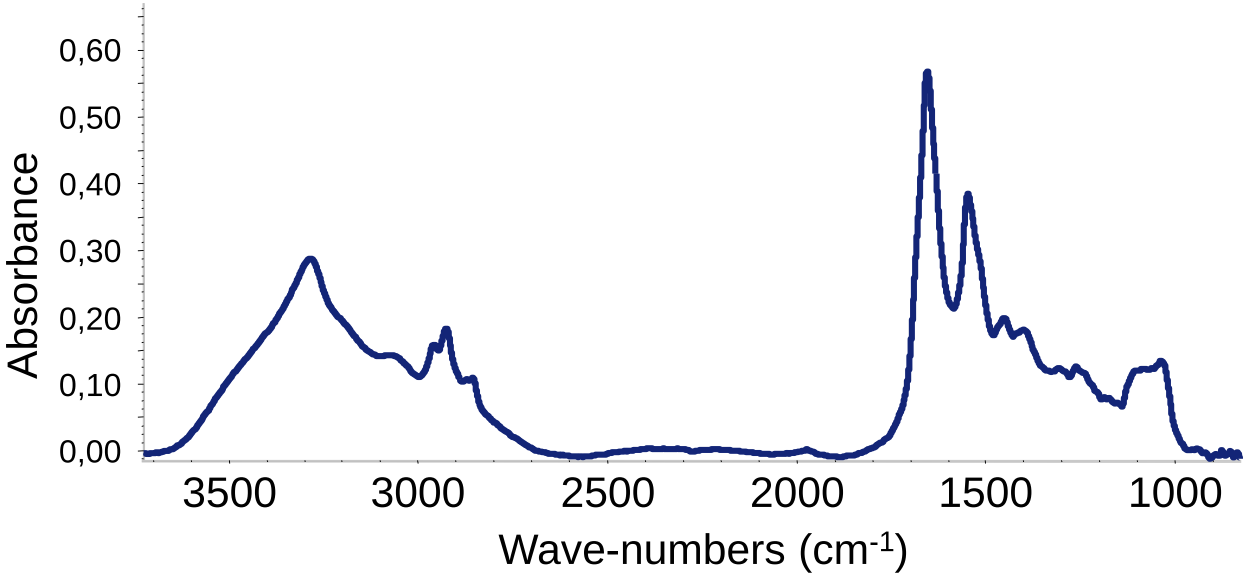


absorbance=
$-\log(I/I_0)$



microscope





synchrotron

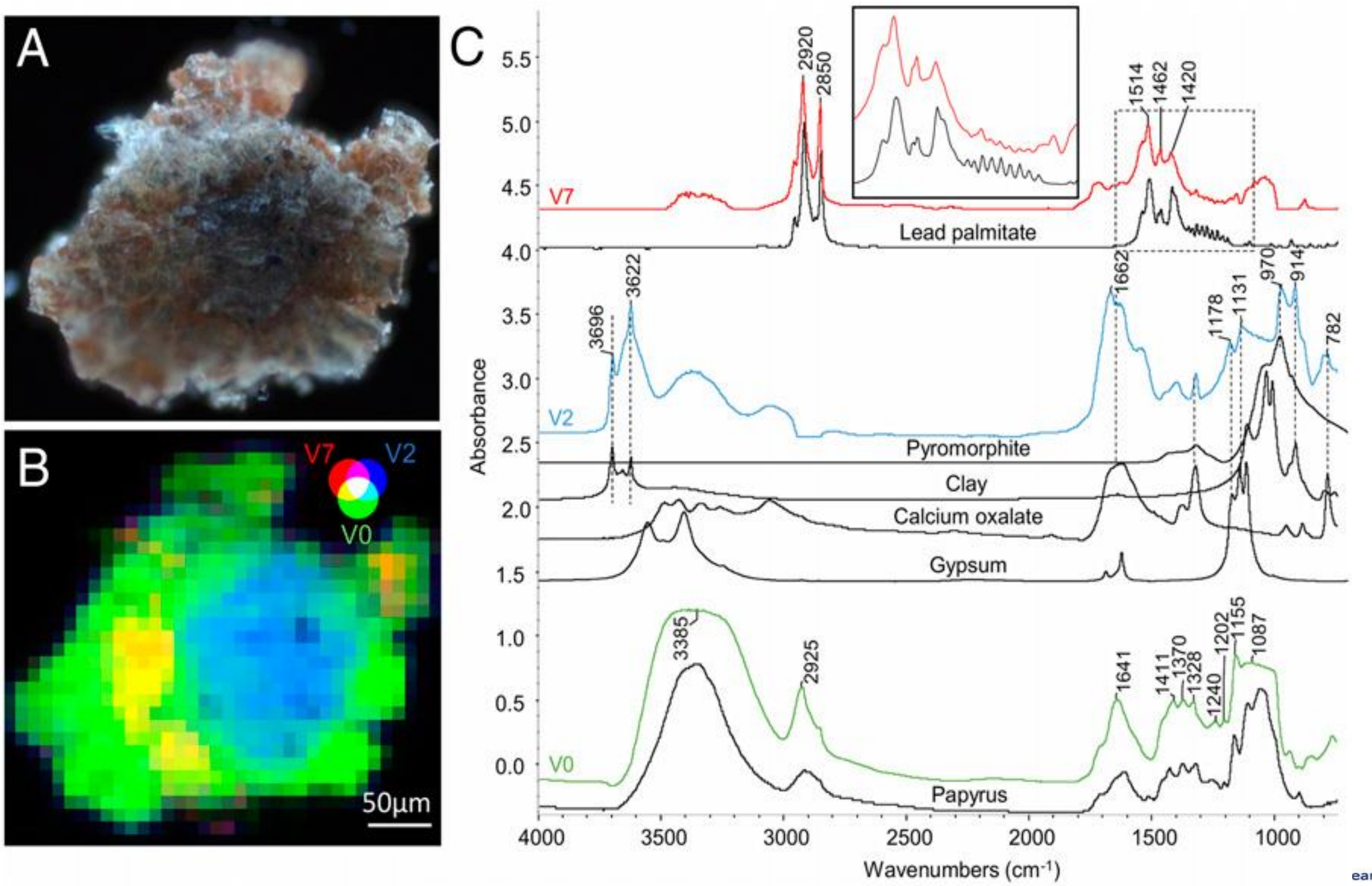
$\Rightarrow$ Molecular imaging

5x5 μm^2

IR

UV X- rays

FTIR ANALYSIS OF A FRAGMENT FROM PAPYRUS



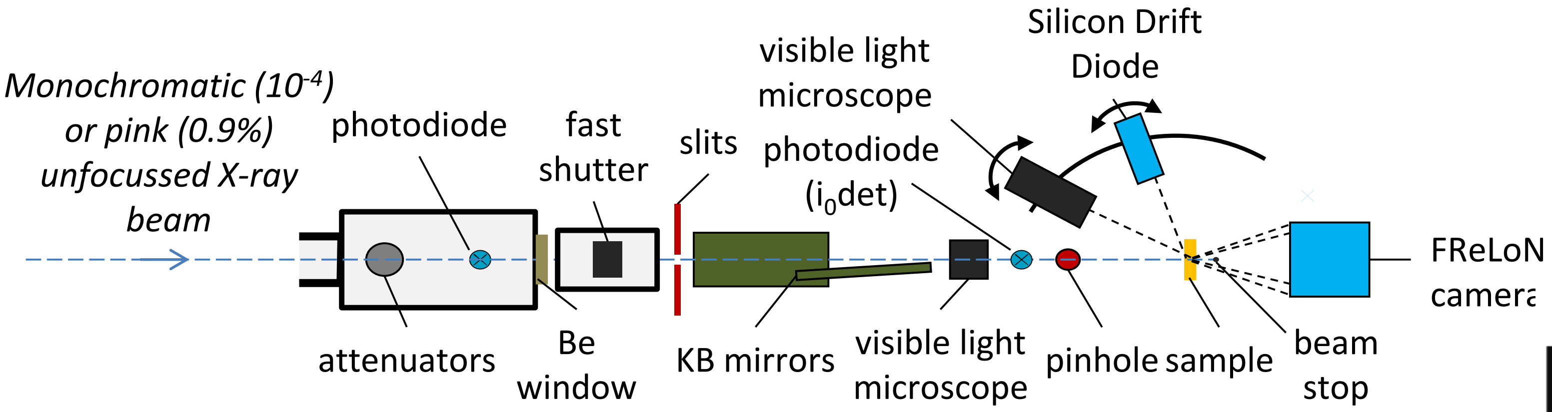
Part 3: how to obtain identification and location on crystallized compound?

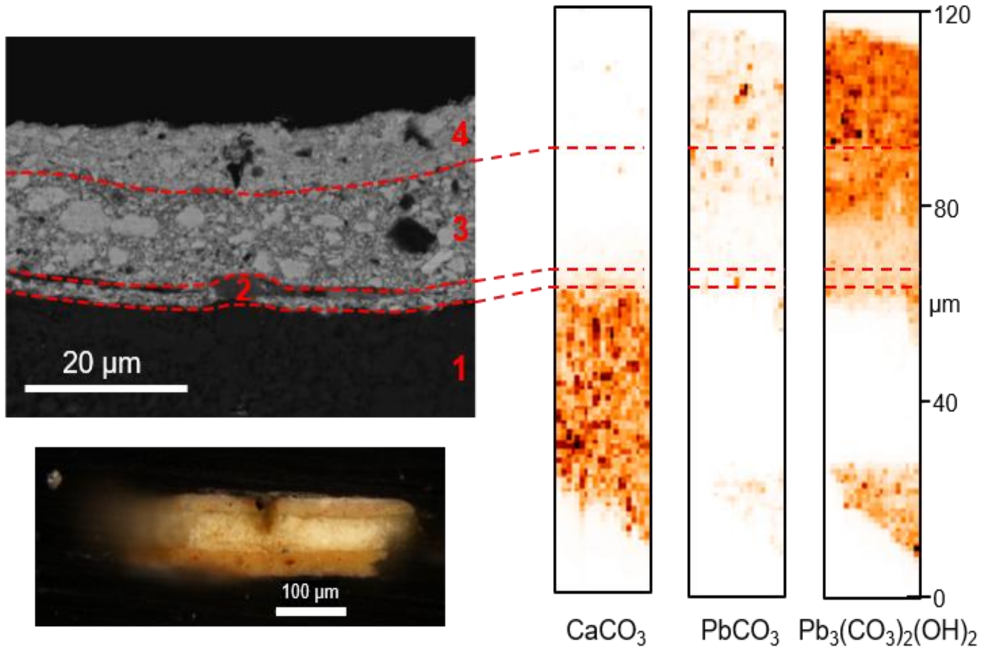
High lateral resolution X-ray diffraction (ID13, ex ID21, ID16B, ID11…)

- Micro-beam (≤ 1×1 µm²)
- 2D mapping for phase identification and localization

High-lateral resolution XRD
ID13, ESRF

13 keV
2 x 2 µm² beam

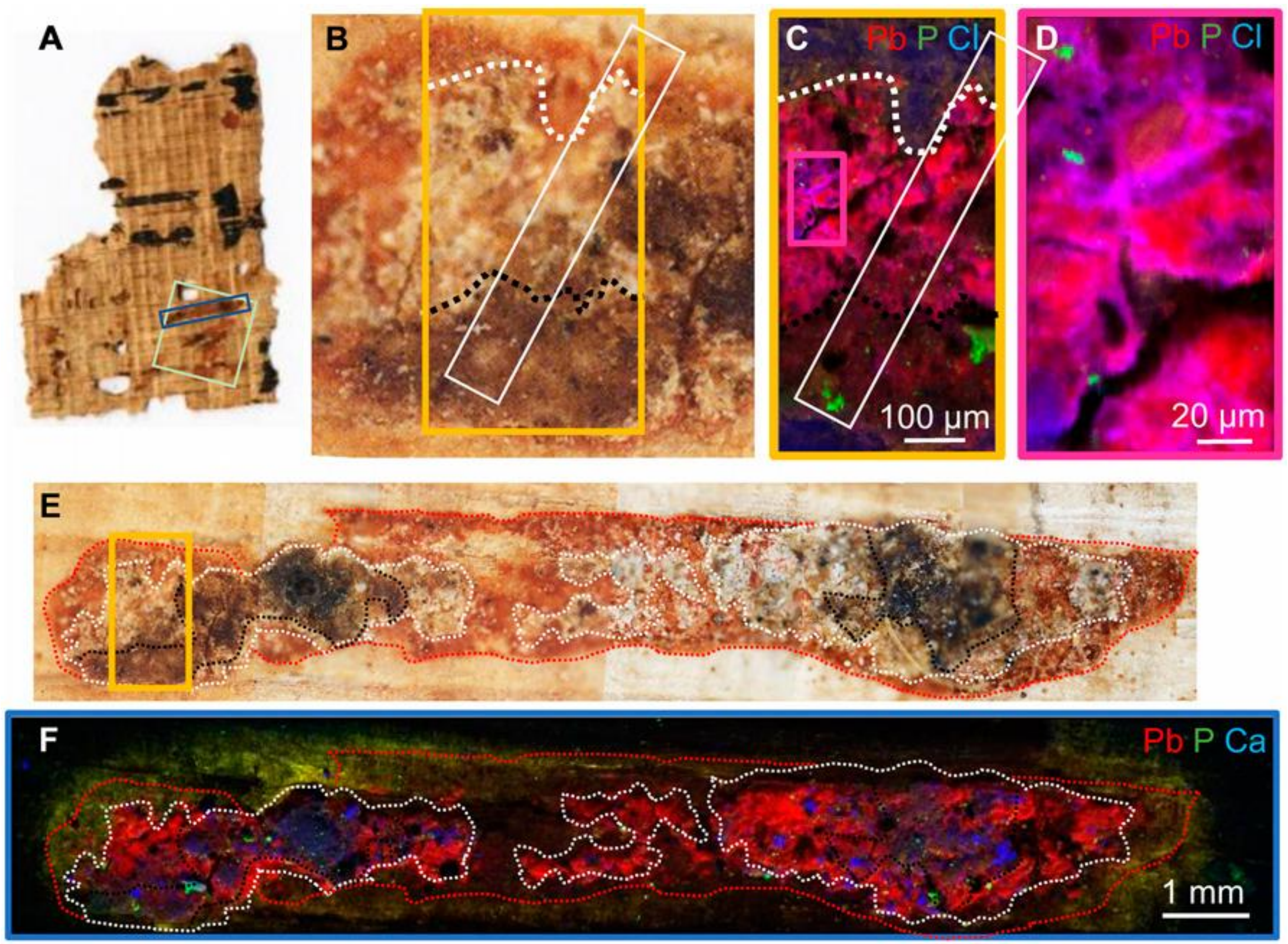


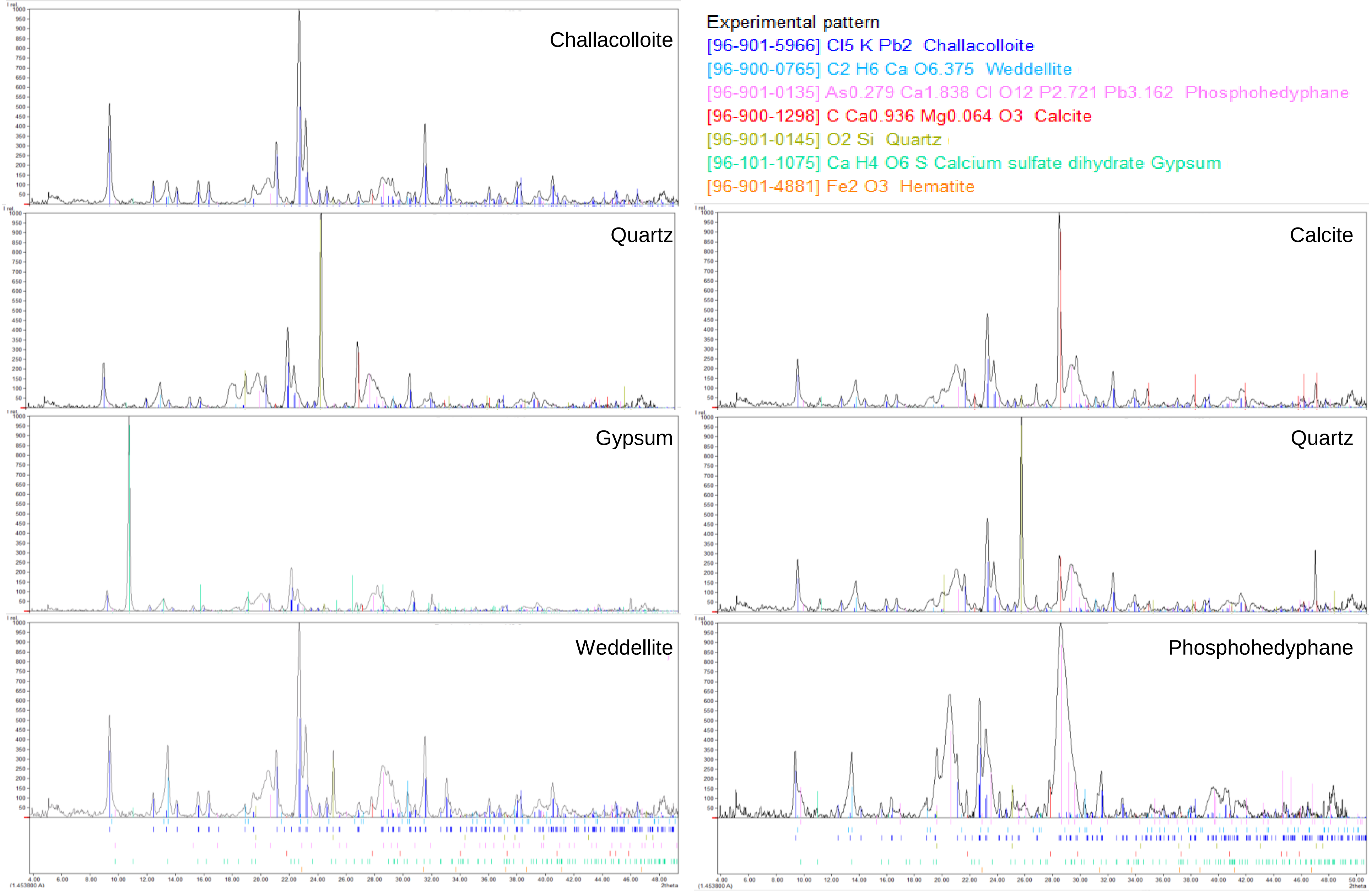


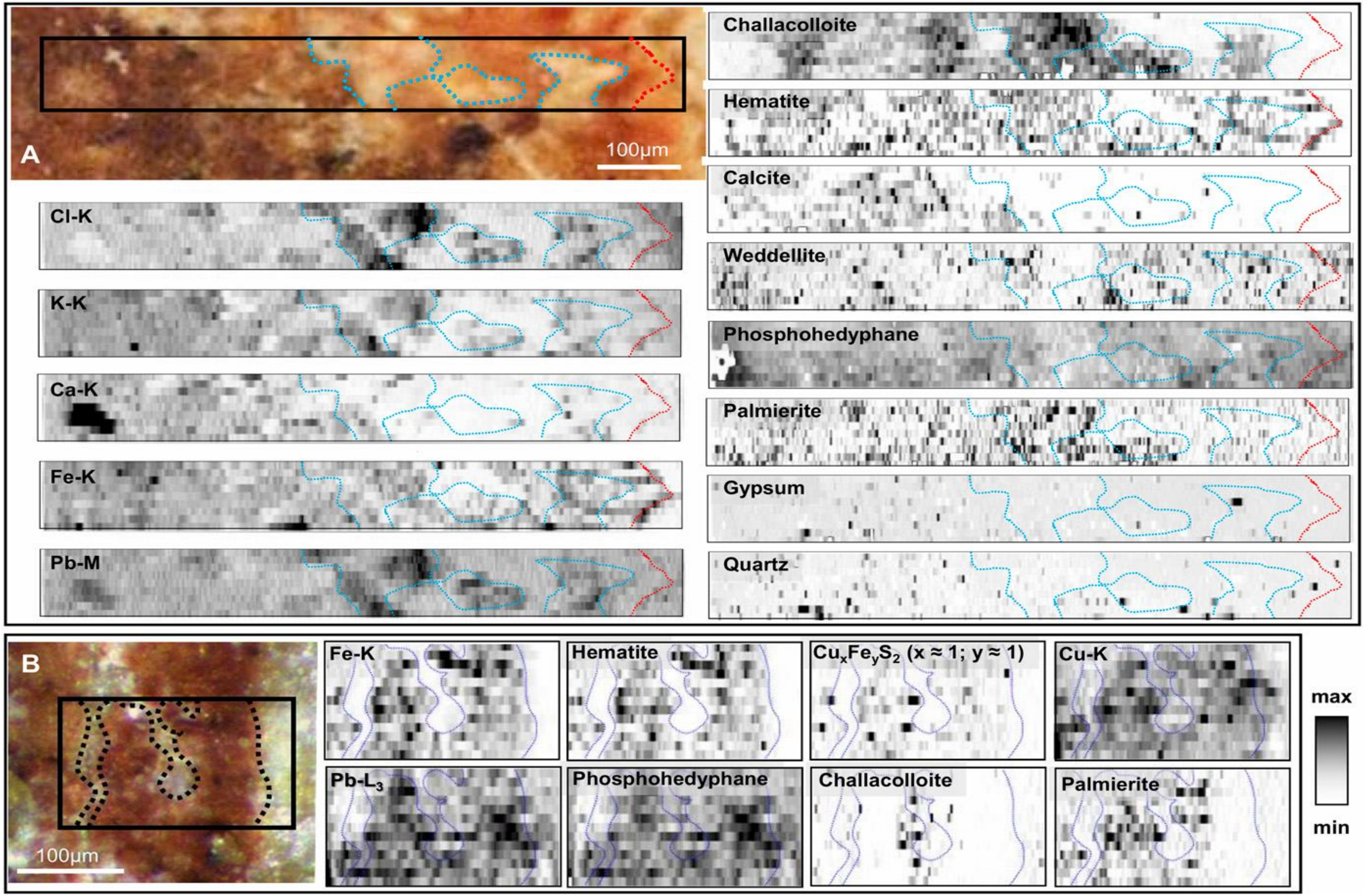
☺ Differentiate each micrometric layer
☹ Qualitative only because of orientation effects

Towards the identification of lead compounds

How to identify and map crystalline phases?




Experimental pattern
[96-901-5966] Cl5 K Pb2 Challacolloite
[96-900-0765] C2 H6 Ca O6.375 Weddellite
[96-901-0135] As0.279 Ca1.838 Cl O12 P2.721 Pb3.162 Phosphohedyphane
[96-900-1298] C Ca0.936 Mg0.064 O3 Calcite
[96-901-0145] O2 Si Quartz
[96-101-1075] Ca H4 O6 S Calcium sulfate dihydrate Gypsum
[96-901-4881] Fe2 O3 Hematite
Challacolloite
Quartz
Gypsum
Weddellite
Calcite
Quartz
Phosphohedyphane



XPb_2Cl_5 X=K or NH_4

Fe_2O_3

$CaCO_3$

$CaC_2O_4 \cdot 2H_2O$

$Ca_{1.838}Pb_{3.162}[PO_4]_{2.7271}[AsO_4]_{0.279}Cl$

K_2PbSO_4

$CaSO_4 \cdot 2H_2O$

SiO_2

THE TWO MAIN PUBLICATIONS

RESEARCH ARTICLE | ANTHROPOLOGY |

PNAS

Insights into the composition of ancient Egyptian red and black inks on papyri achieved by synchrotron-based microanalyses

Thomas Christiansen, Marine Cotte, Wout de Nolf, +10, and Sine Larsen Authors Info & Affiliations

Edited by Katherine Faber, California Institute of Technology, Pasadena, and accepted by Editorial Board Member Tobin J. Marks September 21, 2020 (received for review March 10, 2020)

October 26, 2020 | 117 (45) 27825-27835 | https://doi.org/10.1073/pnas.2004534117

SCIENTIFIC REPORTS

OPEN

The nature of ancient Egyptian copper-containing carbon inks is revealed by synchrotron radiation based X-ray microscopy

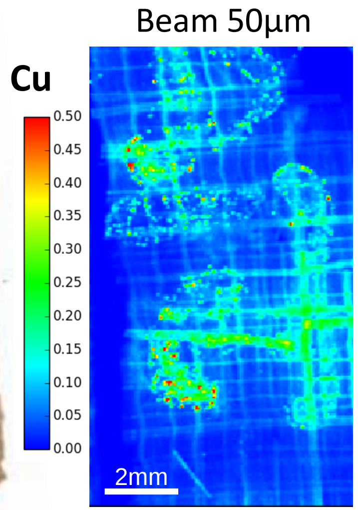
Received: 31 August 2017
Accepted: 31 October 2017
Published online: 10 November 2017

Thomas Christiansen[1,7], Marine Cotte[2,3], René Loredo-Portales[4], Poul Erik Lindelof[5], Kell Mortensen[5], Kim Ryholt[1] & Sine Larsen[6]

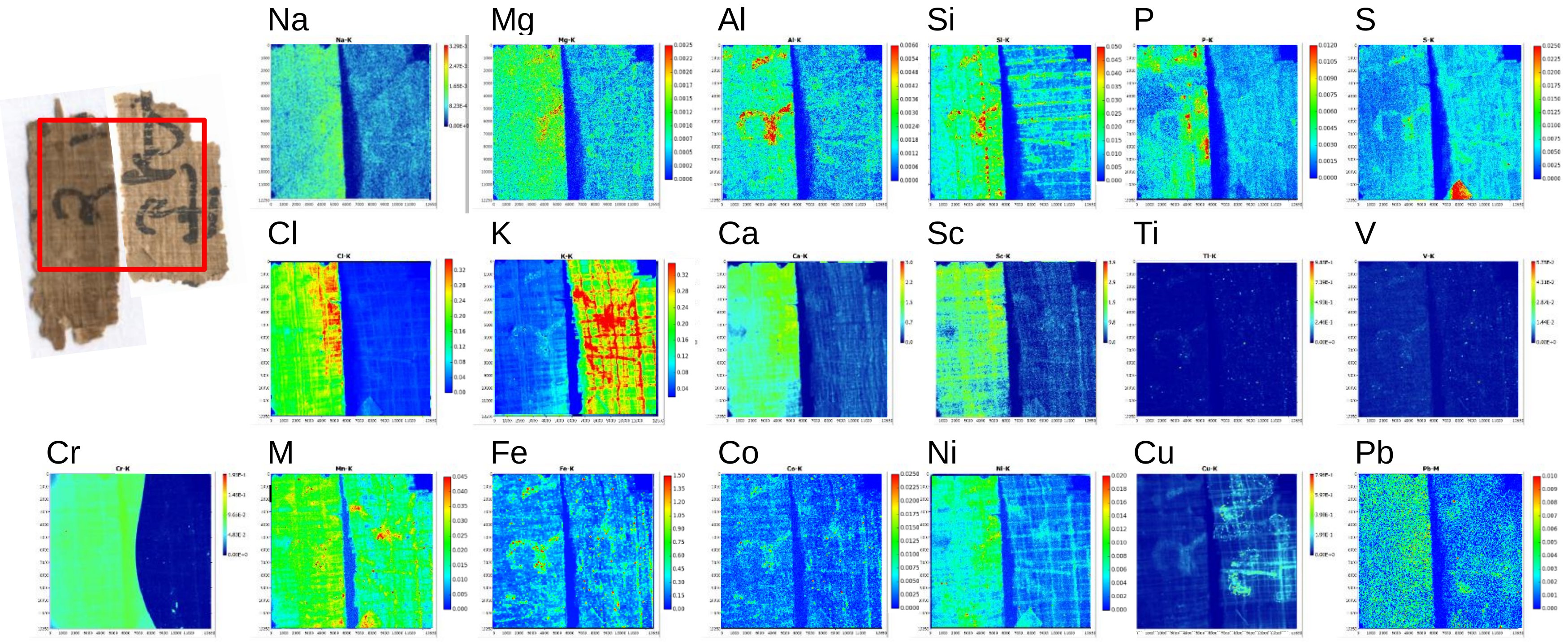
SCiEnTiFiC REPORTS | 7: 15346 | DOI:10.1038/s41598-017-15652-7

COPPER IN BLACK INK: MACRO/MICRO XRF MAPS AND Cu K-EDGE XANES ANALYSES

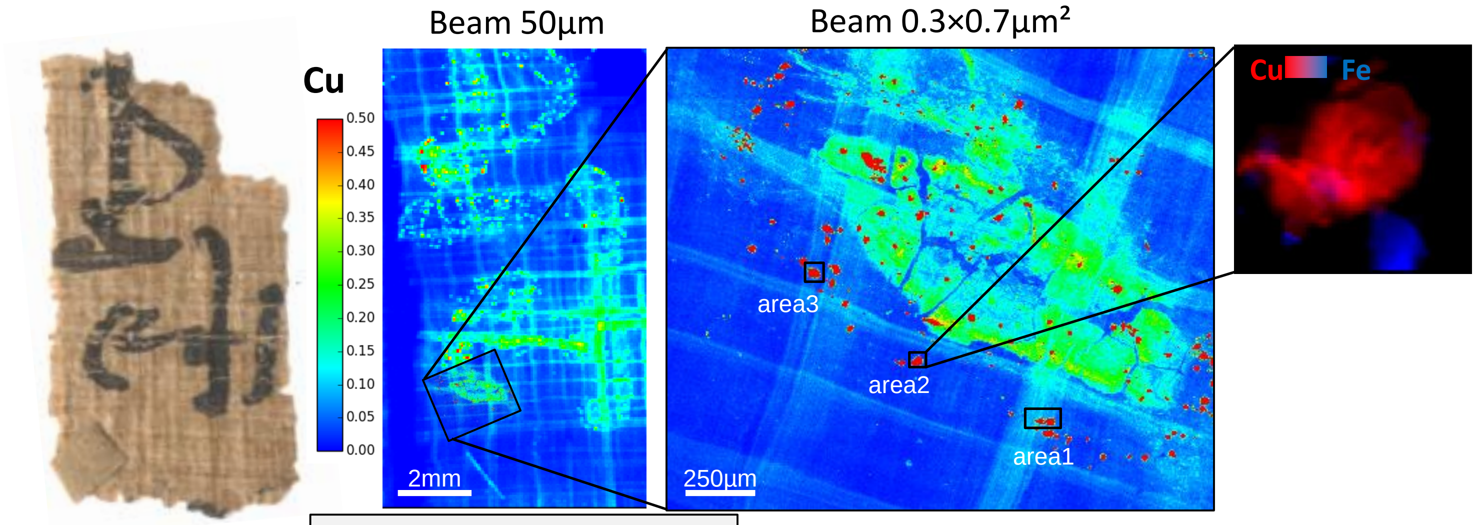
P. Carlsberg 839
Pathyris, 134 BCE



=> Cu is present in ink, and diffused in papyrus fibers

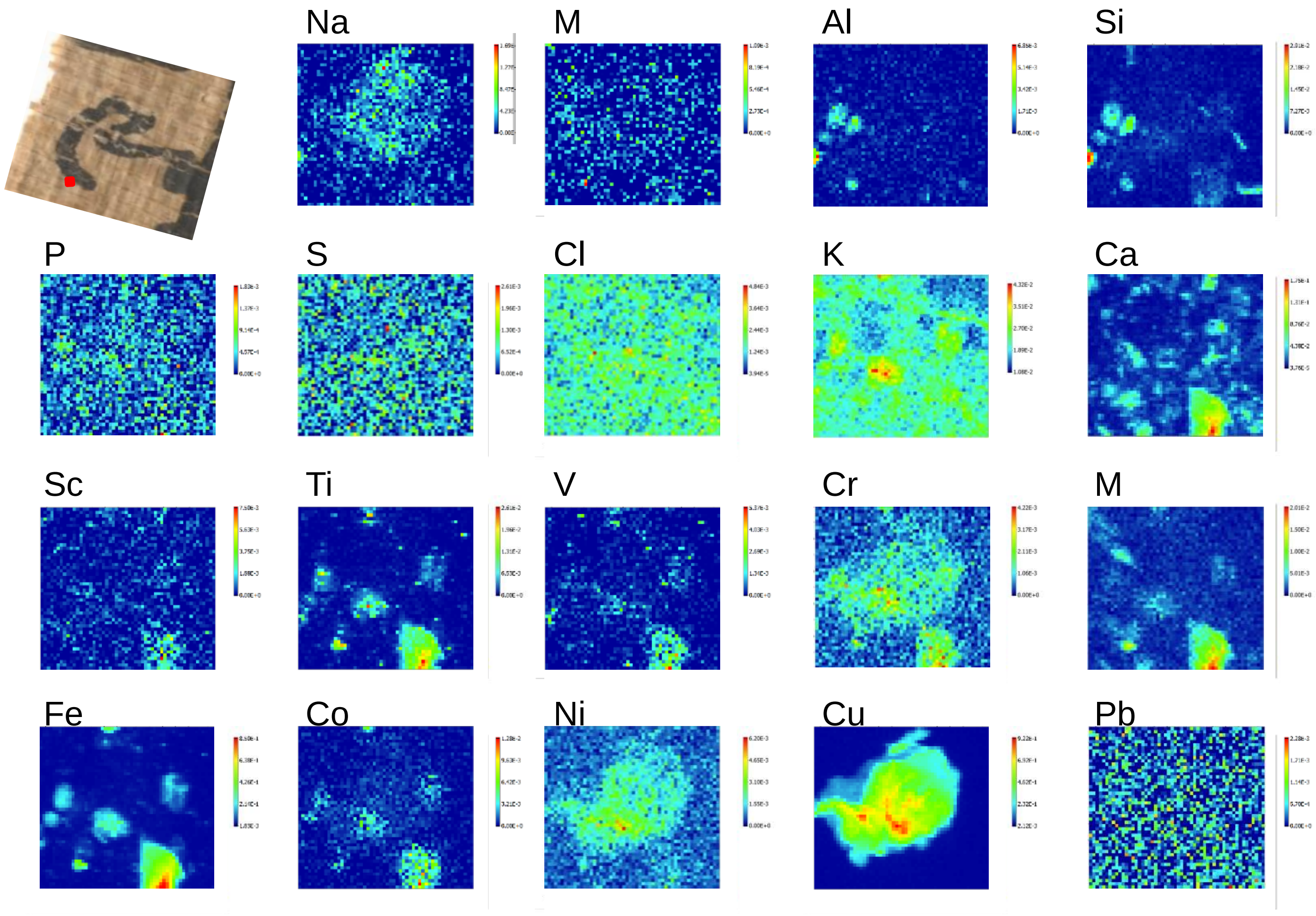

Na
Mg
Al
Si
P
S
Cl
K
Ca
Sc
Ti
V
Cr
M
Fe
Co
Ni
Cu
Pb

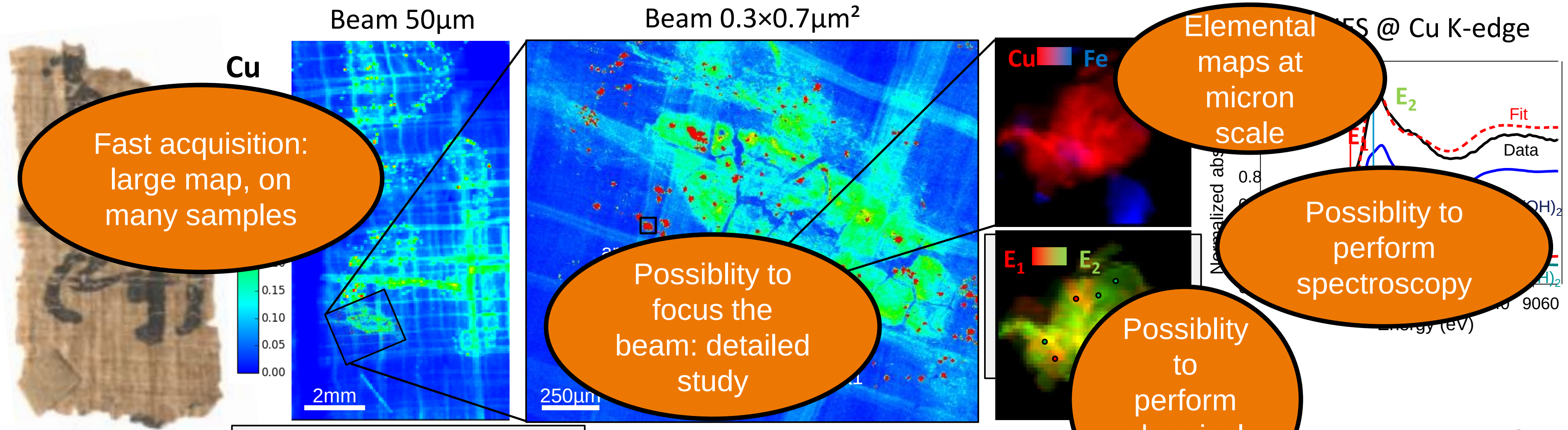
COPPER IN BLACK INK: MACRO/MICRO XRF MAPS AND Cu K-EDGE XANES ANALYSES



P. Carlsberg 839
Pathyris, 134 BCE

=> Cu is present in ink, and diffused in papyrus fibers


Na
M
Al
Si
P
S
Cl
K
Ca
Sc
Ti
V
Cr
M
Fe
Co
Ni
Cu
Pb



P. Carlsberg 839
Pathyris, 134 BCE

=> Cu is present in ink, and diffused in papyrus fi

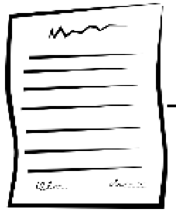
Cu under different speciations, Cu(II) and Cu(I)
=> Black pigment material (soot) was probably obtained as by-products of technical metallurgy

“The soot tha ... (ῇ οἱ ζωγράφοι χρῶνται) is taken from glass-making factories (ἐκ τῶν ὑελουργείων), for this is the best”,
Dioscorides, De materia medica, 50-70AD

Cu is not present under a unique composition, at the letter scale, and at the micron scale
=> cannot be used to identify a specific production (time/ place)

GETTING BEAMTIME AT A SYNCHROTRON FACILITY: THE PEER-REVIEW PROCESS

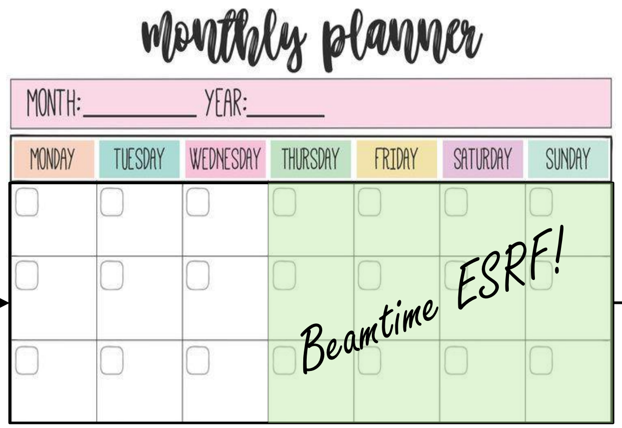
Idea



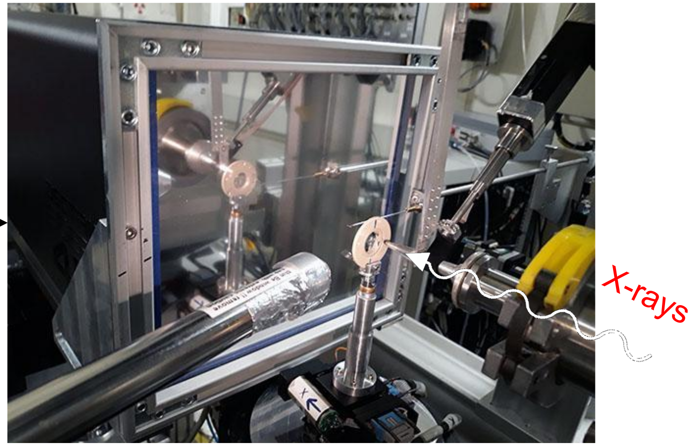
2-page proposal

01/03
10/09

Peer-review process: scientific excellence



From 1 to 6 days
24/24



High tech instruments

THE "HISTORICAL MATERIALS" BLOCK ALLOCATION GROUP: A NEW SHARED ACCESS

TU Delft – Delft University of Technology

University of Antwerp

RIJKS MUSEUM

ESRF – The European Synchrotron

THE COURTAULD Institute of Art

cnrs

école normale supérieure paris–saclay | université PARIS-SACLAY

POLITECNICO MILANO 1863

Centre de Recherche et de Restauration des Musées de France | IRCP Institut de Recherche de Chimie Paris

SCITEC – Istituto di Scienze e Tecnologie Chimiche Giulio Natta

UPC – UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

ISPC – ISTITUTO DI SCIENZE DEL PATRIMONIO CULTURALE

13 European teams + Metropolitan Museum

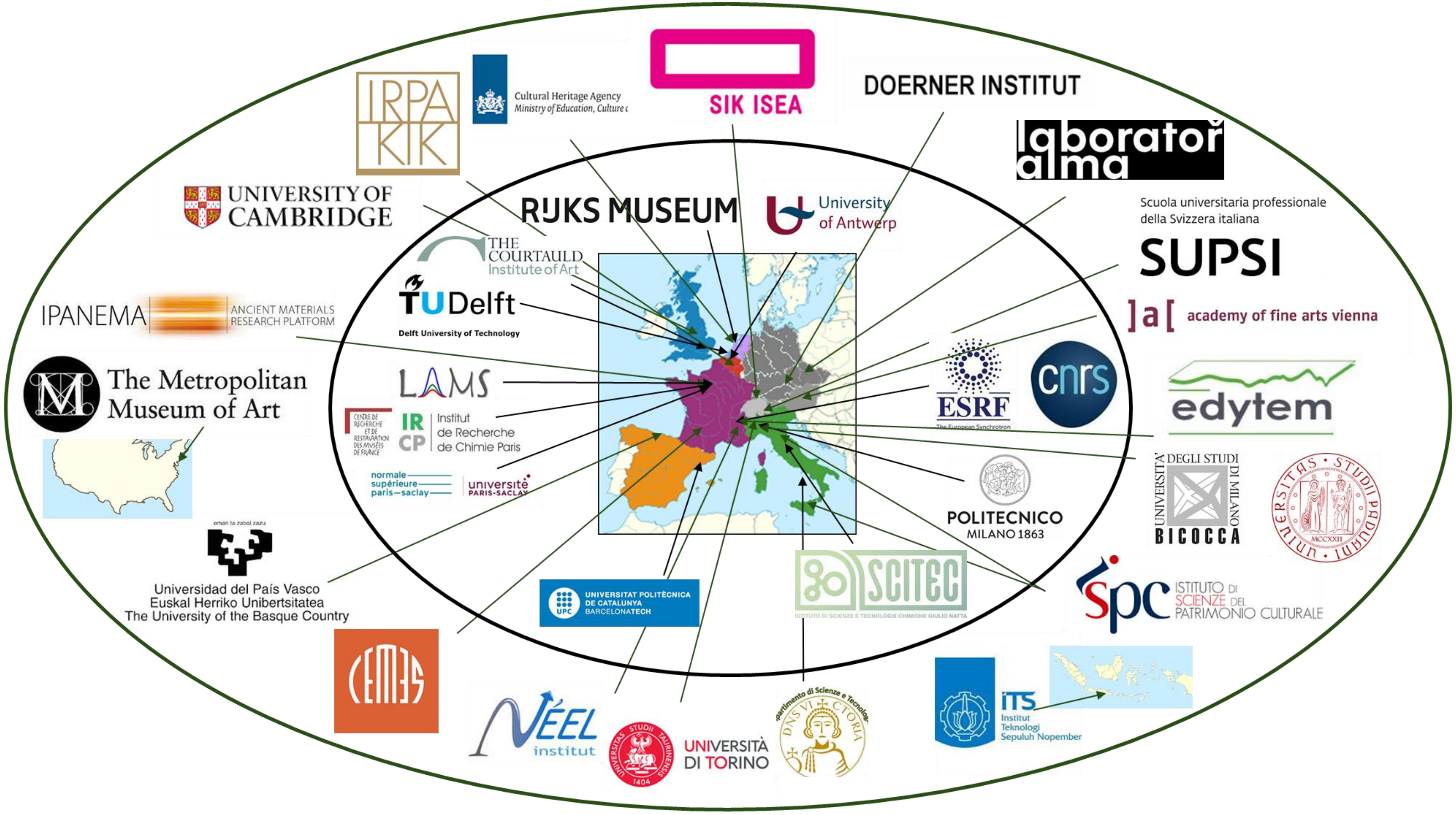
- ENS Paris-Saclay (former Rijksmuseum): V. Gonzalez
- Rijksmuseum (ex University of Antwerp, KIKIRPA): F. Vanmeert
- CNR-SCITEC: L. Monico
- ESRF, LAMS: M. Cotte, C. Holé, G. Robertson
- Courtauld Institute of Art: A. Nevin, A. Burnstock
- Politecnico di Milano: D. Comelli
- Rijksmuseum: K. Keune
- IRCP/C2RMF: I. Reiche
- Universitat Politècnica de Catalunya: N. Jiménez
- IRCP: G. Wallez
- TU Delft: M. Alfeld
- ISPC-CNR: A. Suzuki
- AXES: K. Janssens
- Metropolitan Museum (ex Univeristy of Cambridge): E. Purdy

https://www.esrf.fr/BAG/HG172

Heritage-bag@esrf.fr

Access to ID22 and ID13 ONLY! Twice a year at the 2 beamlines

AN EXTENDED NETWORK!

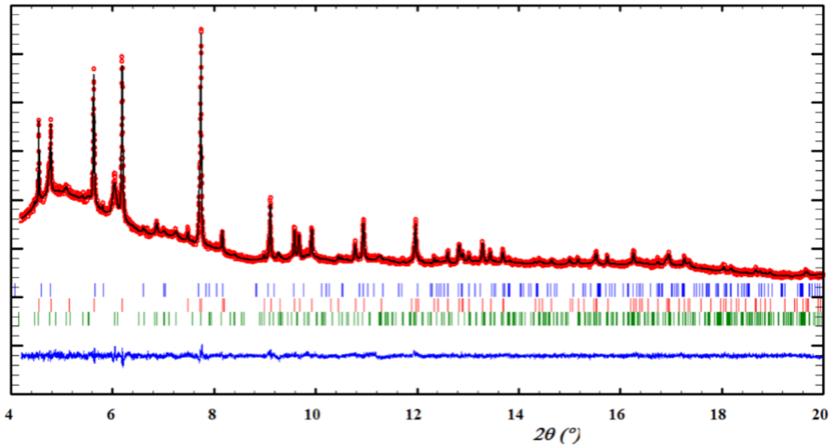


First ring: partners of the initial BAG proposal
Second ring: indirect partners through collaborations

ID22 : High-angle resolution XRD

- Energy: ~35 keV
- Scan range 2θ: 3 – 20°
- Analysis time: ~20 min/powder;~2 h/historical sample
- Instrumental function 2θ (FWHM of (111) Si peak) ~ 0.0027°
- Samples in capillaries

⇒ **precise and sensitive detection of crystalline phases, their identification, and the characterization of their microstructural and structural properties**

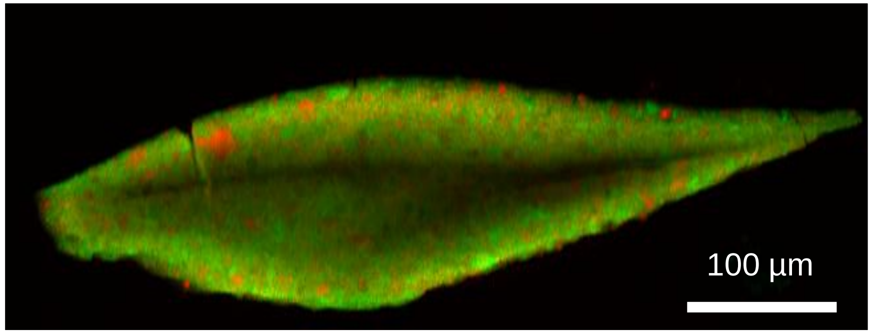


2 days every 6 months
Local contact : Catherine Dejoie
catherine.dejoie@esrf.fr

ID13 : High-lateral resolution XRD

- Energy: ~13 keV
- Analysis time: ~10 min -2 h/map (15ms/ pixel)
- Beam size ~ 2×2µm²
- Samples as thin sections (preferable) or cross-sections

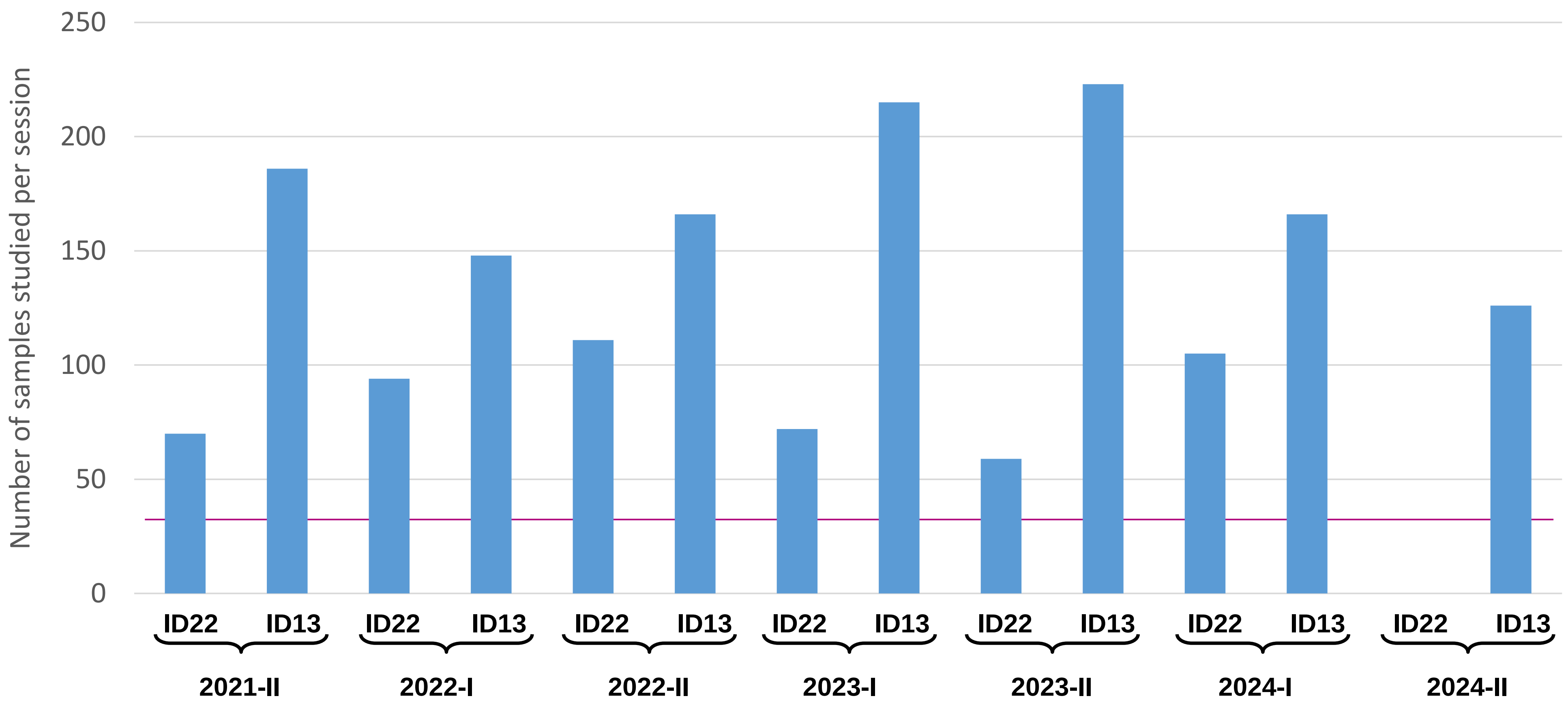
⇒ **stratigraphical distribution of crystaline phases at the micrometer scale**



4 days every 6 months
Local contact : Manfred Burghammer
burgham@esrf.fr

THE "HISTORICAL MATERIALS" BLOCK ALLOCATION GROUP: A HIGH THROUGHPUT!

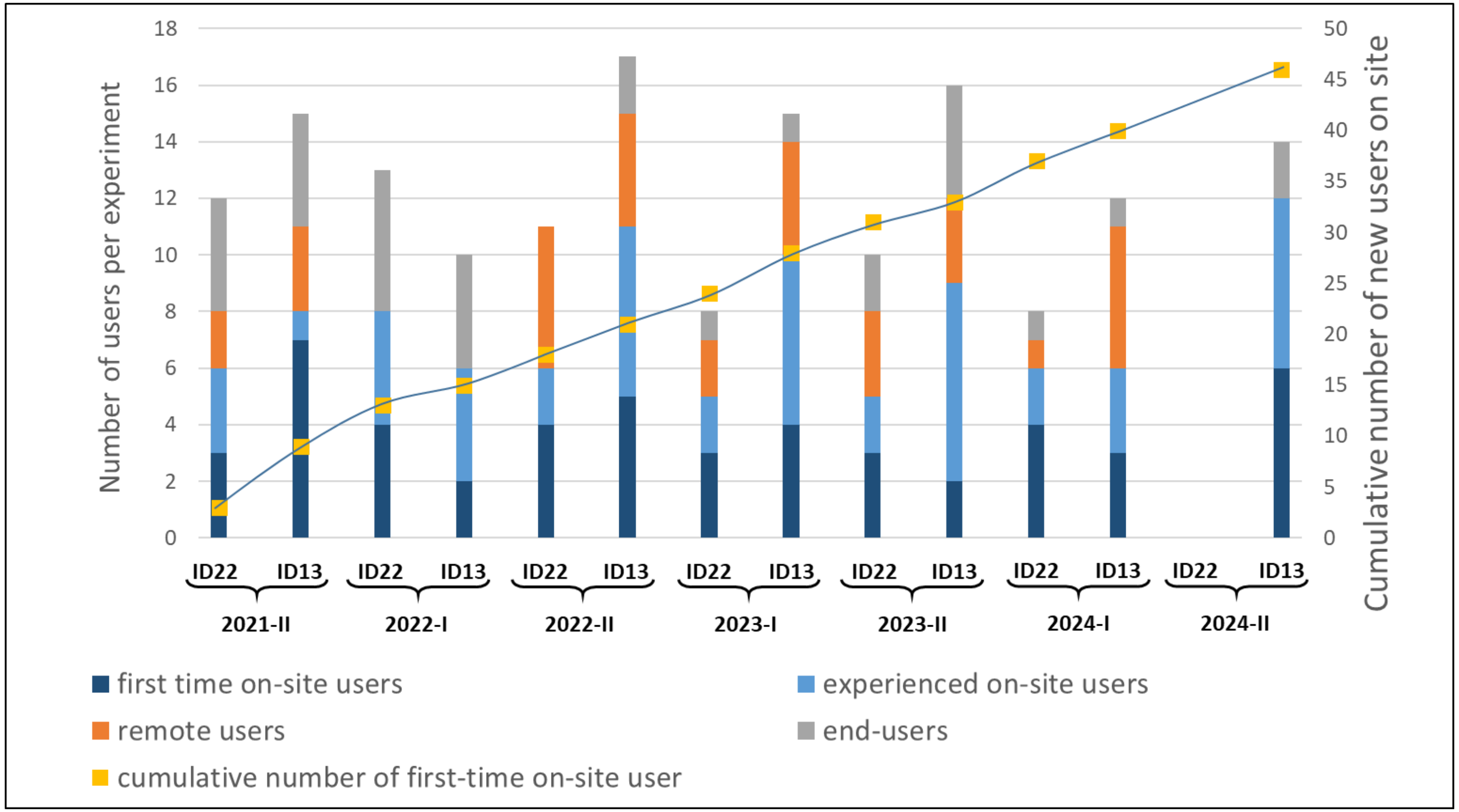
The success of the BAG relies on the capacity to analyze tens of samples per experiment.

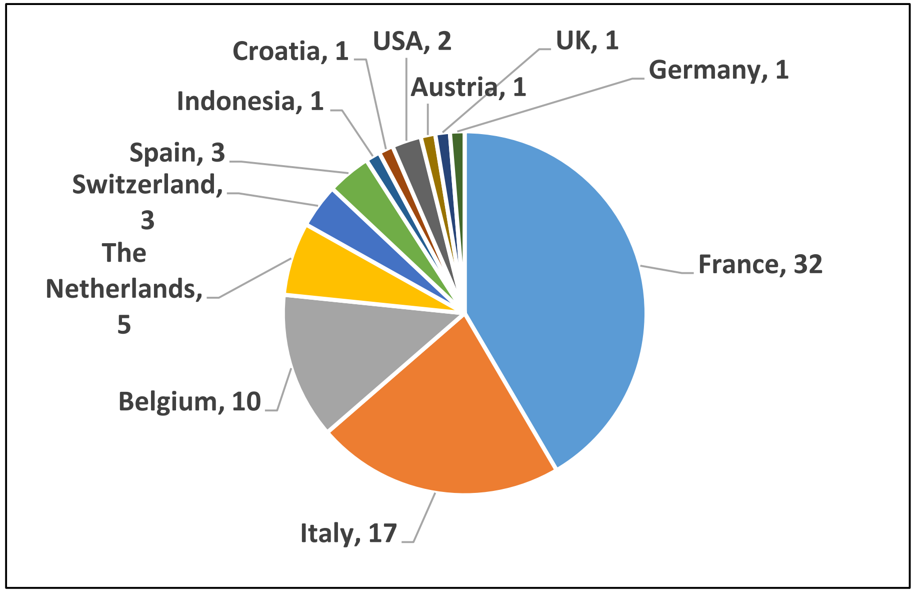


Before BAG or with standard proposal:
~<30 samples/ experiment

THE “HISTORICAL MATERIALS” BLOCK ALLOCATION GROUP: A VERY EFFICIENT WAY TO TRAIN NEW USERS

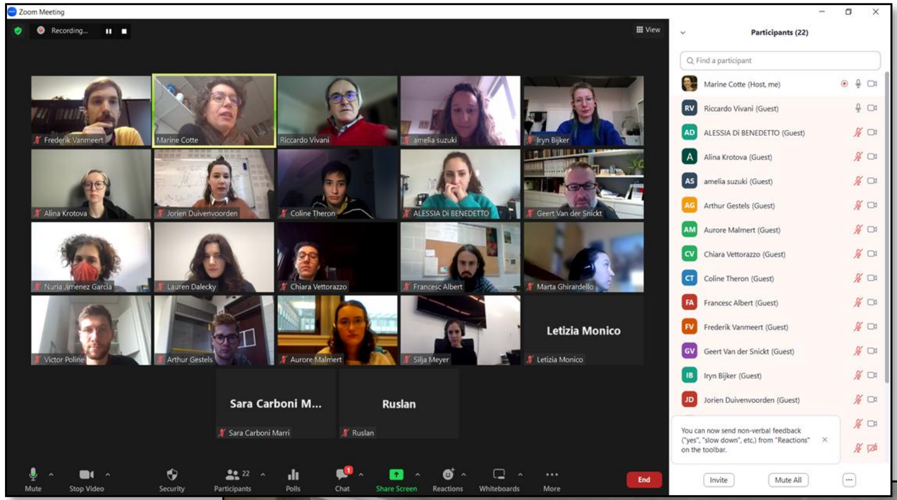
BAG gives an easy access to beamtime, in particular to **new users**, who can be trained by working with expert users

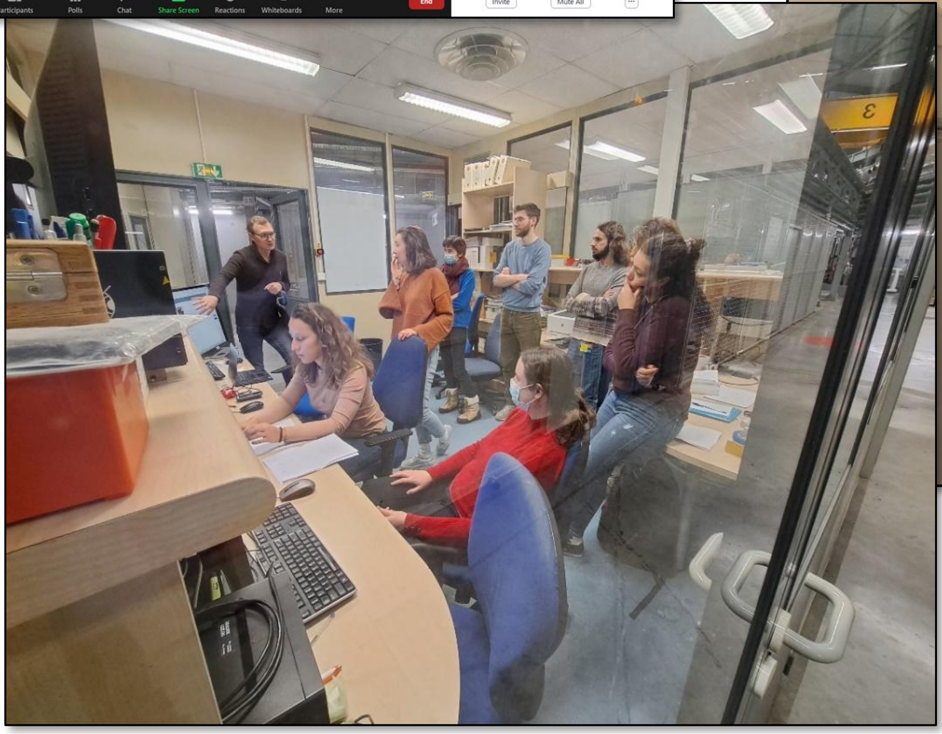


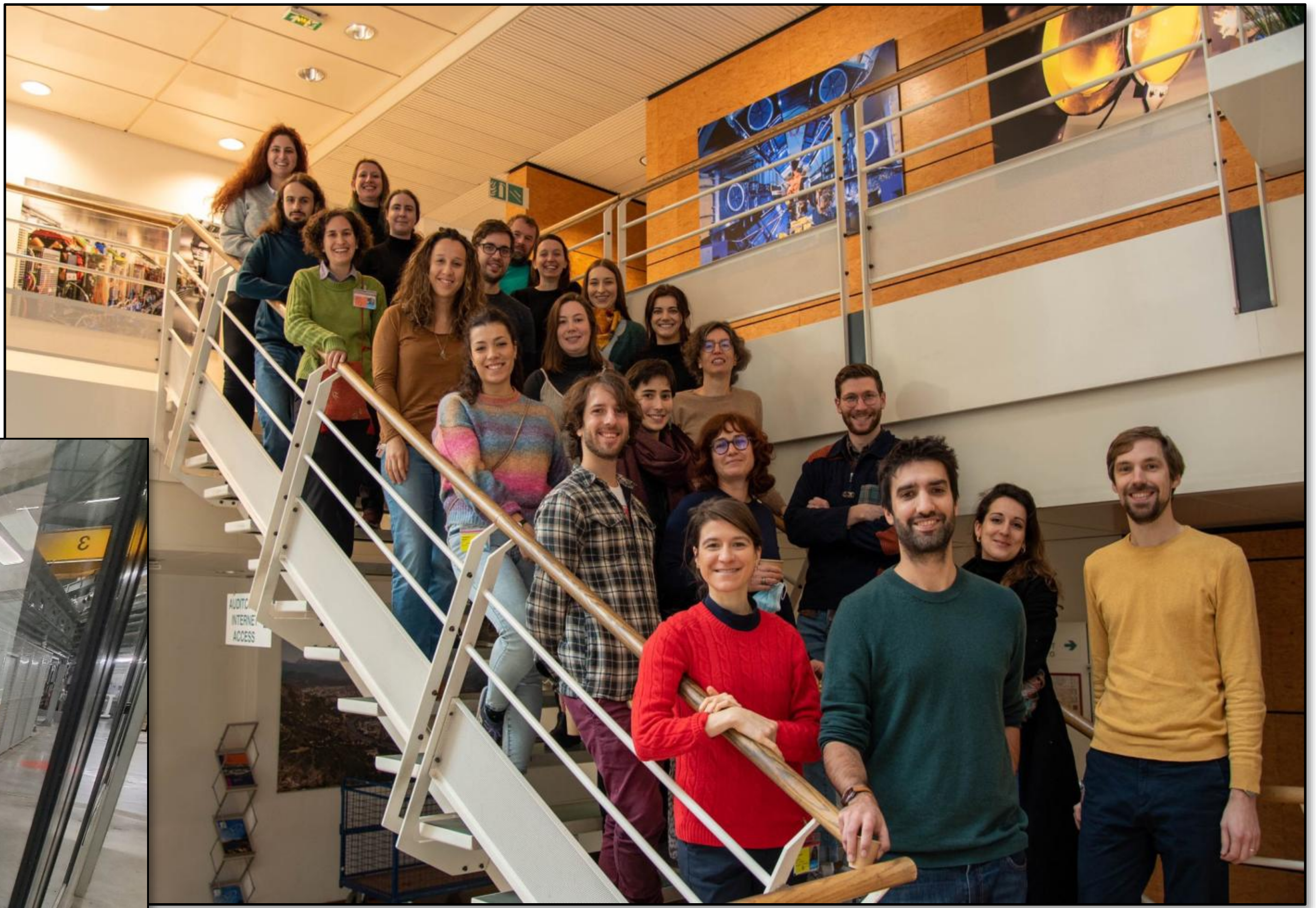


Around 10 users per experiment
Already 47 first time on-site users in 3.5 years
A total of 78 users (on-site, remote, end-user)
A total number of 120 partners

TRAINING THROUGH EXPERIMENTS, COURSES AND TUTORIALS







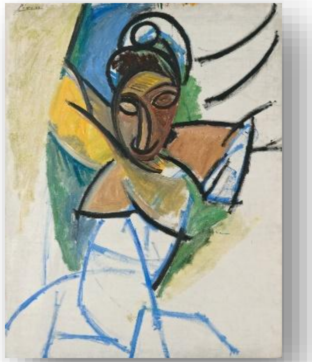
SOME RECENT OUTCOMES OF THE HISTORICAL MATERIALS BAG

molecules MDPI

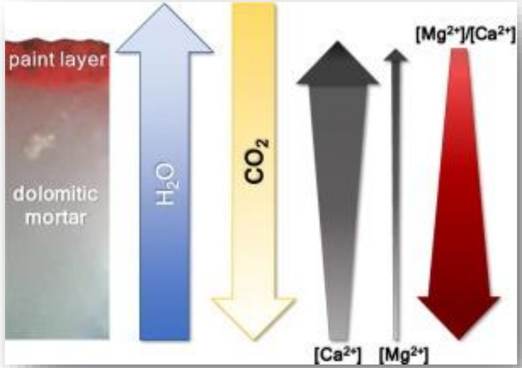
Article

The "Historical Materials BAG": A New Facilitated Access to Synchrotron X-ray Diffraction Analyses for Cultural Heritage Materials at the European Synchrotron Radiation Facility

Marine Cotte [1,2,*], Victor Gonzalez [3,*], Frederik Vanmeert [4,5,*], Letizia Monico [4,6,7,*], Catherine Dejoie [1], Manfred Burghammer [1], Loïc Huder [1], Wout de Nolf [1], Stuart Fisher [1], Ida Fazlic [1,8], Christelle Chauffeton [9,10,11], Gilles Wallez [9,11,12], Núria Jiménez [13], Francesc Albert-Tortosa [13], Nati Salvadó [13], Elena Possenti [14], Chiara Colombo [14], Marta Ghirardello [15], Daniela Comelli [15], Ermanno Avranovich Clerici [4,16], Riccardo Vivani [17], Aldo Romani [6,7], Claudio Costantino [6,7], Koen Janssens [4,8], Yoko Taniguchi [18], Joanne McCarthy [1], Harald Reichert [1] and Jean Susini [1,†]



Picasso's *Femmes*
M. Ghirardello, *Microscopy and micro analysis*



Carbonation of fresco paintings, N. Oriols, *Cement and Concrete Research*

Cadmium yellow degradation in Miro's paintings, N. Gomez Lobon, *Heritage Science*

Black stains on the passepartout of Codex Atlanticus Folio 843 by Leonardo da Vinci, N. Guarnieri, *Scientific Reports*

Architectural Bricks from Khorsabad and Susa Sites: Characterization of Black Glazes, E. Beauvoit, *Heritage*

Since first beamtime in 2020-II:
- 18 publications
- >25 oral presentations
- >15 posters

SUMMARY

- Unique insight accessible thanks to synchrotron-based techniques
- Most of the analyses are done on fragments, rarely on objects
- Most of the analyses track chemical composition (rather than morphology)
- Chemistry records track of original manufacturing processes and later degradation phenomena
- Often, different techniques are combined (portable/ lab / ESRF, X-rays/ infrared/ UV-vis…) as they offer various contrasts and information

Li-Hill, 2019, Grenoble

Thank you for your presence and your attention!

Particular thanks to all colleagues involved in beamlines development and maintenance, in the operation of the ESRF and

to all users, ESRF colleagues and services making this research possible

https://www.esrf.fr/BAG/HG172

Heritage-bag@esrf.fr
cotte@esrf.fr