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NEED FOR PORTABLE ACCELERATORS IN CULTURAL HERITAGE

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Abstract

Ion Beam Accelerators (IBA) centres have provided researchers with powerful techniques to analyse objects of cultural significance in a non-destructive and non-invasive manner. However, in some cases it is not feasible to remove an object from the field or museum and transport it to the laboratory. In this contributed talk, we present as a manner of a short review, examples of the benefits provided from these techniques in the study of material culture and discuss the initial steps to consider when investigating the feasibility of a compact accelerator that can be taken to sites of cultural significance for PIXE analysis. In particular, we consider the application of a compact, robust 2 MeV proton accelerator that can be taken into the field to perform PIXE measurements on rock art. We detail the main challenges and considerations for such a device.

INTRODUCTION

Ion Beam Accelerators (IBA) and synchrotron light source facilities have proved their worth in examining items of cultural heritage. As an example, the non-destructive nature of Ion Beam Analysis and X-Ray Fluoresce has allowed researchers to identify the exchange networks of variscite ($AlPO_4{\cdot}4H_2O$) in Southern Europe during the Neolithic [1]. Variscite was then a highly valued funerary jewel, commonly found in tombs, and these studies lead to identifying social inequalities during this period [2]. Other IBA contributions include the revelation of hidden portraits through measuring elemental maps in, for example, Van Gogh's *Patch of grass* [3], Degas' *Portrait of a Woman* [4], and many others.

These examples illustrate the powerful accelerator techniques that can be used to reveal secrets of artworks and material culture. However, some immovable items cannot take advantage of these techniques. A portable proton accelerator would be needed to study frescos, rock art, elements of the built environment, some archaeologically sites, or even sensitive items in museums that curators would prefer to not risk transporting. Presently, the only way to analyse these immovable objective with particle accelerators is by taking small destructive samples.

In these proceedings we take a close look at the need for a portable accelerator for rock art. Whilst there are many clear examples of cultural heritage that could benefit from a portable accelerator, rock art is possibly the most challenging, requiring robustness for operating in remote areas, and a design with optimised efficiency and minimal footprint and weight. If these more stringent challenges can be met, then the accelerator could equally be used in the other cases.

CASE STUDY: ROCK ART

Rock art can be found in many countries around the world. In some cases it's tens of thousands of years old, and forms a rich part of shared cultural heritage [5]. Unfortunately, with time, rock art fades. Often researchers take photos of the rock art, upload them to an image processing software like Photoshop or similar, and then adjust the contrast in order to better see how the rock art originally looked. This process is called digital enhancement [6, 7]. For examples of digital enhancement, see [8–11]. The fact that digital enhancement is so effective, means we know the pigments are still present, but the contrast between the pigments and the rock substrate is so close, we cannot easily make the distinction with our eyes.

Measuring 2-D elemental maps, that would outline where the pigments are located, could allow us to build up an image of the rock art (similar to the XRF examples that revealed hidden portraits). The remaining rock art pigment may exist in trace amounts or obscured by dust, grime or graffiti.

In our IPAC21 paper [12], we outline some of the main challenges and possible solutions to these challenges for a portable 2 MeV RFQ accelerator with the specific application of rock art.

OPTIONS FOR A PORTABLE DEVICE

The main requirements for an accelerator for cultural heritage investigations is that the beam be non-destructive and the accelerator be portable. An external beam is required, meaning that the particle beam exits the vacuum of the accelerator and travels through air in the last few centimeters between the sample and a thin window (for example SiNx).

Particle Induced X-ray Emission (PIXE) is a non-invasive and non-destructive technique, that can determine the elemental compositions of samples [13]. The basic principle of PIXE is as follows: particles (often protons, typically 2-5 MeV) are fired at the object, ionising an electron from an inner shell. When an electron from a higher energy shell falls down to fill the vacancy, it emits a characteristic X-ray photon, which can be used to identify the elements in the sample.

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RFQ Accelerator

Radio frequency quadrupole (RFQ) structures can simultaneously focus, accelerate, and bunch the beam, making it well suited for high intensity low energy protons, where space charge is an issue [14]. CERN's 750 MHz RFQ structure is capable of accelerating protons to 2 MeV over 1 meter [15–17], and could provide a compact source of protons for PIXE analysis.

The MACHINA (Movable Accelerator for Cultural Heritage In-situ Non-destructive Analysis) project, which is a collaboration between CERN and INFN, will use 750 MHz RFQ structures for a dedicated PIXE accelerator that will be based in INFN, Italy [15, 16].

These works could be considered as the "stepping stone" towards studying a design for a portable RFQ accelerator for in-situ PIXE analysis in cultural heritage sites.

Alpha-PIXE

Another option for a portable, compact device for cultural heritage is using alpha-PIXE. Just like protons, alpha particles can be used for PIXE. Alpha-PIXE has been used, and is currently being used, on the Mars rovers [18], with a small device called the Alpha Particle X-Ray Spectrometer (APXS). APXS uses a ^{244}Cm source for a combination of PIXE and XRF to detect 16 elements (where the XRF signal is largest for higher energy characteristic X-rays and the alpha-PIXE signal is largest for lower energy characteristic X-rays). The alpha particle emitted at approximately 5.8 MeV alpha particles and the X-rays emitted range from 100-120 keV [19].

In cultural heritage, alpha-PIXE is used to complement portable XRF devices. The INFN alpha-PIXE device, for example, has been used to study forgeries in coins and documents, it uses a polonium source emitting alpha particles of 5 MeV energy [20–22]. With a beam spot size of 18 mm diameter, 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.

OTHER OPPORTUNITIES

Parallel to the technical challenges to develop powerful portable devices for in-situ elemental mapping, and the direct social benefits derived from it, the authors would like to highlight the need to engage with various local, indigenous and cultural groups (either directly or through archaeologists and other groups who have existing relationships) to gain a better understanding of the different perspectives and relations towards their cultural materials. Early stages of this engagement has begun to identify where this work is wanted, needed, and welcomed.

It will be important to gather further input from archaeologists, anthropologists, sociologists, and historians, to better paint a picture of possible uses and benefits. For example: being able to determine 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, etc. Furthermore, it may be possible that these studies provide insights in how better preserve rock art in some regions, especially in regions with increasing humidity due to climate change.

Collaborations with museums, universities, and historical societies could provide further understanding of the utility of portable accelerators in different areas of cultural heritage.

CONCLUSION

The duality stemming from the fact that rock art is both widely spread around the world, representing one of the most important cultural heritage belonging to human kind, and its often remote location, where accessibility, terrain, and weather conditions pose one of the most challenging operating conditions for a PIXE device, lead us to believe that rock art, as a most challenging case, is a good case study for designing a portable device capable of performing non-destructive element mapping analysis. Application in other areas of cultural heritage should follow.

We do not pretend to deceive the reader to think that all rock art sites could be serviced by such a device, specially at this early stage, neither to confuse the term *portable* with *hand held*. What the authors would like to stress in this contributed talk, is that, any steps towards such a portable device will have huge impact in the study of a plethora of cultural material and just as one must "learn to walk first, to be able to run", in order to reach that point, efforts need to be made to study how to make more compact, robust, and efficient systems for cultural heritage applications.

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