2023 LNL User Community Meeting

Nov 16, 2023, 2:00 PM → Nov 17, 2023, 1:30 PM Europe/Rome

Sala Villi (Laboratori Nazionali di Legnaro)

Cultural heritage at LNL

Activities of INFN Torino Division at AN2000 accelerator

Alessandro LO GIUDICE

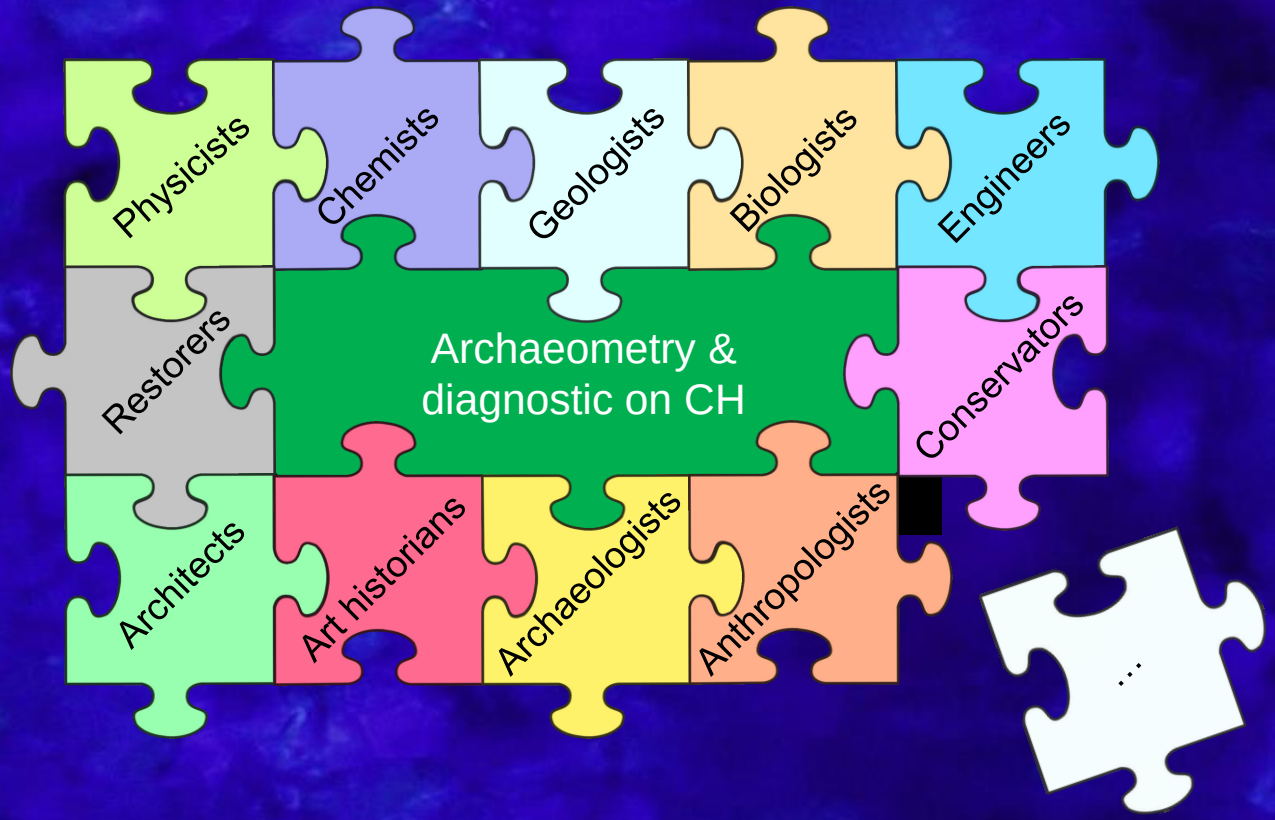
Laura GUIDORZI, Alessandro RE, Marta MAGALINI

Physics Department, University of Torino and INFN, Torino division

http://www.solid.unito.it/research/culturalheritage/index.html

Physics for Cultural Heritage: collaborations

Multidisciplinarity



Physics for Cultural Heritage … *an important impact on society*

Collaboration with…. local (but not only) institutions

Museums

MUSEO EGIZIO

museo d'arte orientale
asian art museum

Musei Reali Torino

REGIONE PIEMONTE
MRSN
MUSEO DI ANTROPOLOGIA ED ETNOGRAFIA
UNIVERSITÀ DI TORINO

Restoration Center

CENTRO CONSERVAZIONE RESTAURO LA VENARIA REALE

Superintendence

SABAP TO
SOPRINTENDENZA ARCHEOLOGIA BELLE ARTI e PAESAGGIO PER LA CITTA' METROPOLITANA DI TORINO

Information on:

- conservation state of artworks
- manufacturing techniques
- materials used
- provenance of raw materials (carried out in Legnaro)
- authentication ……

Physics for Cultural Heritage: an example of what physicists can do in CH

Examples of Ancient Egypt objects

MUSEO EGIZIO

MAF

Use of techniques based on:

X-Rays (XRF, Radiography, Tomography)
Protons (PIXE, IBIL)
Neutrons (Tomography, Diffraction, PGAA)

X-RAYS

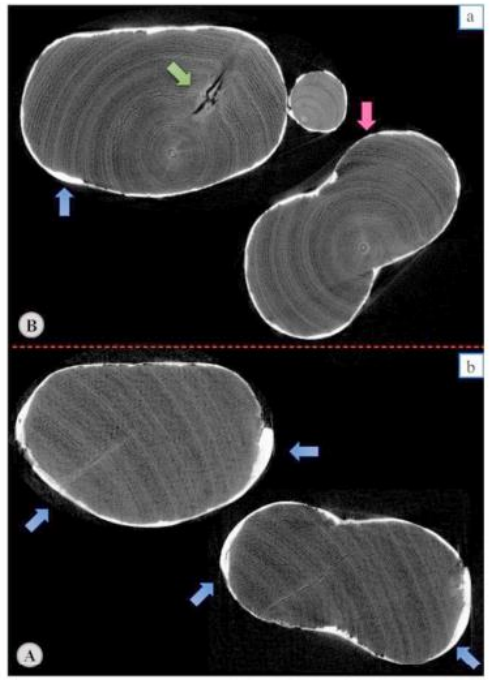


Fig. 4. CT horizontal slices of the two statuettes (a: statuette B; b: statuette A) in which the preparation layer is visible (pink arrow: lack of material; blue arrow: thicker preparation layer; green arrow: defects).

L. Vigorelli et al, ***Journal of Archaeological Science: Reports 44 (2022) 103518***

CCR La Venaria Reale (X-rays)

NEUTRONS

TU Delft in Netherland (neutrons)

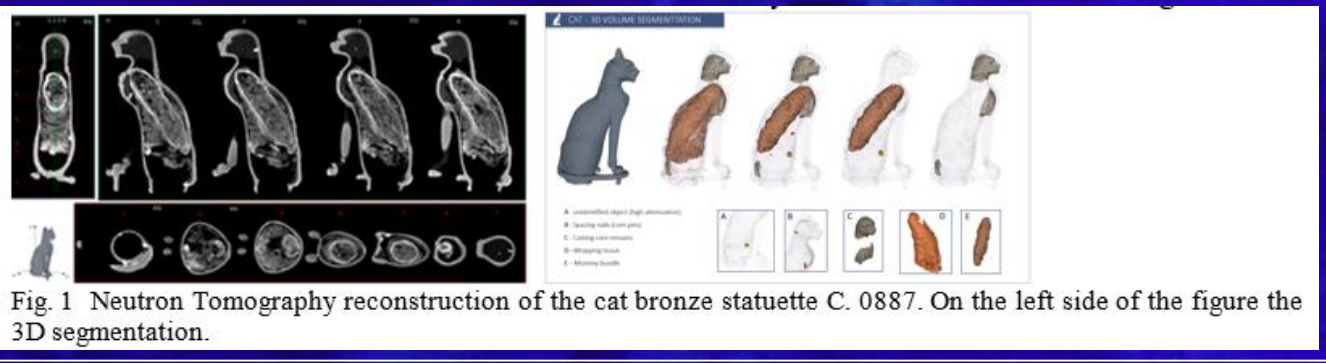


Fig. 1 Neutron Tomography reconstruction of the cat bronze statuette C. 0887. On the left side of the figure the 3D segmentation.

PROTONS

A. Lo Giudice et al, ***Archaeological and Anthropological Sciences (2017) 9: 637-651***

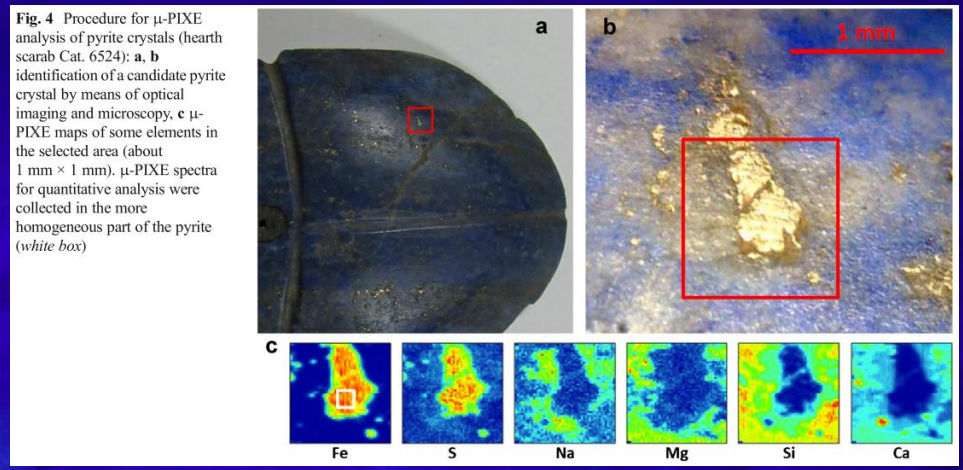
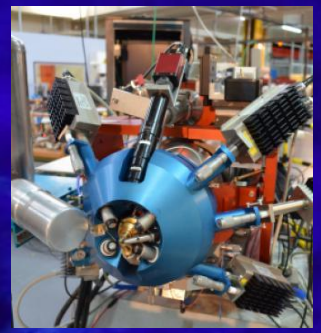


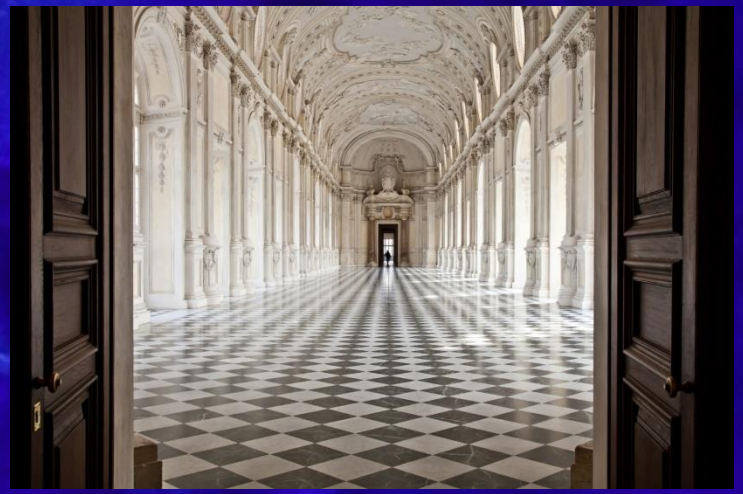
Fig. 4 Procedure for μ-PIXE analysis of pyrite crystals (hearth scarab Cat. 6524): **a**, **b** identification of a candidate pyrite crystal by means of optical imaging and microscopy, **c** μ-PIXE maps of some elements in the selected area (about 1 mm × 1 mm). μ-PIXE spectra for quantitative analysis were collected in the more homogeneous part of the pyrite (*white box*)

AGLAE in Paris (protons)



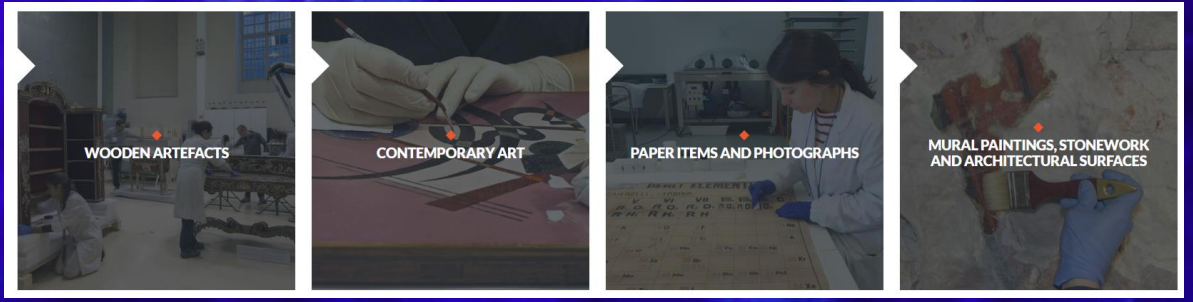
Paper under submission...

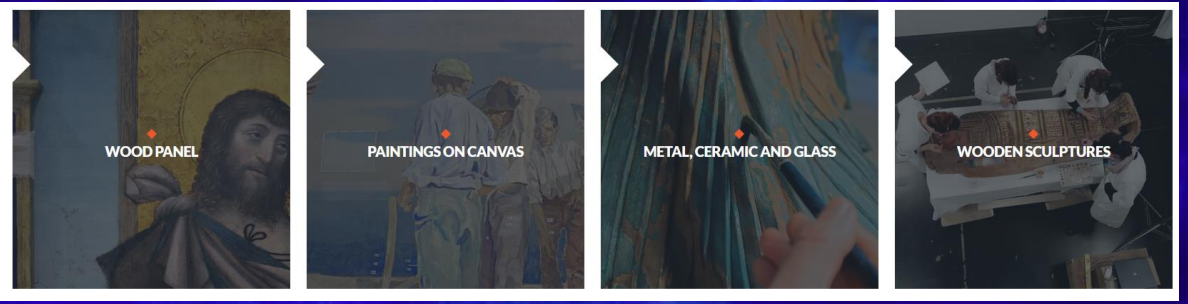
Physics for Cultural Heritage: the importance to collaborate with institutions

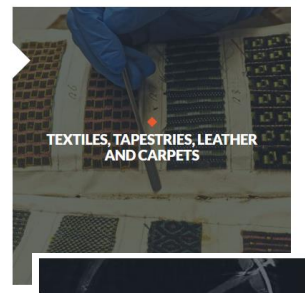


CENTRO CONSERVAZIONE RESTAURO LA VENARIA REALE

Physics for Cultural Heritage (CH) : the importance to collaborate with institutions







Cultural Heritage: applied physics who can produce excellent spin-offs and visibility with institutions!

Progetto neu_ART (2010-2013), finanziato da: REGIONE PIEMONTE

INFN Istituto Nazionale di Fisica Nucleare Sezione di Torino

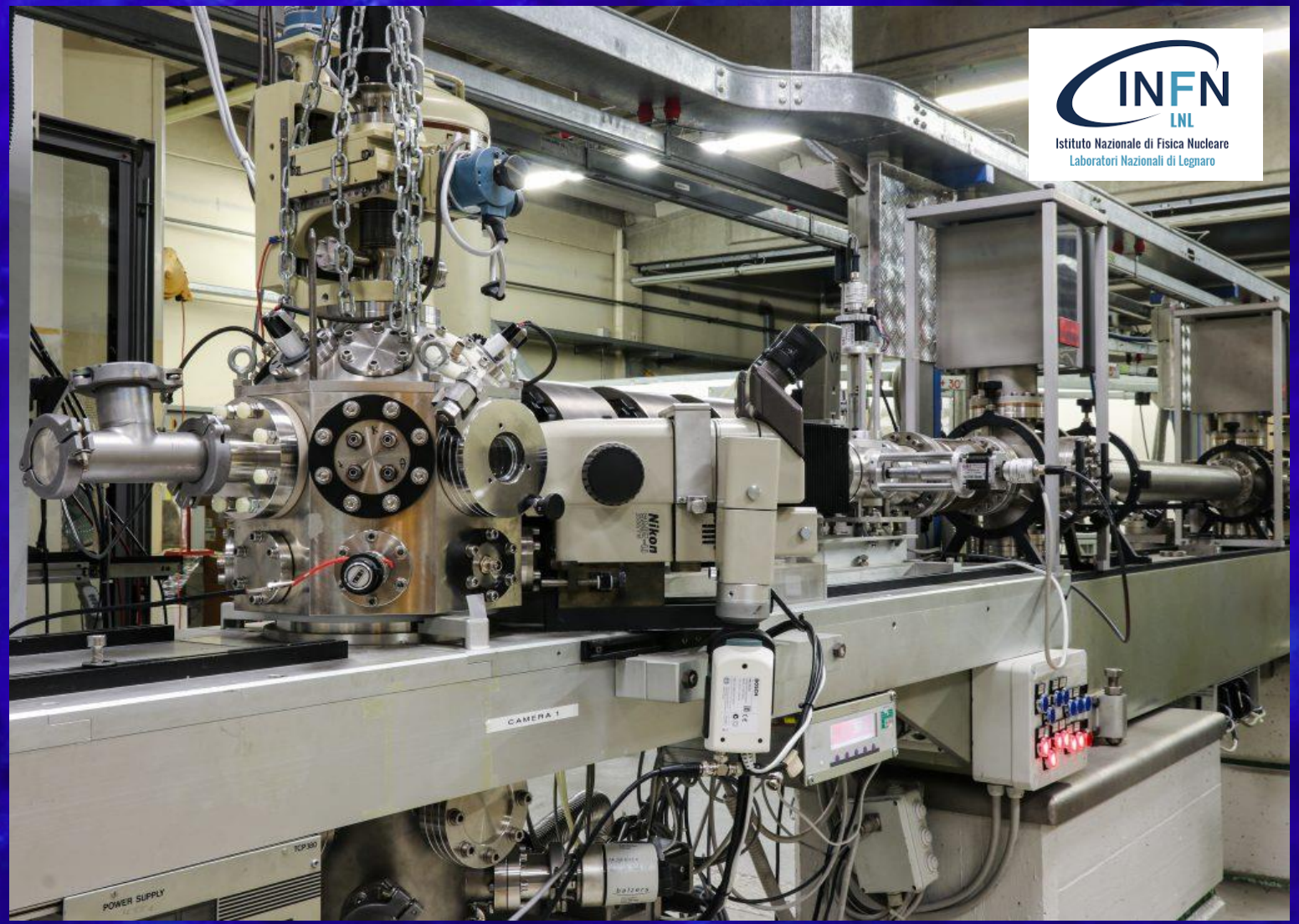
Centro Conservazione e Restauro La Venaria Reale

UNIVERSITÀ DEGLI STUDI DI TORINO Dipartimento di Fisica

Coordinator: Nadia Pastrone

Part of the instrumentation was developed in the framework of the CMS experiment and readapted for this project ! IMPORTANCE OF FUNDAMENTAL RESEARCH !

Ion Beam Analysis for archaeological materials in Legnaro (AN)



AN2000

Experiment: ALCHIMIA

Spokeperson: Dr. Laura GUIDORZI

Alessandro LO GIUDICE,
Alessandro RE, Marta MAGALINI

In Vacuum

Line: 0°

Microbeam

(beam diameter around 5-6 μm)

Energy: 2 MeV

Current < 0.5 nA

Analysis: mainly μ-PIXE, μ-IBIL

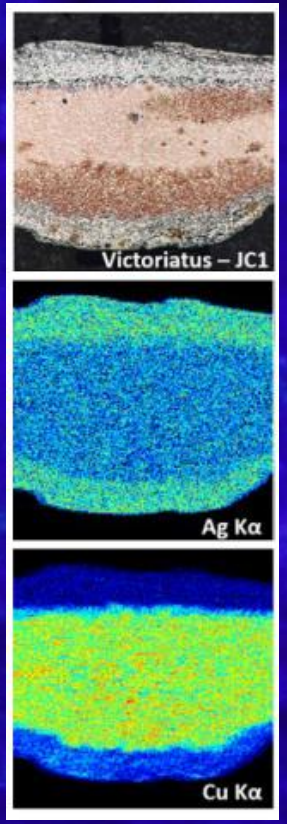
In average, about 10 days/year

24h/24h (more than 100 hours for a 5 days run)

Ion Beam Analysis for archaeological materials in Legnaro (AN)

Ancient Roman and pre-Roman Coins

Question: study of surface silver-enriched layer, corrosion layer, trace elements and contaminants



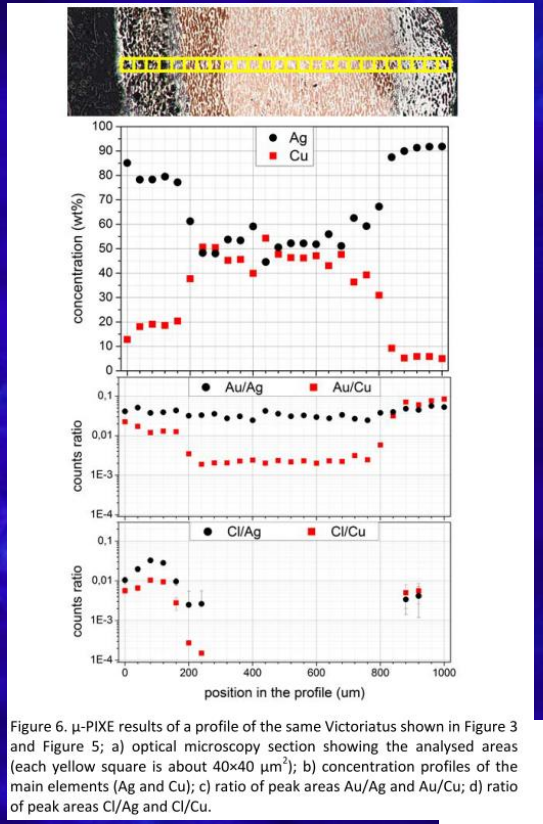


Figure 6. μ-PIXE results of a profile of the same Victoriatus shown in Figure 3 and Figure 5; a) optical microscopy section showing the analysed areas (each yellow square is about 40×40 μm^2); b) concentration profiles of the main elements (Ag and Cu); c) ratio of peak areas Au/Ag and Au/Cu; d) ratio of peak areas Cl/Ag and Cl/Cu.

Period: 3rd to 2nd century BCE

Main study by means of neutrons (not invasive)

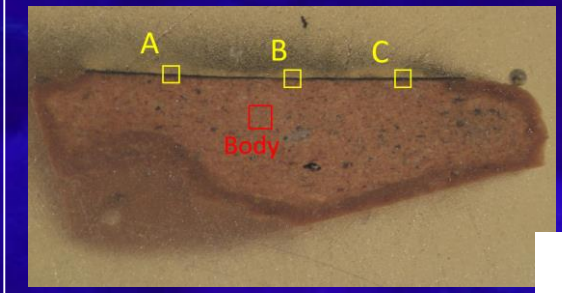
In few cases cross sections were prepared

μ-PIXE analysis in vacuum chamber

Figure 3. Obverse and reverse images of one of the investigated victoriatus JC1 (RRC: 166)

Ancient Greek ceramics

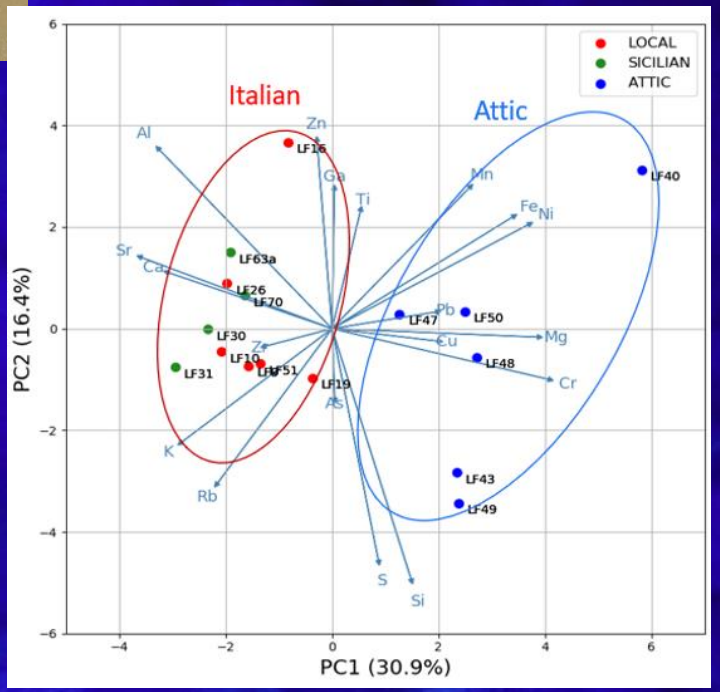
Question: provenance study of red-figured pottery shards of Southern Italy (distinguish Attic, Calabrian and Sicilian production)



Period: 6th to 4th century BCE

Study on micro-sample cross sections (body and slip)

μ-PIXE analysis in vacuum chamber



The main topic of our research in Legnaro: Provenance study of Lapis Lazuli

Raw

Polished

Provenance study of Lapis Lazuli

BLUE COLOUR: LAZURITE

$(Na, Ca)_{7.5-8}\ (Si, Al)_{12}\ (O, S)_{24}\ (SO_4\ , Cl)_{1.3-2}$

GOLD COLOUR
PYRITE
FeS_2

WHITE COLOUR

DIOPSIDE
$CaMg(SiO_3)_2$

WOLLASTONITE
$CaSiO_3$

K-FELDSPAR
$KAlSi_3O_8$

CALCITE
$CaCO_3$

Lapis lazuli is a rock.... more than 30 mineralogical phases in lapis lazuli rocks have been reported so far in literature...

Lapis Lazuli in ancient and recent time

"Tutankhamun's pectoral"
(Around 1300 BCE)
Egyptian Museum, Cairo, Egypt

Ebih II, found in Mari, Syria
(about 2400 BCE), Louvre Museum, Paris

Where did the raw material used for artworks come from?

"The Ram in the Thicket" from Ur, Iraq
(around 2600 BCE)
The British Museum, London (UK)

Lapis lazuli beads from Ur
(3rd milleniuim BCE),
The British Museum, London (UK)

St. Isaac's Cathedral in St. Peterburg, Russia
XIX century CE

Museo degli Argenti, Firenze
XVI century CE

Provenance study of Lapis Lazuli

Due to compositional and isotopic variability in samples from the same area, need for high statistics

Where did the raw material used for artworks come from?

need for a lot of beam time at micro-IBA facilities… a long work….

Comparison between chemical-physical properties of the raw material and artworks

(mainly, differences in chemical composition, both minor and trace elements, and isotope ratios)

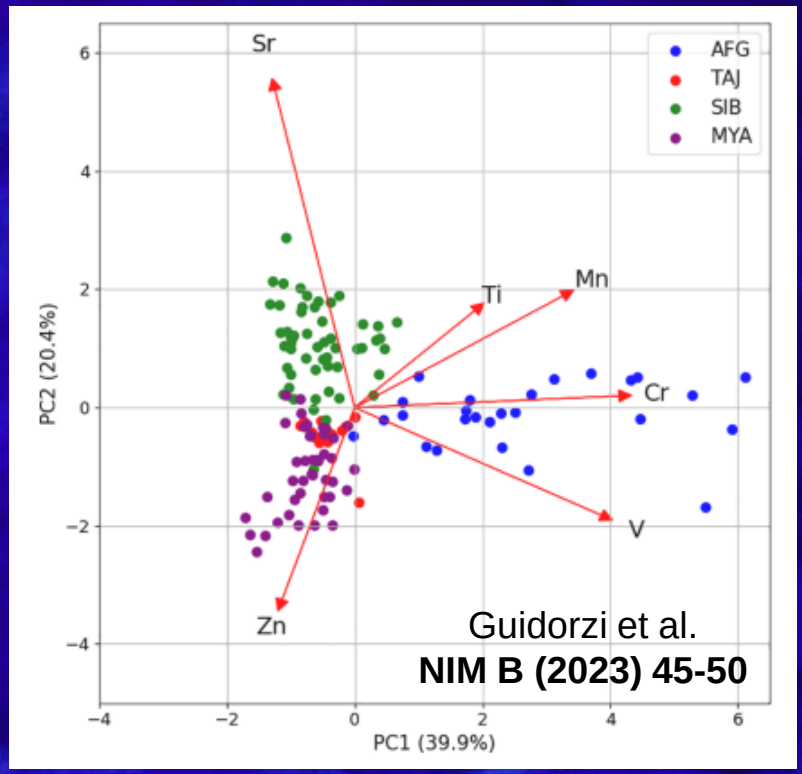
Lapis lazuli

Museo Archaeologico di Firenze

Rock Data Base

Afghanistan
Tajikistan
Myanmar
Siberia

Each point is a μ-PIXE measurement that need more than 1 hour !



Lapis Lazuli provencance: an interdisciplinary collaboration

Research started in 2007

Physicists, Chemists, Geologists and Petrologists, Conservation Scientists, Curators and Directors of Museums, Archaeologists

Egyptian Museum of Florence

The aim

To find one (or more) NOT INVASIVE way to distinguish among provenances of lapis lazuli raw material used for artworks and archaeological finds

to reconstruct old trade routes

to improve the knowledge about the story of lapis lazuli employment

Egyptian Museum of Florence

Lapis Lazuli provencance: an interdisciplinary collaboration

Research started in 2007

A long and patient work

4 PhD (Physics, Earth Science, Material Science, Technologies for Cultural Heritage);

15 Master Degree (4 Physics, 9 Material Science, 1 Archaeology);

5 Bachelor Degree (1Physics, 4 Material Science)

In 2022-2023 we presented (oral presentation) the work on lapis lazuli in 3 international conference/workshop:

IAEA Workshop on Innovative Approaches of Accelerator Science and Technology for Sustainable Heritage Management, 13/16 June 2022, Wien (Austria)

ICNMTA 2022 - 18th International Conference on Nuclear Microprobe Technology and Applications, 11- 6 September 2022, Ljubljana (Slovenia)

TECHNART 2023 - International conference on analytical techniques in art and cultural heritage, 7-12 May 2023, Lisbon (Portugal)

We published 15 papers on ISI/SCOPUS journals (306 citations, the most cited 41 citations)

For the end of 2024 we think to reach a number of about 20

http://www.solid.unito.it/research/culturalheritage/index.html

https://www.euronews.com/next/2013/11/04/art-detectives-team-up

Lapis Lazuli provencance: an interdisciplinary collaboration

Research started in 2007

Last 2 publications (2023)

Eur. Phys. J. Plus (2023) 138:175
https://doi.org/10.1140/epjp/s13360-023-03768-x

THE EUROPEAN PHYSICAL JOURNAL PLUS

Regular Article

Micro-PIXE and micro-IBIL characterization of lapis lazuli samples from Myanmar mines and implications for provenance study

Laura Guidorzi[1,2], Alessandro Re[1,2,a], Marta Magalini[1,2], Debora Angelici[2], Alessandro Borghi[3], Gloria Vaggelli[4], Fulvio Fantino[5], Valentino Rigato[6], Leonardo La Torre[6], Quentin Lemasson[7,8], Claire Pacheco[7,8], Laurent Pichon[7,8], Brice Moignard[7,8], Alessandro Lo Giudice[1,2]

[1] INFN Sezione di Torino, Via Pietro Giuria 1, Torino, Italy
[2] Dipartimento di Fisica, Università di Torino, Via Pietro Giuria 1, Torino, Italy
[3] Dipartimento di Scienze della Terra, Università di Torino, Via Valperga Caluso, 35, Torino, Italy
[4] CNR - Isitituto di Geoscienze e Georisorse, Via Valperga Caluso, 35, Torino, Italy
[5] Turin Thermoluminescence Analysis, Via Felice Cavallotti 33, Cuneo, Italy
[6] INFN Laboratori Nazionali di Legnaro, Viale dell'Università 2, Legnaro, Padova, Italy
[7] Centre de Recherche et de Restauration des Musées de France, C2RMF, 14 quai François Mitterrand, Par
[8] Fédération de Recherche FR3506 New AGLAE, 14 quai François Mitterrand, Paris, France

Received: 2 November 2022 / Accepted: 1 February 2023

Nuclear Instruments and Methods in Physics Research B 540 (2023) 45–50

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Nuclear Inst. and Methods in Physics Research, B

journal homepage: www.elsevier.com/locate/nimb

Application of principal component analysis to μ-PIXE data in lapis lazuli provenance studies

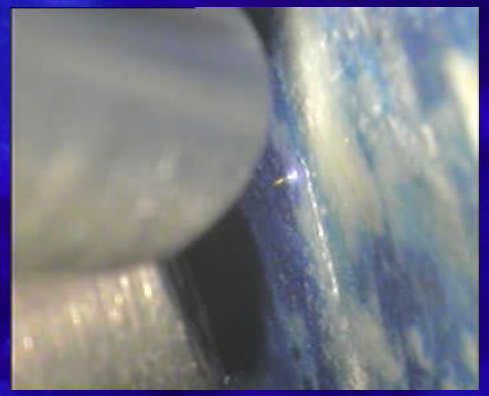
Laura Guidorzi [a,b,*], Alessandro Re [a,b,*], Marta Magalini [a,b], Alessandro Lo Giudice [a,b]

[a] INFN – Sezione di Torino, Via Pietro Giuria 1, 10125 Torino, Italy
[b] Dipartimento di Fisica, Università degli Studi di Torino, Via Pietro Giuria 1, 10125 Torino, Italy

The most suitable technique we have found: Ion Beam Analysis

Comparison between chemical-physical properties of the raw material and artworks
(mainly, differences in chemical composition, both minor and trace, and isotope ratios)

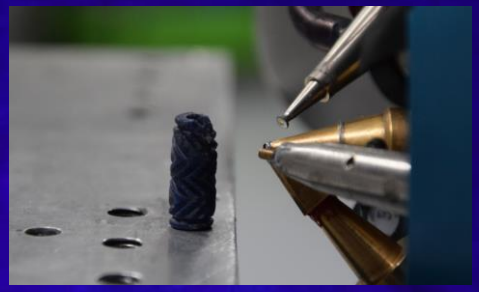
Museo Archaeologico di Firenze



All the markers we have found are observable in a **NOT INVASIVE** way by means of **in air micro-IBA**

μ-PIXE: Particle Induced X-ray Emission
μ-IBIL: IonoLuminescence

Environment	In air (helium flux)
Proton Energy	3 MeV
Current	~ 500 pA
Beam dimension	30 - 40 μm
Scanning Area	3 x 3 mm^2

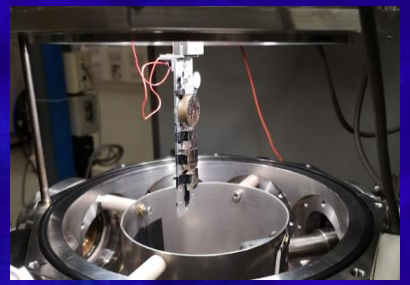


OUR STRATEGY FOR MARKERS IN LAPIS LAZULI

- Presence or absence of a mineralogical phase
- Trace elements inside a mineralogical phase
- Luminescence properties of a mineralogical phase

But… to speed up the analysis on reference rocks and when small archaeological production waste fragments of lapis lazuli are studied, also in vacuum IBA can be used

Environment	In vacuum
Proton Energy	2 MeV
Current	~ 200 pA
Beam dimension	5-6 μm
Scanning Area	2 x 2 mm^2



PYRITE FeS_2

WOLLASTONITE $CaSiO_3$

CALCITE $CaCO_3$

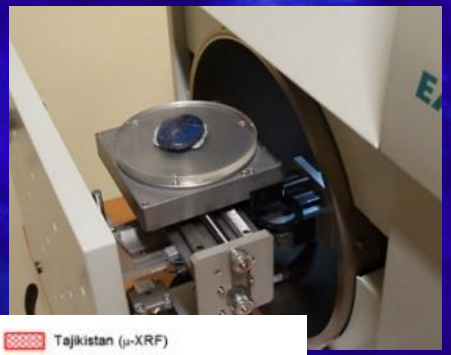
DIOPSIDE $CaMg(SiO_3)_2$

Need for high statistics ➡ large amount of IBA measurements

The most suitable technique we have found: Ion Beam Analysis

We have tried other techniques, but they have (for now) limitations.

μ-XRF (X-Ray Fluorescence)



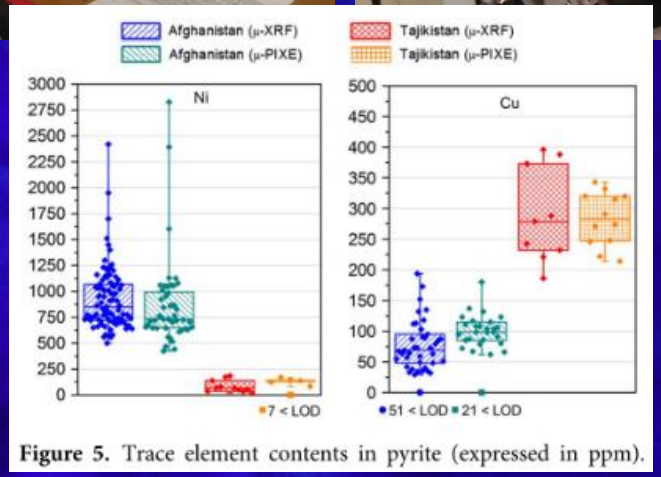
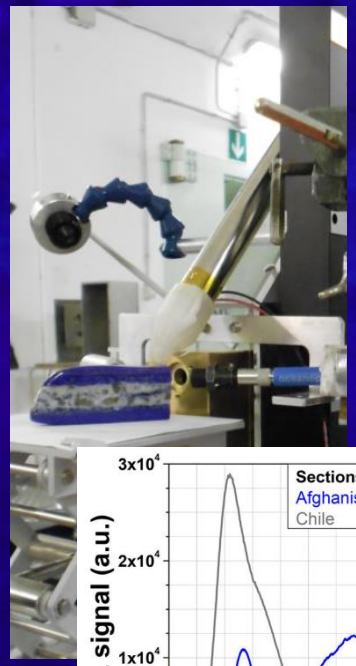
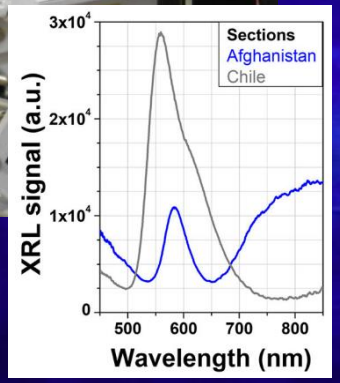


Figure 5. Trace element contents in pyrite (expressed in ppm).

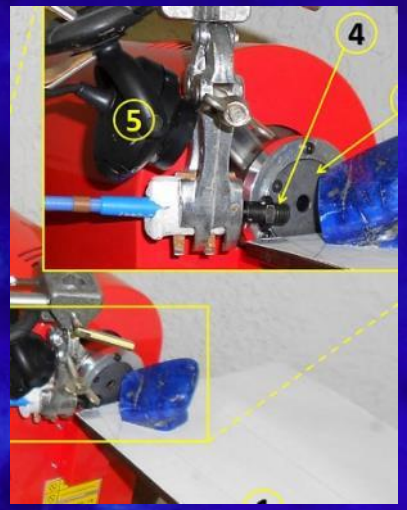
D. Angelici et al.
Microscopy and Microanalysis 21 (2015) 526-533

p-XRL (X-Ray Luminescence) and p-XRF





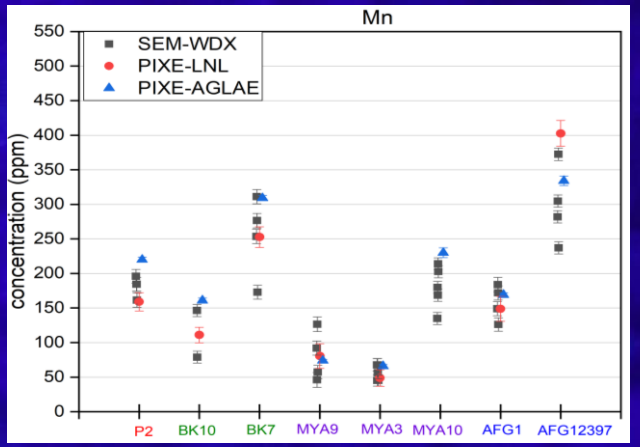
Development of
p-XRF/XRL apparatus



A. Re et al.
European Physical Journal Plus (2018) 133: 362

SEM-WDS (not for objects)

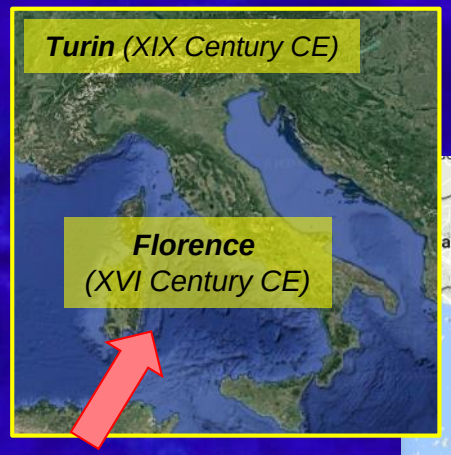
OKAYAMA UNIVERSITY

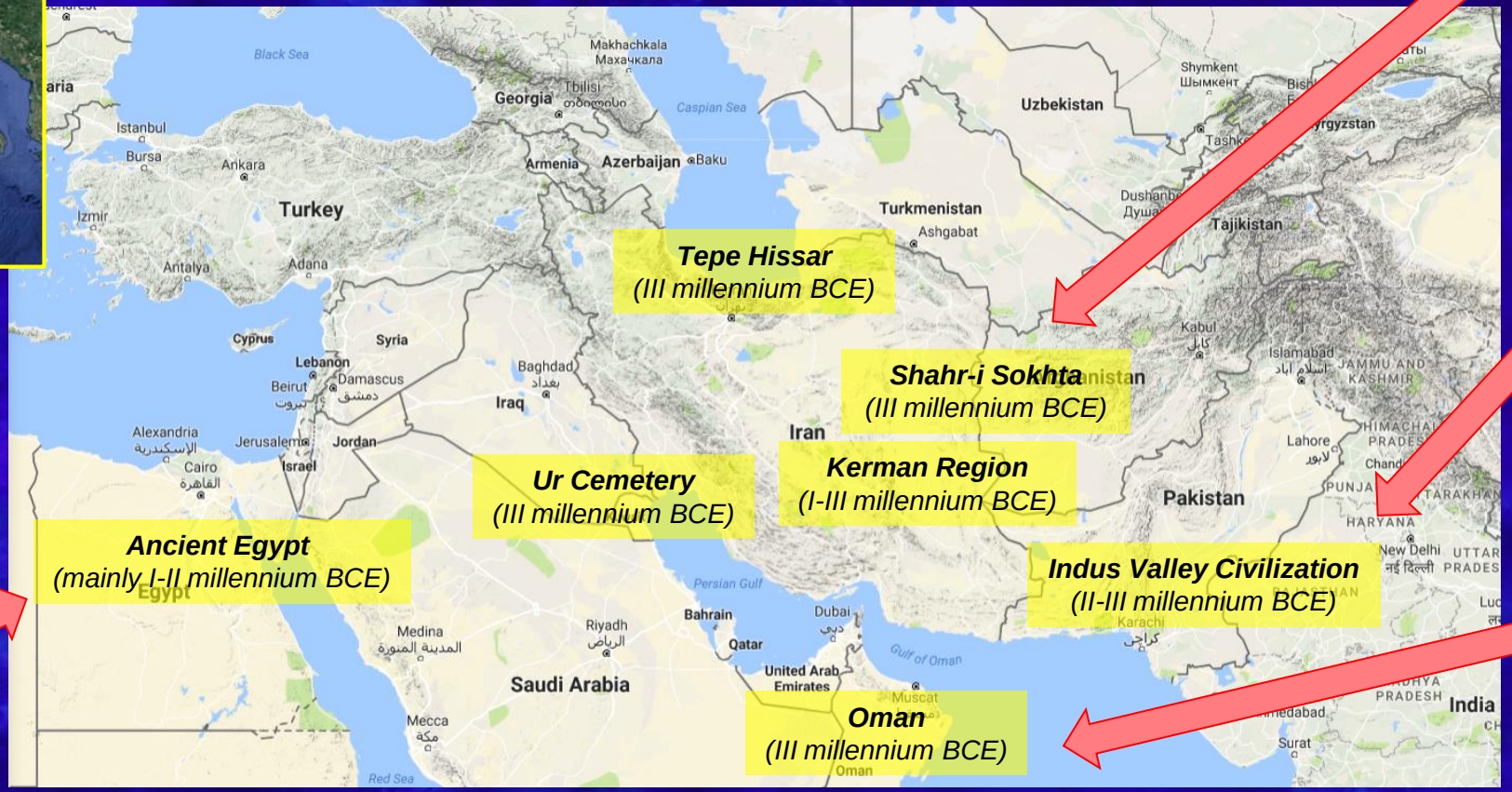


Paper under submission...

A worldwide research.... amazing objects

It is the most extensive work in the world on this topic and we are highly rated in the archaeological community.





Università degli Studi di Padova

Prof. M. Vidale

WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

Prof. J.M. Kenoyer
& Dr. R. Law

College of Liberal Arts

Prof. K.D. Williams

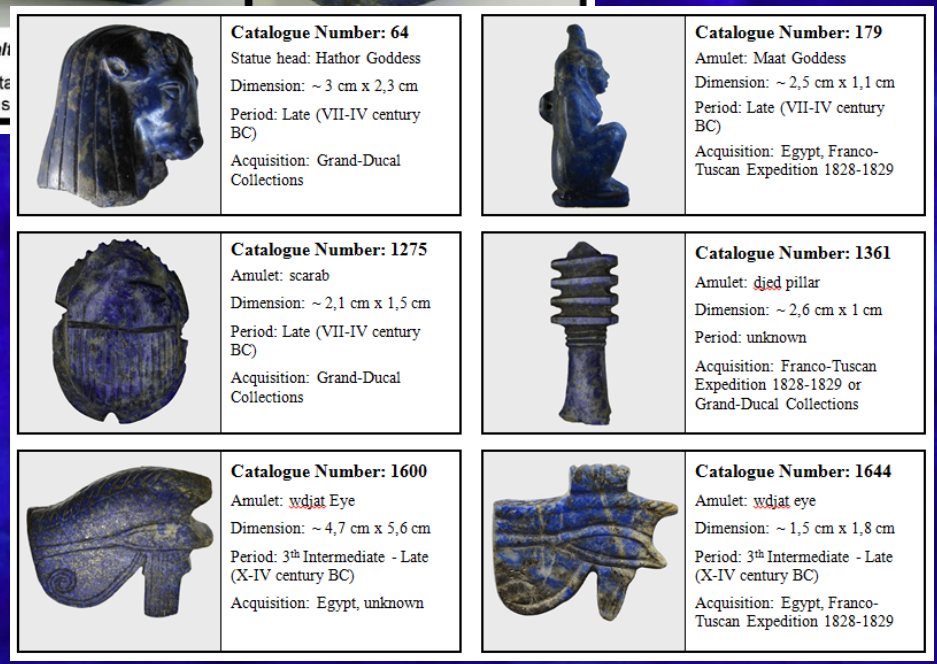
Museo di Storia Naturale e del Territorio
Università degli Studi di Pisa

MAF

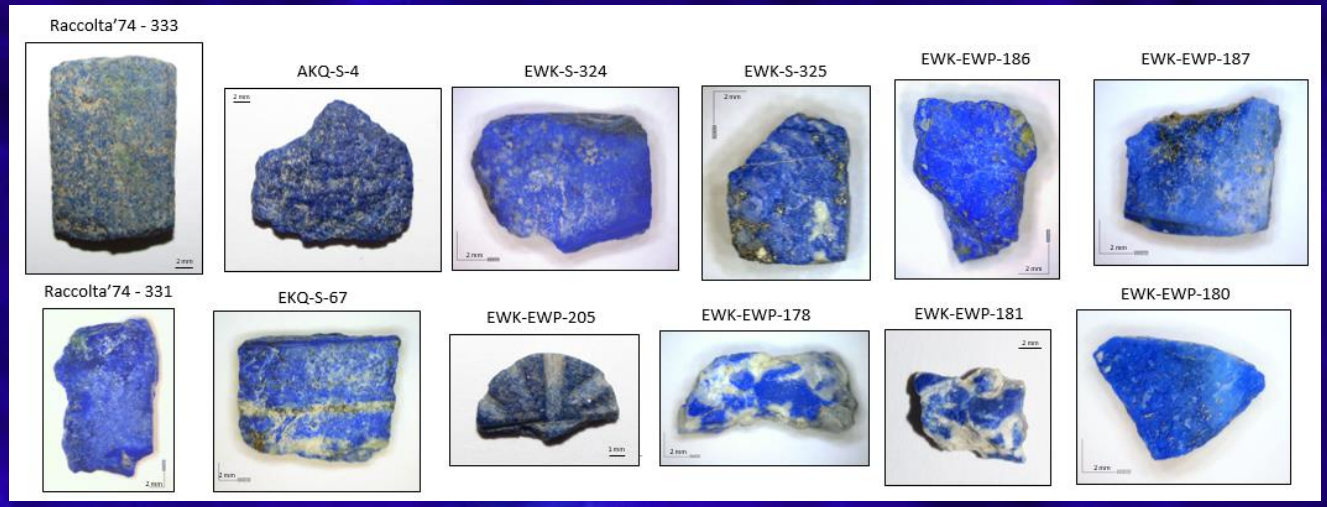
MUSEO EGIZIO

A worldwide research.... amazing objects

A. Re et al.
Nuclear Instruments and Methods in Physics Research B 348 (2015) 278-284



A. Lo Giudice et al,
Archaeological and Anthropological Sciences (2017) 9: 637-651

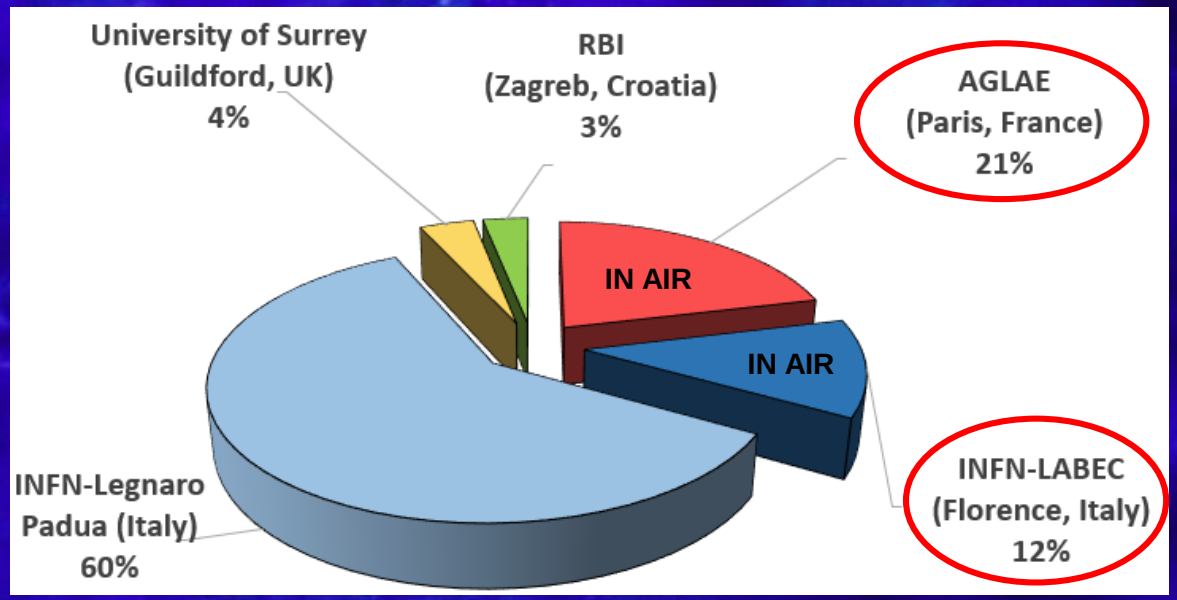


Small production waste fragments from Unesco site of Shahr-i Sokhta (III millennium BCE)

Paper under submission...

IN AIR FACILITIES: used mainly for artistic and archaelogical objects

Research started in 2007



INFN-LABEC (19 days):

Access: INFN projects with INFN-LABEC
Period: 2007 – 2012
Spokeperson: Alessandro Lo Giudice
Measurements in the years: 2007, 2009, 2011-2012
Materials: Medicean collection (Florence), Ancient Egypt objects (Florence)

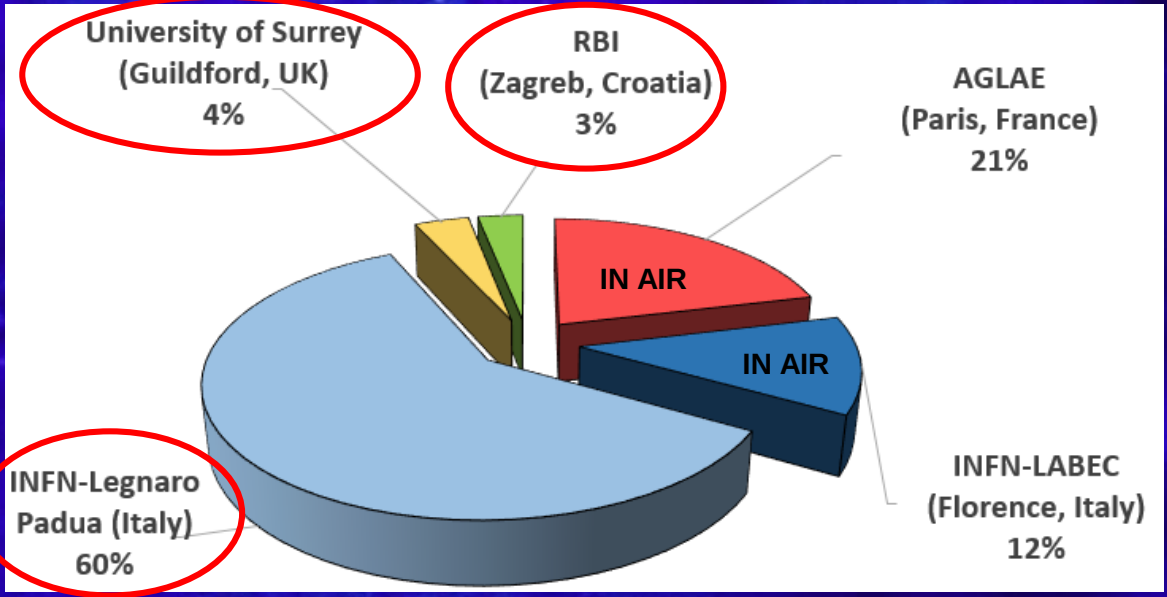
AGLAE (29 days):

Access: European programs (Charisma, Iperion CH, Iperion HS)
Period: 2012 – 2023
Spokepersons: Alessandro Re, Laura Guidorzi
Measurements in the years: 2012 - 2013, 2019 - 2023
Materials: King Carlo Alberto collection (Torino), Ancient Egypt objects (Florence), II – III millennium BCE archaeological material from sites in Oman, Mesopotamia, Iran, Indus Valley

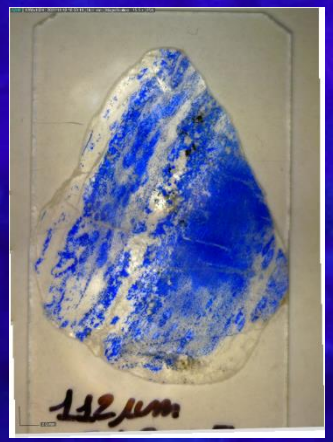
https://www.euronews.com/next/2013/11/04/art-detectives-team-up

IN VACUUM FACILITIES: used mainly for rocks and archaelogical small working flakes

Research started in 2007



Rock: thick section



Archaelogical samples (cross section)

INFN-LEGNARO (96 days):

Access: call for users
Period: 2007 – 2023
Spokepersons: A. Lo Giudice, A. Re, L. Guidorzi
Measurements in the years: 2009-2023
Materials: Rocks; small production waste fragments from II – III millennium BCE archaeological sites (Iran and Indus Valley)

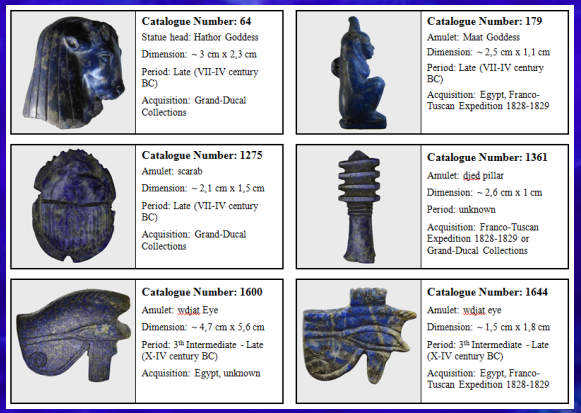
University of Surrey (6 days):

Access: European programs (RADIATE)
Period: **2023**
Spokeperson: Marta Magalini
Measurements in the years: 28th March – 5th April 2023
Materials: Rocks; small production waste fragments from II – III millennium BCE archaeological sites (Iran and Indus Valley)

Ruder Boskovic Institute (5 days):

Access: European programs (CERIC)
Period: **2023**
Spokeperson: Marta Magalini
Measurements in the years: 23rd – 27th October 2023
Materials: Rocks; small production waste fragments from II – III millennium BCE archaeological sites (Iran and Indus Valley)

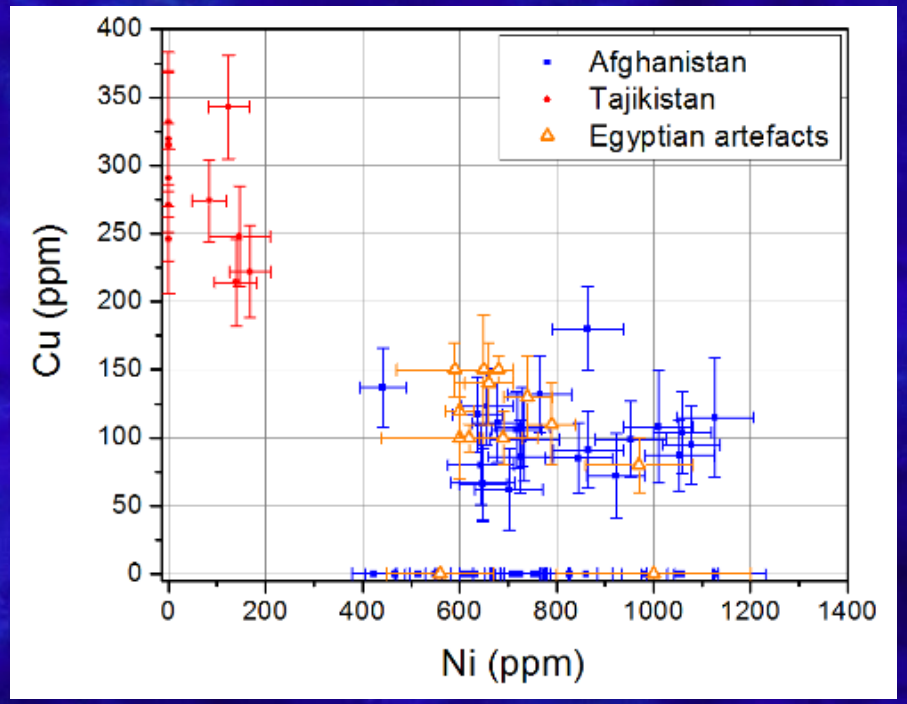
Some Results (all the database on referenced rocks was obtained at AN)



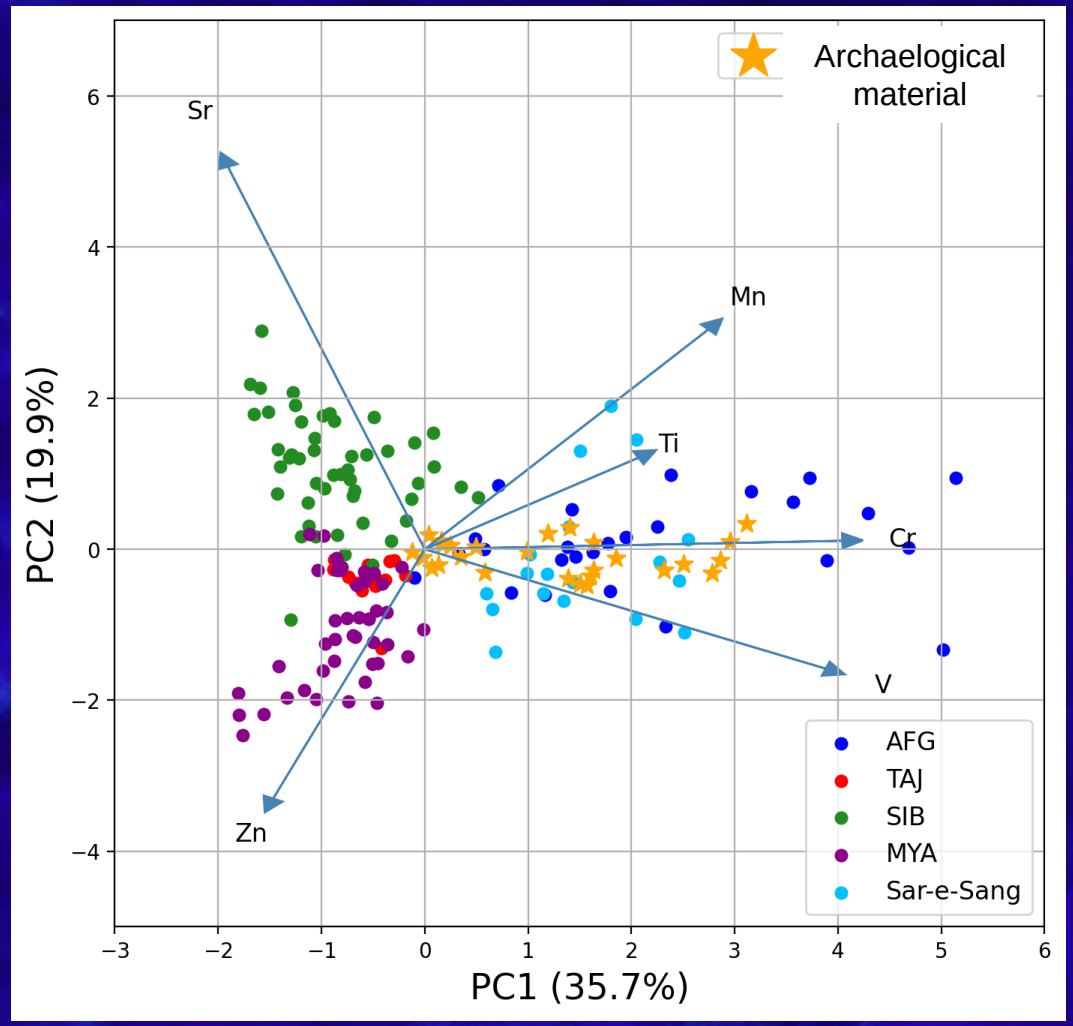
Compatibility with an Afghan provenance

A. Lo Giudice et al, **Archaeological and Anthropological Sciences (2017) 9: 637-651**

Trace elements in **pyrite**

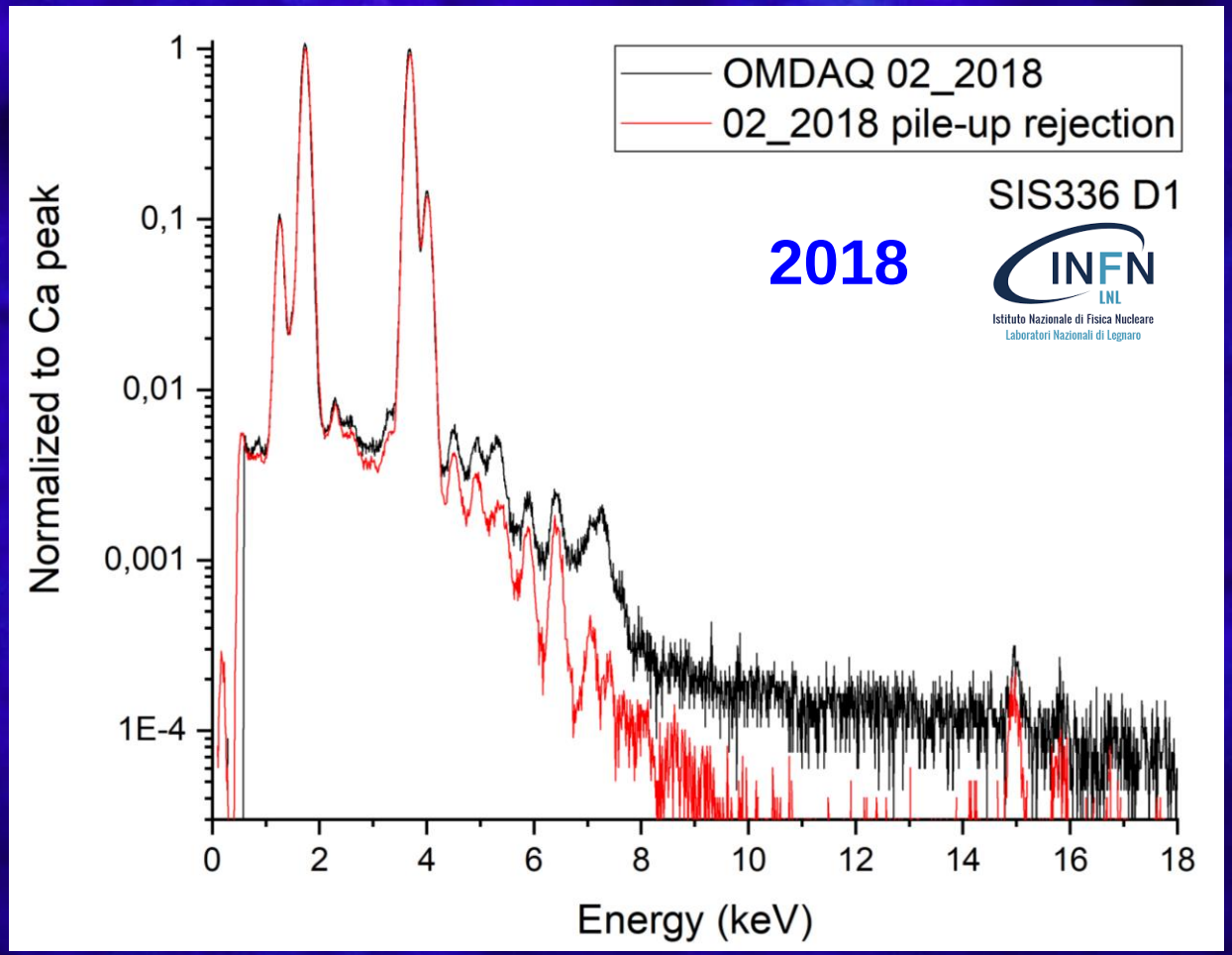


Trace elements in **diopside - PCA**

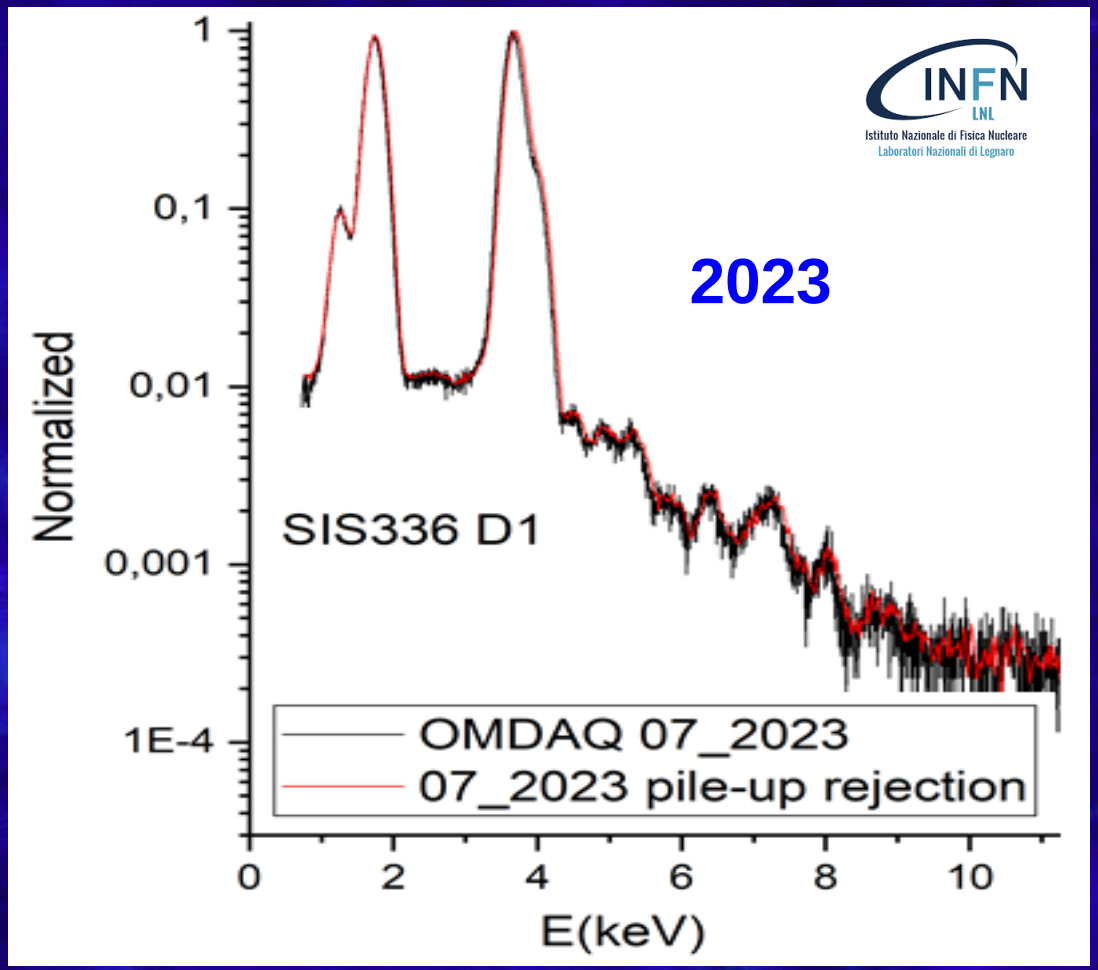


Problem with PIXE detector in Legnaro (AN).

Strong reduction in PIXE detector performance over time...(despite the great efforts made in 2023 by the Legnaro researchers linked to AN2000 activities to try to recover the actual detector/electronics)

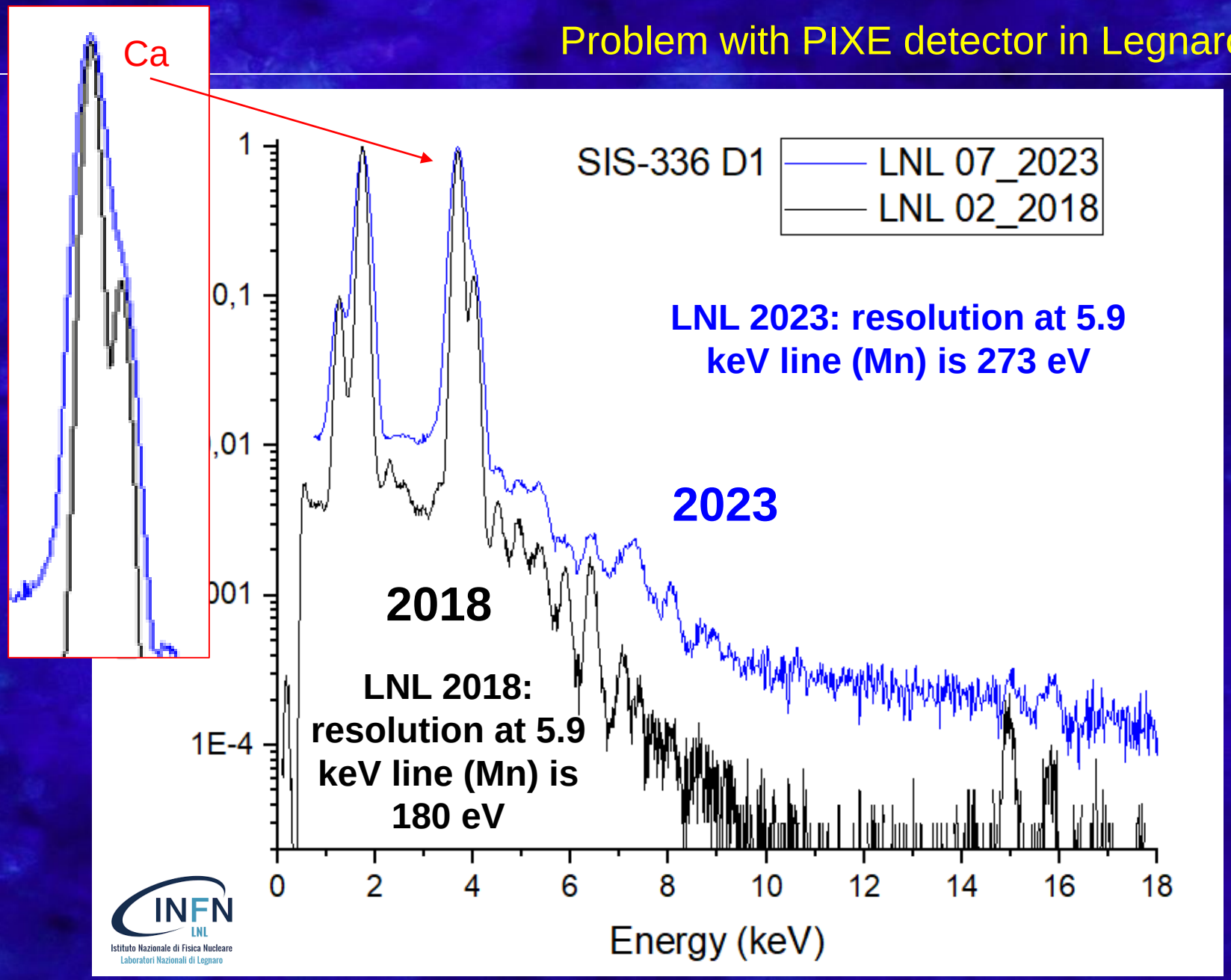


In 2018: pile-up rejection works!



In 2023: pile-up rejection doesn't work!

Problem with PIXE detector in Legnaro (AN).



Energy resolution is very bad!

In 2023: energy resolution @5.9 keV is 273 eV

In 2018: energy resolution @5.9 keV was 180 eV

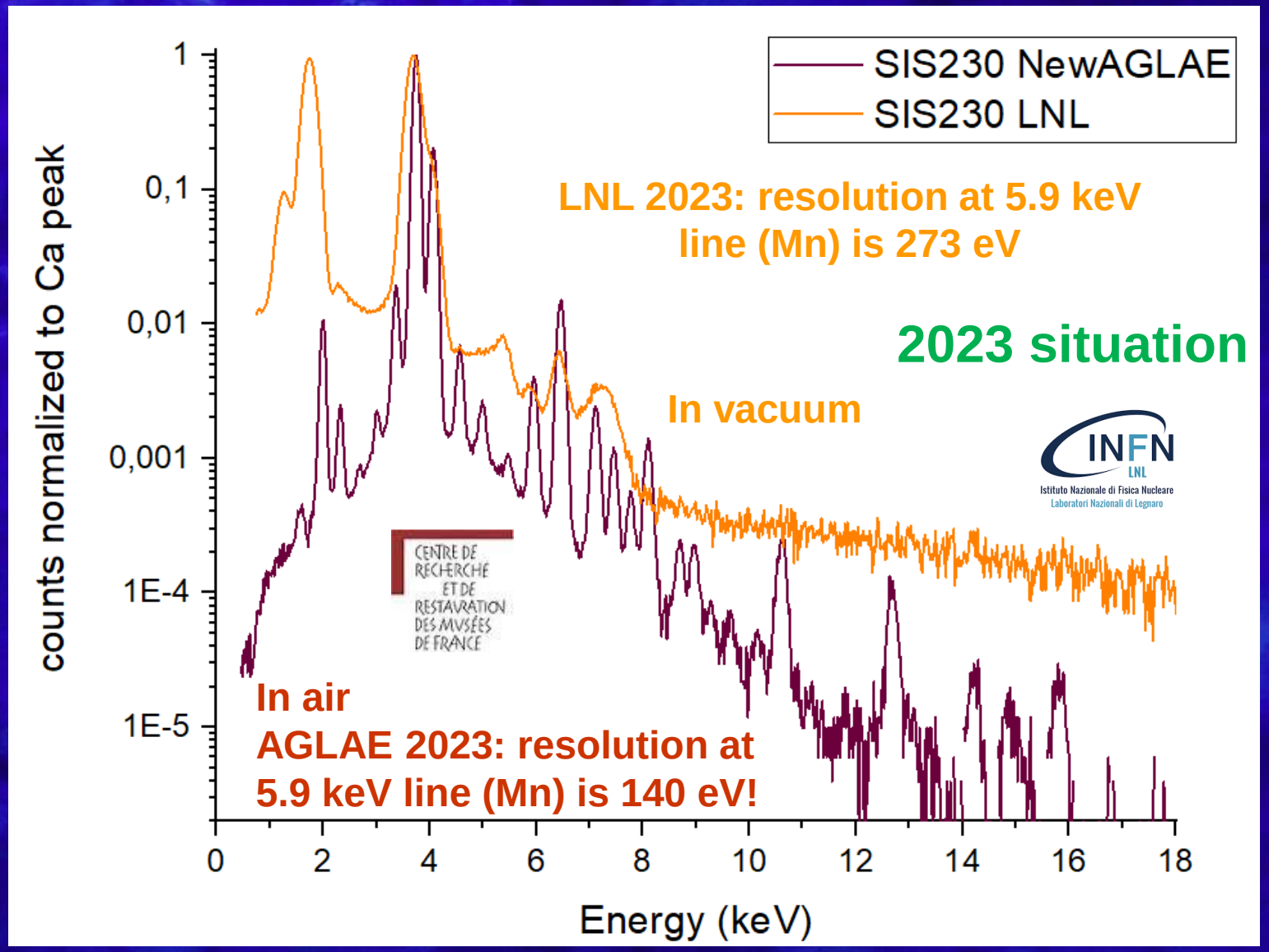
(sufficient for our research, but in any case not so good. SDD detectors used in other facilities for PIXE measurements have a resolution of 130 eV – 140 eV)

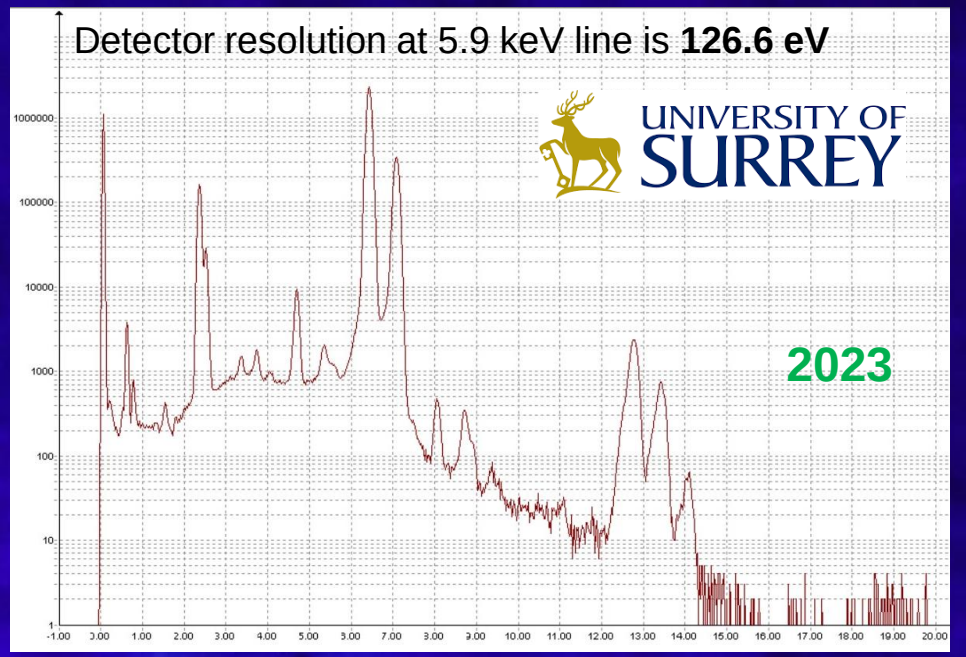
Last 2 runs

Part of the data acquired in December 2022 are unusable

All the data acquired in July 2023 are unusable

Problem with PIXE detector in Legnaro (AN). Comparison with other facility used in 2023.....



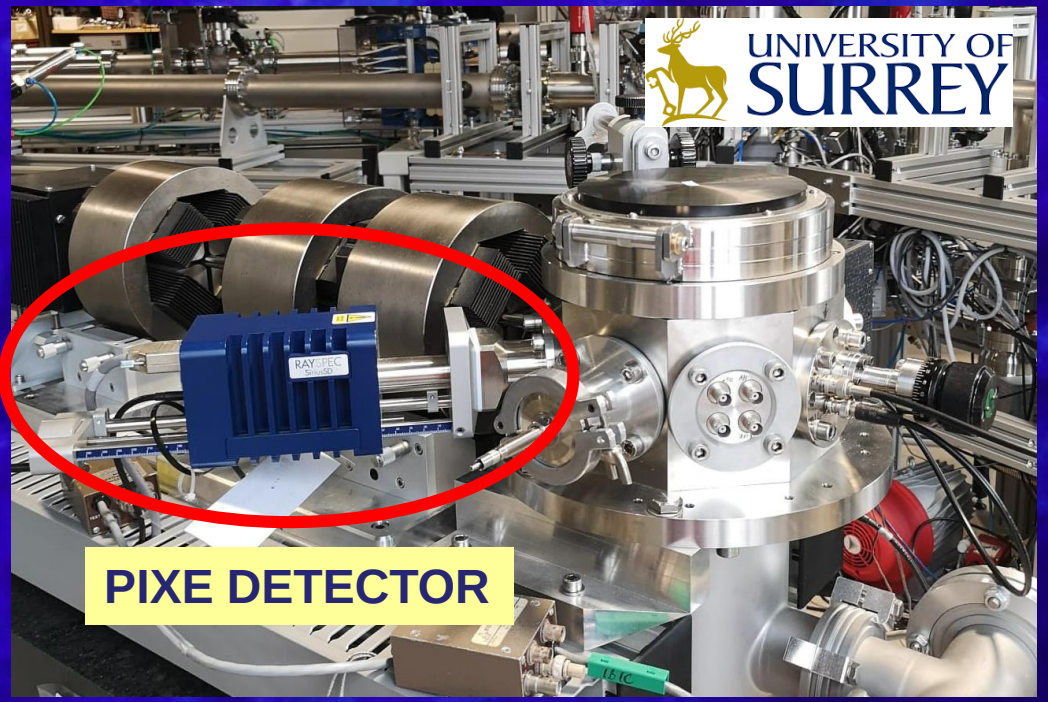


Similar good results in Zagreb
Run was carried out 2 weeks ago
(work in progress)

Institut Ruđer Bošković

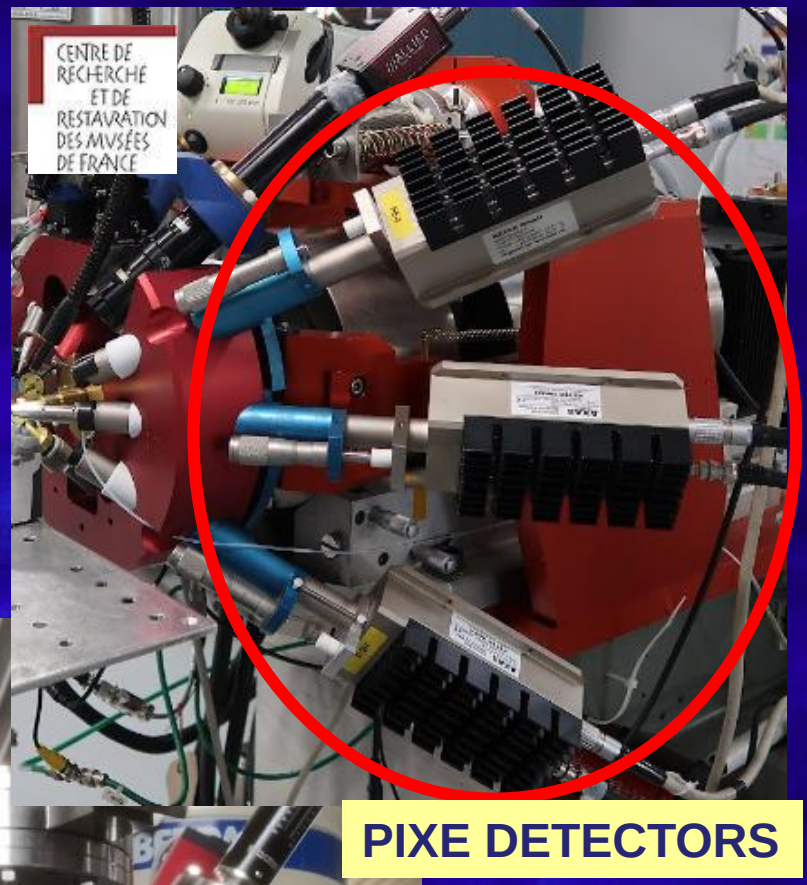
My thoughts in the form of cultural heritage……

Problem with PIXE detector in Legnaro. Comparison with other facility.....



…to attract new users in this field at LNL and to obtain better results, we would suggest ...

….to add a SDD Detector for 0° line @ AN2000 as in Surrey, Paris and Zagreb



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PhD: Alessandro Re, Debora Angelici, Laura Guidorzi and Marta Magalini (3° year)

Thank you for your attention

http://www.solid.unito.it/research/culturalheritage/index.html
https://chnet.infn.it/en/home-3/