Need for Portable Accelerators in Cultural Heritage

Tessa Charles, *University of Liverpool and Cockcroft Institute*
Alejandro Castilla, *Lancaster University and CERN*
Ryan Bodenstein, *Thomas Jefferson National Accelerator Facility*

Photo Credit: Pedro Szekely

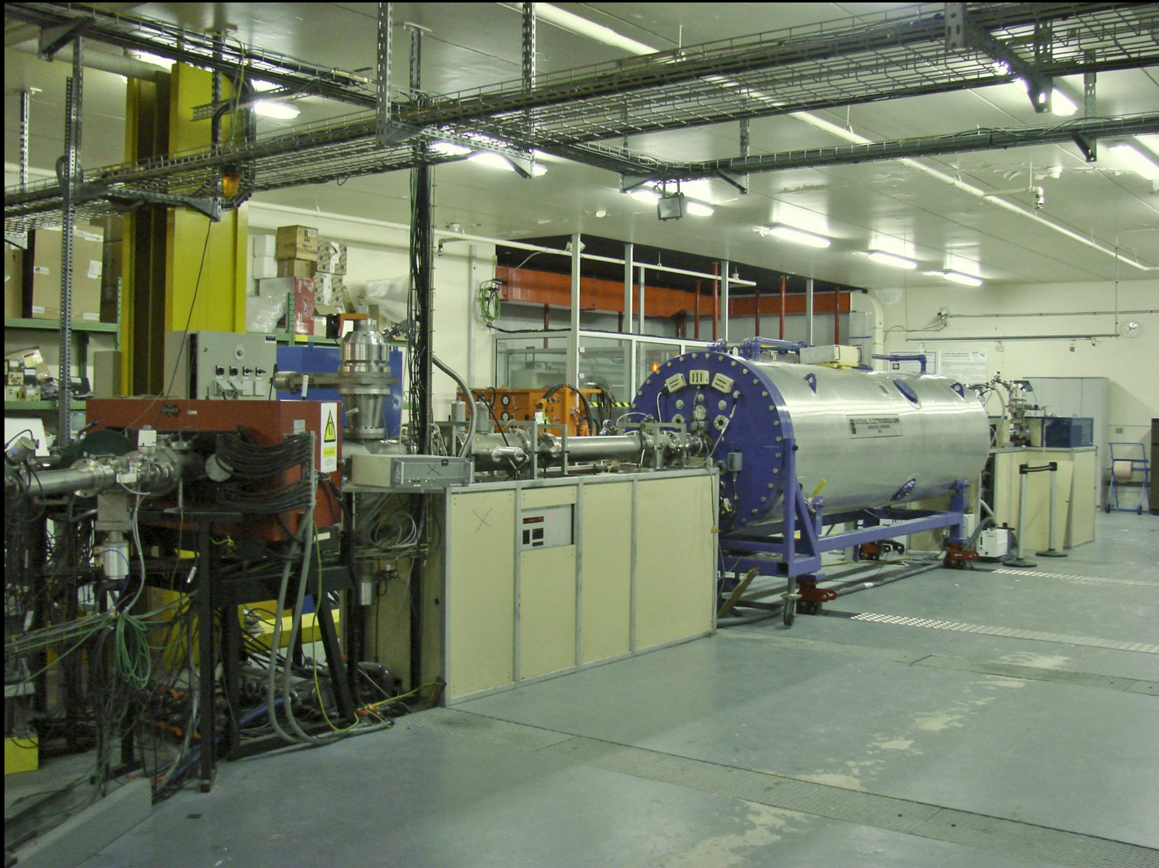
New AGLAE (Accélérateur Grand Louvre d'analyse élémentaire) Facility

AGLAE is a 2 MeV electrostatic pelletron accelerator.

100% dedicated to the study of Cultural Heritage (CH).

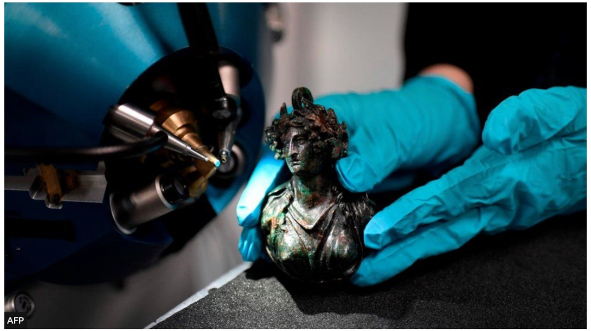
Ion Beam Analysis (IBA) techniques used:

- PIXE: Particle Induced X-ray Emission
- PIGE: Particle Induced γ-ray Emission
- RBS: (Rutherford) Backscattering Spectroscopy



World's only particle accelerator for art is back at the Louvre

23 November 2017



The machine bombards sculptures with helium and hydrogen atoms

The world's only particle accelerator used regularly in the analysis of art has gone back into use at the Louvre museum in Paris.

The accelerator has been rebuilt to allow it to investigate paintings without risking damage to the artworks.

The upgrade cost €2.1m (£1.8m; $2.5m). The machine is 37m (88ft) long.

Paintings were rarely analysed with earlier versions of the accelerator because of fears that the particle beam might change the colours.

The first objects to be tested by the newly configured accelerator, known as Aglae, included Roman votive statues of the household gods, the Lares, AFP news agency reports.

https://www.bbc.com/news/world-europe-42094003

physics MDPI

Article

Ion Beam Analysis and ^{14}C Accelerator Mass Spectroscopy to Identify Ancient and Recent Art Forgeries §

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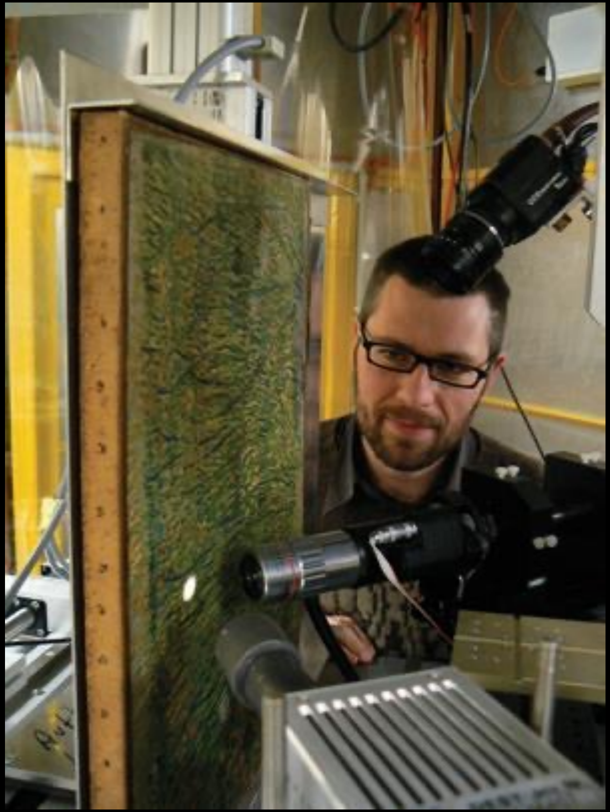
§ This article is dedicated to the memory of dear missing colleagues Claire Berthier (CEA), Thierry Borel and Joseph Salomon (C2RMF).

Abstract: Forgeries exist in many fields. Money, goods, and works of art have been imitated for centuries to deceive and make a profit. In the field of Cultural Heritage, nuclear techniques can be used to study art forgeries. Ion beam analysis (IBA), as well as ^{14}C accelerator mass spectrometry (AMS), are now established techniques, and the purpose of this paper is to report on their capacity to provide information on ancient, as well as modern, forgeries. Two case studies are presented: the production of silver counterfeit coins in the 16th century and the detection of recent forgeries of 20th century paintings. For the counterfeit coins, two silvering processes were identified by IBA: mercury silvering (also called amalgam silvering or fire silvering) and pure silver plating. The discovery of 14 mercury silvered coins is an important finding since there are very few known examples from before the 17th century. In the detection of recent forgeries, among the five paintings examined, ^{14}C dating showed that three of them are definitely fakes, one is most likely a fake, and one remains undetermined. These results were obtained by using the bomb peak calibration curve to date canvas and paint samples.

Beck, L. Ion Beam Analysis and 14C Accelerator Mass Spectroscopy to Identify Ancient and Recent Art Forgeries. *Physics* **2022**, *4*, 462–472.
https://doi.org/10.3390/physics4020031

Cultural heritage studies at synchrotron light sources

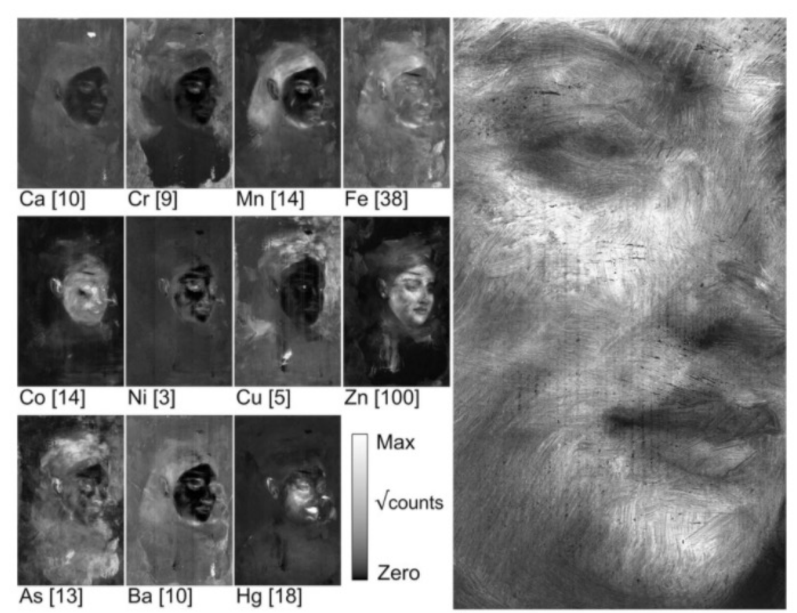


Vincent van Gogh, “Patch of Grass”, Apr-June 1887

J. Dik et al Anal. Chem. 2008, 80, 6436–6442

Another example of X-ray Fluorescence (XRF)

Edgar Degas' 1876
Portrait of a Woman



D. Thurrowgood et al Scientific Reports | 6:29594 | DOI: 10.1038/srep29594

Immovable items cannot take advantage of these techniques.

Image credit: Mark Byzewski on Flickr.

Moab “Birthing Rock”, Moab, Utah, USA

What could be discovered if it were possible to take rock art to an Ion Beam Accelerator or Synchrotron Light Source facility…

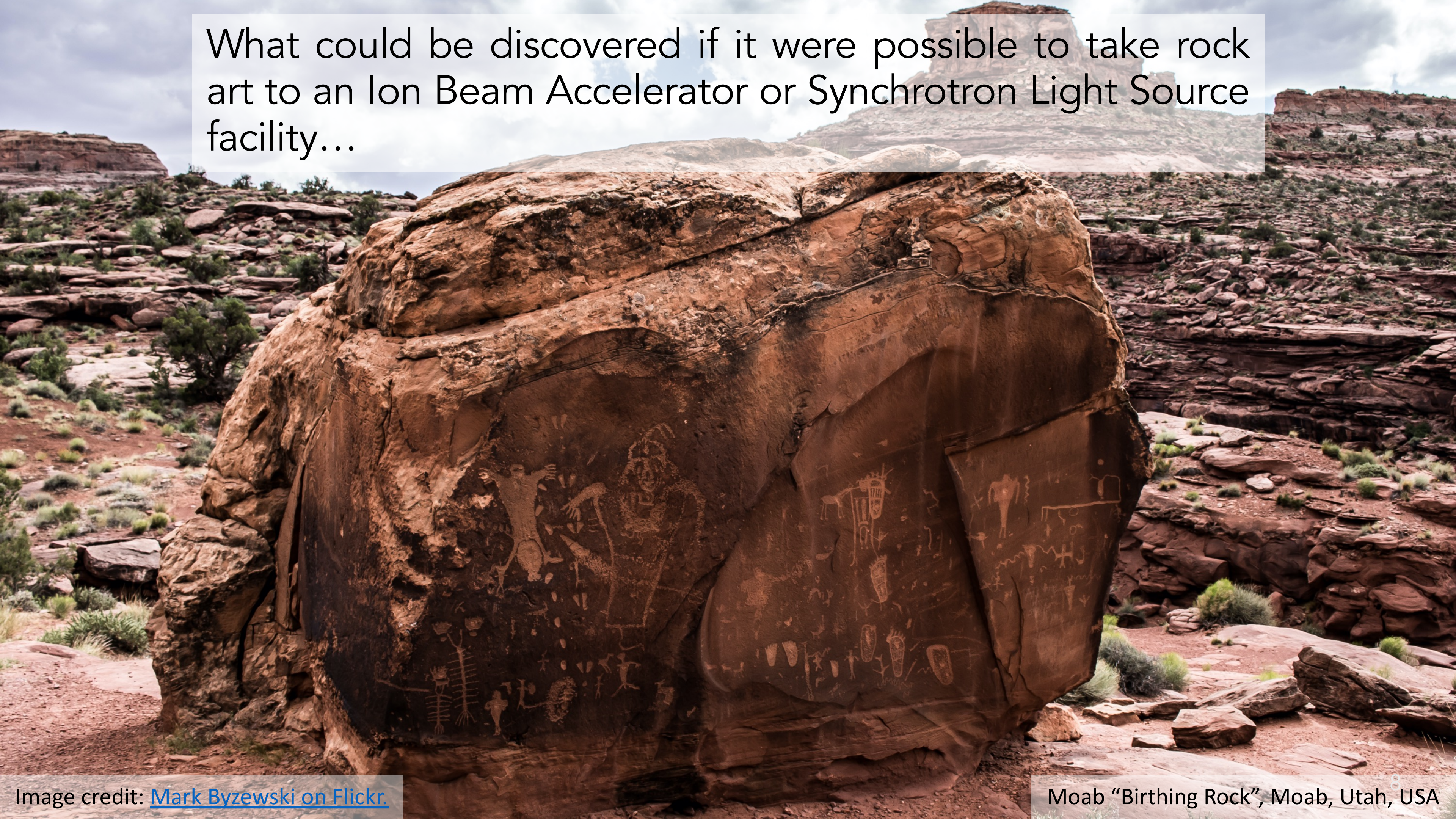


Image credit: [Mark Byzewski on Flickr.]

Moab “Birthing Rock”, Moab, Utah, USA

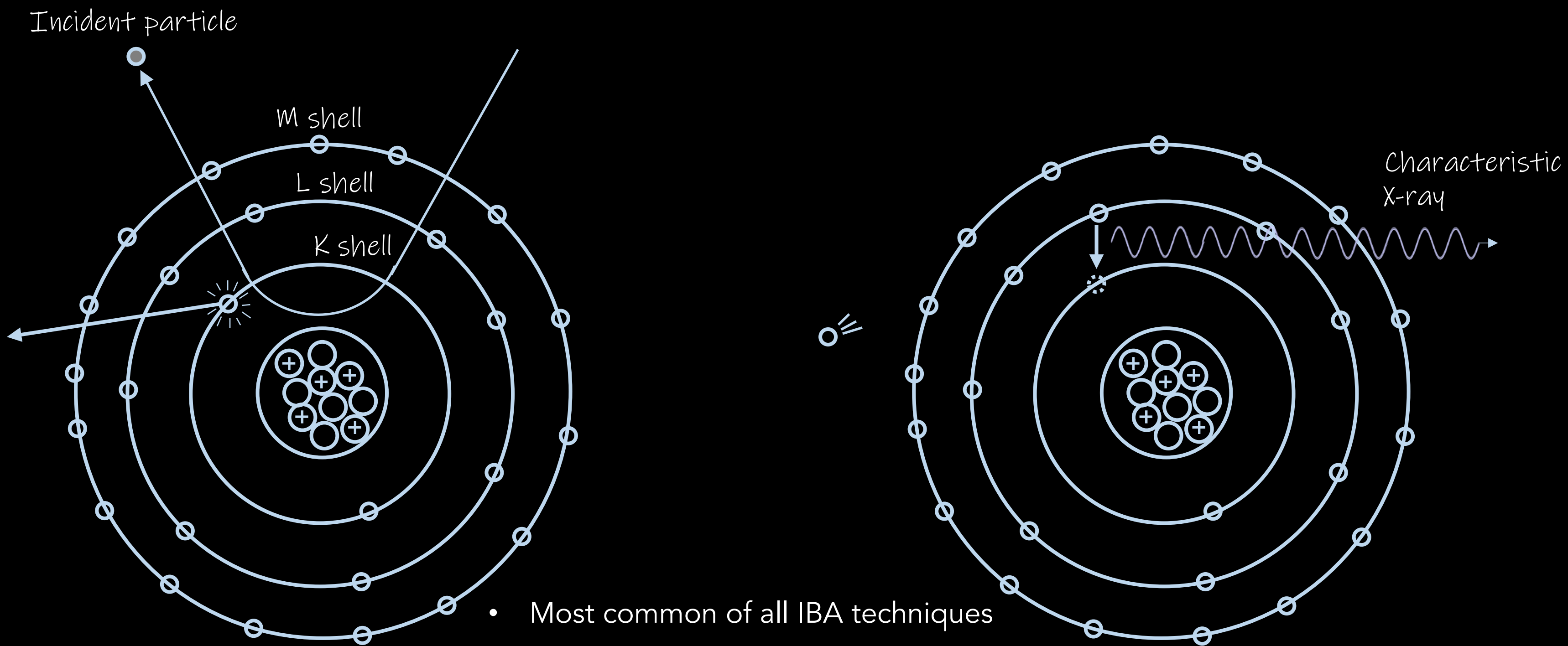

Quinkan rock art sites in Cape York, Australia. Photo: Matt Glastonbury

We can’t bring the rock to the beamline.

But we might be able to bring the accelerator to the rock.

We would need a compact, portable 2 MeV proton accelerator capable of performing in-situ PIXE analysis.

PIXE (Particle Induced X-ray Emission)



- Most common of all IBA techniques
- Non-invasive, non-destructive
- Fast multi-elemental technique
- Highly sensitive to low-Z materials
- Provides information on elements present (not molecules)

Image credit: Shumla Archaeological Research and Education Center.

Why PIXE and not XRF?

Portable X-ray Fluorescence (PXRF) devices exist, but they have limitations.

Limitations:

- large spot size
- long dwell times
- best suited for larger-Z elements

Over time, rock art fades

Figure 15.5 Panel A.
Source: Photograph by Robert Gunn.

Figure 15.9 Panel B.
Source: Photograph by Robert Gunn.

Image credit: "The Archaeology of Rock Art in Western Australia Arnhem Land, Australia".
Edited by B. David, P.SC Taçon, J-J. Delannoy and J-M. Geneste, ANU Press, ACT Australia 21007

Over time, rock art fades

Figure 15.5 Panel A.
Source: Photograph by Robert Gunn.

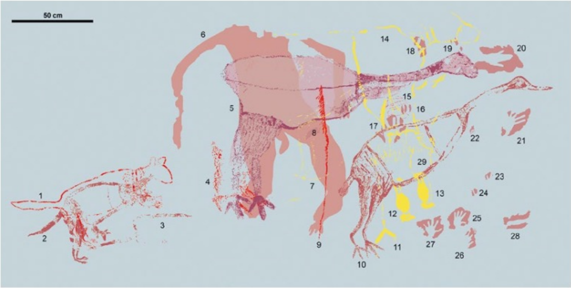


Figure 15.6 Photo-tracing of the Panel A images.

Figure 15.9 Panel B.
Source: Photograph by Robert Gunn.

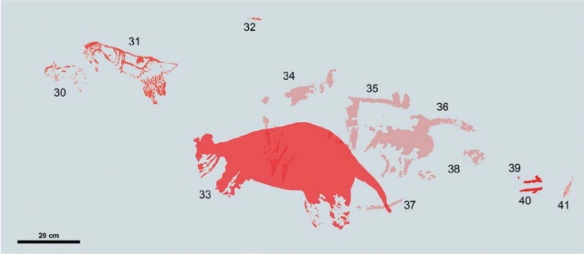
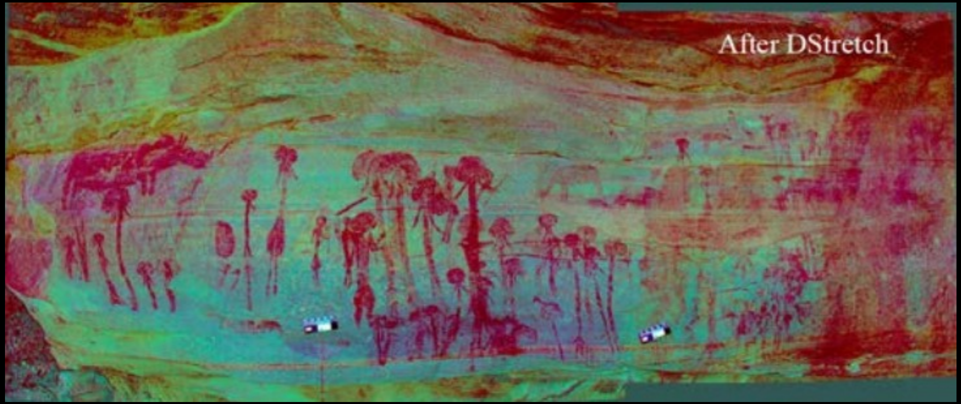


Figure 15.10 Photo-tracing of the Panel B images.
Source: Digital tracing by Robert Gunn.

Image credit: “The Archaeology of Rock Art in Western Australia Arnhem Land, Australia”.
Edited by B. David, P.SC Taçon, J-J. Delannoy and J-M. Geneste, ANU Press, ACT Australia 21007

Digital enhancement can make rock art more visible



Location: Kondoa Rock Art World Heritage Site, Tanzania
Image source: Benjamin Smith, (2017), "Recording rock art", In: Livingstone Smith et al. (eds) The Field Manual for African Archaeology: 138-141.

Other applications

- frescos, archaeological sites, built environment, etc…
- museums (insurance costs to move artworks can be prohibitive).
- Items that can’t be moved out of the country.

Options for a portable accelerator

Beam requirements

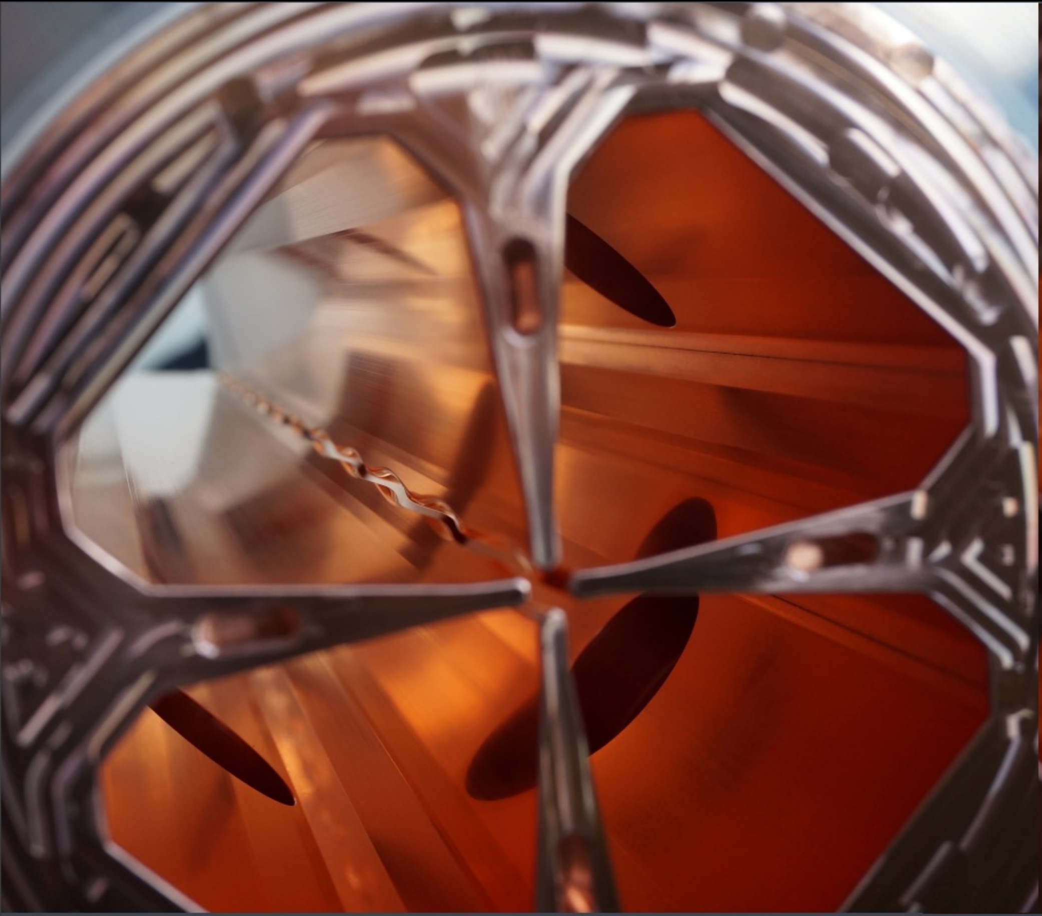
IBA ion beam energy:

- > 1 MeV for good RBS approximation, and PIXE cross-sections.
- < 4 MeV to avoid (inelastic) nuclear reactions (background noise).

External beam

- Museum curators abhor a vacuum.
- 100 nm x 5 mm x 5 mm SiNx windows now available.

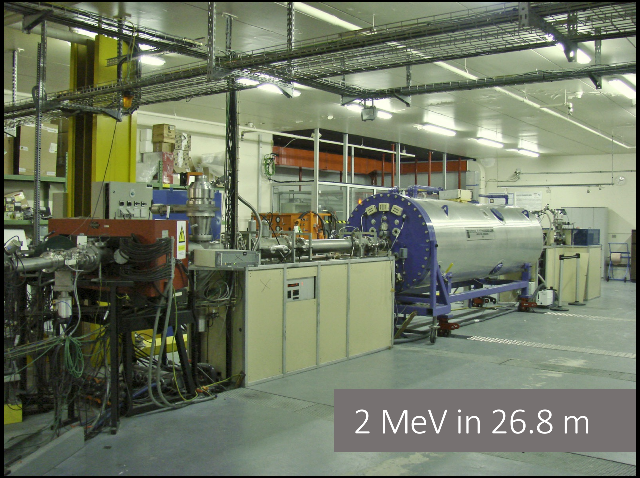
Radio Frequency Quadrupole (RFQ)



RFQs do three things:

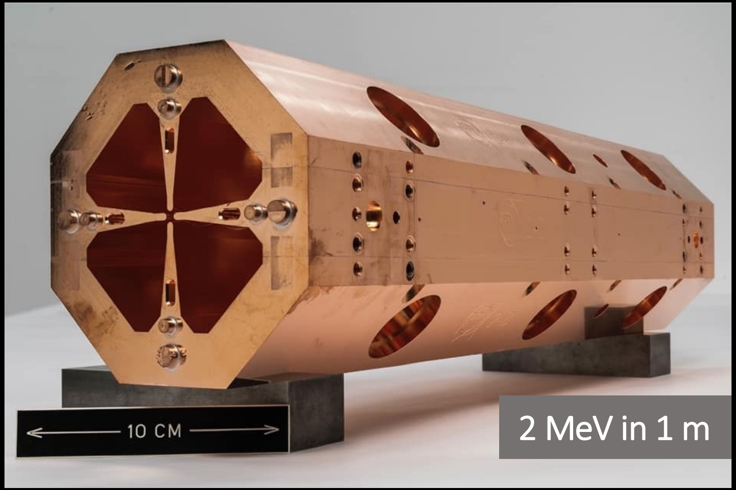
1. transversally focus
2. accelerate
3. bunch the beam

Comparison of size



Located under the Louvre museum in Paris, France, is the accelerator, Accélérateur Grand Louvre d'analyse élémentaire (AGLAE).

Photo credit: Jean-Pierre Dalbéra.



CERN 750 MHz RFQ structure.

Credit: Maximilien Brice/CERN

Slide from Francesco Taccetti, LABEC laboratory

Movable Accelerator for Cultural Heritage In-situ Non-destructive Analysis.

MACHINA: the system

Low Energy Beam Transport (LEBT)

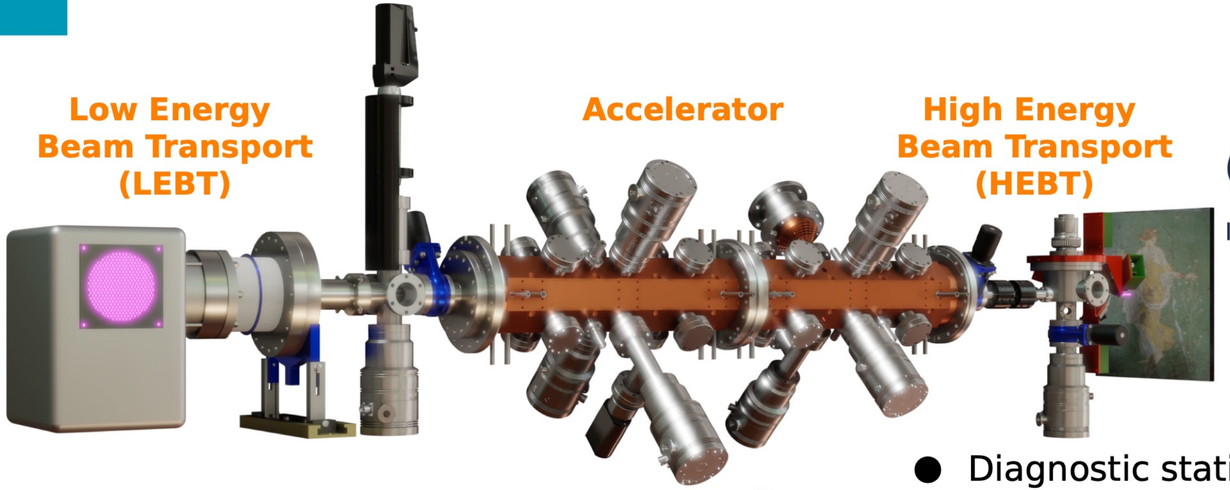
- RF ion source
- Diagnostic station

Accelerator

- Power supplies
- Vacuum system
- Control system
- Interlocks handling
- Cooling system
- Radio-protection

High Energy Beam Transport (HEBT)

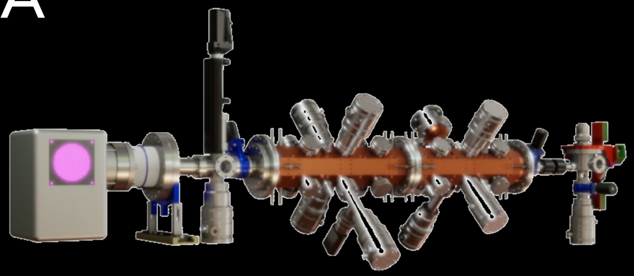
- Diagnostic station
- Exit snout
- Detectors



INFN CHNet
Istituto Nazionale di Fisica Nucleare
Cultural Heritage Network

CERN technology

MACHINA



MACHINA Main Components:

LEBT – low-energy beam transport
- RF capacitively coupled ion source (H+)
- Einzel lens
- Faraday cup

RFQ – radio-frequency quadrupole
- 2 accelerating modules

HEBT – high-energy beam transport
- Beam diagnostics (quartz, Faraday cup)
- Foils for reducing beam energy
- User defined beam spot: 50 μm -> 1 mm

MACHINA parameters*

2 MeV RFQ	
RF frequency [MHz]	750
RFQ length [mm]	1073
Input energy [keV]	20
Output energy [MeV]	2
Output energy spread FWHM [keV]	8
Average current [nA]	5
Peak current [nA]	200
Repetition rate [Hz]	200
Pulse duration [ms]	0.125
Duty cycle [%]	2.5
Vane voltage [kV]	3.5
RF wall plug power [kVA]	≤6

*Many thanks to Francesco Taccetti and Lorenzo Giuntini for this information

Alpha-PIXE

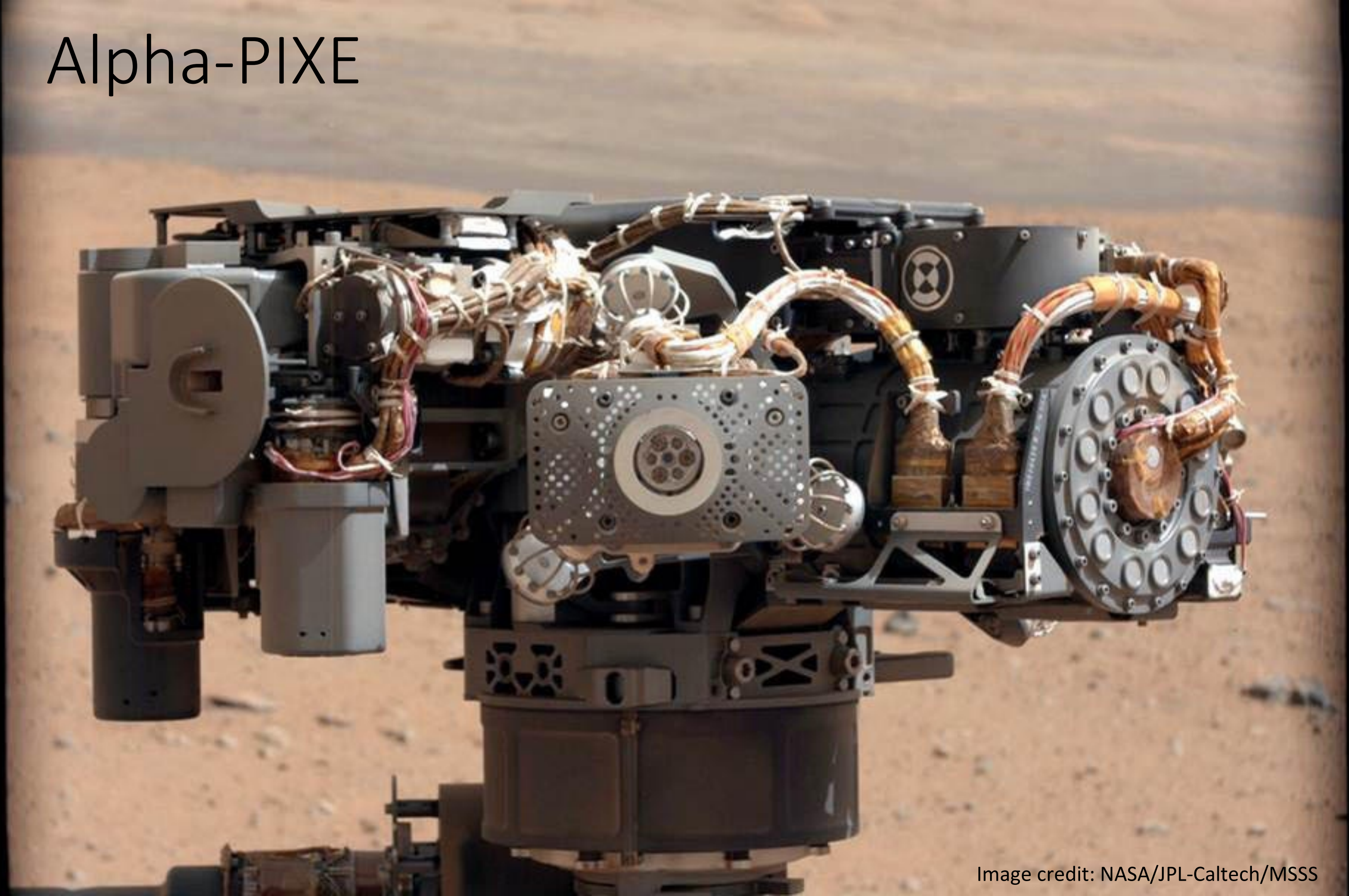


Image credit: NASA/JPL-Caltech/MSSS

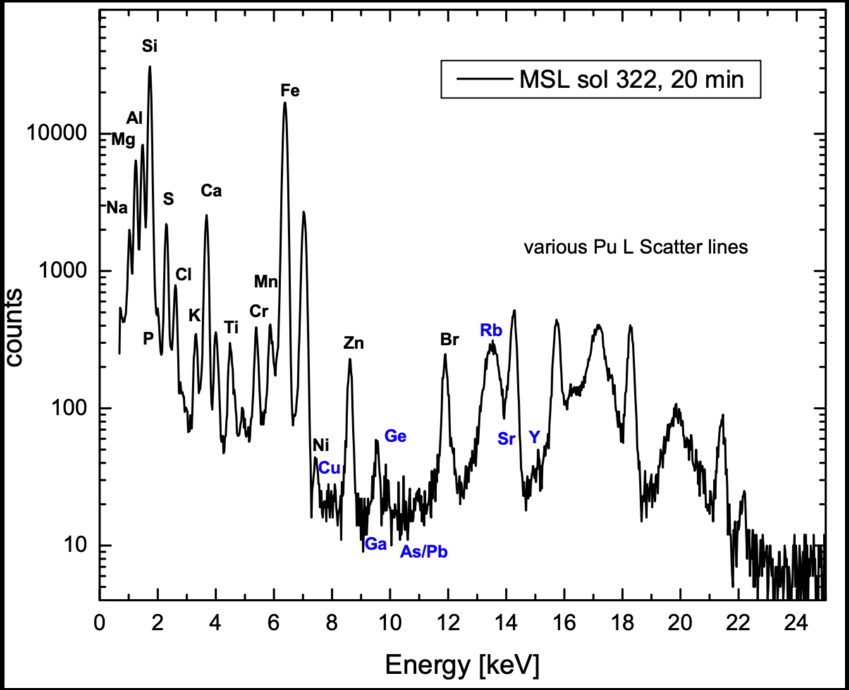
Alpha Particle X-Ray Spectrometer (APXS) on the Mars Rovers

A ^{244}Cm source is used for a combination of PIXE and XRF to detect 16 elements.

~5.8 MeV alpha particles and X-rays ranging from 100-120 keV.

PIXE and XRF occur together
- XRF signal is largest for higher energies
- PIXE signal is largest for lower energies

So far APXS has measured:
~15 samples from Pathfinder, 220 samples from Spirit, 350 samples from Opportunity, and 150 samples from Curiosity.



INFN portable alpha-PIXE

- Consists of a polonium source emitting alpha particles of 5 MeV energy.
- It is based on an annular geometry and it is coupled to a 25 mm^2 SDD detector with a high energy resolution of 125 eV at 5.9 keV.
- Beam spot = 18 mm diameter
- Has been used to detect forgeries in coins.

Photo credit: Paolo Romano

alpha-PIXE device pros and cons and opportunities

Pros:

- Very portable
- Non-destructive and non-invasive

Challenges for our application:

- Time per spot (can be up to 30 minutes)
- Large spot size (18 mm diameter)
- Surface technique

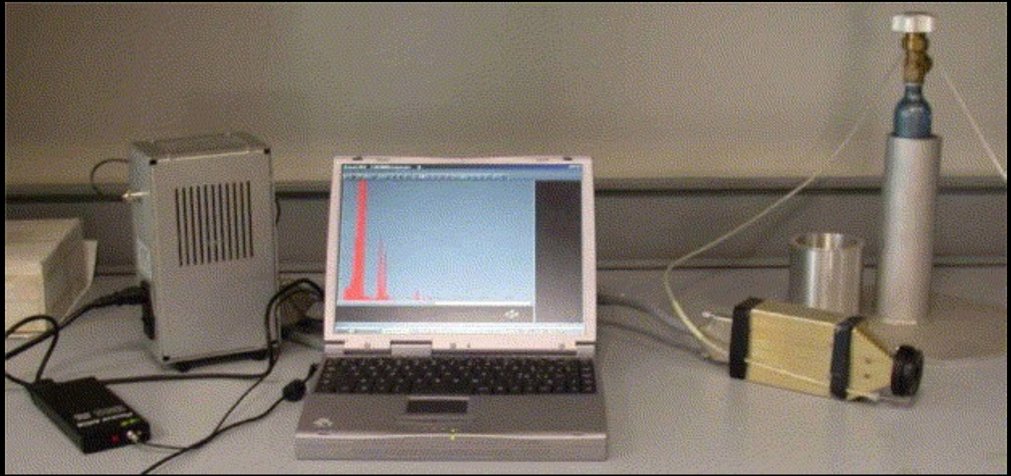


Photo credit: Paolo Romano

Challenges to address / overcome

Technical:

- Radiation safety
- Remote environments requires robustness
- Power consumption and utilities
- Uneven surface morphologies could make it challenging to maintain constant distance between detector and rock.
- Raster scanning
- Variable proton energy for differential PIXE
- Limit RF peak voltage
- Provide enough focusing, whilst maximizing beam acceptance.
- Minimize sensitivity to machining errors (tolerances)
- Optimize for weight and footprint (e.g. auxiliaries)

Opportunities

Social / Cultural:

- Engage with various local indigenous, tribal, and cultural groups to understand their views, and make sure that this work is wanted, needed, and welcome.
- Gather further input from archaeologists, anthropologists, sociologists, and historians, to better paint a picture of possible uses.
    - Examples: determining the materials and pigments used in creating rock art and the provenance of those materials; if paint components were sourced locally or traded; investigating regions where different cultures overlapped (such as Jordan); etc…
- Determine how to better preserve the rock art. Increased humidity due to climate change is problematic in some areas (this is a concern in the southern U.S.).
- Collaborate with museums, universities, and historical societies to further understand the utility of portable accelerators.

"A portable accelerator that can be used at archaeological sites in the field would have an incredible impact on the work we do, especially on immovable artefacts, such as rock art. Rock art is a crucial part of our shared global cultural heritage, but it is constantly under threat from natural and anthropogenic forces. A portable accelerator would enable us to study this invaluable resource without causing further harm."

- Prof Jamie Hampson, Exeter University

"The benefit would extend to museums and heritage collections in countries where they might not have access to this kind of technology. Bringing objects to a central lab in-country, as opposed to shipping things across the globe, could be a game changer for many under-resources nations."

- Dr Courtney Nimura, University of Oxford

Conclusions

- These independent solutions for a portable accelerator could feed into the ultimate goal of a fully portable accelerator for CH.
- Accelerator R&D can have far reaching impact, beyond the initial application. The theme of curiosity-driven science leading to unexpected outcomes is a highlight of our field. Accelerators are one bridge from fundamental exploratory science to high-impact societal benefit.
- There is a need for a portable accelerator to unlock CH secrets though analysing immoveable objects, such as rock art, frescoes, archaeological sites, museum artifacts, etc…

Postdoc position open for applications

Work on **beam dynamics** for particle accelerators for cultural heritage applications at the University of Liverpool and the Cockcroft Institute.

More details: bit.ly/Postdoc

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