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List of abbreviations:

CT	Computed tomography
EMME	Eastern Mediterranean and Middle East
IR	Infra-Red
MRI	Magnetic resonance imaging
MX	Macromolecular Crystallography
PBI	Propagation-based imaging
PCI	Phase-contrast imaging
SAC	Scientific Advisory Committee
SAXS	Small-Angle X-ray Scattering
SR	Synchrotron radiation
SXCT	Synchrotron X-ray computed tomography
WAXS	Wide-Angle X-ray Scattering
XAS	X-ray Absorption Spectroscopy
XPS	X-ray Photoemission Spectroscopy
XRF	X-Ray Fluorescence
μCT	Microtomography

PREFACE

This report outlines and elaborates the scientific case for the so-called BEATS tomography beamline at the research center SESAME in Jordan. The document is a crucial project deliverable of the BEAmline for Tomography at SESAME (BEATS) project funded within the H2020 program of the EU with the main mission to design, procure, construct and commission a dedicated beamline for hard X-ray full-field tomography at SESAME.

The report begins with an introduction to Synchrotron X-ray computed tomography (SXCT) and the current SXCT landscape in Europe and the Middle East, giving context to BEATS. The major sections of this report focus on the scientific case domains identified, services to industry and private sector, and user community building activities. The four main domains of science applications focused on are Archaeology and Cultural Heritage; Health, Biology and Food; Material Sciences and Engineering; and Geology and Environment. It should be noted that applications within other domains are also envisaged, and that these four domains simply identify key areas for the scientific case for BEATS in the SESAME region as viewed currently.

The science case areas that were defined for BEATS and documented in this report are based on close interactions with the scientific communities of current and potential synchrotron users in the SESAME region and on broad consultations with international experts. Therefore, special emphasis is given to the regional relevance of the presented scientific examples taking stock of existing research contributions from the region.

The beamline BEATS is primarily an enabling tool and maximizing scientific impact needs also a continuous fostering and growth of the relevant scientific communities. Thus, the report addresses also user community building, support and coordination activities as well as future plans and targeted actions. Together with documented science cases this report represents then a full scientific agenda with the immense potential to create positive social, economic and health benefits for the region in the medium and long term.

This document has been prepared by an editorial team within Work Package 2 of the BEATS Project. The assistance and advice of many experts and specialists is greatly appreciated.

INTRODUCTION

Non-destructive 3D characterization of materials and objects

Tomography is a non-destructive imaging technique which delivers virtual volume images of a sample by using penetrating radiation. Frequently, the volume images are a stack of (axial) sections. The method is used in a large range of scientific and technological applications ranging from medicine, biology, and materials science to archaeology and earth & planetary sciences. Some of the most prominent examples comprise magnetic resonance imaging, positron emission tomography, electron tomography, and X-ray (micro-) computed tomography. Commonly, the volume images are derived from multiple projection images covering a wide range of angular views based on the mathematical procedure of *tomographic reconstruction*. Depending on the wavelength of the probe spatial resolutions down to a few nanometres have been achieved.

The characterisation of the three-dimensional microstructure is paramount for an exhaustive understanding of materials, objects, and organisms. 3D images allow architectural and topological information to be retrieved about a specimen such as the shape, composition, orientation and size of its individual internal constituents, as well as the connectivity and correlations between these. Contrary to laboratory-based X-ray sources, where X-ray imaging was the first technique ever used, the introduction of tomographic X-ray imaging at synchrotron light sources (SXCT) started rather late in the middle of the 1980s. The advent of dedicated synchrotron X-ray sources (rather than the parasitic use of synchrotron X-rays at storage rings, optimised for high-energy particle physics), led to rapid, ground-breaking developments in SXCT. Together with tremendous improvements in detector technology, data storage and processing capabilities this has led to a boost of high-end synchrotron tomography with a wide range of different applications. Spatial resolutions from 50 μm^3 voxel size down to 0.2 μm^3 are routine, and the most advanced nano-imaging experimental stations (beamlines) provide resolutions down to 10 nm^3. Furthermore, the high brilliance of synchrotron X-rays allows time-resolved tomographic studies, typically with a few Hz up to a few hundred Hz acquisition rates, and the recording of single projection images with nanoseconds resolution. The contrast of the images is either generated via the difference in the photo-electric absorption (absorption contrast) or electron density (phase contrast) of the constituent elements. Further contrast enhancement can be achieved via tuning of the X-ray energy to an absorption edge of one of the constituent elements or by using contrast agents.

While other imaging modalities such as magnetic resonance imaging (MRI) and computed tomography (CT) with conventional X-ray sources can both attain 3-dimensional (3D) micrometric resolution, their main limitation is linked to the achievable contrast, spatial and temporal resolution. In comparison, SXCT in phase-contrast mode provides a sensitivity to light elements about 2-3 orders of magnitude greater than that of absorption CT in the hard X-ray regime (Cloetens et al. 1996; Snigirev et al. 1995).

Due to its advantages, SXCT is today a frequently used and increasingly demanded non-destructive technique for 3D imaging and analysis of a large variety of objects and materials. Its use is widely explored and appreciated in several research fields, including cultural heritage (Tafforeau et al.

2006), biomedical and life sciences (Rawson et al. 2020; Suortti and Thomlinson 2003), materials science and engineering (Baruchel, Buffiere, and Maire 2000) as well as earth and geological sciences (Cnudde and Boone 2013; Taina, Heck, and Elliot 2008).

Synchrotron X-ray tomography in Europe and the Middle East

Figure 1 shows the location of tomography beamlines currently operating (in blue colour), under construction or planned (in red colour) in Europe and Western Asia. In this overview soft X-ray microscopy, nano-tomography and non-full-field tomography such as diffraction, fluorescence, etc. are not included. In total 15 beamlines are operational (Table 1). Compared to other important SR techniques such as X-ray diffraction and X-ray absorption spectroscopy, this number is comparatively low, and the current capacity is not sufficient to respond to the demands of the rapidly growing user community (Figure 2). With this in mind, ALBA in Spain, SESAME in Jordan and ESRF in France are currently constructing hard X-ray tomography beamlines (FAXTOR, BEATS, BM18), and SOLARIS in Poland, MAX-IV in Sweden and PETRA III in Germany have plans for the construction of tomography beamlines, though corresponding funds are not yet secured.

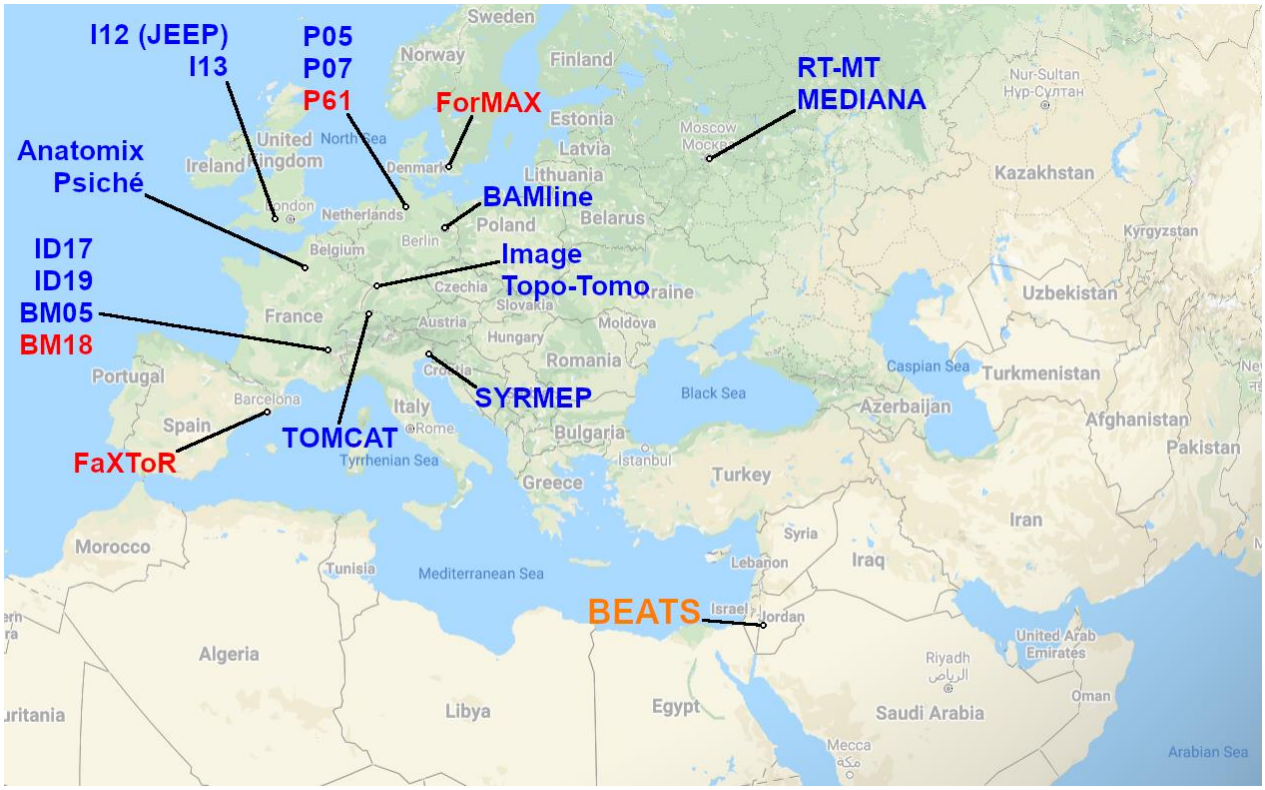

Figure 1: Map showing BEATS together with all synchrotrons tomography beamlines (BLUE: operational, RED: under construction or planned) in Europe and Western Asia.

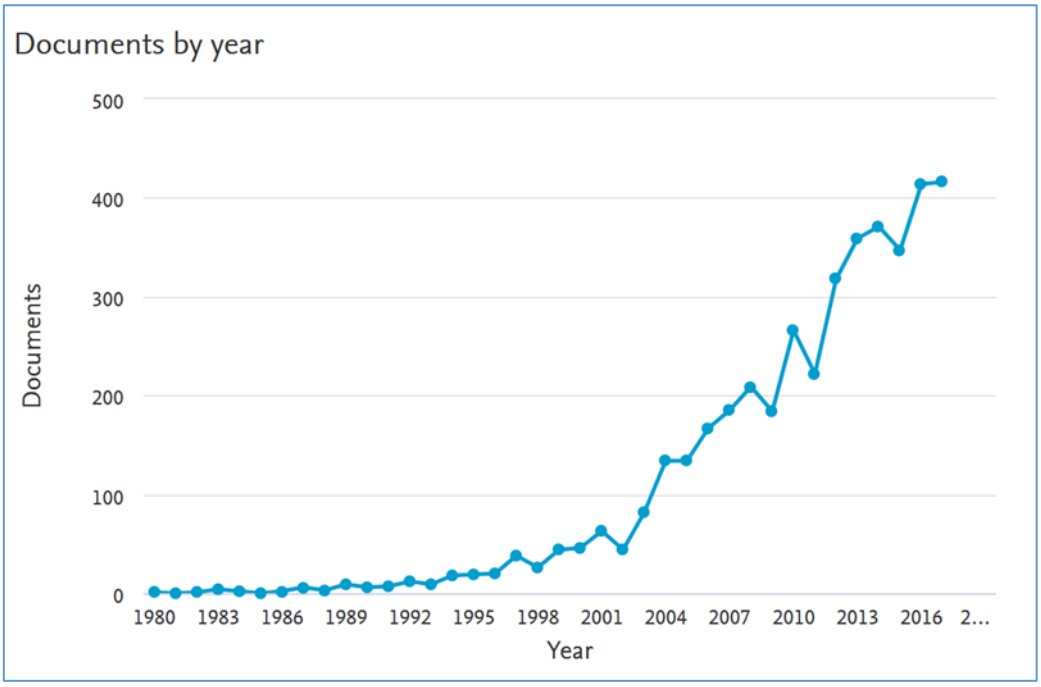

Figure 2: Increase of the annual number of SXCT relevant research publications. The data are output of a bibliographic search in SCOPUS using "synchrotron" and "tomography" as key words. In total there are about 4500 publications (status spring 2019).

Within this landscape, BEATS offers the unique possibility of an analytical facility tailored specifically to the needs of the SESAME region. Among the large diversity of applications, the following four science drivers were identified to be of particular relevance:

- **Archaeology and Cultural Heritage** – archaeological materials; human bioarchaeology, plant remains, animal remains and artefacts of animal bone, antler and teeth
- **Health, Biology & Food** – bone; dentistry; *in vitro* imaging of the brain vascular and neuronal network and other organs such as eye, heart, lung, liver, etc; musculoskeletal system; soft tissue; biomineralisation; entomology; and food science
- **Material science and Engineering** – light materials, energy materialss
- **Geology and Environment** – digital rock physics, petroleum science and engineering

Specific examples of applications in the above four fields and their connection to the SESAME user community will be presented in more detail in the later sections.

Beamline	Facility	Web link
I - Operational beamlines		
IMAGE	KARA	http://www.ips.kit.edu/5926.php
TOPO-TOMO	KARA	http://www.ips.kit.edu/5927.php
BAMline	BESSY-II	https://www.helmholtz-berlin.de/pubbin/igama_output?modus=einzel&sprache=en&gid=1658
I12 (JEEP)	DIAMOND	https://www.diamond.ac.uk/Instruments/Imaging-and-Microscopy/I12.html
I13	DIAMOND	https://www.diamond.ac.uk/Instruments/Imaging-and-Microscopy/I13/Diamond-Manchester_Imaging_Branchline.html
SYRMEP	ELETTRA	https://www.elettra.trieste.it/it/lightsources/elettra/elettra-beamlines/syrmep/syrmep.html

ID17	ESRF	https://www.esrf.eu/UsersAndScience/Experiments/CBS/ID17
ID19	ESRF	http://www.esrf.eu/home/UsersAndScience/Experiments/StructMaterials/ID19.html
BM05	ESRF	https://www.esrf.eu/UsersAndScience/Experiments/XNP/BM05
P05	PETRA III	https://photon-science.desy.de/facilities/petra_iii/beamlines/p05_imaging_beamline/index_eng.html
P07	PETRA III	https://photon-science.desy.de/facilities/petra_iii/beamlines/p07_high_energy_materials_science/index_eng.html
TOMCAT	SLS	https://www.psi.ch/en/sls/tomcat
PSICHÉ	SOLEIL	https://www.synchrotron-soleil.fr/en/beamlines/psiche
ANATOMIX	SOLEIL	https://www.synchrotron-soleil.fr/fr/lignes-de-lumiere/anatomix
RT-MT	NRC-KI	http://kcsni.nrcki.ru/pages/en/beamlines/rtmt/index.shtml
MEDIANA	NRC-KI	http://kcsni.nrcki.ru/pages/en/beamlines/mediana/index.shtml
II - Beamlines in planning or under construction		
BM18	ESRF	https://www.esrf.eu/UsersAndScience/UserGuide/Applying/beamline-status
ForMAX	MAX IV	https://www.maxiv.lu.se/accelerators-beamlines/beamlines/formax/
FAXTOR	ALBA	https://www.cells.es/en/beamlines/phase-iii-beamlines-1/2014_10_3_faxtor-bl-alba-phase-iii.pdf/view
P61	PETRA III	https://petra3-extension.desy.de/e84814/e85529/

Table 1: List of operational tomography beamlines, and beamlines in planning or under construction in Europe. The KARA beamlines are no longer accessible through a general user programme.

Tomography at SESAME

In line with SESAME's mission to provide special support to work of relevance to the region, and scientific, industrial and private sector research, SESAME shall foster scientific and technological excellence in the Middle East and neighbouring countries (and prevent or reverse the "brain drain") by enabling competitive research. With this in mind, SESAME's beamline portfolio (see Table 2) was constructed.

No	Beamline	Energy Range	Source Type	Comments	Status
1	**XAFS/XRF**	4.5-30 keV	Bending Magnet	Based on a donation by the Helmholtz-Zentrum Dresden-Rossendorf/ESRF Novel Detector to be provided by INFN	Operational
2	**Infrared Spectromicroscopy**	0.001-3 eV	Bending Magnet	New beamline designed in collaboration with SOLEIL	Operational
3	**Materials Science**	5-25 keV	2.1 Tesla MPW	Based on donation by PSI XO4SA (including Wiggler and front-end components) It hosts a 300k Dectris Detector donated by Dectris	Construction

4	Macromolecular Crystallography	~4-~13 keV	IVU	Not yet funded	Planned
5	**X-ray tomography; BEATS**	~8 – 50 keV	3-pole wiggler	New beamline; funded by EC under grant agreement No 822535	Construction
6	**Soft X-ray Spectroscopy; HESEB**	70-2000eV (depending on polarisation)	56 mm APPLE-II undulator (from HZB)	New beamline; funded by Helmholtz Gemeinschaft Germany	Construction
7	Small-angle/wide-angle X-ray Scattering			Not yet funded	Planned

Table 2: SESAME beamline portfolio. MPW: multi-pole wiggler, IVU: in-vacuum undulator

In the SESAME beamline plan developed in 2008, no provision was made for X-Ray tomography. Most of the plan was based on the re-utilisation of entire beamlines and/or beamline components donated by other SR laboratories. The idea of introducing a new tomography beamline in the scientific plan was presented to the SESAME Science Advisory Committee (SAC) during its November 2014 meeting. The SAC recommended discussing the details of the proposal once a possible source of funding would be identified. Examples of applications of X-ray tomography were subsequently presented to the SESAME Council in May 2016. After the publication of the INFRASUPP 01-2018-2019 call (Policy and international cooperation measures for research infrastructures) in 2017, the idea of submitting a proposal for the realisation of an X-ray tomography BL at SESAME was presented to the SESAME SAC, which endorsed it. The SESAME Council during its fall 2017 meeting approved the submission of the proposal. The scientific motivation to postpone the construction of other BLs (such as a Small Angle X-Ray Scattering beamline) was based on the idea that tomography will complement the existing portfolio of beamlines, in particular the XAFS/XRF, the IR, and the Materials science beamlines for the analyses of cultural heritage and archaeological specimens, which since the early days of SESAME were identified as a strategic research area. Moreover, the available budget of the call, 6 Mio €, allows for the construction of a state of the art tomography BL, but not for the construction of a competitive undulator or wiggler based BL. Following the successful grant application the BEATS project was presented to the SESAME SAC in December 2017, which endorsed the project, and to the SESAME Council, which approved it.

SXCT is considered currently as an essential technique in the synchrotron radiation community, and each SR facility strives to operate at least one instrument of this kind. The addition of BEATS to the portfolio is therefore a mandatory and strategically correct choice. BEATS, together with the X-ray spectroscopy, Materials Science and Infrared beamline, are powerful instruments for the study of materials at length scales ranging from the molecular to the micrometric level. Only a quantitative analysis of materials and objects over several length scales allows full understanding of its functionality and open the door for the smart design of materials. The connection to macromolecular crystallography (MX) is less direct, however, the role of MX in the design of pharmaceutics goes hand in hand with the characterisation of drug formulation in pills by SXCT in order to detect local inhomogeneity. Another natural link is the study of degenerative diseases on the molecular level (studied by MX and IR) and its consequences on the vascular and tissular level (studied by SXCT).

Thanks to the involvement of key European partners BEATS is naturally embedded into the European tomography landscape. Furthermore, SESAME is an associate partner in LEAPS, the League of European Accelerator-based Photon Sources, as well as represented at ESUO (European Synchrotron and free-electron laser User Organisation). It can therefore be expected that not only users from SESAME members, but also users from Europe will perform experiments at SESAME. In particular, this can be expected during the next 10 years or so when the major European sources (with the exception of ESRF) will upgrade their facilities. The development of remote control and mail-in services will play an important role in this context.

First overview of the user communities in the region

The following table shows a first overview of the identified institutional user community contacts in the region broken down into the four relevant scientific application areas. It reflects efforts undertaken within the BEATS project (after 18 months) and beyond. Initial efforts were focused on Archaeology & Cultural Heritage as this domain was identified early on during discussions of the SESAME science cases as very strong, with an excellent match of the envisioned SESAME Beamline portfolio (the IR, XAFS/XRF, and tomography beamlines).

Present Status of Contacts:	Cultural Heritage	Health, Bio and Food	Materials Science & Engineering	Geology & Environment
Cyprus	***	***		*
Egypt	***	*		*
Iran	***		*	*
Israel	***	**	*	*
Jordan	**		*	*
Pakistan	***	**	***	
Palestine	**			*
Turkey	***		*	*

*Table 3: Snapshot of current contacts with the user communities of SESAME members in the four main science applications of BEATS as of July 2020. The number of stars in the table represents a simple scale to quantify the number of institutional contacts in the region which were identified as existing or potential users of SXCT. The detailed list and documentation of all institutional contacts can be found in Annex II of this report. *: 1-2; **: 3-4; ***: > 5 institutions.*

Table 3 will dynamically evolve in the course of the project. The planned user community building activities, detailed further below in the present document, will specifically target SESAME members and scientific fields which are currently underrepresented in Table 3. We expect that by the end of the BEATS project, we will have gained a complete picture of the user communities, and the final

table will offer a realistic picture at that point in time. Naturally, user communities will continue to evolve and develop beyond the project.

References

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ARCHAEOLOGY AND CULTURAL HERITAGE

The region of SESAME and its members is known for its richness in archaeological and cultural heritage. Many highly-esteemed research institutions and universities in the region have departments dedicated to the scientific and art historical research into their heritage. BEATS will constitute a highly useful new research tool for researchers, conservators, and cultural heritage specialists in the area, with wide applicability across the domains of archaeology and cultural heritage at large. Here, we give a brief overview of the types of research which can be performed using SXCT through cultural heritage and archaeological case studies. We highlight examples ranging from archaeological artefacts to plant remains, animal remains, and archaeological human remains. Specifically, when dealing with material which is fragile or of poor preservation, and/or highly valuable due to its historic or archaeological significance, SXCT is an essential tool for archaeology and cultural heritage in the region, enabling researchers and domain professionals to visualize, analyse, understand and publish knowledge and findings regarding heritage in high resolution, non-destructively (or through minimally destructive approaches), and without having to transfer these valuable archaeological and cultural heritage items outside their region of origin. We will discuss the case studies in the following order:

- ***Archaeological Materials***
    - *Artefacts of unknown material*
    - *Faience*
    - *Pottery and Ceramics*
    - *Glass*
    - *Textile*
    - *Wood*
    - *Manuscripts*
- ***Human bioarchaeology***
- ***Plant remains***
- ***Animal remains and artefacts of animal bone, antler and teeth***

Archaeological materials

SXCT is a useful tool for the examination of different types of artefacts including ceramics, stones, pottery, wood, tablets, scrolls, swords, bronzes, and other metal objects (Maher 2020). Additional areas of research involve glass and ceramics petrography, traditionally undertaken with cross-sections.

Artefacts of unknown material (Souskiou-Laona, Cyprus)

SXCT may assist in determining the composition of artefacts, recovered from archaeological sites and assemblages, for which this information cannot be obtained otherwise. An example of such artefacts comes from the Chalcolithic (c. 3000 BCE; c. 5000 years ago) site of Souskiou-*Laona* in southwestern Cyprus. Significant amounts of faience and metal artefacts were recovered from the site, first evidence for use and manufacture of metal artefacts on the island of Cyprus. Three pendants of an unknown material were also found as seen in Figure 3a, with contextual images in Figure 3b. SXCT may enable us to discern the material which these pendants are made of. Are they faience? This is of importance as to understanding early metal working, and furthering our understanding of resource exploitation and trade in Chalcolithic Cyprus. SXCT could be used in similar cases from other archaeological sites, which have recovered artefacts of unknown materials.

***Figure 3a**: Pendants of unknown material recovered from tomb 207 from Souskiou-Laona Chalcolithic cemetery, Cyprus (Peltenburg et al. 2019)*

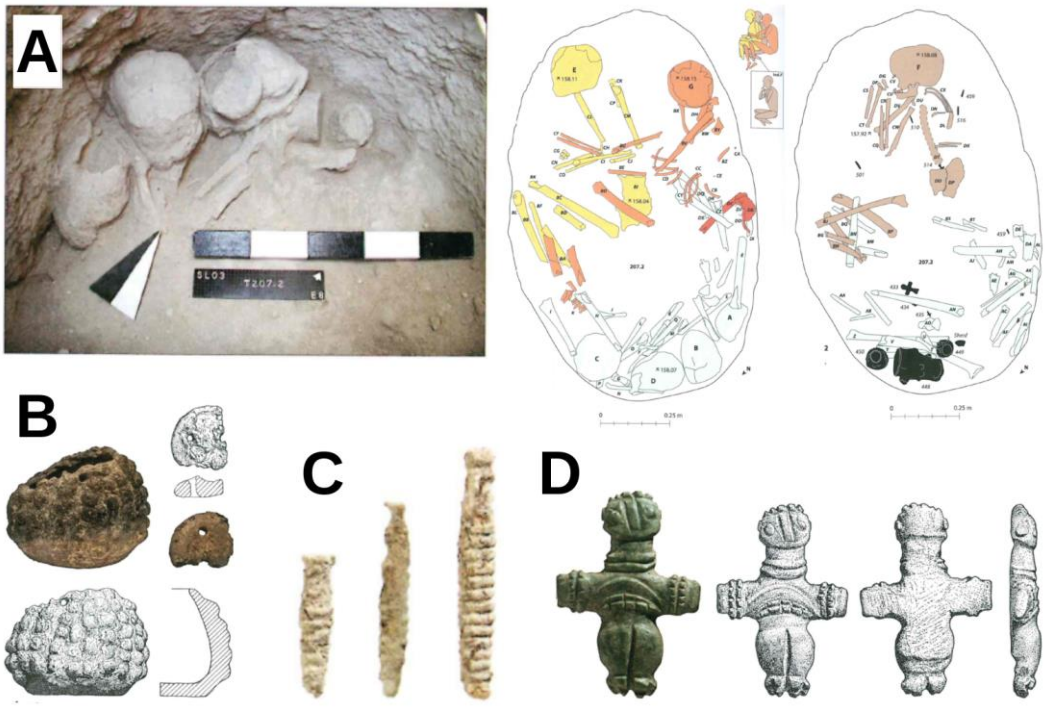

Figure 3b: A) *Tomb 207 of Cyprus Souskiou-Laona cemetery - 3000 BCE, beginning of metal work. Pottery vessels* ***(B)****, beads* ***(C*** *– unknown material****)****, pendants and figurines* ***(D)*** *of picrolite stone, bone and faience (Figure layout Bianca Casa and Gianluca Iori, based on Peltenburg et al. 2019; Lorentz 2019).*

Faience

SXCT has been used to investigate characteristics of faience production. Faience production is a complicated craft to master, and was used by artisans in the past to create high quality goods for the elite. In a study conducted by Gu et al. (2016) faience beads from the Harappa site in Pakistan, dating to around 2600-1900 BC were investigated using SXCT (Figure 4). Shape analysis based on the microstructure of the beads revealed new information about the materials and technology applied in their production. Two recipes for faience production were being used in this region, possibly by different workshops or from different time periods. It was consequently possible to conclude that all the beads were in this case produced using the same technology.

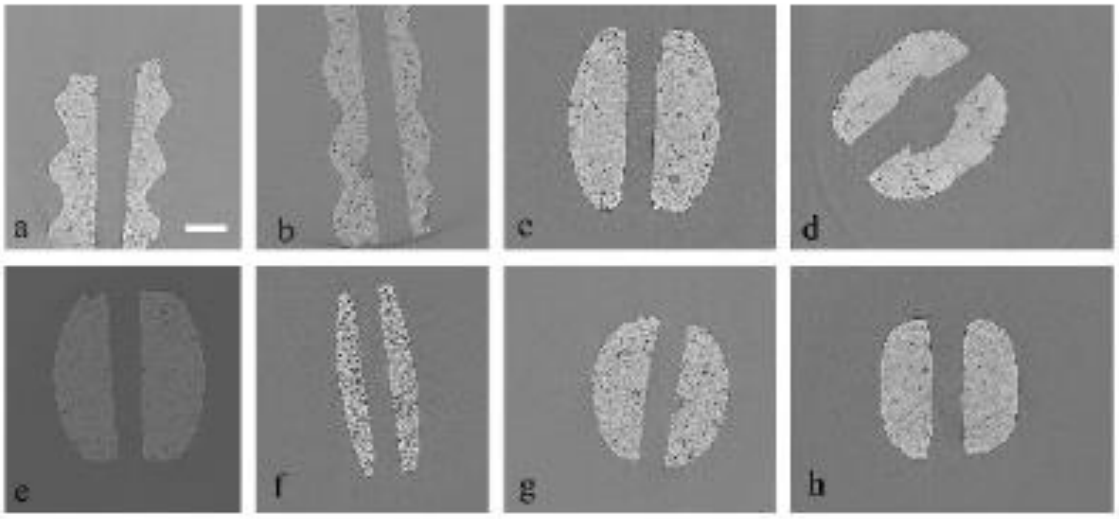

***Figure 4**: SXCT slices of Harappan faience (Gu et al. 2016). The images have the same scale and the white scale bar is 2mm*

Pottery and ceramics

Studies relating to primary forming techniques of pottery are relatively scarce in the field of ceramic studies. This is, in part, due to the difficulty in obtaining information about the inner structures of pottery vessels in a non-destructive way. SXCT is a non-destructive technique, which allows the precise visual and computable detection of clay fabric microstructures. More precisely, this method allows direct visual detection and measurement of coils, slabs, and other construction units; the recording of the orientation of voids and inclusions; and the documentation of specific forming technicalities. These features can be highly indicative of specific techniques, and they can thus help to identify even individualised craft behaviours (Kozantsas *et al.* 2018). Ceramics and ceramic techniques also form one of the main routes through which archaeologists date the large number of archaeological sites and periods in the SESAME region, the cradle of civilisation as we know it. The BEATS beamline will enable non-destructive and non-invasive (or minimally invasive) data acquisition.

Glass

The examination of archaeological glass using SXCT enables observations on the distribution of pigments and inclusions in glass samples. MicroCT was used to analyse Dvaravati glasses from Southeast Asia, which were likely transported and traded on the Silk Road which

connected Eastern and Western Asia. The SXCT imaging revealed that there are opaque materials distributed throughout the yellow glass matrix. In combination with other synchrotron X-ray techniques such as X-ray Absorption (XAS) and Fluorescence Spectroscopy (SR-XRF), the authors deduced that these opacities were lead (Pb) which was present on the surface, and distributed throughout the glass matrix (Saminpanya *et al.* 2019). Although there are no studies of glass using SXCT in the Eastern Mediterranean and Middle East (EMME region), there is a very large corpus of archaeological glass finds, and therefore potential as well as a need for future studies with SXCT, particularly in conjunction with XAS and SR-XRF.

Textiles

Textile fibres from archaeological contexts do not often survive. However, certain circumstances such as proximity to metal objects can help preserve such materials. This is the case for mineralized linen fragments discovered on the surface of copper-containing artefact fragments which originate from ancient Mesopotamia (5^{th} - 2^{nd} millennium BC) and the Indus area (4^{th} - 2nd millennium BC) (Bellato et al., 2018). 2D and 3D synchrotron-based micro-imaging techniques were used to characterise these textiles and the corrosion compounds from the metal objects associated with them. SXCT was used to identify the specific copper corrosion phases based on their different densities. Furthermore, the internal structure of these mineralized textile fibres could be observed in the context of their corrosion phenomena. Ultimately the technique allowed for a better understanding of this specific preservation phenomenon. The microstructures of the textile fibres themselves also provide valuable information, enabling identification, and interpretations based on the types of fibres (plant components, animal hair) present, and pre-preparation and weaving techniques used.

Wood

Identification of wood species used in artefacts and architectural components provides a wealth of information of (valuable) wood trading in the ancient world. Ancient Egyptians imported such species as cedar, cypress, pine and the aromatic wood of juniper through sea trade from around the Mediterranean and the Near East (Giachi et al. 2016). Wood identification requires microscopic observation from three directions; transverse, radial and tangential (Mizuno et al. 2010). The conventional method is to make thin sections from all three directions, but these cannot be obtained in cases where only very small samples are available, samples are too brittle for sample preparation, or the curator of the wooden

artefact does not allow destructive sampling due to the precious nature of the artefact. By using SXCT, Mizuno et al. (2010) identified non-destructively the species of an old wooden mask, which was said to have been brought from the Korean peninsula to Japan in the 16th century (Figure 5). The identified species supported their hypothesis that the mask was not made in Japan but was brought over from the Korean peninsula instead. Wood identification is critical to the understanding of the above trade in precious woods, in the Eastern Mediterranean and Middle East region, as well as to further the understanding of works of art, ancient icons and other such pictorial representations painted on wooden substrates, as well as understanding of architectural elements. Ultimately, these studies contribute to the understandings of elite behaviour in complex societies engaging in long-distance trade and tribute procurement.

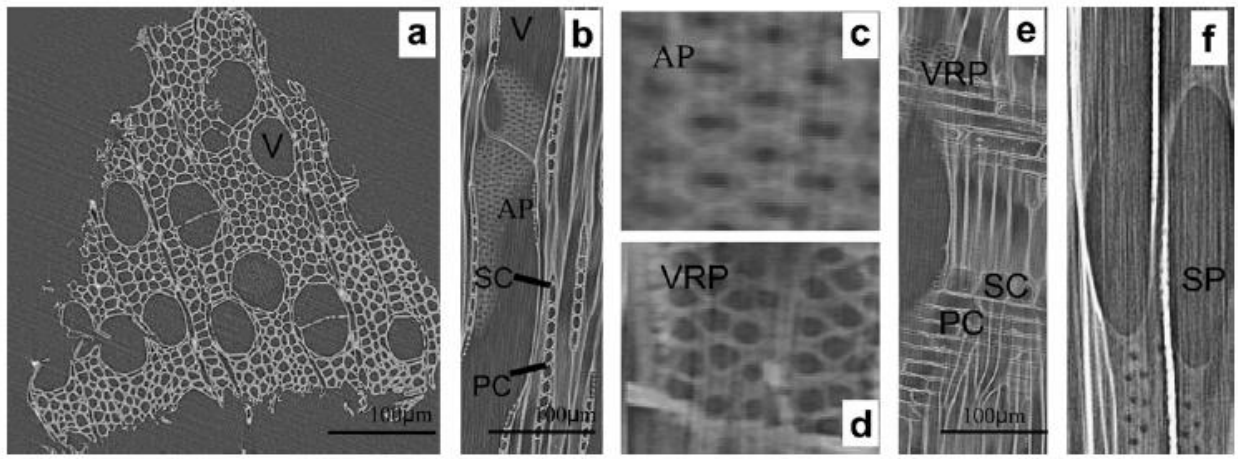

Figure 5: *Pseudo-sections of wood constructed from a SXCT dataset of SPring-8: cross section (a), tangential section (b), magnified area of the alternate pitting (c), vessel-ray pitting (d), radial section (e), simple perforation (f). Note that V: vessel, SC: square cell, SP: simple perforation, PC: procumbent cell, AP: alternate type pitting, and VRP: vessel-ray pitting (Mizuno et al. 2010).*

Manuscripts

The legibility of historical documents is determined by their level of preservation, often severely damaged and extremely fragile. Consequently, the contents of these historical documents have often remained ambiguous. In addition, several types of inks were used for papyri and carbon-based inks cannot be imaged exploiting absorption edges in the hard X-rays range. Recent advances in three-dimensional (3D) scanning based non-invasive digitisation approaches have the ability to derive substantial new historical evidence in the

form of single letters or pages without altering or opening the manuscripts. Although conventional micro-CT can be used for some of these projects, the material and X-ray properties of some manuscripts limit their suitability to this technique. SXCT has the ability to meet these limitations due to its brighter and more monochromatic X-rays, and improved sensitivity and spatial resolution. SXCT can produce improved page separation and clearer visualisation of small and degraded writings which appear in these historical documents. SR radiography and tomography have been recently applied to Papyri found on the Elephantine Island in Egypt, in combination with Fourier-transform infrared spectroscopy (FT-IR), element-sensitive absorption edge and X-ray fluorescence mapping (Arlt et al. 2019), Figure 6, techniques which are state-of-the-art at the IR and XAFS/XRF beamlines at SESAME. The synergy between these techniques at synchrotron light sources is expected to allow the analysis of text from folded or rolled papyri without manually opening the fragments.

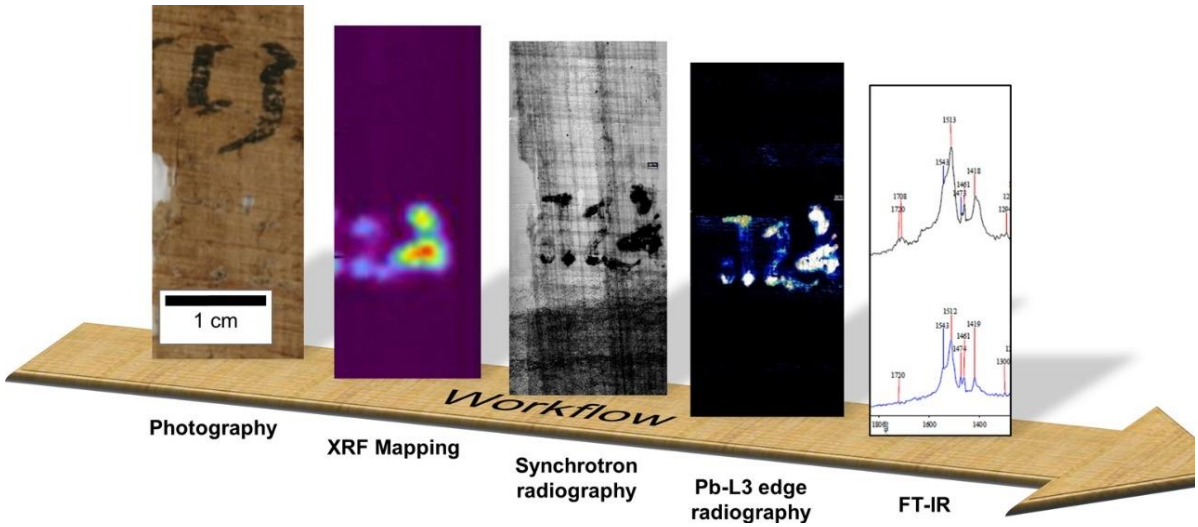

***Figure 6**: Workflow (Arlt et al. 2019).*

Human bioarchaeology

Human remains comprise one of the most direct forms of evidence on past people. Information on diet, lifestyle and activity patterns, and health and illnesses, among many other aspects, can be elucidated by examination of human remains through various techniques. A number of domains, including the study of pathologies, burial conditions, and preservation status, can benefit highly from SXCT.

Pathologies

SXCT has the potential to help verify and image several pathological conditions in the skeleton, such as external auditory exostoses (EAEs). These bony growths occur in the human auditory canal of the temporal bone (i.e. the ear canal) and are a proxy for repetitive exposure to cold water over a prolonged period of time, i.e. repetitive aquatic activity. For differential diagnosis (differentiating from osteomata) external auditory exostoses have typically been observed macroscopically, and not through histology (as this would involve destructive sample preparation). EAEs were discovered in the ear canals of individuals disposed of in the oldest known water wells in the world (c. 10.000 years old), at Kissonerga-*Mylouthkia* in southwestern Cyprus (Lorentz 2020; Figure 7, Figure 8), and their presence has been confirmed through SXCT analyses (Lorentz et al. *in preparation*). External auditory exostoses are differentially diagnosed from osteomata by their shape, location, and histological characteristics. SXCT provides data on accurate measurement of the dimensions of exostoses, as well as their precise locations within the auditory canal, any associated microstructures, and most importantly, histological characteristics. Furthermore, SXCT enables a clear distinction between exostoses and osteomata to be made, based on bone microstructures. The impact of such a pathological condition on the living person may have involved some form of hearing loss and/or cerumen impaction, often leading to secondary infections. Most importantly however these early EAEs, verified by SXCT, tell us about the broadening of food resource procurement with the inclusion of aquatic resources, in the context of the so-called Broad Spectrum Revolution (a key issue in the SESAME region), leading to the development of agriculture, and therefore the human lifestyle modes we know. These lesions have been found in archaeological skeletal remains from several other sites in the Eastern Mediterranean and Middle East (see Figure 9), highlighting the broad applicability of such studies, using BEATS at SESAME.

Figure 7: *Right temporal bone from a probable male individual from Kissonerga-Mylouthkia, Cyprus (lateral view). Note the oval bony growth on the anterior wall of the external auditory canal, an external auditory exostosis (Lorentz 2020: 100).*

Figure 8*: Right temporal bone from a male individual from Kissonerga-Mylouthkia, Cyprus (lateral view). Note the two oval bony growths on the posterior and anterior wall of the external auditory canal, external auditory exostoses (Lorentz 2020: 101).*

Figure 9: *Map of the Mediterranean and Near East displaying sites with individuals with external auditory exostoses (Lorentz 2020: 102).*

Bone microstructures and taphonomy

MicroCT can be used extensively in human bioarchaeology, as it enables visualisation of bone microstructures non-invasively and non-destructively, without damaging, sectioning, or sampling the remains. To our knowledge, no such studies using microCT or SXCT have yet

been published for the SESAME region, but the potential is however clear. A human bone specimen from Gough's Cave in the Mendip Hills, Somerset, UK, was analysed using microCT. This human bone displayed evidence of human activity, which has been interpreted as butchering. MicroCT revealed several cut marks and human tooth marks. However, as the magnification and the laboratory source microCT scanner used in this study had to extend the full length of the bone, the resolution of the images was not high enough to observe details such as bone microstructures like osteons, which may be used to provide an approximate age of an individual (Bello and Galway-Witham, 2019). These limitations will be overcome by the use of SXCT, which provides higher resolution imaging than possible by standard CT or microCT facilities.

Plant remains

Study of plant remains from archaeological contexts is critical for understanding processes of domestication, one of key stones of human civilisation as we know it. SESAME region overlaps with the region known as the cradle of civilisation, where agriculture first emerged. Traditional methods to characterise plant material comprise morphological (species identification), metric, and other analyses, such as the analysis of contaminants in charred samples, radiocarbon dating, dendrochronological studies, wood characterisation, and the identification of carpological vestiges. MicroCT analysis was considered a suitable complementary method to evaluate maize grain morphology and mineralized preservation of sets of plant remains. Figure 10 shows an example of such a study from Calo et al. (2019) which aimed to provide a detailed description of the morphological and internal anatomical traits of the samples and to compare them with those of maize grains, in order to confirm whether they belong to the species Z. mays (Calo et al. 2019). This study mainly used the X-ray MicroCT in absorption mode, but some details were accessed using X-ray propagation based phase contrast microCT via synchrotron radiation. Another example is from Murphy and Fuller (2017) where SXCT provided evidence for seed coat thinning between 2,000BC and 1,200BC, in southern Indian (Monte Castelo) archaeological horsegram (Macrotyloma uniflorum). The thinning of seed coat is one of the traits in domesticated beans, key to understanding the above critical questions for the archaeology of the region. This approach has the potential to be also applied in the SESAME region, overlapping with one of the oldest areas of plant domestication.

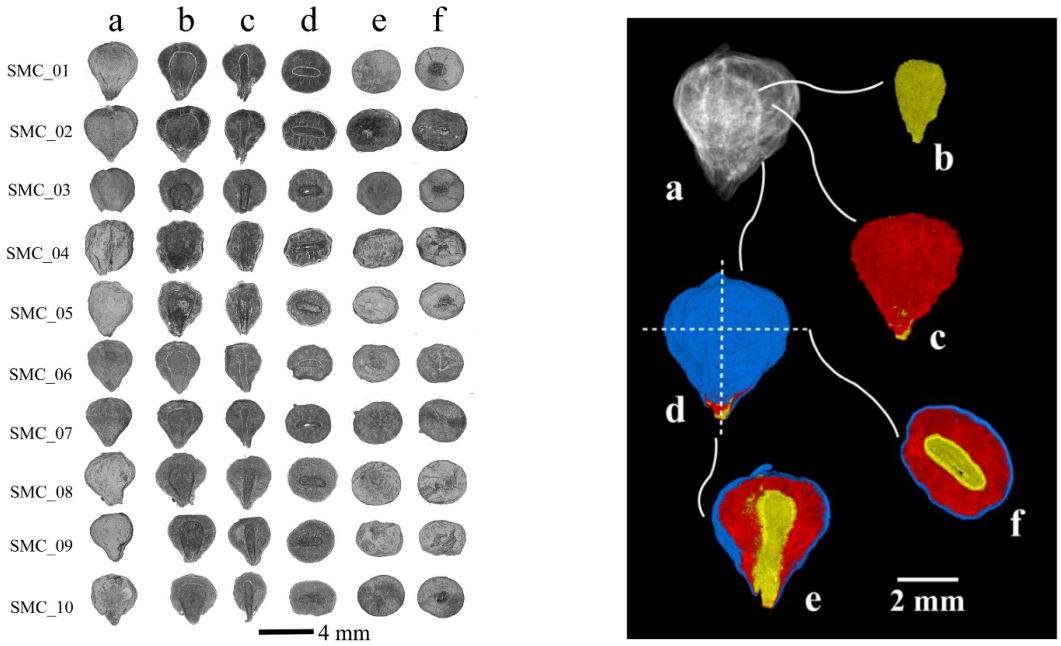

Figure 10: *Left panel: 3D Micro CT images of maize grain and a - reconstructed volumes of samples and internal configuration, shown consecutively by b - anteroposterior cut, c - lateral longitudinal cut, d - transversal cut, e- rounded ends and f- pointed ends (right panel). Right panel: Example of the three tissue layers, a- Attenuated volume image, allows visualisation of the internal structures of the grain by increasing the level of transparency of the imaged tissues; b- Inner layer volume in yellow; c- Medial layer volume in red, wrapping the inner layer in yellow; d- Outer layer volume in blue, wrapping the medial and inner layer in red and yellow, respectively; e- f- Longitudinal and transverse cuts showing the three-layered structure of the maize grain. Taken from Calo et al., 2019.*

Animal remains and artefacts of animal bone, antler and teeth

Animal remains are an invaluable source in archaeology. They give us information on past dietary practices, tool use, ornament use, and can give us a clear understanding of technological advancement and dietary choices over time and geographical regions. SXCT can be used to differentiate bone fragments from different animal species. One such study was conducted by Reiche et al (2011) to differentiate archaeological objects made out of animal bone (marine and terrestrial) and ivory. Modern and archaeological bone materials

(Palaeolithic) were studied using both a conventional laboratory microCT as well as SXCT from the BESSY II synchrotron source (Vercoutère et al. 2011, see Figure 11 & 12). The study concluded that it was possible to differentiate between whalebone and terrestrial animal bone, ivory and antler for the modern samples. Diagenetic alterations were observed in the archaeological material. Despite this, their microstructure was sufficiently preserved for characterisation. The laboratory microCT, in contrast to SXCT, was not able to attain high enough resolution to show the micromorphology of ivory. Ivory/bone/antler artefacts are frequently found on archaeological sites in SESAME region. Antler, bone, and ivory would have had different acquisition routes and prestige in the past and therefore it will be of importance to differentiate between these materials. SXCT at BEATS will allow the non-destructive identification of raw material as well as the study of the manufacturing process of these and other artefacts from the SESAME region.

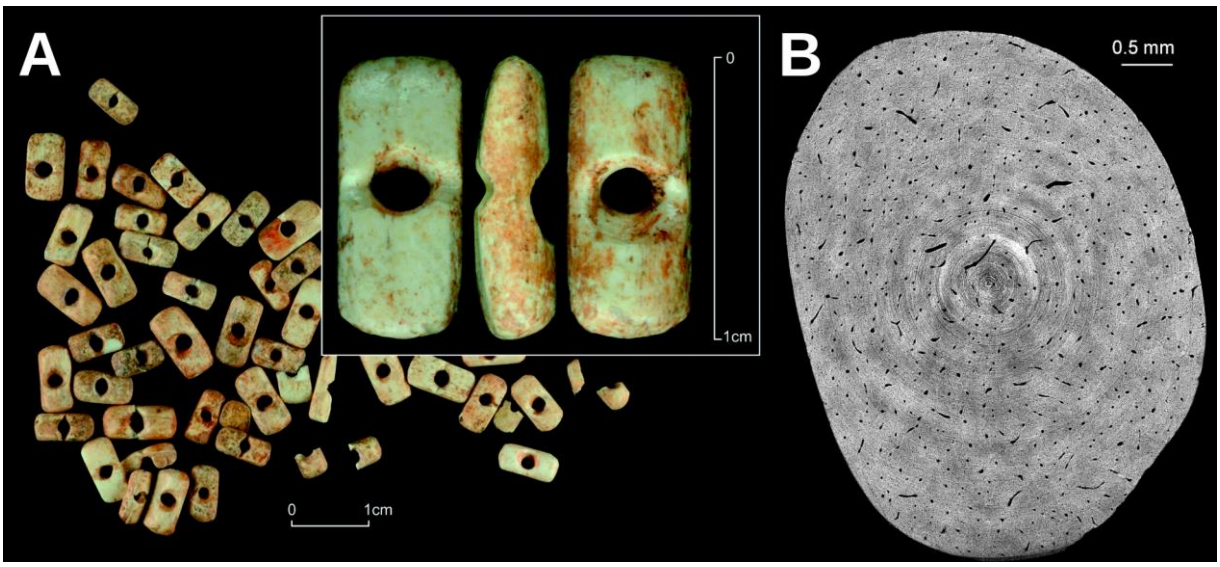

***Figure 11**: A) Rectangular mammoth ivory beads from the Final Gravettian of the abri Pataud (Les Eyzies-de-Tayac, Dordogne, France). B) Virtual SXCT cross section through one of the beads (bone) that differs from the rest of the samples. Synchrotron absorption CT data acquired with monochromatic beam (15 keV) at the BAMline tomography station of BESSY-II. Object pixel sizes for these scans were 0.44 to 3.5 µm. Adapted from (Vercoutère et al. 2011).*

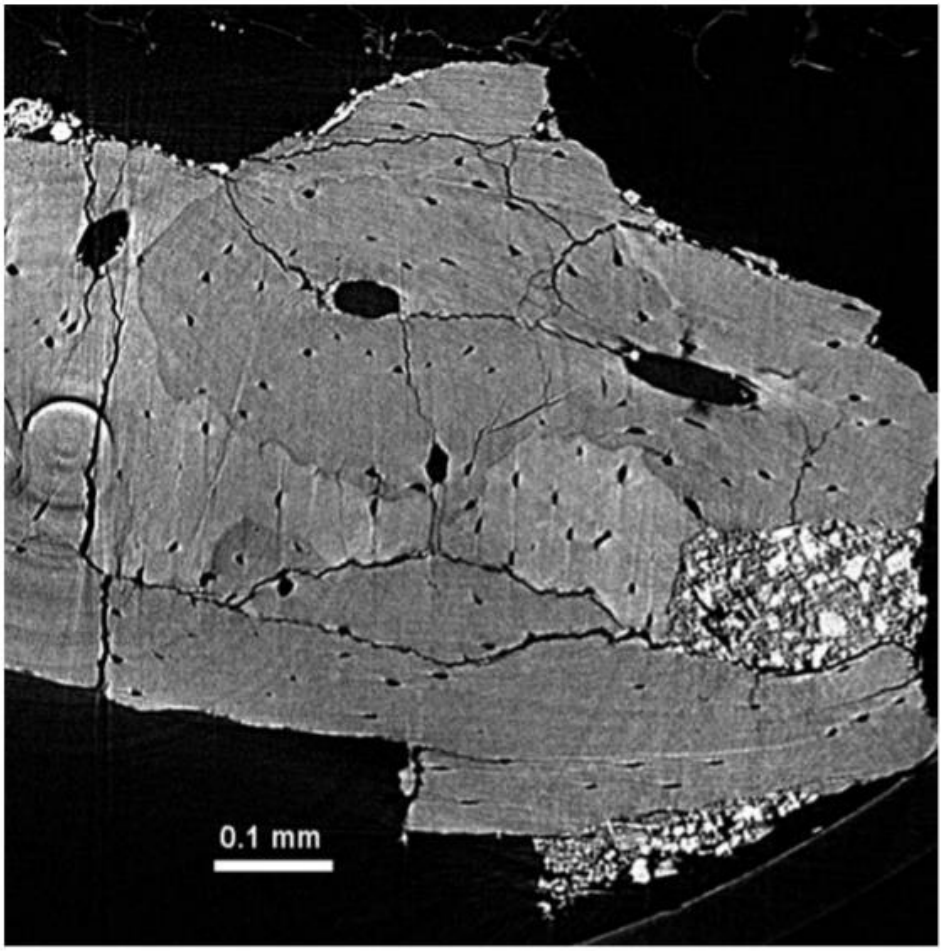

Figure 12: *SXCT CT virtual slice of the archaeological sample AB_AP_8 from Abri Pataud, demonstrating the use of SXCT for the analysis of the consistency and composition of archaeological artefacts. In the work from (Vercoutère et al. 2011), the composition of delicate body ornaments found in the Gravettian level of the Abri Pataud was discovered.*

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HEALTH, BIOLOGY AND FOOD

Developments in SXCT and more in general in computed tomography applications have expanded the possibility to inspect and analyse biological tissues at micron and sub-micron resolution in 3D and without damaging the tissue. This is paramount to understanding structural-functional relationships in living tissues and organs as well as the effect of medications and external agents on these. Therefore, the potential of SXCT imaging for the characterization of soft and hard biological tissues is broad, and its application in medicine and biology widely explored (Rawson et al. 2020, Suortti et al. 2003). Furthermore, the field of applicability of SXCT remains broad even when an animal facility is not present, such as in the case of SESAME. We have therefore excluded studies on fresh or living tissues from the present science case.

It is expected that many among the regional institutions performing research or industrial product development in the health and life sciences will benefit from the specific capabilities of BEATS. The following paragraphs highlight opportunities and possibilities associated with SXCT imaging for research in health, biology and food science.

Health

Bone microstructure and microporosity

Bone sustains and transmits the forces generated by the interaction of the organism within a gravity environment. Bone has evolved to provide rigidity to the skeletal system and protect at the same time vital organs. Mechanically, this is accomplished by a self-repairing, lightweight composite with outstanding stiffness, strength and toughness (Wegst et al. 2015). The pores included in bone are the site of blood production by hematopoietic stem cells and offer a fractal-like surface for calcium exchange, storage and homeostasis. This unique combination of mechanical and biological functions is accomplished thanks to a finely tuned hierarchical arrangement of the bone structure spanning several length scales: from the atomic level of mineral particles to the external shape of bones. Since its introduction for clinical applications on living subjects in 1971, computed tomography has been the method of choice for the 3D imaging of bone segments. Due to the high resolution and contrast achieved, SXCT has become the gold standard for investigations of the morphology and

architecture of bone from the millimetre down to the nanometre scale (Mader et al. 2013; Maggiano et al. 2016; Andronowski et al. 2017). Examples of (ex vivo) bone research enabled by SXCT include works on both human tissue as well as animal models. Prominent applications involve the study of skeletal diseases such as osteoporosis (Chappard et al. 2013; Zimmermann et al. 2011), osteoarthritis (Chappard et al. 2006) and osteogenesis imperfecta (Carriero et al. 2014) or the characterization of microstructural changes as a function of age (Bach-Gansmo et al. 2016), tissue formation (Bortel et al. 2017) and therapy (Borah et al. 2006). SXCT has also advanced greatly our understanding of the interplay between the microstructural properties of bone and the activity of cells inhabiting it. Bone formation and mechanosensation (the capacity to sense and adapt to mechanical loads) are regulated by different types of bone cells including, from the same lineage, osteoblasts and osteocytes. Osteocytes are entrapped in the bone extracellular matrix during tissue formation to form a network of living, mechanosensing cells pervading the bone matrix in a system of microscopic cavities. Surprisingly neoteleost fish, representing a large group of vertebrates, lacks osteocytes entirely. In two works from 2019, Ofer et al. investigated the microstructural phenotype and cellular components of anosteocytic bones of medaka fish (see figure 13). Phase-contrast SXCT revealed strong structural similarities with the osteocytic bone of zebrafish as well as the presence of mineralized objects in the matrix of anosteocytic bone (Ofer, Dean, et al. 2019; Ofer, Dumont, et al. 2019).

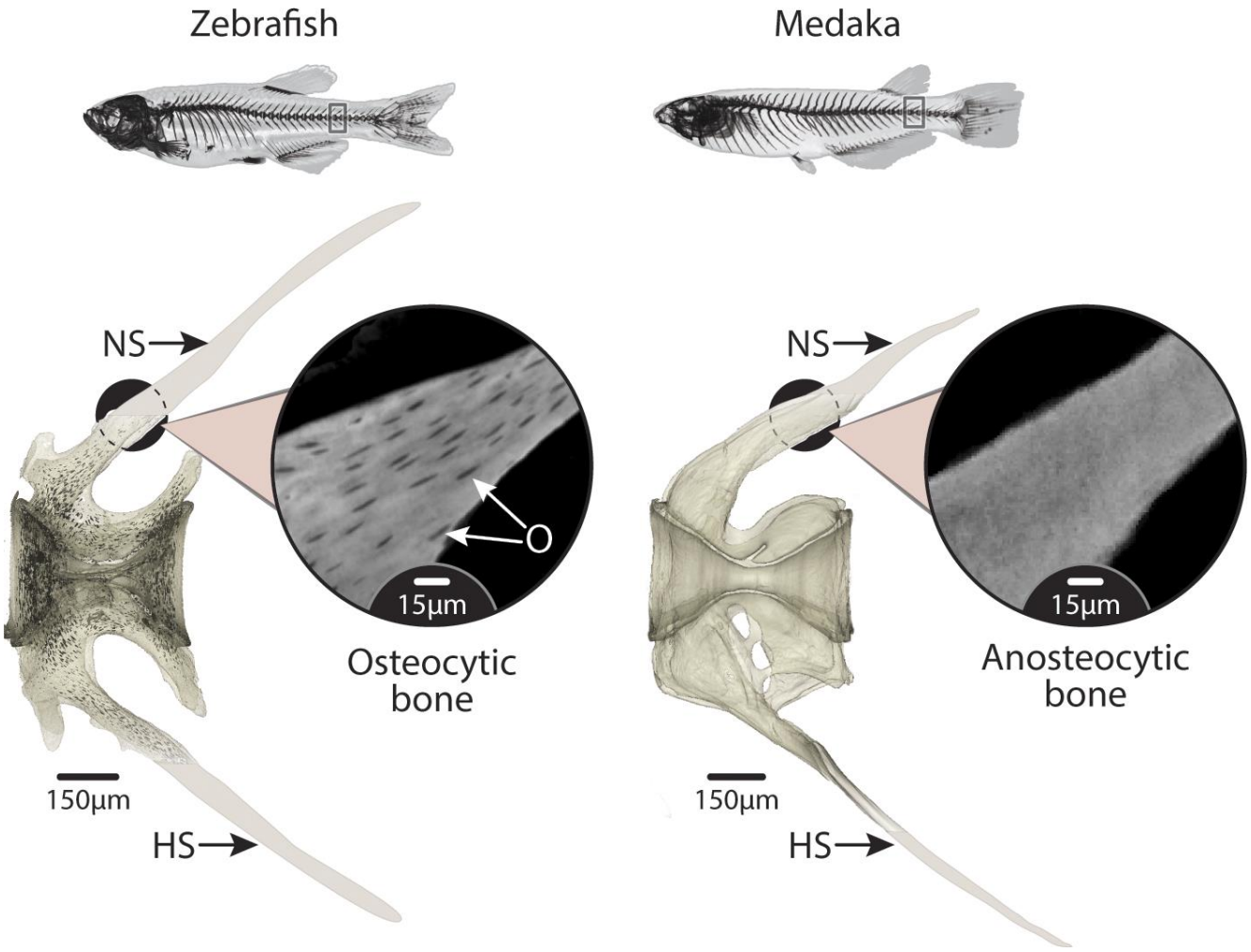

Figure 13: *SXCT of vertebrae of zebrafish (left) and medaka (right). Numerous osteocyte lacunae (O) are visible in the zebrafish scan. Such cells are absent from medaka bone material. Inset images show unsegmented tomography slices at a higher magnification. Reproduced from (Ofer, Dean, et al. 2019).*

Bone tissue regeneration

Bone tissue regeneration is a research field with high scientific and social importance. Understanding the complex and hierarchical structure of bone requires an imaging modality able to assess the tissue microarchitecture with high resolution and at different length scales. SXCT can provide relevant insight on the mechanisms of tissue growth and implant integration, with a crucial impact in the fields of bone tissue regeneration, development of implants and tissue engineering. Figure 14A shows a 3D rendering obtained with SXCT of the integration between bone and engineered bioceramic particles for tissue regeneration. The sample (a sheep bone) was scanned with SXCT ex-vivo following implantation and without the need for further staining of the tissue (Rack et al. 2008). In a similar fashion, Campi et al. utilized high resolution phase-contrast SXCT in combination with synchrotron micro X-ray

diffraction to reveal tissue formation mechanisms on engineered bone grafts (Campi et al. 2015). Importantly, imaging with SXCT exposes the investigated tissue to ionizing radiation but is otherwise non-destructive and allows the conservation of the tissue integrity.

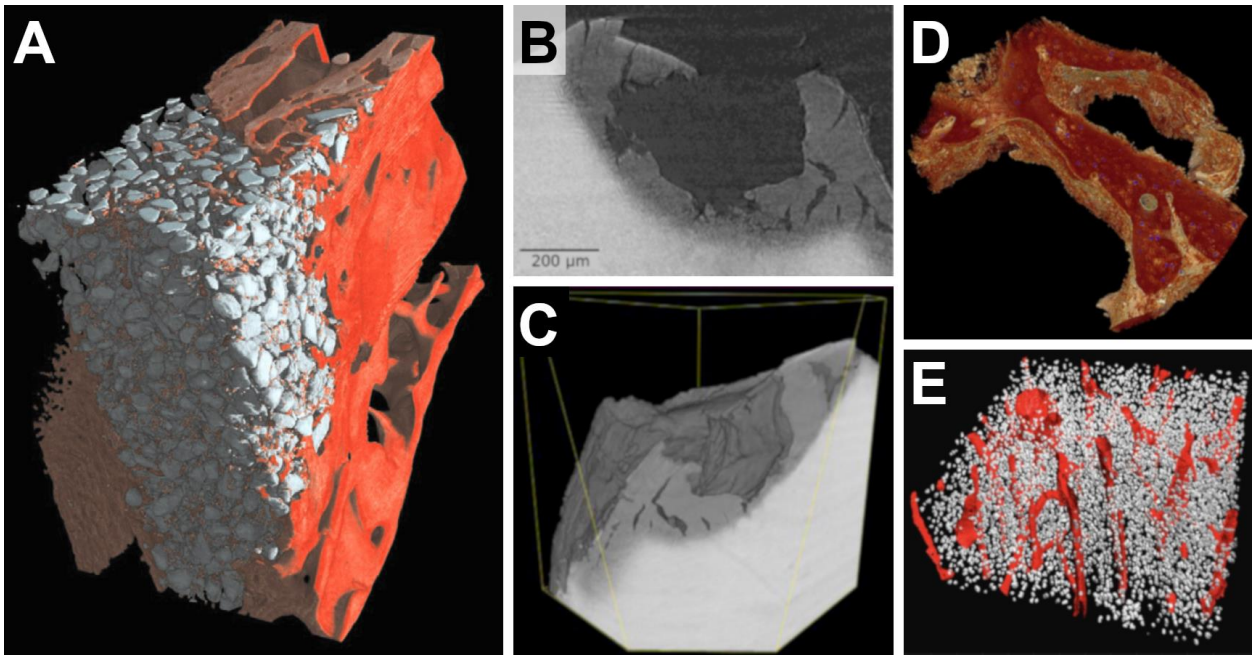

Figure 14: *Examples of application of SXCT to bone and dentistry research.* ***(A)*** *3D reconstruction of sheep bone sample showing tissue-implant integration of bioceramic particles after implantation for bone regeneration. BAMline (BESSY-II) SXCT data (absorption-contrast; 27 keV; 7 µm voxel size). Reproduced from (Rack et al. 2008).* ***(B)*** *Cross-section and* ***(C)*** *3D reconstruction of human enamel sample showing severe demineralisation. BAMline (BESSY-II) SXCT data (absorption-contrast; 25 keV; 7 µm voxel size). Modified from (Lautensack et al. 2013).* ***(D)*** *SXCT reconstruction of human cancellous bone sample.* ***(E)*** *SXCT 3D render of a human cortical bone sample showing vascular porosity (red) and osteocyte lacunae (grey). BMIT beamline data (Canadian Light Source); absorption-contrast; 0.9 µm voxel size; 31 keV. Reproduced from (Andronowski et al. 2017).*

Bone-metal implant interface

A recent research focuses on improving the understanding of the mechanical characteristics of bone-metal implant interface. The successful bone formation, ingrowth and implant adaptation are fundamental for the long-term stability of endosseous implants. These parameters define the mechanical properties of the newly formed bone-implant interface. Phase-contrast SXCT during mechanical loading tests (in situ loading) can improve our understanding of the local processes leading to bone damage and failure. In the case here reported (Le Cann et al. 2019) (see figure 15), titanium screws were implanted into rat tibiae.

After enough time for implant integration in the bone, the animals were euthanized and in-situ pull-out tests were performed while SXCT imaging the samples on the TOMCAT beamline (SLS, PSI, Switzerland). Higher trabecular bone content was quantified in the surrounding of the screw in the treated groups, which correlated with increased mechanical strength and stiffness. Differences in screw implantation, such as contact between threads and cortex as well as minor tilt of the screw were also correlated to the mechanical parameters. In situ loading allowed the investigation of crack propagation during the pull-out, highlighting the mechanical behaviour of the interface. In particular, it was shown that not only treatment and bone formation impact the mechanical resistance of the interface, but also the implantation of the screw and parameters such as the contact with the bone cortex, the implant distance from the tibial plateau and the angulation of the screw.

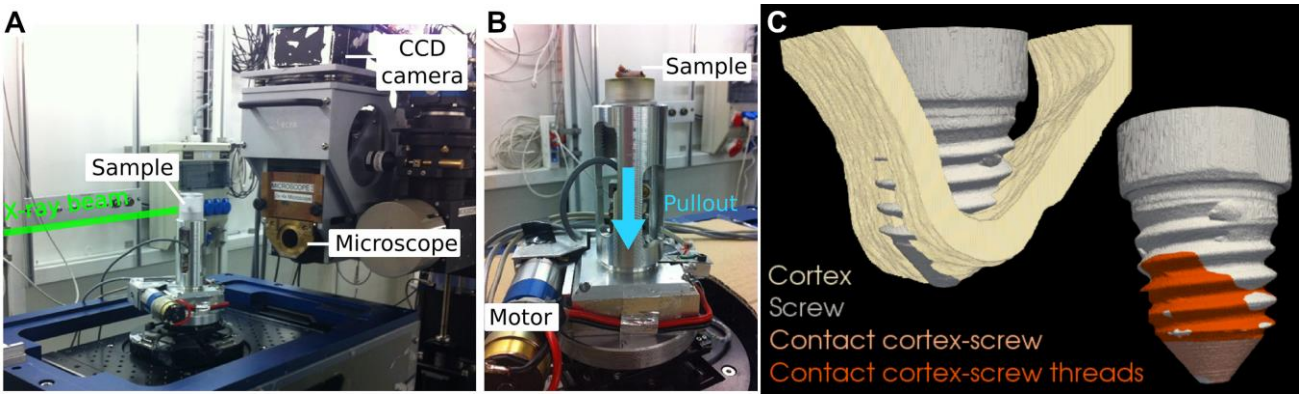

Figure 15: (A) *In situ loading set-up at the TOMCAT beamline, SLS, PSI, Switzerland.* ***(B)*** *Custom made loading device used to pull the screw out of the tibia (sample placement is illustrated without surrounding chamber). The blue arrow indicates the pull-out direction.* ***(C)*** *3D rendering of the contact between screw threads and bone cortex. Modified from (Le Cann et al. 2019).*

Dentistry

Imaging techniques such as optical and electron microscopy have been applied to gain an understanding of the kinetics of enamel demineralisation in caries. Since demineralisation initiates underneath the enamel surface, techniques with high penetration depth are more favourable for the imaging of caries. SXCT can provide 3D data for the quantitative analysis of the enamel morphology and density profile during demineralisation. The disadvantage of this approach is that demineralised teeth must be extracted prior to imaging. An in-situ alternative allowing the exposure of enamel samples to the oral cavity of humans for longer periods of time has been proposed by (Lautensack et al. 2013). Subjects recruited for this study carried enamel samples in their oral cavity for 21 to 29 days using intraoral mandibular appliances.

The method was applied to investigate naturally developed demineralisation in the human oral cavity without causing any decay of the natural dentition. After removal of the intraoral appliances, samples were scanned by SXCT at the BAMline of BESSY-II (Figures 14B and C). This pilot study demonstrated the use of intraoral appliances and SXCT for the quantification of the local degree of enamel demineralisation using methods from 3D image analysis.

Musculoskeletal system

The musculoskeletal system provides mechanical stability and allows complex articulation of the body of all vertebrates. Access to three-dimensional, high-resolution, artefact-free imaging of tissues such as bone, cartilage, ligaments, muscles or whole joints is essential for the study of musculoskeletal pathologies and for the development of new medications.

Virtual histology by means of SXCT has proved the capability of reliable and high-resolution visualisation of phenotypic alteration of the bone-articular cartilage interface in *ex vivo* samples from cases of osteoarthritis and rheumatoid arthritis (Chappard et al. 2006). Understanding articular degeneration and these diseases implies the analysis of both soft (cartilage) and hard (subchondral bone) tissues.

Other imaging techniques suffer from various limitations in this context. Medical and conventional modalities such as clinical CT, ultrasound and MRI often do not provide sufficient image quality and resolution for an adequate visualization of the cellular and microstructural details of biological tissues. Techniques based on visible light microscopy on the other hand lack penetration depth and provide only 2D images. By combining the properties of high 3D spatial resolution and high sensitivity in a non-destructive investigation, SXCT can play an important role for studies cartilage and muscle degeneration as well as for disease evolution or therapy effect monitoring.

Figure 16 shows an example of the application of phase-contrast SXCT for the quantitative assessment of the 3D-cell distribution in *ex vivo* cartilage and muscles from a developing salamander limb: an important animal model for the study of musculoskeletal tissue regeneration (Tesařová et al. 2018). The cellular resolution and superior contrast provided by phase-contrast SXCT allowed the segmentation and characterization of the microscopic orientation of single cells and tissue fibers for the whole animal limb.

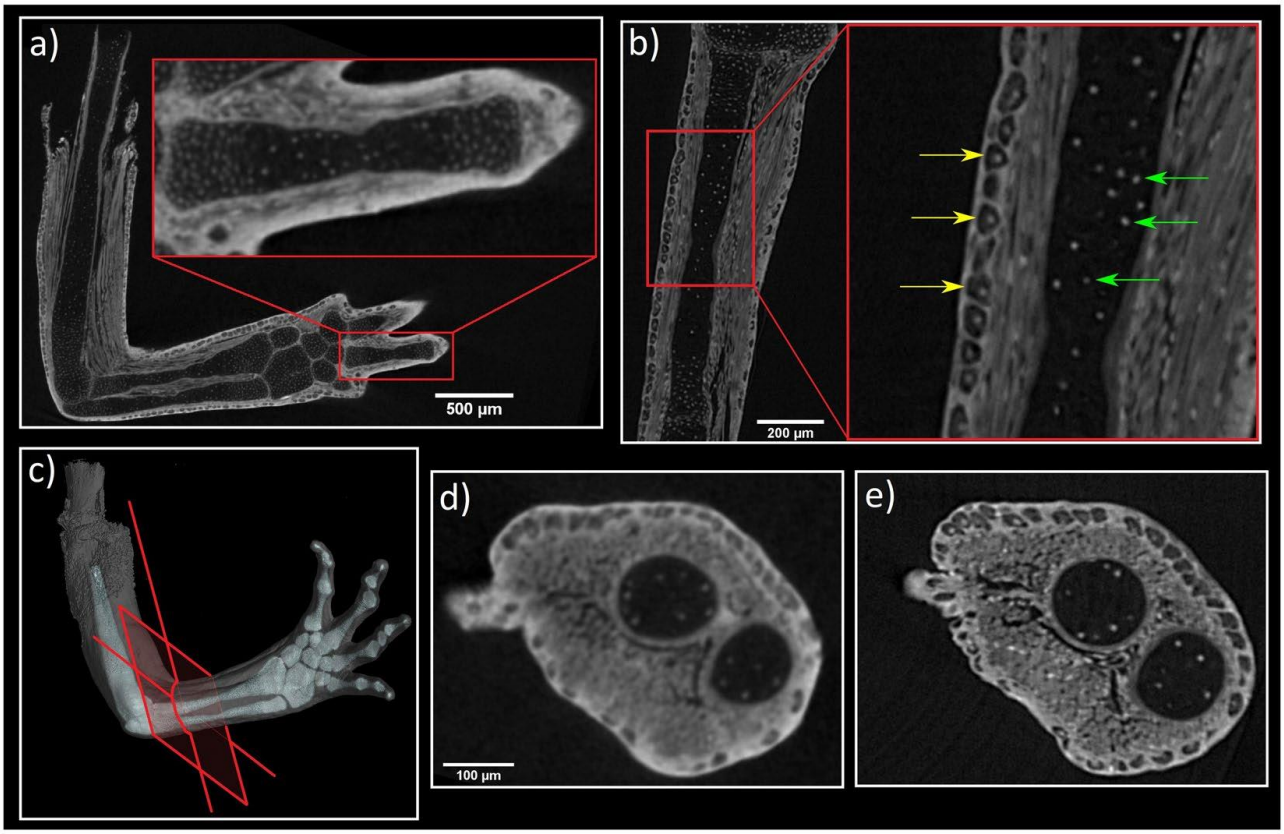

Figure 16: *Comparison between tomographic acquisitions of a salamander forearm obtained ex vivo by conventional and synchrotron XCT.* ***(a)*** *Slice through the salamander limb showing detail of one finger.* ***(b)*** *Phase-contrast SXCT images acquired at the SYRMEP beamline of the Elettra synchrotron facility. The axial sections through the forearm demonstrate the superior resolution of SXCT* ***(e)*** *when compared with a conventional µCT setup* ***(d)****. Reproduced from (Tesařová et al. 2018).*

Soft tissue

With the soft tissue wording, a multitude of different fields of research is included. Besides the specificity of the different research areas, the main limitations of classical imaging modalities for soft tissue remain the same: (i) low penetration allowing only 2D representations when visible light is used; (ii) low X-ray absorption contrast achievable: it is difficult with conventional X-ray techniques to visualize small tissue density differences; (iii) limited achievable spatial resolution using conventional techniques; (iv) alteration of the sample characteristics and/or morphology in certain cases (e.g. staining, sectioning..). SXCT coupled with both absorption and phase contrast modalities provides a powerful tool for the 3D imaging of soft tissues and organs without altering the sample characteristics and providing at the same time high resolution and sensitivity to small differences in density.

Phase contrast SXCT was already applied for imaging cardio/vascular tissues (Fratini et al. 2015; Cao et al. 2015; Garcia-Canadilla et al. 2019; Dejea et al. 2019), liver (Liu et al. 2016; Qin et al. 2017), human cochlea (Iyer et al. 2018) and uterus (Giuliani et al. 2019).

One relevant example of application of phase contrast SXCT for liver imaging is illustrated in figure 17 (Qin et al. 2017). This study visualized the morphological structures of proliferative bile ductules with liver fibrosis samples induced by bile duct ligation (BDL) in rats. Experimental results demonstrated that phase contrast SXCT images can match very well the quality of histological staining and imaging for the visualization of proliferative bile ductules. In particular, it was found that the 3D density of proliferative bile ductules increased with the progression of liver fibrosis. SXCT accurately revealed the architecture of proliferative bile ductules in 3D, including the ductular ramification, the elongation and tortuosity of the branches, and the corrugations of the luminal duct surface. Experimental measurements were performed at the biomedical application beamline (BL13W1) of the Shanghai Synchrotron Radiation Facility in China.

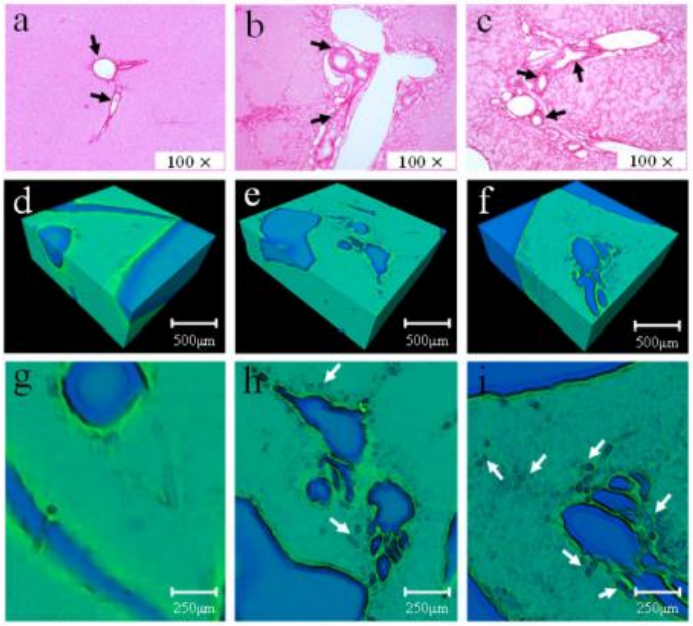

Figure 17: *Illustration and quantification of fibrosis and proliferative bile ductules in liver fibrosis progression.* ***(a-c)*** *Reference histological sections stained by Sirius Red showing pathological tissue and one image (a) of the control group.* ***(d-f)*** *Volume rendering from SXCT.* ***(g-i)*** *Amplified images of the upper surface in (d), (e) and (f). The black and white arrows indicate the fibrous bands and proliferative bile ductules, respectively. Images obtained on the BL13W1 beamline of the Shanghai Synchrotron Radiation Facility with a sample-detector distance of 30 cm; photon energy of 14 keV and voxel size of 3.5 µm). Modified from (Qin et al. 2017).*

Neuronal network

The possibility to answer questions about the structural and functional organization of the brain relies on the acquisition of high quality data on the locations, dynamics, fluctuations, magnitudes, and types of brain activity and structural changes in it. Two broad neuroimaging categories exist: (i) structural imaging which deals with the structure of the nervous system and the diagnostic of large scale intracranial disease and injury; (ii) functional imaging, that is used to diagnose metabolic diseases and lesions on a finer scale, for example the Alzheimer's disease, but also for neurological and cognitive psychology research.

Magnetic resonance (MR) imaging (MRI) and computed tomography can both attain 3D micrometric resolution using small animal micro-MRI and micro-CT scanners. The main limitation linked to the use of the MR is the limited achievable maximum spatial resolution. By combining the properties of synchrotron radiation in terms of beam spatial coherence and high flux SXCT can greatly overcome this limitation. In addition, neuroimaging too finds great advantage in the class of phase-contrast modalities that are enabled by synchrotron radiation. Phase-contrast provides a sensitivity to light elements about 2 to 3 orders of magnitude greater than that of absorption contrast tomography in the hard X-ray regime. Several studies have demonstrated the feasibility of propagation-based, phase-contrast imaging of neurological tissues at synchrotron light sources (Beltran et al. 2011; Zhang et al. 2015; Zhao et al. 2012; Barbone et al. 2018; Massimi et al. 2019). Given its characteristics, BEATS may provide a powerful tool within the neuroimaging research field.

An active field of research in neuroimaging is linked to the Alzheimer's disease. Alzheimer's disease (AD), the most common form of dementia, is a progressive neurodegenerative disorder associated with aberrant production of beta-amyloid (Aβ) peptide depositing in brain as amyloid plaques. Animal models allow investigation of disease progression and therapeutic efficacy. However, the technology to fully dissect the pathological mechanisms of this complex disease at cellular and vascular levels is lacking. Through phase-contrast SXCT, (Massimi et al. 2019) could perform advanced non-destructive 3D multi-scale direct imaging of brain tissues with exceptional contrast and spatial resolution (Figure 18). Phase-contrast SXCT was used *ex vivo* to simultaneously analyse disease-relevant vascular and neuronal networks in AD mouse brain, without the need for sectioning and staining of the tissue. Different typologies and internal structures of Aβ plaques were identified, together with their interaction with the patho/physiological cellular and neuro-vascular microenvironment. Phase-contrast SXCT enabled a detailed visualization of amyloid-angiopathy at capillary level, which is impossible to achieve with other approaches. The work was conducted in two

sessions of experiments: one of micro-tomography (SXCT) and one of nano-tomography. SXCT measurements were carried out on the TOMCAT beamline of the Swiss Light Source.

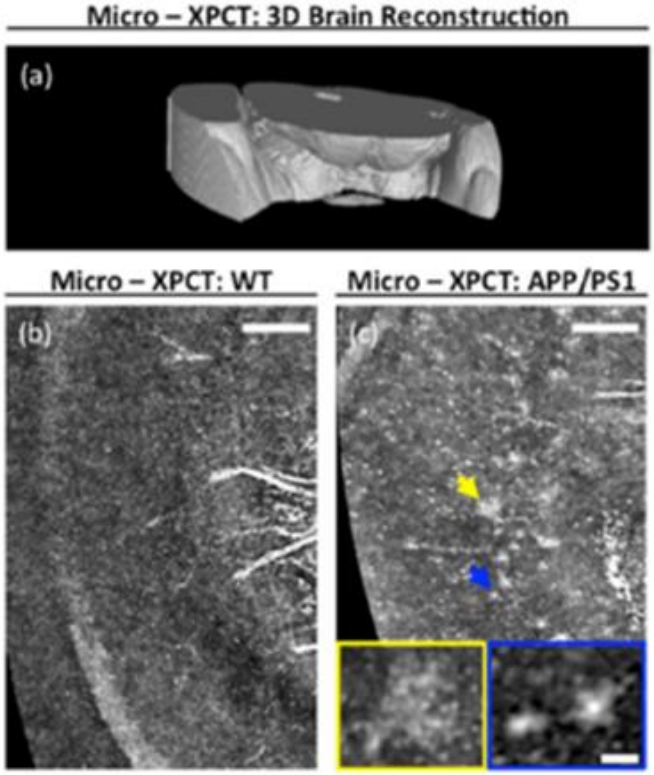

Figure 18: *Phase-contrast SXCT allows a deep investigation of Aβ plaques in Alzheimer's disease.* ***(a)*** *3D SXCT rendering of the virtually selected portion of mouse brain. SXCT slices showing* ***(b)*** *absence of plaques and* ***(c)*** *clearly detectable Aβ plaques in hippocampus of WT and APP/PS1 mice, respectively. (Scale bar=200 µm). Images obtained on the TOMCAT beamline of the SLS (sample-detector distance: 5 cm; photon energy: 17 keV; voxel size: 1.625 µm). Reproduced from (Massimi et al. 2019).*

Another important area of application of SXCT in neuroimaging is the study of Multiple Sclerosis (MS). MS is an autoimmune disease of the central nervous system (CNS) which leads to demyelination, axonal damage and neuronal loss in the brain and spinal cord. Research with animal models can enable the study of MS disease mechanisms as well as the development of new therapeutic approaches. For successful research on animal models, it is central to image with high resolution the microstructural changes occurring in the neuronal tissue in the early demyelination stages of the disease. In particular, microscopic alterations and remodelling of the vasculature are a central component of the demyelination in MS.

Animal studies performed through histology and laboratory CT have described how vascular remodelling in MS is strongly linked to disease progression. However, conventional imaging

techniques often involve sample staining or sectioning, altering the shape, structure and connectivity of the tissue and introducing a potential bias for the quantitative analysis of the tissue morphology. In this context, several works have demonstrated the advantage of phase-contrast SXCT in providing a fully non-invasive 3D characterization of MS lesions in the mouse brain and spinal cord with micro- to nanometre resolution (Cedola et al. 2017; Bukreeva et al. 2017; Begani Provinciali et al. 2020; Fratini et al. 2015). Figure 19 shows an image from the study of (Fratini et al. 2015), in which phase contrast SXCT was applied at the TOMCAT beamline of the SLS to obtain a fully non-invasive (free from staining) characterization of the 3D microvasculature network of mice spinal cord samples. Phase contrast SXCT at BEATS will allow the *ex vivo* study of microstructural modifications and damage of the vascular network in the spinal cord and brain of mice, with implications for serious neurodegenerative pathologies such as MS.

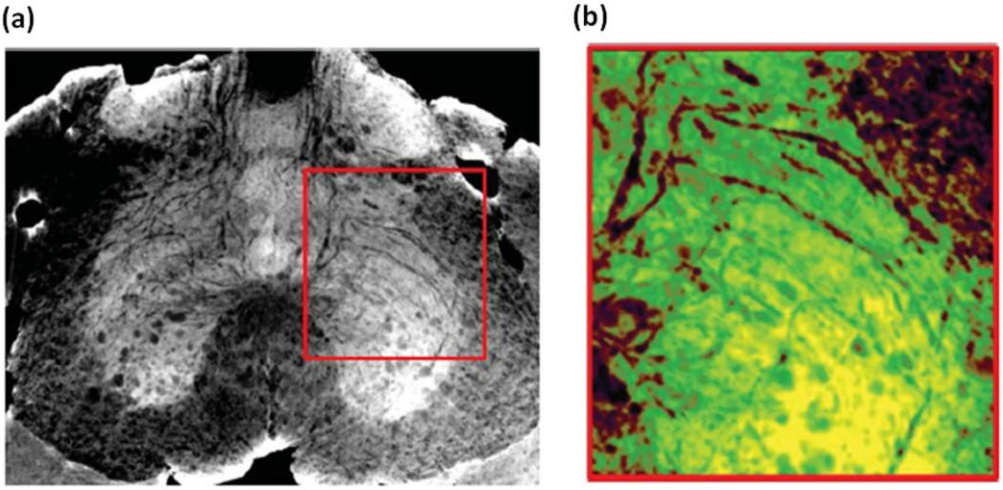

Figure 19: (a) *Phase contrast SXCT reconstructed volume of the mice spinal cord. Image obtained on the TOMCAT beamline at the SLS with a pixel size of 0.64 µm without the use of contrast agent. The photon energy of the beam was tuned to 17 keV and the sample-detector distance was 50 mm.* ***(b)*** *Magnified region demonstrating the possibility to visualize both blood vessels (purple) and nerve fibers (green). Modified from (Fratini et al. 2015).*

Biology

Biomineralisation

Biomineralisation explores the fundamental processes by which organisms produce minerals, increasing our understanding of how biominerals grow, how they achieve their submicron hierarchical architectures and their precise control over crystal orientation and habit, how they are able to stabilise non-thermodynamically favoured mineral polytypes. At the same time, this research area seeks answers to how biomineralisation processes might be harnessed or mimicked to produce new nanostructured, multi-component functional materials for medicine and technology. biomineralisation processes are relevant to biology, geology, biotechnology and medicine, and provide inspiration for chemistry, materials science and nanotechnology.

Synchrotron sources now enable diffraction enhanced imaging, X-ray microbeam analysis, computed tomography (Murdock et al. 2013; Pérez-Huerta et al. 2009; Frølich et al. 2015; Guo et al. 2019) and phase radiography to probe the heterogeneous microstructures of biominerals. Chemical information is obtained from soft X-ray photoemission and infrared spectromicroscopy techniques and these experiments have submicron spatial resolution. High resolution diffraction, small-angle scattering, and X-ray absorption methods all contribute to the picture of the crystalline and amorphous phases formed. Finally, many of these experiments are sensitive to the crucial organic components: the matrix of proteins and polysaccharides that help give biominerals their special properties.

An example of SXCT is reported in (Frølich et al. 2015) in which the pore structures in the biomineralised byssus of Anomia simplex is studied (see Figure 20). Underwater attachment is a significant challenge, and the interest linked to the marine bivalve mussel Anomia simplex is that they use a biomineralised byssus to permanently anchor themselves to substrates. The byssus has a highly complex hierarchical structure and contains over 90 wt% $CaCO_3$. The byssus features a complex set of porosities, presumed to be highly important for the function of the attachment system. The pore space is the focus of the work of (Frølich et al. 2015). The pores network branching was studied in 3D by means of SXCT at the TOMCAT beamline of the Swiss Light Source.

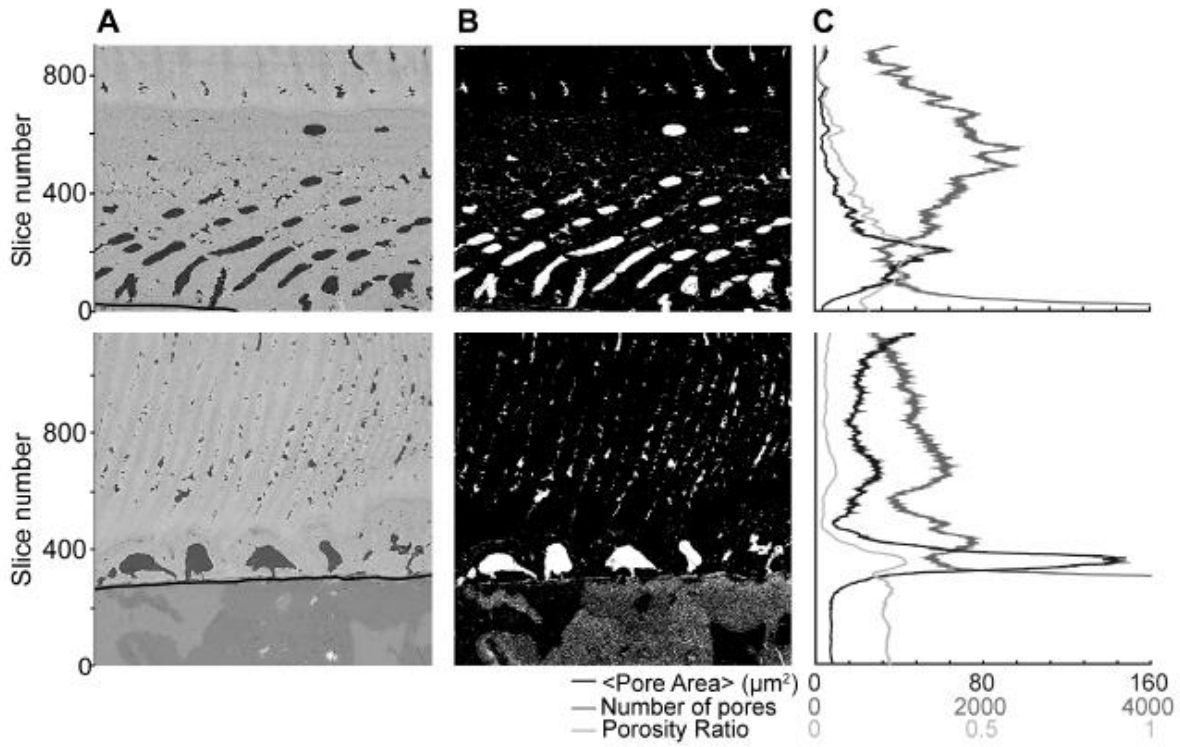

Figure 20: *Image analysis of the pore space in the Anomia simplex byssus in byssus sample 1 (bottom) and 3 (top). Both samples were attached to stones and the substrate is in the bottom part of the slices; for sample 3 the substrate is only partially visible.* ***(A)*** *Orthogonal slices through the byssi, i.e. perpendicular to the slices used as input for region properties characterization. The boundary towards the substrate is marked with a black line.* ***(B)*** *Binarized images of (A) used as input for the porosity analysis.* ***(C)*** *Quantitative porosity characterization: average pore area (dark grey), number of pores (grey), and porosity ratio (light grey) as a function of position in the image stack. Reproduced from (Frølich et al. 2015).*

Another example of application of SXCT for the study of biomineralisation in nature's material is illustrated in Figure 21. The picture shows an axial cross-section and 3D reconstructions of the intricate microstructure of Jania sp., a species of coralline red algae found in the eastern Mediterranean Sea (Bianco-Stein et al. 2020). In this case, SXCT (performed on the ID19 beamline at the ESRF) allowed the researchers to elucidate the sophisticated mechanisms contributing to the low-weight, high-strength structure of the algae. This is achieved by means of a hierarchical organisation of pores along a helical nano- and microstructure which is reinforced by mineral deposition and allows the algae to endure the outer stresses applied by its natural habitat (Bianco-Stein et al. 2020).

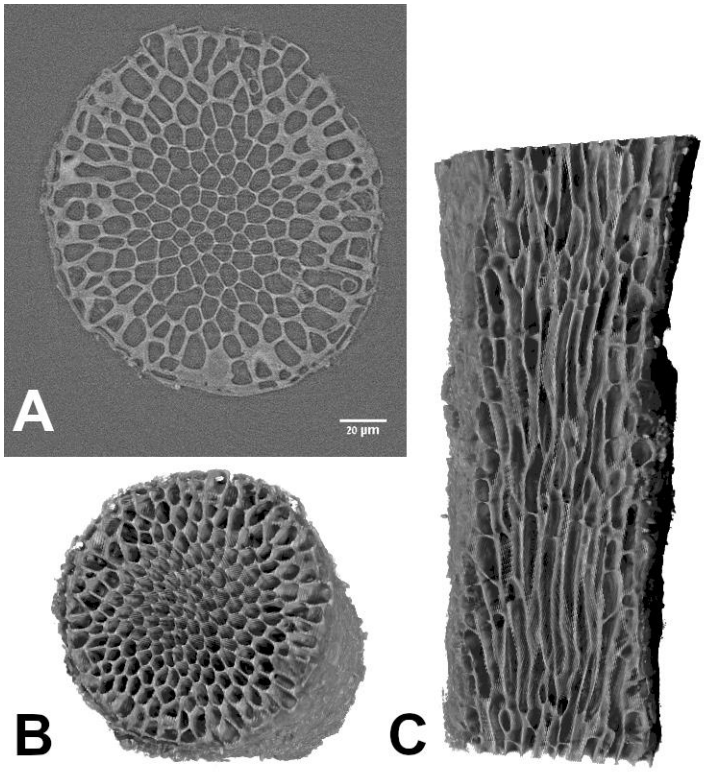

Figure 21: (A) *Cross section of Jania sp. imaged at ID19 of the ESRF using SXCT (Bianco-Stein et al. 2020).* ***(B)*** *and* ***(C)*** *3D reconstruction of Jania sp. based on SXCT data. Courtesy of Prof. Boaz Pokroy.*

Entomology

SXCT offers the opportunity to acquire reliable, high-resolution 3D images of insects. Phase contrast modalities can boost the contrast of images of otherwise low-absorbing anatomical structures. Thanks to the combination of high resolution and contrast as well as to its non-destructive character, SXCT has become an important tool for research in entomology. Figure 22 shows an example of the application of SXCT for the observation and description of a new fossil species of Pycnomerus Erichson (Coleoptera: Zopheridae) from Baltic amber (Bukejs et al. 2019). SXCT imaging was conducted at the BioMedical and Imaging Therapy (BMIT) Insertion Device (ID) beamline of the Canadian Light Source (CLS) synchrotron facility in phase-contrast mode. SXCT allowed reconstructing the 3D morphology of this fossil insect with outstanding resolution without compromising its amber cover.

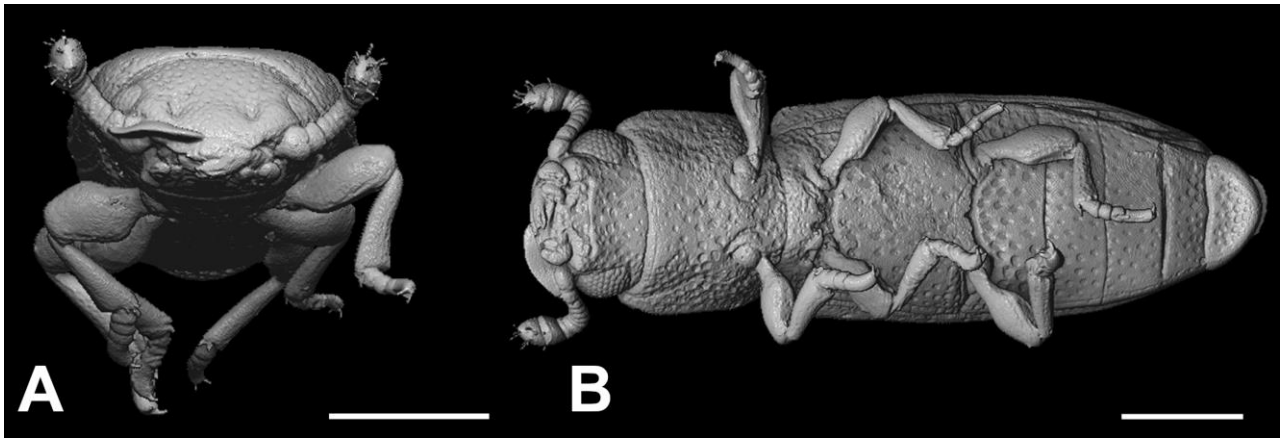

Figure 22: *Characterization of morphological characteristics of a new fossil species of coleoptera: Zopheridae by SXCT imaging. Frontal habitus* ***(A)*** *and ventral habitus* ***(B)****. Scale bars represent 0.5 mm. Phase-contrast SXCT images captured at 30 keV at the BMIT beamline of the Canadian Light Source with sample to detector distance of approximately 16 cm and voxel size of 0.9 microns (Bukejs et al. 2019).*

Researchers from the Agricultural Research organisation Volcani Center in Israel used SXCT to reveal the microstructure of bacteriomes containing endosymbionts located within an adult leafhopper (Weintraub et al. 2014) (figure 23). The 3D image of the bacteriome permitted the researchers to view the structures of the bacteriome – cap and stem – from all angles and with improved detail and contrast in comparison with what is achievable by a standard laboratory CT scanner. Such in-depth views of internal structures of the body of insects allow formulating and answering questions about the form and function of internal organs.

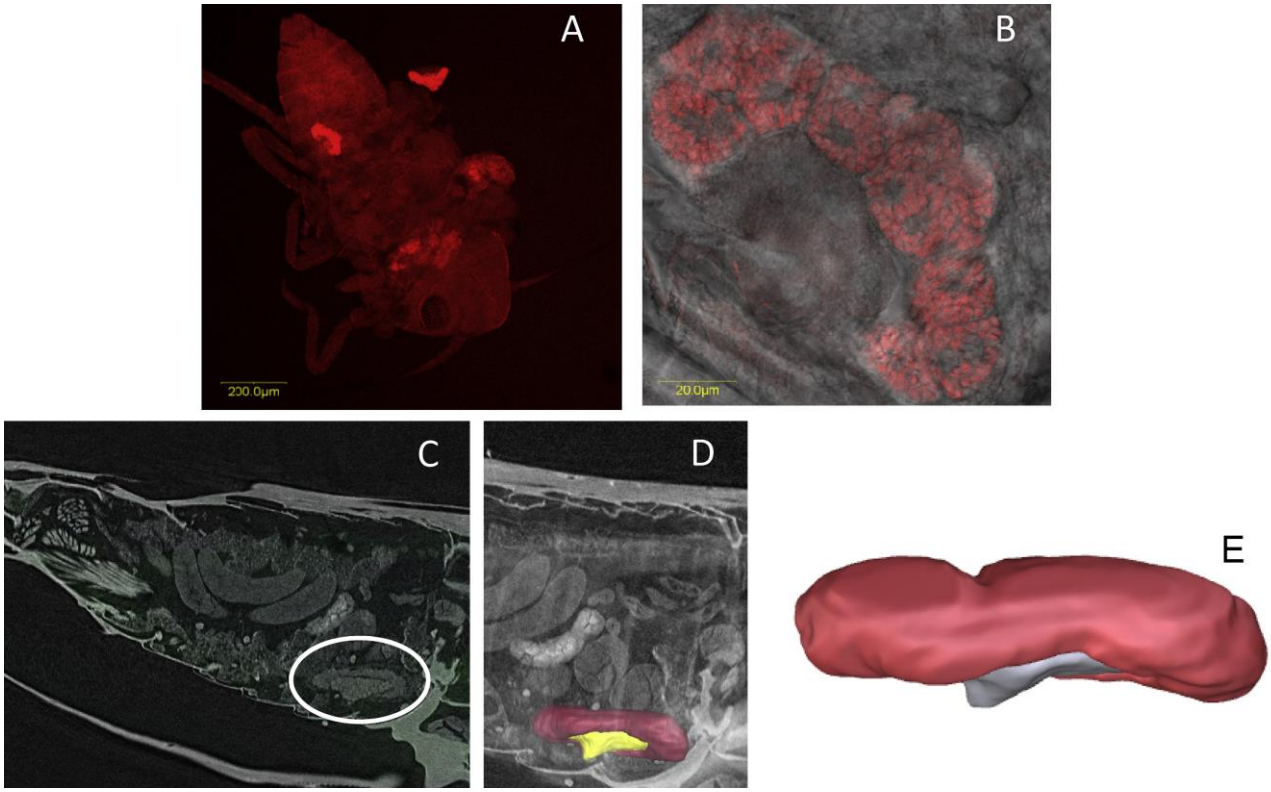

Figure 23: *In situ images of Orosius albicinctus bacteriomes. (A) Bacteriome located in the anterior abdomen in a first-instar nymph. Confocal microscope image with the scale bar indicating 200 microns. (B) Close-up of the bacteriome with the scale bar indicating 20 microns. (C) SXCT lateral view of the abdomen in sagittal plane mid-section through the bacteriome (circled). (D) and (E) 3D SXCT reconstruction of the bacteriome with artificial colouring of the stem and bacteriome. The length of the bacteriome is ca. 650 microns. Reproduced from (Weintraub et al. 2014).*

Food

Microstructure plays a fundamental role in the physiochemical, functional and in some cases nutritional properties of food. The quantitative analysis of the food microstructure has become of critical importance to understanding the physical and rheological behaviour as well as sensory attributes of foods. SXCT is the technique of choice for the visualization of these systems. The quality and identity of the food can be linked to the presence of elements like air bubbles or cells, starch granulates, protein assemblies and food biopolymer matrices (Aguilera 2005; Aguilera and Stanley 1999). Many of those macroscopic properties are poorly understood because of their complex nature, deriving from multiple interactions of processes and food micro-components (Aguilera 2005).

It is possible to find examples of the interconnections between the microstructure and complex physicochemical processes as well as an impact of texture on the taste and flavour quality in many products like bread, coffee, fruits, etc. (Babin et al. 2006; Demirkesen et al. 2014; Koksel et al. 2016; Guillermic et al. 2018; Pittia et al. 2011; Arendse et al. 2016; Mebatsion et al. 2009; Mendoza et al. 2007). Examples from two such studies are shown in Figure 24.

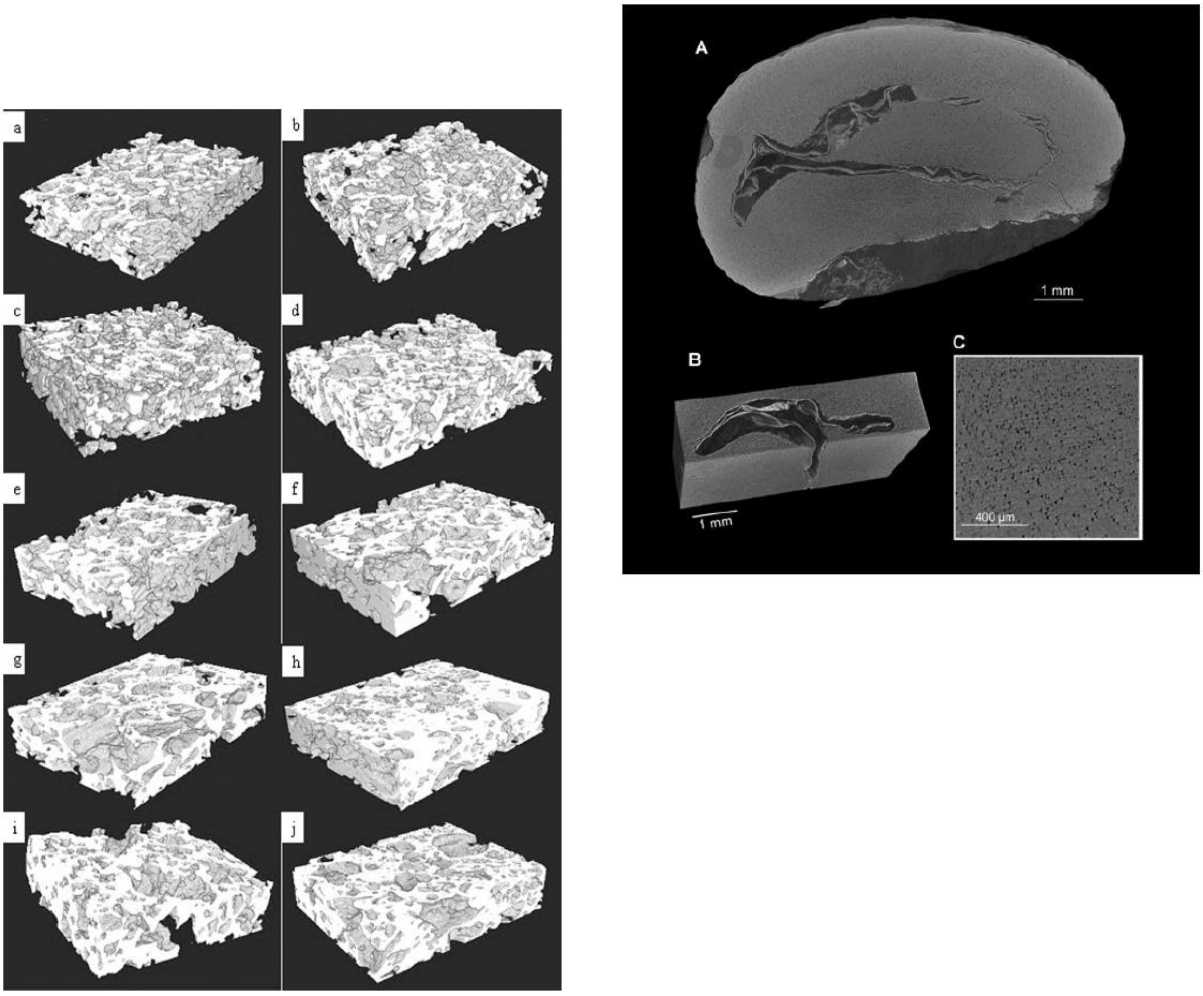

Figure 24: *Right: Green bean 3D rendering images:* ***(A)*** *volume rendering of a portion of the green bean to show global features,* ***(B)*** *volume rendering of the tegumentum zone,* ***(C)*** *zoom of a slice to highlight the bean porosity characteristics. Reproduced from (Pittia et al. 2011).*

Left: Desktop X-ray µCT images of gluten-free bread samples prepared with different gums or gum blends. a-Control breads, b-Breads prepared with methylcellulose, c-Breads prepared with agar, d-Breads prepared with locust bean, e-Breads prepared with guar, f-Breads prepared with xanthan, g-Breads prepared with carboxymethylcellulose, h-Breads prepared with hydroxypropylmethylcellulose, i-Breads prepared with xanthan-locust bean gum blend, j-Breads prepared with xanthaneguar gum blend. Reproduced from (Demirkesen et al. 2014).

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MATERIAL SCIENCES AND ENGINEERING

There are broad applications of µCT techniques in material sciences and engineering characterizing materials in a non-destructive manner. Routine applications include porosity measurements (of closed-cell specimens), depicting cracks or dimensional inspections. The potential of µCT for materials research investigations can be substantially extended with SXCT: drastically increased photon flux allows for short exposure times up to *in situ* studies or excellent signal-to-noise ratio or both. Due to the high flux density, narrow bandwidth radiation can be considered which naturally increases the contrast.

Finally, the almost parallel beam propagation allows for extension of the source-sample distance up to several hundreds of meters which suppresses the impact of the finite source size and therefore gives access to even more sensitive contrast modalities. This section outlines potential uses of the BEATS tomography beamline with respect to materials research and engineering applications with a special emphasis on the user community of the SESAME synchrotron light source.

Light Materials

Engineering of light materials is an essential step in the design of modern transportation systems and construction materials. Weight reduction in packaging and vehicles leads to reduced energy consumption with beneficial effects for the environment. Classical light elements considered for the production of light materials are Aluminium but more recently also Magnesium. Important applications for SXCT in this field are (i) metallurgical investigations on (Aluminium) alloys and (ii) morphological analysis of materials. For the former, a topic attracting high attention are alloys using recycled Aluminium. Due to the recycling process impurities are introduced in the process leading to alteration of the alloys microstructure. Hence, approaches are studied that can control the process and ensure a similar microstructure and therefore the same material performance when recycled Aluminium is used. This can be done with ultrasound or magnetic fields applied during casting.

SXCT is an excellent solution for the analysis of the product microstructure in a non-destructive manner. In situ as well as semi-in situ (the process is interrupted for tomography scans and then continued) studies allow one to reveal the efficiency and impact of the different methods used to trim the microstructure. When operated in high-flux mode, the BEATS beamline will be able to study structures in situ. At the same time a high-sensitivity mode (with a secondary source ensuring improved beam coherence) will allow to investigate the microstructure at high resolution on static samples.

The second field of application (i.e. morphological analyses) is of high relevance for additive manufacturing and foaming of metals. Additive manufacturing consists in the printing of complex shapes and structures using metals such as Aluminium. Controlling the microstructure of the final product remains challenging due to the ultra-fast cooling rates involved as well as to the increased roughness and potential defects (porosity) leading to stress concentration and failure. More generic and hence with high potential for industrial mass production are metallic foams (Figure 25), which can be cast from iron and steel (Kaya et al. 2019). Such porous structures promise substantial weight reduction, while a high specific stiffness is maintained (an ideal solution for damping or support purposes). Classical challenges for metal foams are the standardization of a homogeneous pore structure as well as its reproducibility. Similar as above, different in situ and ex situ studies can be performed at BEATS, which are useful for the optimization of foam properties and to gain knowledge about the casting process.

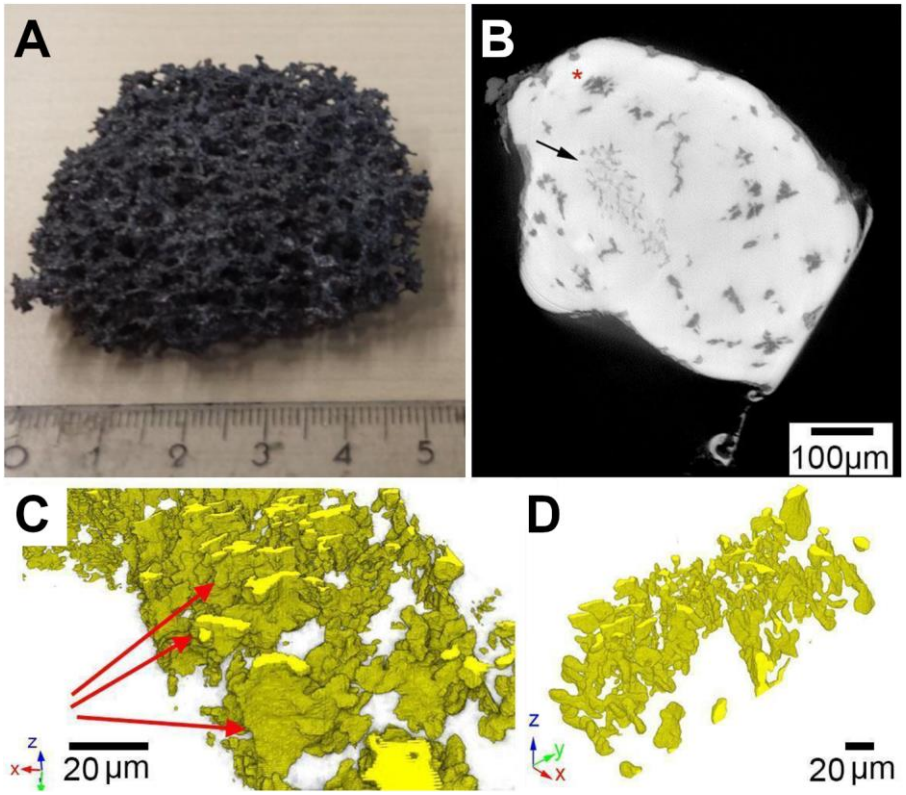

Figure 25: A) *Open-cell grey cast iron foam specimen.* ***B)*** *slices through SXCT reconstruction of a single strut from the foam in A. Different graphite forms can be distinguished. The black arrow points to fine type-d (so-called undercooled) graphite particles, while the red asterisk indicates a single flake graphite particle.* ***C)*** *and* ***D)*** *show 3D renderings with details of different graphite particles of the strut in B. Absorption contrast SXCT experiments were performed at the BAMline of BESSY-II using a double multilayer monochromator (dE/E:1.5%), a photon energy of 34 keV and object pixel size of 2.176 µm. Modified from (Kaya et al. 2019).*

Energy Materials Research

SXCT is a unique source of information on the internal 3D structure and morphology of energy-related materials during operation. Time-resolved, in-situ SXCT has become a standard for the non-destructive observation and characterization of processes related to energy production and storage. Examples of SXCT application in this field are the analysis of degradation of battery electrodes (Schröder et al. 2016), hydrogen storage materials (Gondek et al. 2011), electrolyser cells (Panchenko et al. 2018) as well as operation of fuel cells (Markötter et al. 2019).

Polymer electrolyte fuel cells (PEMFCs) are a promising type of fuel cells for automotive and stationary applications. Understanding water behaviour inside PEMFCs is crucial for a better management of the fuel cell state and in order to guarantee stable and prolonged performance of the device (Hartnig and Roth 2012). SXCT imaging has provided unprecedented insight on the distribution of liquid water (see Figure 26) within operated PEMFCs, allowing the identification and tracking of water droplets that interfere and modify the morphology of the gas diffusion layer (GDL) (Eller et al. 2011). Droplets down to few microns in diameter can be distinguished exploiting phase-contrast, allowing for a superior quality in the segmentation of water and cell material (Markötter et al. 2019).

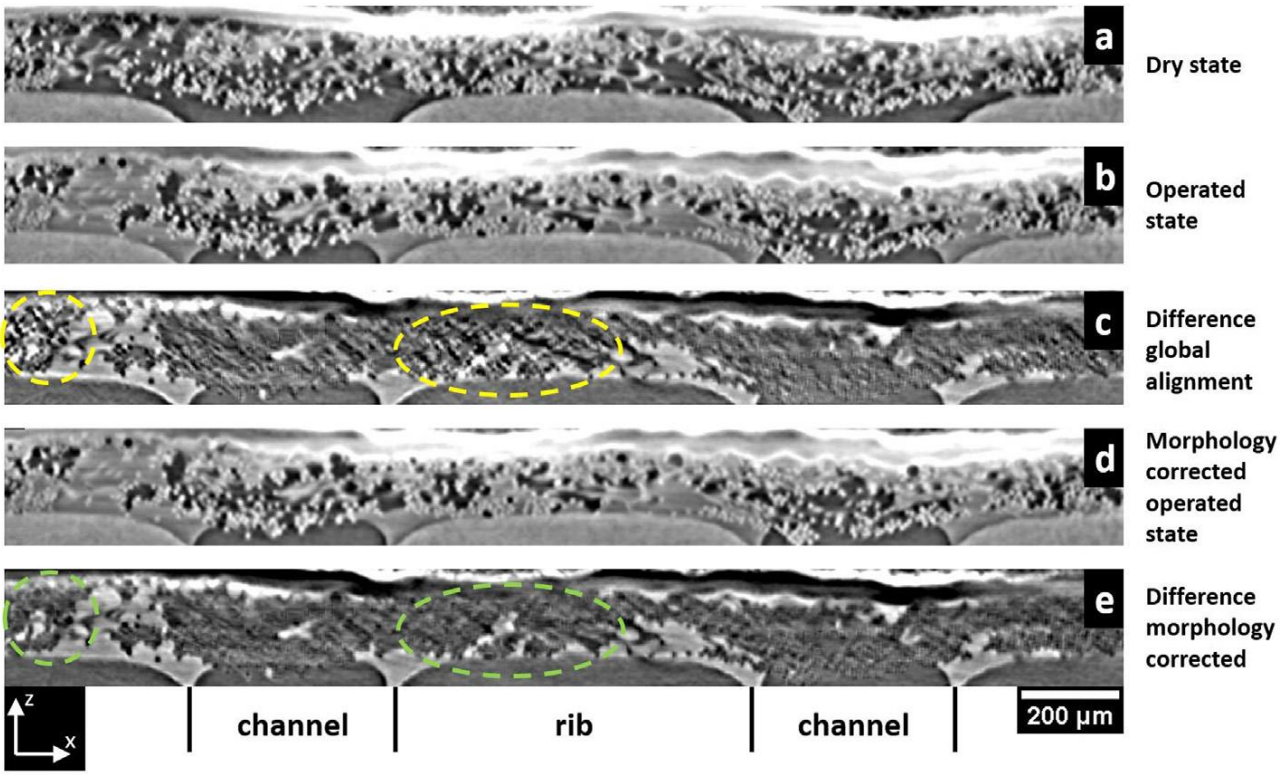

Figure 26: *Analysis of liquid water distributions from SXCT reconstructions of polymer electrolyte fuel cells (PEMFCs). Two datasets are acquired with identical imaging conditions when the fuel cell is dry* ***(a)*** *and operated* ***(b)****. The dry state image is then subtracted* ***(c)*** *from the operated state image. The study from (Markötter et al. 2019) demonstrates a method for the quantitative analysis of water amounts in the cell after correcting for morphological changes of the gas diffusion layer (****d*** *and* ***e****). Phase contrast SXCT data from the BAMline station of BESSY-II (34 keV, double multilayer monochromator dE/E: 1.5%, object pixel size: 2.17 µm. Reproduced from (Markötter et al. 2019).*

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GEOLOGY AND ENVIRONMENT

SXCT provides a broad variety of applications in the fields of Geology and Environment. Important applications in geology include 3D grain analysis to determine grains size, shape and distribution, 3D petrography, as well as the study of porosity and fluid flow analysis. SXCT technique can be successfully applied to investigations in the fields of petroleum/oil geology, rock mechanics and soil science. The following section showcases potential applications of BEATS that are expected to have special relevance for the SESAME user community.

Digital Rock Physics

SXCT can provide simultaneous measurements of several 3D morphological properties of a rock sample and of its internal pore structure with microscopic resolution, providing a fundamental tool for the geological and earth sciences. Compared with conventional laboratory x-ray sources, synchrotron radiation provides order of magnitude higher photon flux which can be exploited by filtering the low energies of the polychromatic "pink" beam. At the same time, high-sensitivity modalities are enabled, for example through the exploitation of phase-contrast imaging. This allows a detailed analysis through digital computation of different properties of rock samples (Digital Rock Physics) such as porosity, permeability, elastic modulus, and wave velocity. Figure 27 illustrates the application of pink beam, phase-contrast SXCT for the analysis of several morphometric and fluid-dynamics-related properties of sandstone core (reservoir) samples from the subsurface of an oil field.

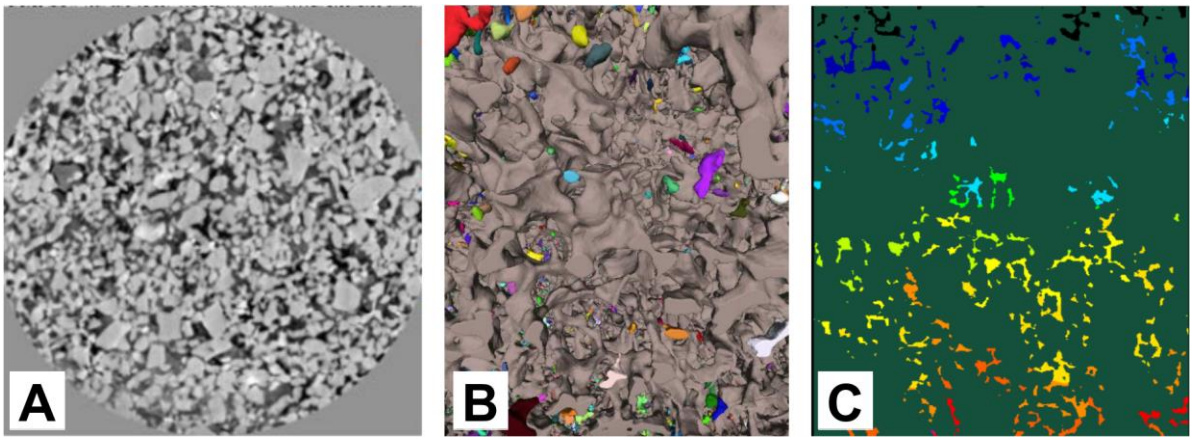

Figure 27: A) *2D slice through sandstone core acquired @ ID19 of the ESRF. Phase-contrast SXCT data collected with pink beam and 2.25 µm voxel size.* ***B)*** *and* ***C)*** *Screenshots illustrating the 3D analysis of*

the rock porosity including average percolation path and tortuosity. (Kakouie et al., n.d.). Courtesy Shiva Shirani.

Figure 28 shows an example of the application of pink-beam phase-contrast SXCT for the non-destructive quantitative analysis in 3D of microstructural changes of limestone samples after treatment with nanolime suspensions, a common procedure in cultural heritage conservation works

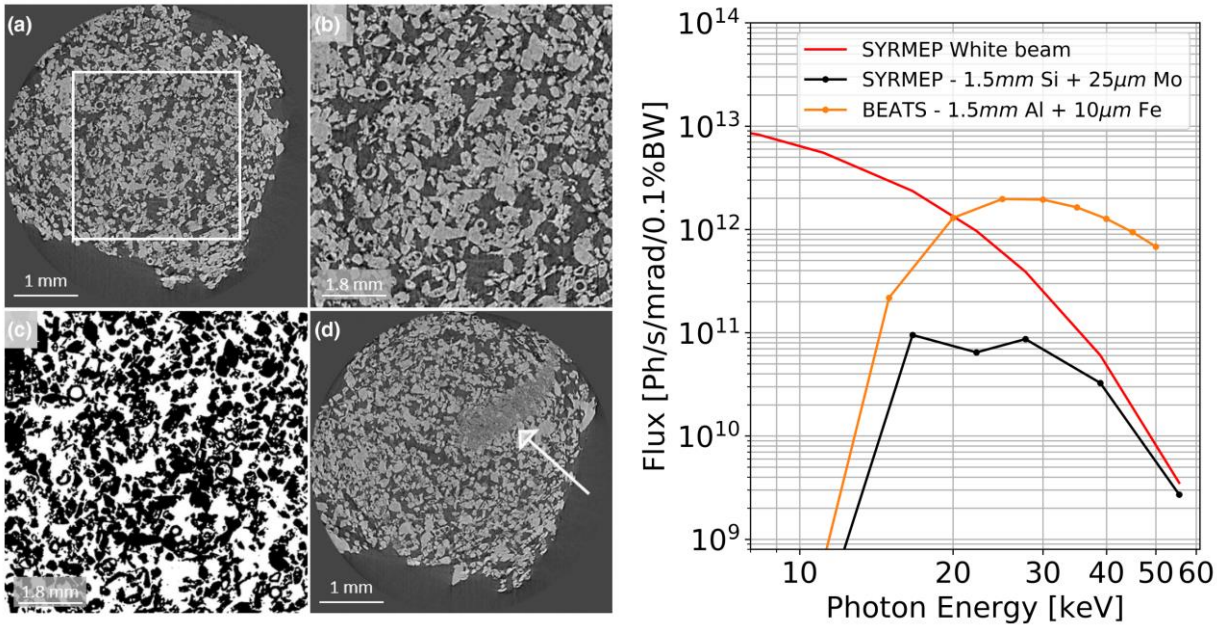

Figure 28: LEFT: *Pink beam phase-contrast SXCT axial slice* ***(A)*** *of Maastricht limestone sample. Detail of the white rectangular region of interest before* ***(B)*** *and after* ***(C)*** *image segmentation for quantitative analysis.* ***D)*** *Detail of dense solid heterogeneity. Phase-contrast images were taken at the SYRMEP beamline of Elettra using a pink beam with average photon energy of 24 keV and object pixel size of 1.4 µm.* ***RIGHT:*** *plot showing a comparison of the simulated pink beam flux (in 1 mrad) used at SYRMEP for this study (black) with the expected pink beam of BEATS tailored to similar energies (orange). Right image reproduced from (Ševčík et al. 2020).*

Petroleum science and engineering

The increasing demand of energy and dependence on energy imports is a critical concern for some SESAME members as they do not have conventional fossil fuel reserves. However, there are significant non-conventional deposits in form of oil shales and extensive volumes of natural gas in the Eastern Mediterranean. Oil shales exist in organic-rich and fine-grained

sedimentary rock containing kerogen (a solid mixture of organic chemical compounds) from which liquid hydrocarbons can be produced. The known deposits underlie about 60% of Jordanian territory and the reserves stretch to Egypt, Israel, Syria and Turkey. According to different surveys and estimations the oil shale deposits in Jordan alone amounts to 30-60 billion tons, which are probably the 8th largest oil shale resources in the world.

Until 2005 no detailed exploration and extraction of the oil shale deposits in Jordan was done. However, due to increasing energy demands in the region Jordan granted concessions to several international oil and petroleum companies to develop oil shale extraction in some deposits with concrete plans to utilize its combustion for power generation.

There is a large economic potential of oil shales at least in Jordan. Several geological and petrochemical studies have been carried out in the region to characterize the deposits and the quality of the oils shales. In that respect microscopic analysis, for instance, of the mineral distributions in shales has received much attention. Moreover, the detailed understanding and modelling of morphology, microstructure, fluid transportation properties and fracturing of shales remain key tasks in petro science and engineering for which X-ray micro-tomography has the highest potential to become an important and inevitable analytical tool.

In non-conventional sites, as in oil shales the hydrocarbons are tightly confined and their extraction is often difficult and not always economically viable. The usual method to extract the hydrocarbons is pyrolysis, in which the kerogens are converted into liquid or gaseous phases while breaking up the shales. Although this method has been applied for many years, the process is from a petrochemical and –physical aspect still poorly understood. A better knowledge of the various mechanisms on the microscopic level involved in the production and migration of hydrocarbons in porous media could lead to much better and more efficient extraction processes.

The power of X-ray micro-tomography to characterize and analyse the evolution of the fractures in oil shales during pyrolysis was impressively demonstrated at the TOMCAT beamline at SLS (Saif et al. 2019). Time-resolved SXCT allowed the study of the pore-scale dynamics and the evolution of fracture initiation, growth, coalescence and closure. A laser-based heating system was used to pyrolyse an oil shale sample up to 600 °C. The sample was taken from the Eocene Green River formation in the US. The work provided quantitative guidelines for the application of oil shale pyrolysis, showing how the connectivity of the micro-fracture network developed from around 350 °C onward. The results demonstrate that such a state-of-the-art imaging with synchrotron X-ray tomography combined with laser-based

heating can provide a powerful method to characterize the dynamics during oil shale pyrolysis and to help to optimize hydrocarbon recovery.

It is evident that BEATS would allow many opportunities to characterize the full range of hydrocarbon extraction in oil shales also for Jordan and for the other deposits in the SESAME members. The oil shales from the Jordan deposits, for instance, are of higher quality with larger caloric values than the US samples and are on the pathway of being utilized on an industrial scale. Thus, tomographic measurements would provide valuable information for the science, engineering and technology of oil shale related processes.

More generally, such tomography methods are also useful to analyse and model any multi-phase fluid systems in permeable media. A wide range of geological phenomena involves porous media and the understanding of migration, flow and reaction, for instance, in subduction zones, aquifers, or in sediments and rocks.

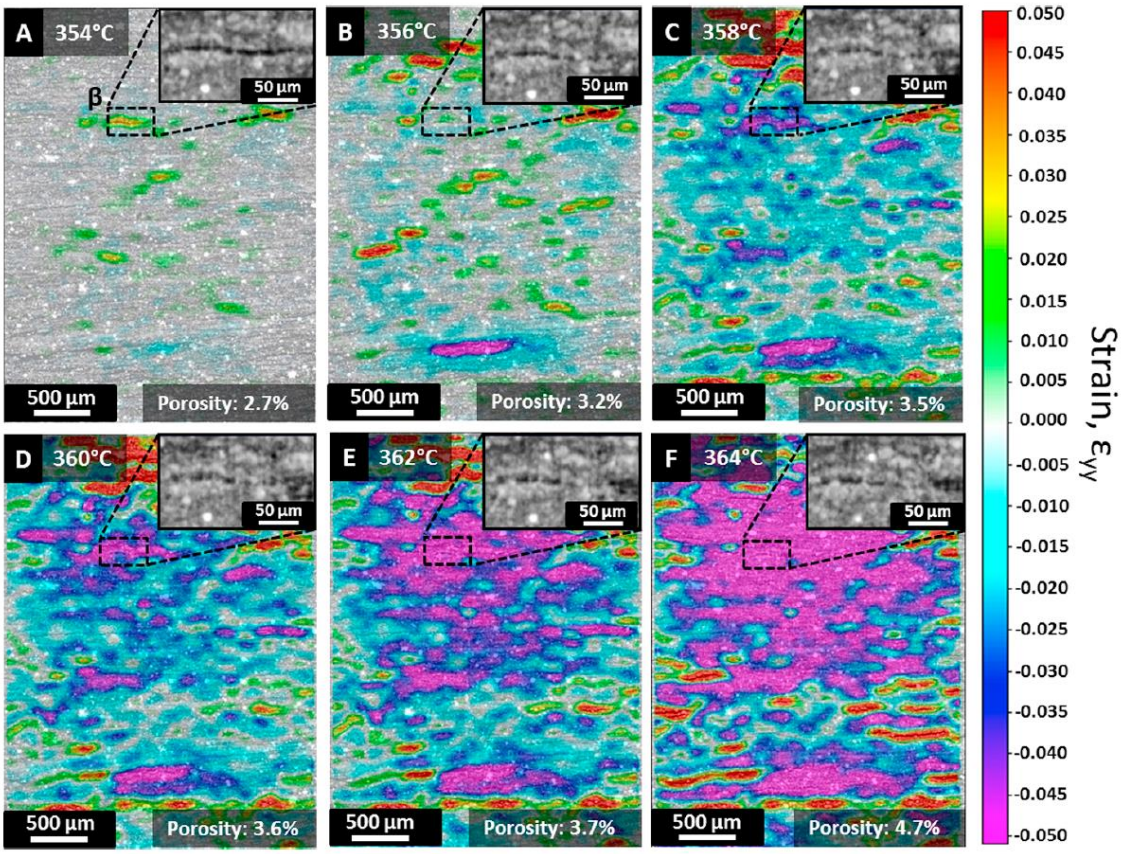

Figure 29: *Taken from reference (Saif et al. 2019): The development of the micro-fractures and strain components εyy during oil shale pyrolysis between 354°C and 364°C revealing that with increasing pyrolysis temperature there is temporary closure of minor fractures due to local compressive stresses.*

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SERVICES TO INDUSTRY AND PRIVATE SECTOR

Synchrotron radiation is used increasingly as tool for R&D, driving forwards innovation for enterprises and industry across advanced and developing economies around the world.

Structural biology, using X-ray diffraction and small-angle scattering, has long been the mainstay of industrial use of light sources with its daily use in drug discovery pipelines within pharma and biotech companies. Nowadays, all medium and high-energy synchrotron light sources provide services for pharma through easy-to-use remote access and mail-in protein crystallography services. Much effort has gone into creating these routine, cost effective services, with common standards and developments, and benefits spill over from the industrial service drivers to also support the public access/peer review user programmes.

But other techniques are seeing increasing commercial demand with use by industry in areas such as aerospace, agriculture and food, health technology, consumer products, energy, engineering and metallurgy, nanotech and catalysis, to name but a few. Indeed, the last decade has seen an increasing interest by industry related to the life cycle of materials: development, manufacturing, operation, ageing, wear-and-tear, preservation, restoration, recycling, evaluation and more. Applications cover many fields, including pharmaceuticals and biotechnology, chemistry and catalysis, consumer products, construction and transport engineering, nanotechnologies, energy, environment, metallurgy and advanced materials. Powder diffraction, Small- and Wide Angle X-ray Scattering (SAXS/WAXS), Infrared (IR) spectroscopy, X-ray Photo-electron Spectroscopy (XPS), X-ray spectroscopy and X-ray microscopy are also requested regularly by industrial clients of the synchrotron light sources.

Another such technique is Synchrotron X-ray computed tomography (SXCT) or ultra-high-speed radiography, with its broad applicability across many scientific disciplines. SXCT is now on the cusp of emerging into such a regime of democratised commercial access mirroring macromolecular X-ray diffraction and scattering. Below, typical industrial applications in the context of the identified BEATS Science & Technology drivers are given. They are mostly taken from the ESRF Industry brochure (http://www.esrf.eu/files/live/sites/www/files/Industry/documentation/ESRF-Indus-2018.pdf), but they are representative for industrial applications of the SR centres in Europe.

Cultural Heritage, Archaeology, Palaeontology

Cultural Heritage: Art characterisation (art galleries, art museums, private collectors, governmental organisations, religious institutions); accurate high resolution (digital or 3D printed) replicas for display in museums/galleries other than the original, or in remote locations; securing records of irreplaceable/indispensable/fragile works of art; conservation, preservation, restoration pre-characterisation, intervention documentation, and monitoring.

Archaeology: Characterisation of remains/artefacts (private museums, state museums, private collectors, governmental organisations, religious institutions); accurate high resolution (digital or 3D printed) replicas for display in museums/galleries other than the original, or in remote locations; securing records of irreplaceable/indispensable/fragile museum objects or remains; conservation, preservation, restoration pre-characterisation, intervention documentation, and monitoring.

Palaeontology: Characterisation of paleontological remains (private museums, state museums, private collectors, governmental organisations); accurate high resolution (digital or 3D printed) replicas for display in museums/private collections other than the original, or in remote locations; securing records of irreplaceable/indispensable/fragile paleontological remains; conservation, preservation, restoration pre-characterisation, intervention documentation, and monitoring.

Health & Food

Health: Characterisation of implant structures and follow-up of their fatigue and ageing; watching medical devices under operation; following bone structure modifications in e.g. osteoarthritis; visualisation of three-dimensional vascular and neuronal systems for pre-clinical investigation of neurodegenerative pathologies; tracking locations of injectable drugs; following pill dissolution to allow for better release mechanics.

Nutrition: Understanding how the microstructure of food changes due to temperature abuse; improvement of freezing and unfreezing procedures for dehydrated fruits and vegetables;

texture analysis to improve food qualities; enhancing cooking and processing procedures; seed structure for improved crop tolerance and yields.

Material Science & Engineering

Advanced Materials: High-resolution strain microscopy to control the strain field in silicon close to copper-filled through silicon vias (TSVs).

Aerospace & Automotive: Behaviour of advanced high-strength steels under tensile stress to track void nucleation; energy-absorption properties under deformation of a dense foam, such as expanded polypropylene (EPP), inside headrests and bumpers that decelerates passengers to minimise stresses on them in case of accidents.

Energy: *In situ* studies to follow materials in batteries under operating conditions; watching manufacturing processes to optimise energy use.

Engineering and metallurgy: track changes occurring inside materials during formation on the static to millisecond scale; look inside concrete mixtures for phase and structure mapping during wetting; Follow aging processes at microscopic scales with long-term sample monitoring; damage and failure testing on coatings using X-ray micro-tomography; watch material flow in casting and injection processes; monitor solidification processes in melts and alloys.

Environment & Geology

Modelling rocks for oil and gas industry; soil analysis for environmental remediation; permeability and determination of microstructure of rocks; use of digital rock analysis to extract sub micrometric to centimetre scale geological and petrophysical information, as well as multi-phase fluid-flow data based on pore-scale displacement processes from digitised rock samples.

Industry at SESAME – an outlook

Industry access and support in the context of BEATS, and in general for SESAME, needs to be clear and adapted to serve the industrial needs in the region. This is required as SESAME's statutes forbid commercial confidential access. Nevertheless, the creation of an "industry liaison" or "business development" office, or a "SESAME task force", comprising the beamline principal scientists and senior management should be envisaged to provide a firm anchor point for activities linked to industry engagement.

To open the way for industry to be able to benefit from the capacities and skills available at SESAME, research relationships between the SESAME light source and industry for use of the facilities need to be created. This can happen via academic multipliers, thereby ensuring publication of results to agreed standards (e.g. peer review papers, patents, public reports), with industry access to light sources via the public peer review programmes. It should be noted that the vast majority of participants to the OPEN SESAME supported Industrial and Applied Science workshop held at SESAME in 2019 were from academia (http://opensesame-warehouse.org/index.php/workshops/2-uncategorised/16-sesame-1st-industry-and-applied-science-workshop).

It seems realistic therefore that industrial links at SESAME will, at least initially, grow via its academic networks, and this is an opportunity to be seized. In Europe, it is generally estimated that between 25-40% of work done via the peer review programmes has industrial involvement in some way – for example via pre-competitive research collaborations, funded PhD student implication or exploitation of the results. At some light sources, industry has taken a direct interest in operating actual beamlines, via either ownership or a strong partnership, permitting a strong implication and use of the technique. Examples include beamlines at the Advanced Photon Source (United States), Swiss Light Source (Switzerland), MAX IV (Sweden) and SPring8 (Japan). Building upon the established science and technology drivers for the BEATS beamline, the above concepts need to be further developed for all the SESAME beamlines, as they constitute an important element for the long-term sustainability of the facility.

BEATS USER COMMUNITY BUILDING AND PROSPECTS

In comparison to the more established SXCT user communities in Europe (as canvassed e.g. through ESUO, the European Synchrotron and free-electron laser User Organisation) the user communities in the SESAME region (EMME region and beyond) are rather incipient (as canvassed through systematic contact with existing tomography beamline scientists and SR facility user offices in Europe, as well as through BEATS partners, with requests for any information on any incoming SXCT users from the SESAME region – this query brought in a close to nil result; through SESAME SUC Representatives; through a survey on user expectations on BEATS; and through on location observations). This may be seen as a challenge, but also as an opportunity. Below we present the ongoing **targeted efforts and action as to advancing future BEATS SXCT user communities** in the SESAME region and its neighbourhood. Within this section we describe what **actions have already been undertaken as to BEATS User Community Building**, followed by a **detailed outline of plans** for the remaining 30 project months. In this context we also review what is **outlined in the original project proposal**. We will focus fully on User Community Building (WP2, tasks 1.2-1.4) in this section – the four Scientific Case (WP2 Task 1.1) domains are covered in separate sections. The user community building activities comprise targeted BEATS User Community Building workshops in each SESAME Member (Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, Palestine Turkey), industrial engagement, and e-learning/blended learning materials for (future) users. A final section focuses on **actions and opportunities to align BEATS with other projects, networks and initiatives**, regionally, and at the level of EU, as well as on the global scale, in order to further enhance BEATS User Community building activities through synergies with these. Links to these networks bring benefits and added value to make user communities for SESAME's BEATS tomography beamline stronger.

Table 3 in the Introduction provides a first overview of the identified institutional user community contacts in the region broken down into the four relevant scientific application areas. It reflects efforts undertaken within the BEATS projects (after 18 months), and serves as a guideline for future actions as presented in detail below.

Targeted efforts and actions to advance BEATS user communities

Based on consultations and analytical discussions with regional users, SESAME SAC, SUC and Council Members, SESAME Directorate, LAAAMP representatives from the region, and other stakeholders and experts, we determined specific targeted efforts and actions as to advancing these user communities in the SESAME region and its neighbourhood. These comprise of (1) user community building workshops (see table below), coupled with (2) targeted one-on-one in-person meetings and frequent follow-ups with individuals and organisation heads with clear applicability of SXCT as to their research domain (see e.g. Cyprus, Palestine, and Turkey success stories below), (3) submission of substantial project proposals for external funding (BioMERA, awarded, 1 million Eur 2019-2023; builds up user community for SESAME BEATS, with users readying themselves with BioMERA custom-built walk-in hutch microCT facility use, enabling them also to select the optimal samples for BEATS data capture) (see table below), (4) mentoring on preparatory laboratory analyses, sample selection, mounting options, and beamtime proposal submission (two governmental organisation beamtime proposals already submitted within this framework; several more research organisation beamtime proposals; these organisations will therefore be more ready for BEATS submission call), (5) graduate and postdoctoral level teaching on SR and Cultural Heritage/(Bio)archaeology in Cyprus (this has also by now resulted in beamtime proposals to SESAME being submitted by PhD students; expected number of postdocs and students submitting beamtime proposals to BEATS once operational: 7 [from Cyprus]).

BEATS User Community Building Events		
Event	**Date**	**Status**
BEATS Scientific Case Workshop, Nicosia, Cyprus	27-28 June 2019	Completed
BEATS User Community Building Event, Nicosia, Cyprus	11-12th November 2019, with additional events until 15th Nov	Completed
BEATS User Community Building Event, SESAME, Allan, Jordan	30th November and 1st December 2019	Completed
BEATS session at the 45th International Nathiagali	20-21 July 2020	Completed

Summer College (INSC), Pakistan		
Iran: BEATS User Community Building Event (interactive online event)	16-17 September 2020	In preparation
Pakistan: BEATS User Community Building Event (interactive online event)	7-8 October 2020	In preparation
Turkey: BEATS User Community Building Event (interactive online event)	11-12 November 2020	In preparation
In-person follow up events planned for Iran, Pakistan and Turkey (when pandemic measures allow), including e.g. at 46th INSC, Pakistan	2021	Planned
Israel: BEATS User Community Building Event	2021/2022	Planned
Egypt: BEATS User Community Building Event	2021/2022	Planned
Palestine: BEATS User Community Building Event	2021/2022	Planned

NB. In addition to the above, intense personalised contact modes are pursued with organisations and individuals in all SESAME members and beyond (including via funded projects such as BioMERA, cf. elsewhere in this document).

Externally funded initiatives contributing towards BEATS User Community Building		
Project	**Funding**	**www page**
BioMERA Platform project	1 million Eur Funding from: RIF Cyprus (2019-2023)	https://biomera.cyi.ac.cy
FF-MAC project	>1 million Eur Funding from: RIF Cyprus (2019-2022)	https://face2face.cyi.ac.cy
LAAAMP	FAST Grants (1888 Eur per researcher per 2-month stay at a participating AdLS) Funding from: ISC (International Science Council)	https://laaamp.iucr.org

COMULIS	Travel funds under STSM (Short term Scientific Missions) Funding from: EU H2020 COST Action	https://www.comulis.eu
Pending project proposal: SESAME School for Synchrotron Applications	Pending Funding applied from: Abdus Salam ICTP	

BioMERA (https://biomera.cyi.ac.cy) is a new research platform involving a custom-designed walk-in hutch micro-CT at the Cyprus Institute, unique in Cyprus and the region, as well as other instrumentation, sample preparation facilities, data management and analysis (including HPC), and expertise. It involves a research infrastructure for the study of human health (both ancient and modern) with opportunities for applications in archaeology, cultural heritage, heritage science and all other domains with material samples. The enhancement of this new research unit through the Host Organisation (The Cyprus Institute) contribution of additional instrumentation, such as FTIR (Fourier transform infrared spectroscopy), XRF (x-ray fluorescence), and high magnification digital microscopy, enables cutting edge analyses of human tissues and remains, and pharmaceuticals, in combination with the micro-CT facility. The BioMERA micro-CT and other instrumentation, expertise and sample preparation facilities available through the BioMERA platform will also provide a wide variety of opportunities for applications in heritage science, health and biology, environment and geology, as well as materials science. Further, material samples, key to research in all Cyprus Smart Specialisation Strategy domains, can be explored through the BioMERA platform. The BioMERA platform has key links to synchrotron radiation facilities and major national and European projects (FF-MAC, RIF – https://face2face.cyi.ac.cy; COMULIS - https://www.comulis.eu; Iperion HS - http://www.iperionhs.eu, E-RIHS - http://www.e-rihs.eu). The BioMERA platform (INFRASTRUCTURES/1216/0009) is co-financed by the European Regional Development Fund and the Republic of Cyprus through the Research and Innovation Foundation (RIF; 1 million Euros, 2019-2023).

All the above, beyond the user community building workshops, is over and above what we stated in the project proposal, and brings added value, as well as increased strength and diversity to the user communities being built up for BEATS. Another key domain of focus is the industrial/enterprise engagement, through project activity on industrial brochure which is being planned. Further actions to engage the industry have included the engagement of Medochemie, the major pharmaceutical company based in Cyprus, with over 30% share of all

Cyprus exports, into the BioMERA project, and through this, into exploring BEATS and SESAME use. Meetings between SESAME beamline scientist (IR) and the company representative have already taken place.

As to the e-learning and blended learning materials, this activity is scheduled for the second half of the project, after a more detailed, overall view is at hand as to the range and diversity of the future BEATS user communities in all SESAME members. User community building activity is on track with two user workshops already organised, and the 2020 scheduled user workshops with Pakistan, Iran, and Turkey transformed into online interactive webinars with close follow-up. We look forward to the opportunity to re-schedule these as in-person meetings, following closely the governmental guidelines as to COVID-19 in each BEATS workshop location.

Actions already undertaken on BEATS User Community Building

The two major user community building events which already took place are the following: (1) Cyprus, and (2) Jordan. In addition to these, user engagement as to all SESAME members took place also within the Scientific Case Workshop, with participation across SESAME members, in Turkey (main event in the future, see below), as well as online for Pakistan, within the framework of the 45th International Nathiagali Summer College (see below, and Annex 1).

The Scientific Case Workshop took place over two days (27-28 June 2019) involving future regional users, directly following the SESAME Council meeting held in Cyprus, and in connection with the Signing Ceremony of the Memorandum of Understanding between SESAME and the Cyprus Institute. This meant that the workshop was held in the presence of SESAME Directorate (SESAME Director, Scientific Director, Technical Director and Administrative Director), SESAME Council President, SESAME SAC Chair, as well as members of the SESAME Council and SAC. Further participation included the National Chief Scientist for Cyprus, and delegates from the Ministry in charge of research, technology, and innovation in Cyprus. The workshop focused on exploring various application domains of SXCT, and in specific, applications relevant to the SESAME region (Cyprus, Egypt, Iran, Israel, Jordan, Turkey, Pakistan, Palestine). The workshop was open for participation by all researchers and interested parties across academic disciplines, industry, governmental services, and other

interested parties, regardless of domain, as any area with material samples can benefit from the application of high-resolution tomography to specific problems or research questions. The workshop took place at the Cyprus Institute (www.cyi.ac.cy) in Nicosia, Cyprus, with 61 registered participants, and with additional non-registered participants. The participants consisted of regional delegates and researchers, local participants as well as SESAME SAC, SESAME Council Members, SESAME Directorate and other SESAME personnel, BEATS partners, and external experts. Invited presentations laid the ground for discussions on science applications, and how these may feed into the design of the BEATS tomography beamline at SESAME, the first in the region. Talks covered the following topics: Status of SESAME, BEATS layout and plans, applications of tomography in Archaeology, Cultural Heritage, and Palaeontology, in Health and Biomedical research, in Geology, in Chemical and Industrial Engineering, in fuel cells and battery research, and in Materials and Nano Science, as well as the role of managing big data. BEATS and expert talks were delivered by Axel Kaprolat (ESRF), Giorgio Paolucci (SESAME), Marco Stampanoni (PSI), Alexander Rack (ESRF), Kirsi O. Lorentz (CyI), Mirjam van Daalen (PSI), B. Bijeljic (Imperial College), E. Alp (APS), L. Mancini (Elettra), F. Zanini (Elettra) and others. Further presentations (podium and poster) were presented by regional participants, representing the range of use cases for the BEATS beamline. The variety of case studies, together with keynote speakers, and the lively discussions which ensued, led to fruitful interactions among the participants, and enabled the BEATS specialists to evaluate and discuss the potential, capabilities and requirements for and of the BEATS beamline at SESAME, developing the Scientific Case, but also contributed significantly to the user community building effort. For further detail on this event, please see Annex 1.

The Cyprus BEATS User Community Building event took place over two days within the framework of the ICAS-EMME2 international congress on Archaeological Sciences in the EMME region (Eastern Mediterranean and the Middle East); https://www.cyi.ac.cy/index.php/component/k2/beamline-for-tomography-at-sesame-eu-h2020-user-community-building-event). The ICAS-EMME2 conference was attended by over 100 archaeological science professionals and researchers, and the BEATS workshop was open to additional participants from other domains, including Health, Environment, and Materials Science. Several BioMERA partners from the Human Health domain attended, as did partners from the Cyprus Geological Survey. The formal presentations day was followed by beamtime proposal writing surgery sessions, targeting both experienced researchers, and graduate students. These sessions, and close follow-up during the run-down to SESAME Call '2' resulted in four PIs new to SESAME submitting beamtime proposals early 2020. Two of these PIs are

from governmental organisations (Cyprus Geological Survey; Department of Antiquities, Cyprus), and two are doctoral students, one also connected with the COMULIS EU H2020 project (see below), as well as BioMERA. The other graduate student is connected to the FF-MAC project (another 1 million Eur project funded 2019-2022 focusing on human bioarchaeological research, which also enables connections to BEATS use; https://face2face.cyi.ac.cy). Once BEATS will be operational these users will be ready to begin using BEATS (with more than 60 other users who have already registered their interest, over 40 of whom are affiliated or partners in the BioMERA project), as they are already working on their samples through laboratory analyses, identifying the most suitable and critical samples for BEATS data capture. Enterprise/industrial users are also being readied: a major pharmaceuticals company in Cyprus is preparing for use of the BEATS beamline through the BioMERA Platform, in which it is a key partner; APAC (Andreas Pittas Art Characterisation Laboratories, CyI) and its customers in Art Characterisation – private collectors, public galleries, major bank cultural foundations, antiquities departments, and companies will also be readied for BEATS use. For further detail on this event, please see Annex 1.

The second user community building activity took place in Jordan, at SESAME premises, in connection to the SESAME User Meeting in November 2019, attended by 81 delegates, out of which 60 were Jordanian and regional users. The advantage of this User Community Building event was that in addition to the Jordanian participants, users from all the SESAME Members were attending, and thus this workshop could receive fully international attendance without any additional cost. Further follow-up contact was made with the University of Jordan. As to beamtime proposals, it is difficult to say if any of the proposals from Jordan in the Call '2' were results of inspiration/mentoring in the BEATS context, as naturally, these proposals were submitted for the currently operational beamlines. Full exploitation of the results of this workshop is ongoing, with continuing engagement from University of Jordan in BEATS User Community Building activities, as well as the engagement of the Jordanian Representative in the SESAME SUC. A further outcome from this workshop are the joint beamtime proposals between Cypriot and Turkish researchers (altogether 5 joint proposals submitted in the last round, with the expectation that the same samples will also be explored with BEATS once it becomes operational and beamtime is allocated). We plan to hold BEATS related User Community Building activities every year linked to the SESAME User Meeting, delivering update presentations on progress, as well as mentoring sessions. For further detail on this event, please see Annex 1.

Thus, the two BEATS User Community Building workshops have already been exploited beyond expectations, going beyond the national level (this level was originally planned for in the proposal to optimise the allocation of funds to infrastructure rather than international user community building activities which are costlier than those at national level. In brief: academia/research, governmental, and enterprise/industrial entities and organisations are already readying themselves for use of BEATS, and making sure they have selected the correct samples, with all the relevant laboratory based data. Mentoring is a continuous activity by both BEATS participants, as well as in the wider field, by SESAME SUC, and the LAAAMP Middle East committee members. ESUO (European Synchrotron and free-electron laser User Organisation) is also contributing towards this effort, with joint sessions delivered between BEATS, ESUO, and HESEB delegates at the SESAME User Meeting.

An additional, third more small scale User Community Building event took place at the Hacettepe University in Turkey on 29th February, with three talks and c. 30 participants. A lively discussion ensued about the opportunities BEATS will provide for the Archaeology and Cultural Heritage communities. The formal Turkey edition of BEATS User Community Building Workshop will be organised first as a webinar (see below), and then as a follow-up in-person event when the COVID-19 measures allow. This Turkey visit consolidated a joint beamtime proposal (IR – Lorentz-Buyukkarakaya; submitted-granted-executed, with peer review publication in final stages of preparation) and enabled future proposal planning for BEATS beamline. Further user community building activities which took place include the following: BEATS online user community building event for Pakistan within the framework of the 45th International Nathiagali Summer College (see Annex 1); mentoring for beamtime proposal writing of Palestinian researchers; for other joint beamtime proposals; and for future proposal planning for BEATS. WP2 task 1 Leader visited the Jordan Museum and met with the museum Directorate, with clear interest stated; imminent follow up expected with new SESAME Scientific Director, and the very active SESAME SUC Member for Jordan. The first online BEATS User Community Building Event was organised 21 July 2020 within the framework of the Pakistan 45th International Nathiagali Summer College (INSC, http://www.ncp.edu.pk/insc/index.php), organised since 1976, with very large reach as to appropriate audiences for User Community Building. OpenSESAME also linked with INSC for its roadshows.

Detailed outline of plans in BEATS User Community Building

The detailed plans for the remaining project months as to user community building include all the above in-person and one-to-one contact modes tried and tested in Cyprus and to an extent in Jordan, and found to be highly effective In these efforts we will engage the BEATS Beamline Scientist and the Scientific Director of SESAME who have agreed to explore these approaches, as well as well as contributing with presentations in the BEATS User Community Building events, together with other SXCT experts, including both BEATS project partners and others), as well as invited experts.

The following original dates for in-person BEATS User Community Building Events were set in 2019, but had to be revised into online meetings for the duration of 2020 due to COVID-19 measures:

- Isfahan, Iran: planned in May 2020; rescheduled as online meeting for September 2020
- Islamabad, Pakistan: planned for mid-July 2020; rescheduled as online meeting for October 2020 (as well as July 20-21 2020 in the framework of 45th INSC)
- Nigde, Turkey: planned for mid-September 2020; rescheduled as online meeting for November 2020

It should be noted that as soon as the COVID-19 situation allows, in-person meetings will be resumed, in order to provide a good balance between online meetings and in-person meetings. Whether any mitigation measures are required in 2021 cannot be forecasted at this time, and thus it is simply stated here that the remaining three User Community Building Events will be scheduled in 2021-2022 in Israel, Egypt and Palestine.

Format of online user community building events (Cyprus Institute Green Room) consist of interactive webinars/online meetings with full visual aids and effects. All potential future users are targeted, including academia, governmental organisations, and industry.

- 1st day:
    - presentations by BEATS and other SXCT experts; and questions from the audience;
    - standard set of presentations consists of introduction to BEATS project; SXCT science applications; SXCT and phase 1 beamlines at SESAME; SXCT principles; BEATS beamline design, construction, operation; how to become a BEATS user; importance of prior laboratory based analyses; SESAME member specific presentation/s;
    - breakout 'rooms'/separate zooms as to domain specific question and answer sessions with BEATS and other SXCT experts, SESAME SUC members, LAAAMP Light Source Strategic Plan and Use Committee for Middle East members
- 2nd day:
    - meet the SESAME beamline scientist, SESAME SUC members, LAAAMP Light Source Strategic Plan and Use Committee for Middle East members; others with user community building support functions;
    - preparatory work as to prior laboratory analyses, sample types and mounting options;
    - beamtime proposal writing mentoring and surgery sessions

Follow-up will be fostered with BEATS beamline scientist, SESAME SUC members, LAAAMP Light Source Strategic Plan and Use Committee for Middle East members, and BEATS WP2.1 contributors. Relevant online live event components will be recorded and linked with the BEATS website and OpenSESAME Training Warehouse. Below is the current schedule of BEATS User Community Building events for the remainder of 2020 and the following years as they are known today. These will be organised as interactive webinars.

16-17 Sept 2020 Interactive Webinar BEATS User Community Building: Iran

7-8 Oct 2020 Interactive Webinar BEATS User Community Building: Pakistan

11-12 Nov 2020 Interactive Webinar BEATS User Community Building: Turkey

2021/2022: Israel, Egypt, Palestine, dates to be explored with each SESAME SUC Member.

These online “workshop type” events have and will be complemented by in-person user community building events (including already the Cyprus and Jordan workshops) with presentations (as part of a major international conference on Archaeological Sciences; as part of SESAME User Meeting). Such in-person events in the future include the Pakistan International Nathiagali Summer College, reaching very large audiences since 1976, as well as major regional conferences in the SESAME Members to be identified with the help of SESAME SUC members as well as the LAAAMP Middle East committee members, focusing on the four BEATS Science Case domains. Further complimenting actions include public lectures where applicable (already organised in the framework of the Cyprus User Community Building event); graduate student seminars with SR experts (organised in context of the Cyprus event within a doctoral student programme); networking events (such as the event at Hacettepe University in January 2020); and laboratory analysis, sample selection and beamtime proposal mentoring and coaching (standard part of all BEATS User Community Building events).

In addition to the above webinars and in-person user community building events which all target industry as well as academia and governmental organisations, further measures and actions under WP2.1 include (1) industrial/enterprise engagement through brochure/s and web- and other materials targeting industry, and (2) development of synchrotron radiation computed tomography e-learning/blended learning training materials. A partner workshop at CyI will take place and lead to component development for the BEATS e-learning/blended learning training materials. These actions will be undertaken from project month 22 onwards, as planned (and reported on in future reports). A close link with OpenSESAME Industrial Workshop exists (http://www.opensesame-h2020.eu/en/news/sesame-1st-industry-applied-science-workshop/) and the e-learning/blended learning training materials will be included on the OpenSESAME Training Warehouse platform.

Actions and opportunities to align BEATS with other projects, networks and initiatives

BioMERA Platform (https://biomera.cyi.ac.cy) at the Cyprus Institute provides a very attractive regional platform of access to BEATS and SESAME on Cultural Heritage, Health, Environment, Materials Science and beyond, akin to IPANEMA in relation to SOLEIL. BioMERA, together with its link to APAC (Andreas Pittas Art Characterisation Laboratories; https://apac.cyi.ac.cy) at the Cyprus Institute provides even a wider range of application

domains, while IPANEMA is defined by its focus on Cultural Heritage. IPANEMA (http://ipanema.cnrs.fr) is a centre for the development of advanced methodologies of material characterization in archaeology, paleo-environments, palaeontology and cultural heritage, supporting synchrotron-based research through external users hosted on the platform, especially in connection to SOLEIL. IPANEMA develops and provides a set of techniques for preparing specimens, studying artefacts and samples, and for statistical analyses of SR data sets. The BioMERA PI and IPANEMA Director have established direct collaboration, including future opportunities for joint supervision of PhD students, gearing up to use BEATS in their future (post)doctoral research.

BEATS activity on the domain of Heritage Science can be significantly enhanced through the BioMERA involvement in Iperion HS (Integrated Platform for the European Infrastructure on Heritage Science, http://www.iperionhs.eu), and E-RIHS (European Research Infrastructure for Heritage Science, http://www.e-rihs.eu) at European level, as BioMERA can connect BEATS to these major European initiatives. BioMERA will be part of the Cyprus E-RIHS hub. BioMERA and APAC offer E-RIHS, Iperion HS, BEATS and SESAME aligned and compatible laboratory analyses and sample preparation facilities. BioMERA offers such access-enhancing capability in all BEATS Scientific Case domains. This is key to effective and successful beamtimes, and rapid peer reviewed publication after beamtimes. Thus, results from the Cyprus BEATS User Community Building workshop have, and continue to be, fully exploited. ESUO (http://www.wayforlight.eu/en/users/esuo/) synergies have already been mentioned in terms of its Twinning and Mentoring programme, which also includes SESAME users. LAAAMP (an IUPAP/IUCr project within the ISC grant programme, https://laaamp.iucr.org) FAST Grants (Faculty-Student Grants) also offer the opportunity to build up and nurture (through the LAAAMP FAST Continuation Grant) future user communities for BEATS. Various IAEA initiatives also provide user community building opportunities, for example IAEA RER1018 (https://www.iaea.org/projects/tc/rer1018), and the IAEA-SESAME Cultural Heritage Training Course can be lifted as examples. The EU H2020 COMULIS COST Action (https://www.comulis.eu) STSM (Short term Scientific Missions) tool may also be something that could be considered. ICTP also provides a route for training future BEATS and SESAME users, and indeed the SESAME Scientific Director and the WP2 Task 1 Leader jointly submitted a proposal in February 2020 to ICTP specifically on SESAME as a user training facility.

ANNEXES

ANNEX 1: Reports on Science Case Workshop and User Community Building Events already organised

Report on BEATS Scientific Case Workshop

27-28 June 2019, The Cyprus Institute, Nicosia, Cyprus

BEATS tomography beamline is being designed for SESAME synchrotron (www.sesame.org.jo), enabling research using tomography from 2022 onwards. This workshop focused on exploring various application domains of SXCT, and in specific, applications relevant to the SESAME region (Cyprus, Egypt, Iran, Israel, Jordan, Turkey, Pakistan, Palestine). The tomography beamline will be designed, constructed, and commissioned by the EU H2020 funded project BEATS (Beamline for Tomography at SESAME; [https://beats.esrf.fr/]). A number of clear application domains in the SESAME region have already been identified, including (1) Archaeology and Cultural Heritage; (2) Health and Biomedicine; (3) Geology; and (4) Materials and Nano Science, and Engineering. The workshop was open for participation by all researchers and interested parties across academic disciplines, industry, governmental services, and other interested parties, regardless of domain, as any area with material samples can benefit from the application of high-resolution tomography to specific problems or research questions. Invited presentations laid the ground for discussions on applications, and how these may feed into the design of the tomography beamline, the first in the region. Talks covered the following topics: Status of SESAME, BEATS layout and plans, applications of tomography in Archaeology, Cultural Heritage, and Palaeontology, in Health and Biomedical research, in Geology, in Chemical and Industrial Engineering, in fuel cells and battery research, and in Materials and Nano Science, as well as the role of managing big data. Invited speakers included: Giorgio Paolucci (SESAME), Marco Stampanoni (PSI), Alexander Rack (ESRF), Kirsi O. Lorentz (CyI), Mirjam van Daalen (PSI), B. Bijeljic (Imperial College), E. Alp (APS), L. Mancini (Elettra), F. Zanini (Elettra) and others. Further presentations (podium and poster) were presented by regional participants, representing the range of use cases for the BEATS beamline. The workshop took place 27-28 June 2019 at the Cyprus Institute (www.cyi.ac.cy) in Nicosia, Cyprus. There were no workshop fees (participation in the workshop was free of charge), however all participants were asked to register for better organization, and each participant/institution was responsible for their own flight, accommodation and subsistence costs, unless otherwise advised (regional participants were sponsored by BEATS). The total registered participants numbered 61, with additional non-registered participants. Additional participants included SESAME Council Members (the 34th SESAME Council Meeting took place seamlessly before the BEATS Scientific Case Workshop, from 26-27 June 2019), and further local participants.

The following science cases were suggested for the BEATS tomography beamline through the contributed papers from the SESAME region, and the discussions that ensued. Additional science cases

have also been included as suggested by other SESAME region stakeholders, including e.g. the consortium partners of the BioMERA project (Platform for Biosciences and Human Health in Cyprus: MicroCT Enabled and Synchrotron Radiation Enabled Analyses; PI: K.O. Lorentz, The Cyprus Institute; Funding: 1 million Eur, Research and Innovation Foundation (RIF INFRASTRUCTURES/1216/0009). The BioMERA project includes all medical faculties, and national level medical facilities, including BOC Oncology Center, the Histopathology Department of Nicosia General Hospital, and the Cyprus Institute of Neurology and genetics, as well as the Cyprus Geological Survey and enterprise partners. Science cases and types of samples suggested include the following:

- **Cultural heritage, archaeology, palaeontology**, e.g.:
    - skeletal and dental pathologies
    - ancient skin; structural decomposition
    - tiles, brick, mortar and plaster samples: inner structure
    - pigment layers, e.g. on wooden sarcophagi, works of art
    - paleontological samples
    - archaeological artefacts
- **Health, Biology,** e.g.:
    - bone pathologies; bone structure; healthy and osteoporotic bone; osteoporosis understanding and diagnosis
    - dental implants
    - biominerals, minerals produced by living organisms, highly controlled and elaborated compositions and structures
    - soft tissue pathologies
    - laboratory animals/tissue samples (e.g. kidney disease related samples)
- **Energy and environment** e.g.:
    - characterization of core samples from oil formations
    - geological samples
- **Materials science** e.g.:
    - material behaviour under various types of stresses such as mechanical (tension/compression), phase change and structure evolution in metals, plastics, composites and biomaterials
    - depth and type of defects in semiconductor materials; ion implantation induced defects and their recovery mechanism upon annealing
    - hydrogen Induced Cracking (HIC) in High Strength Low Alloy (HSLA) steel

The following sections include the BEATS Scientific Case Workshop programme, which included the Opening Ceremony of the Workshop, followed by MoU signing ceremony between the Cyprus Institute and SESAME, and the BEATS Scientific Case Workshop sessions themselves. The workshop was concluded by a discussion on BEATS technical specifications, facilitated by Frank Lehner and Kirsi Lorentz. The open component of the workshop was followed by a closed round table session of BEATS

partners, focusing on further discussion of BEATS Scientific Case in relation to BEATS technical specifications. A working dinner with further focus on the above topics concluded the workshop.

BEATS Scientific Case Workshop 27-28 June 2019

Thursday 27 June 2019: BEATS Scientific Case Workshop Opening Ceremony; Joint BEATS and SESAME Council Reception

Venue: The Cyprus Institute New Technologies Laboratories (NTL) Events Room

17:30 – 19:00 **BEATS Opening Ceremony** *(Master of Ceremonies: K. Lorentz)*

Welcome by **C. Papanicolas**, President of the Cyprus Institute – 10'

Opening words by **R.-D. Heuer**, President of the SESAME Council – 10'

Introduction to BEATS Project by **A. Kaprolat**, ESRF – 10'

Science Applications I by **M. Stampanoni**, PSI – 20'

Tomographic X-ray microscopy: a powerful tool for biomedical applications at synchrotrons and beyond

Science Applications II by **B. Bijeljic**, Imperial College – 20'

Applications and potential of x-ray tomography for oil/gas recovery and carbon storage

Science Applications III by **E. Alp**, Chair of the SESAME SAC – 20'

Synchrotron X-Ray Spectroscopy in archaeology and cultural heritage: Lessons learned

19:00 - 19:15 **MoU signing ceremony between CyI and SESAME**

19:15 – 20:00 **Joint BEATS and SESAME Council Reception**

20:00 – 20:15 Transportation

20:15 – 22:00 BEATS Workshop dinner

Friday 28 June 2019: BEATS Scientific Programme

Venue: The Cyprus Institute New Technologies Laboratories (NTL) Events Room

9:00 – 9:30 **SESAME status; BEATS and its technical specifications** (Chairs: Khaled Toukan & Walid Zidan)

- **G. Paolucci**, SESAME Scientific Director: *SESAME status* – 15'
- **A. Rack**, ESRF: *BEATS base layout and plans* – 15'

9:30 – 11:15 Archaeology and Cultural Heritage applications (Chairs: Kirsi Lorentz & Franco Zanini)

- **K.O. Lorentz**, CyI - keynote: *SR tomography applications and potential in Archaeology and Cultural Heritage – 15'*
- **L. Mancini**, Elettra – grounding: *Hard X-ray tomography activity at Elettra supporting applications in Archaeology, Cultural Heritage and Palaeontology – 30'*
- **N. Siddique** – regional (Pakistan): *Study of building materials and ancient artefacts from Pakistani ancient heritage sites – 15'*
- **A. Buyukkarakaya, S. Lemmers, K. Lorentz** – regional (Turkey): *Potential for SR tomography applications in Bioarchaeology of Anatolia: Skeletal pathologies, dental histology, and ancient skin remains – 15'*
- **N.A. Ali** – regional (Egypt): *Investigation of pigments layer on wooden coffins from the old kingdom of the Egyptian cultural heritage – 15'*
- Discussion – *15'*

11:15 – 11:45 Poster Session and *Coffee break*

11:45 – 13:20 Health and Biology applications (Chairs: Marco Stampanoni & Lucia Mancini)

- **M. Stampanoni**, PSI – keynote: *Behind-the-scenes of advanced biomedical imaging at synchrotron and challenges for clinical translation – 20'*
- **F. Zanini**, Elettra – grounding: *Biomedical Imaging at Elettra – 15'*
- **E. Seknazi** - regional (Israel): *The hierarchical nanostructure of a biogenic Mg-calcite single crystal: The case of brittlestar Ophiocoma wendtii calcitic skeletal parts – 15'*
- **L. Koutsantonis** - regional (Cyprus): Single Photon Emission Computed Tomography: Image reconstruction from Simulations Ensemble – *15'*
- **A. Hadjipanteli** – regional (Cyprus): *Assessment of the 3D spatial distribution of the Calcium/Phosphorus ratio in bone – 15'*
- Discussion– *15'*

13:20 - 14:30 Lunch

14:30 – 16:15 **Materials Science, Engineering, Nano Science applications** (Chairs: Javad Rahighi & Felix Beckmann)

- **B. Gharaibeh** – regional (Jordan): *Highlights of the μ-Tomography Applications for Jordan's SESAME users from the University of Jordan user service unit – 15'*
- **M. Usman** – regional (Pakistan): *Opportunities and possibilities with microtomography (BEATS): A case for ion implantation – 15'*
- **A. Rozatian** – regional (Iran): *Studying Hydrogen Induced Cracking (HIC) in High Strength Low Alloy (HSLA) steel – 15'*
- **A. Barhoum** – regional (Egypt): *Nanofiber Electrodes for Electrochemical Wastewater Treatment and Hydrogen Fuel Production – 15'*
- **H. Essawy** – regional (Egypt): *Shifting the Accidental Thermal/Photo Induced Decomposition of Poly(vinyl chloride) to Upgrade Its Mechanical Properties and Resistance to Degradation – 15'*
- **S. Shirani** – regional (Iran): *Characterization of core samples from oil formations – 15'*
- Discussion – *15'*

16:15 – 16:45 Poster Session and *Coffee break*

16:45 – 17:30 **Big Data and BEATS tomography** (Chairs: Mirjam van Daalen & Charalambos Chrysostomou)

- **M. van Daalen** – keynote: *Open research data, data policies and data management* – 15'
- **G. Tsouloupas, C. Chrysostomou** – *The Cyprus Institute High Performance Computing Facility and SESAME* – 15'
- Discussion – 15'

17:30 – 18:00 **Discussion on BEATS technical specifications; Workshop conclusions**

(Facilitators: Frank Lehner, Kirsi Lorentz)

Abstracts in order of presentation

N. Siddique – regional (Pakistan): (Pakistan Institute of Nuclear Science and Technology) ***Study of building materials and ancient artefacts from Pakistani ancient heritage sites***

Objectives: Study of building materials and ancient artefacts from Pakistani ancient heritage sites. Background Indus Valley Civilisation, Bronze Age civilisation (3300–1300 BC), extends from north-eastern Afghanistan to Pakistan and northwest India is one of three early civilisations of the Old World along with ancient Egypt and Mesopotamia and one of the world's earliest human settlements with a highly-developed civilization. For provenance, conservation and to ensure authenticity of historical artefacts and art objects a comprehensive study is required: (1) to study corrosion processes, (2) identify raw materials used to produce archaeological artefacts and (3) to investigate stabilisation, conservation and restoration practices. Motivation Tiles, brick, mortar and plaster samples collected from Lahore Fort's Picture wall were analysed using Neutron Activation Analysis (NAA). [1,2] This work was undertaken to assist Punjab Archaeology Department, Lahore as they lack experimental capabilities. However, the great variety of size and composition that characterizes archaeological artefacts requires tomographic systems. [3-4] High-resolution synchrotron radiation tomography is one of the most powerful non-destructive testing techniques for full-volume inspection of an object, as it gives morphological and physical information on the inner structure of the investigated sample. References 1. S. Waheed, N. Siddique, J. H. Zaidi, J. Radioanal. Nucl. Chem., 289(3) (2011) 765-771 2. N. Siddique, S. Waheed, J. Radioanal. Nucl. Chem, 291(3) (2012) 817-823 3. L. Bertrand, L. Robinet, M. Thoury, K. Janssens, S. X. Cohen, S. Schöder, Appl Phys A, 106(2) (2012) 377-396 4. C. Tuniz, F. Bernardini, A. Cicuttin, M.L. Crespo, D. Dreossi, A. Gianoncelli, L. Mancini, A. Mendoza Cuevas, N. Sodini, G. Tromba, F. Zanini, C. Zanolli, Nucl. Instrum. Methods Phys. Res. A, 711 (2013) 106–110.

Buyukkarakaya, S. Lemmers, K. Lorentz – regional (Turkey): ***Potential for SR tomography applications in Bioarchaeology of Anatolia: Skeletal pathologies, dental histology, and ancient skin remains***

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N.A. Ali – regional (Egypt), Zewail City of Science and Technology: Investigation of pigments layer on wooden coffins from the old kingdom of the Egyptian cultural heritage

The Egyptian cultural heritage is exceptional in many ways, among others due to the wide variety of materials that were used, and are still retrievable in the material culture from this ancient civilisation. The study of pigments is key to understand such materials. One of the most striking properties of Egyptian pigments is that they are almost indestructible in nature: They are highly resistant to concentrated acids, alkalis and organic solvents. This extreme stability explains why many artworks have survived during centuries under the drastic conditions of temperature and humidity of the desert and long periods of burial.

The samples presented in this paper belong to the Late Period, and were found in a tomb belonging to the Old Kingdom, dating to 4200 years. Ancient Egypt reached the highest level of artistic techniques at the fourth dynasty, not only in the paintings palettes but also the manufacturing techniques. The late era artists had the same style and used the same palettes, but there were more complicated connectors used in coffin manufacturing. These were characterised by great number of wood sheets, indicating high status and wealth of the deceased. As a binding material eggs were used,

and in some instances animal-based glue was used as adhesive material. A short description of the samples presented in this study: Double wooden coffin of the length 203 cm, shoulder width 53 cm, covered with overlying clay and then a layer of gypsum, with decorated drawings, has been worked on the inner coffin. The coffin takes the human shape with a typical mummy of a woman inside. The face of the coffin is coloured with red and pink, the chest held a wide coloured necklace, with ends at both sides with a falcon head. Initial measurements were performed on these samples to identify the composition of the pigments. However, the goal is to obtain readings on the exact composition of the pigments; and the previously employed measurement techniques had limitations, and therefore could not give a clear and accurate result. The XRF analysis illustrated that cannot support the organic pigments and the trace elements of the inorganic pigments also XRD could not identify iron oxides and or the organic materials.

The goal of the study on these archaeological samples is to obtain information about the components of the pigments and substrates, and relate this information with archaeological questions (origin of the clays, painting techniques, colours, and binding materials). The use of non-destructive techniques is mandatory in the study of ancient cultural materials, thus rendering most valuable the conjugate application of various X-ray techniques, including absorption spectroscopy such as X-ray detraction and X-ray absorption fine-structure spectroscopy (XAFS) induced by synchrotron radiation, which are penetrative illumination techniques that may be complemented by microscopic analyses. Such analyses are typically performed by means of Fourier transform IR (FTIR) micro spectroscopy for studying the inner structure of pigments of paintings. The use of methods limited to elemental analysis or imaging usually is not sufficient to elucidate the chemical transformations that take place during natural pigment alteration processes. However, synchrotron-based techniques are suitable for such studies.

The major motivations for such analytical methods using synchrotron radiation are

(a) To know precise and accurate information about the fabrication process and the ancient artist's way of working that cannot be detected by classical diagnostics techniques.

(b) The need to assess and predict the current and future states of conservation of artwork.

E. Seknazi - regional (Israel), Department of Materials Science and Engineering and the Russel Berrie Nanotechnology Institute, Technion Israel Institute of Technology: ***The hierarchical nanostructure of a biogenic Mg-calcite single crystal: The case of brittlestar Ophiocoma wendtii calcitic skeletal parts***

Biominerals are minerals produced by living organisms. They often demonstrate excellent properties associated with highly controlled and elaborated compositions and structures. Many marine biominerals are made of calcite, the thermodynamically stable polymorph of calcium carbonate, and contain a certain amount of magnesium, where magnesium atoms can substitute calcium atoms in the calcite, forming Mg-calcite. Using cutting-edge characterization techniques, including synchrotron radiation tomography, we were able to elucidate the hierarchical nanostructure of O. Wendtii brittlestar skeletal parts, which relies on an elaborated distribution of Mg in calcite, and consists in a toughening strategy for brittle calcite. Indeed, this biogenic Mg-calcite was found to contain nanodomains of Mg-rich calcite, coherently included into an Mg-poor calcite matrix. These Mg-rich nanodomains pre-compress and therefore toughen the material. These coherently included nanodomains are moreover organized in a layered manner, promoting crack deflection mechanism.

L. Koutsantonis - regional (Cyprus): Single Photon Emission Computed Tomography: Image reconstruction from Simulations Ensemble

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A. Hadjipanteli – regional (Cyprus): ***Assessment of the 3D spatial distribution of the Calcium/Phosphorus ratio in bone***

The purpose of this study was the development of a technique for the non-invasive assessment of the 3D spatial distribution of the Calcium/Phosphorus (Ca/P) ratio in bone. Computed tomography dual energy analysis (CT-DEA) was developed and optimised for the assessment of Ca/P ratio. As part of this process, density values are provided as a bi-product. The technique was optimised and experimentally applied through a microCT system. The target of the optimisation was to achieve a precision of better than 0.09 in the Ca/P ratio, in order to be able to distinguish between all healthy and osteoporotic regions. Electron dispersive X-ray spectroscopy (EDX) was used to evaluate the performance of CT-DEA on bone apatite. Ca/P ratio measurements were made on the same healthy and inflammation mediated osteoporotic (IMO) rabbit cortical bone surfaces, using CT-DEA and EDX. The mean difference in the Ca/P ratio between the two techniques was 0.11±0.08 (8±6%) and the correlation was R2=0.69, suggesting sufficient confidence in the experimental capabilities of the CT-DEA technique.

Healthy and IMO rabbit, both collagen-free and intact, cortical bone samples were assessed by CT-DEA. Qualitative analysis of the results involved the production of Ca/P ratio and density distribution maps. Quantitative analysis involved the quantification of the Ca/P ratio and density across the whole sample and in volumes of interest, as well as the low Ca/P ratio proportion in each sample. Furthermore, a 3D region growing technique was used to study the uniformity of Ca/P ratio in the samples. Results showed differences in both density and Ca/P ratio between healthy and IMO bone samples, supporting their use as possible osteoporosis indicators and the use of the developed technique for further studies. The technique could be applied on synchrotron facilities to investigate the variation of Ca/P ratio in healthy and osteoporotic bone, and to potentially enhance osteoporosis understanding and diagnosis.

Belal M.Y. Gharaibeh, Sa'ed A. Musmar (Industrial Engineering Department, The University of Jordan): ***Highlights of the μ-Tomography Applications for Jordan's SESAME users from the University of Jordan user service unit***

The coming BEATS beam line at SESAME will open new horizon for researchers in the Middle East including Jordan for which a dedicated tomography beamline allows both researchers at academia as well as major industries to visualize and analysis various sample types in abroad spectrum of science fields in static or time resolved tomography. The University of Jordan and SESAME have joint forces to establish a unit with the aim of cultivating National user community for all SESAME beamlines and to serve as a lab source for all SESAME users as well. In this presentation; a description of the unit's functions and structure is presented as well as the resulted users work groups activities from engineering, science, and heritage applications with focus on material behaviour under various types of stresses such as mechanical (tension/compression), phase change and structure evolution in metals, plastics, composites and biomaterials to the cultural heritage studies of national interest, then

a closure with the need to BEATS beamline at SESAME for further exploration and deeply analysis in Engineering, medicine heritage and life sciences.

M. Usman – regional (Pakistan) National Centre for Physics, Islamabad, Pakistan: *Opportunities and possibilities with microtomography (BEATS): A case for ion implantation*

Ion implantation, being a widely-used method for doping in semiconductors, has several challenges which are continuously under discussion. Such issues involve the energetic ions induced defects production in the material, their depth, and recovery (upon annealing) of crystal lattice for successful applications. These defects could be vacancies, di-vacancies, interstitials, point defects, etc., which are produced due to electronic and nuclear stoppings of impinging ions in the material. These defects and their recovery have significant role in tailoring the electronic and optical properties of semiconductors for targeted applications. Several experimental techniques like ion beam channelling, TEM, SEM, AFM, XRD, etc. have been utilized for understanding ion implantation defects but all of them have limitations. Atomic probe tomography (APT) offers extensive capabilities for both 3D imaging and chemical composition measurements at the atomic scale, is also used but it a destructive method. Ion implantation estimating computer codes, like SRIM, need input for better prediction of implantation damage and depth inside the material. In few materials, e.g. GaN [1] and SiC, ion implantation of heavy ions such as Au, Pt stop at different depths than is predicted by SRIM [2]. Several other reports have shown anomalies in the ion implantation process. Moreover, a certain type of bubble formation in materials like Si and SiC [3,4] is also observed which requires better understanding. Synchrotron radiation based tomography would be a possible way for fundamental understanding of depth and type of defects in semiconductor materials, which no other technique could so far provide. In addition, this will be a non-destructive method providing a high-resolution 3D image of various types of ion implantation induced defects and their recovery mechanism upon annealing. This will result in improving the industrial process of ion implantation contributing to more efficient electronic devices of future. References: [1] Y. Zhang, M. Ishimaru, J. Jagielski, W. Zhang, Z. Zhu, L. V. Saraf, W. Jiang, L. Thome, W. J. Weber, “Damage and microstructure evolution in GaN under Au ion irradiation”, J. Phys. D: Appl. Phys. 43 085303(2010) [2] H. Z.Xue, Y. Zhang, Z. Zhu, W. M. Zhang, I.-T.Bae, W. J. Weber, “Damage profiles and ion distribution in Pt-irradiated SiC”, Nuclear Instruments and Methods in Physics Research B 286 114–118, (2012) [3] R. Siegele, G. C. Weatherly, H. K. Haugen, D. J. Lockwood, L. M. Hower, “Helium bubbles in silicon: Structure and optical properties”, Appl. Phys. Lett. 66, 1319 (1995) [4] M.-F. Beaufort, M. Vallet, J. Nicola, E. Oliviero, J.-F. Barbot, “In-situ evolution of helium bubbles in SiC under irradiation” Journal of Applied Physics 118, 205904 (2015).

A. Rozatian – regional (Iran) Department of Physics, University of Isfahan: *Studying Hydrogen Induced Cracking (HIC) in High Strength Low Alloy (HSLA) steel*

A recent research has been done on HSLA steel in collaboration with the Esfahan’s Mobarekeh Steel Company (one of the largest steel companies in the region). New generation of steel and its alloys play an important role in industry and modern life. In order to satisfy the increasing demand for safety and high-quality structural steels in terms of strength and toughness, many researches have been carried out in order to develop high strength low alloy (HSLA) steels recently. In addition to the suitability of the mechanical properties of steel in the oil and gas industries to improve transmission process and reduce cost, the failure of steel in a wet hydrogen sulphide environment is a significant outcome in oil and gas industries. Hydrogen damages appear as cracks in steel which usually occurs suddenly and unexpectedly. Hydrogen damages may occur in a variety of phenomena such as, Hydrogen Induced

Cracking, Stress Oriented Hydrogen Induced Cracking, Sulphide Stress Cracking and Hydrogen Stress Cracking. In this research, samples of high strength low alloy steels were selected to study the important effective factors. Hydrogen induced cracking tests were carried out to compare these samples before and after the exposure to hydrogen environment. Scanning Electron Microscopy (SEM), Energy Dispersive X- ray (EDX) and X-Ray Diffraction techniques were used to study cracked,

non-cracked and residual stress in selected samples. X-ray Micro-Computed Tomography (micro-CT) technique can also be employed in order to produce high resolution three-Dimensional (3D) images map of the cracks hence the BEATS beamline at SESAME can heavily be used by scientists working closely with the steel companies.

A. Barhoum – regional (Egypt): ***Nanofiber Electrodes for Electrochemical Wastewater Treatment and Hydrogen Fuel Production***

Sunlight is a clean source of energy for the removal of pollutants from industrial wastewater and potential production of H2 fuel. To date, the laboratory demonstrations for the photoelectrochemical (PEC) systems reported the highest solar-to-hydrogen (STH) conversion efficiency up to 30%. PEC cells using highly porous nanofiber electrodes is a hot topic of research. While great interest has been devoted during the last few years to the fabrication of nanofibers for photocatalytic applications, limited efforts have aimed towards their surface modification and property tailoring. However, it is only their surface that comes into direct contact with surrounding media (air, liquids, and solids) and influences their photoactivity. Our research group works at photoelectrochemical (PEC) catalysis to make the world a better place. We create a scientific and technological knowledge platform for developing an efficient and cost-effective PEC device based self-supported nanofiber electrodes for simultaneous treatment of industrial wastewater and hydrogen fuel production. The PEC device will be based on nanofiber electrodes fabricated from exclusively abundant elements by twinning between electrospinning and atomic layer deposition technology as ecologically and economically feasible solutions for future hydrogen production and wastewater treatment.

H. Essawy – regional (Egypt) National Research Centre: ***Shifting the Accidental Thermal/Photo Induced Decomposition of Poly(vinyl chloride) to Upgrade Its Mechanical Properties and Resistance to Degradation***

Silicone rubber bearing vinyl groups was blended with poly(vinyl chloride) (PVC) to convey plasticization and stability against decomposition that is likely to emerge during thermal processing or following exposure to UV radiation. The immiscibility between silicone rubber and PVC was proved from images acquired using scanning electron microscopy (SEM) which revealed worsening of the situation at higher loading (10 wt%) of silicone rubber. The thermal degradation (TG) profiles indicated that the inclusion of silicone rubber advanced the resistance to thermal decomposition at loadings up to 5wt%. This effect is demolished when the loading was doubled, which is matching with SEM micrographs. Fourier Transform Infrared spectra (FTIR) were collected for the blends after exposure to UV radiation for 168 h, from which the absence of dehydrochlorination or change in the nature of the material was confirmed. The hampering of dehydrochlorination is expected to have proceeded by instant attack of any appearing radicals on PVC backbone onto the vinyl groups of silicone rubber thereby building up a thermoplastic elastomeric network.

S. Shirani – regional (Iran): ***Characterization of core samples from oil formations***

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Feedback after the BEATS Opening Ceremony and Workshop, SESAME-CyI MoU Signing Ceremony, and SESAME Council visit to CyI – a selection of messages after the events

'The workshop was very successful and brought together a lot of people, a great opportunity for SESAME.'

Mirjam van Daalen, Chair of the BEATS Steering Committee, Chief of Staff, Photon Science Division, PSI

'…to thank you… for all you did to make the tour of the CyI, the ceremony for the signing of the MoU and the opening ceremony of the BEATS Workshop so very successful. I know from comments I heard that all the participants in the Council meeting greatly appreciated the professional manner in which these events were organized. I also know that they were grateful for having been made to feel so welcome at the CyI. …I should like to thank you for the great amount of work you put into all three events which resulted in the success we all know.'

Ms Clarissa Formosa-Gauci, UNESCO, Secretary of the SESAME Council

'It was a pleasure to be at Cyprus Institute and see Costa's dream come true. It is no small feat to accomplish a world-class institute in the middle of an island, preoccupied by many other social and historical issues.'

Prof. Ercan Alp, APS. Chair of the SESAME Scientific Advisory Committee

'Many thanks for organising the BEATS workshop in Nicosia. It was great to be part of it. I wish you success with the BEATS project.'

Branko Bijeljic, Keynote Speaker at BEATS Opening Ceremony

'Thanks once more for the outstanding hospitality and the great workshop, I really much enjoyed coming to Cyprus.'

Christoph Rau, Diamond Light Source, Expert Speaker at the BEATS Workshop

'I would like to take this opportunity to thank you… It was a great opportunity to meet experts in the field and build strong relations with fellow SESAME users.'

Belal Gharaibeh, Regional Participant to BEATS Workshop

'…really excited by the fantastic organization of the BEATS workshop… so I must thank you again for all your appreciated efforts… I am still inspired…'

Hisham Essawy, Regional Participant to BEATS Workshop

'Thank you very much for a wonderful workshop. I really enjoyed this short but very informative event.'

Muhammad Usman, Regional Participant to BEATS Workshop

'I would like to thank you for kind effort and excellent workshop.'

Ehab Essawy, Regional Participant to BEATS Workshop

'I want to thank you and all your group for that perfect conference organization at the Cyprus Institute.'

Shiva Shirani, Regional Participant to BEATS Workshop

'I would like to express my sincere appreciations to you and your colleagues for organising such a successful workshop in your beautiful country, Cyprus. I enjoyed all presentations and also discussions with other participants.'

Amir Rozatian, Iran Member of the SESAME SUC Committee.

Photographs from the BEATS Scientific Case Workshop, and associated events

BEATS Scientific Case Workshop group photo

Panelists at BEATS Scientific Case Workshop Opening Ceremony – Mirjam van Daalen (Chair of BEATS Steering Committee and Chief of Staff at PSI), Euripides Stephanou (VP Research CyI), Giorgio Paolucci (SESAME Scientific Director), Costas N. Papanicolas (President of CyI), Khaled Toukan (Director of SESAME), Kyriacos Kokkinos (State Chief Scientist for R&I of Cyprus – at the podium at time of the photo), Ioanna Kleanthous (Co-Vice-President of SESAME Council; Director, Directorate General of European Programmes, Coordination and Development, Cyprus), Axel Kaprolat (ESRF, BEATS Coordinator), Kirsi Lorentz (Vice-Chair of BEATS Steering committee)

Signing of Memorandum of Understanding by the President of The Cyprus Institute, Prof. Costas Papanicolas and Director of SESAME, Dr Khaled Toukan, following the BEATS Opening Ceremony

Signing of Memorandum of Understanding by the President of The Cyprus Institute, Prof. Costas Papanicolas and Director of SESAME, Dr Khaled Toukan, following the BEATS opening Ceremony. Rolf Heuer (President of SESAME council and former Director General of CERN) on the left, Dr Kyriakos Kokkinos (State Chief Scientist for R&I of Cyprus) and Ioanna Kleanthous (Vice-President of SESAME Council; Director, Directorate General of European Programmes, Coordination and Development, Cyprus) on the right

Herman Winick, Stanford Linear Accelerator Centre (SLAC) – special address within the BEATS Opening Ceremony

Mirjam van Daalen, PSI / SLS

Report on BEATS User Community Building Event in Cyprus

11-12th Nov 2019 (with satellite events 13-15 Nov) The Cyprus Institute, Nicosia

The Cyprus edition of the BEATS User community building event took place on the 11-12th of November 2019, followed by a series of satellite events focused on BEATS User Community building, until the 15th of November, consisting of science application mentoring, sample selection and preparation mentoring, beamtime proposal surgery sessions, networking, doctoral student and early career researcher sessions, and discussions on future possibilities in the framework of SXCT in the EMME region. The event was open to all researchers and industry representatives in Cyprus, and beyond. The aim of this community building event was to give detailed information to researchers and industry representatives about how SXCT can advance their research on any material samples, and to contribute towards creating a strong user community in Cyprus. A number of clear application domains in the SESAME region (Cyprus, Egypt, Iran, Israel, Jordan, Turkey, Pakistan, Palestine) have already been identified, including (1) Archaeology and Cultural Heritage; (2) Health and Biomedicine; (3) Geology; and (4) Materials and Nano Science, and Engineering, and researchers and representatives with interests and focus on these domains were particularly encouraged and invited to attend the event. To optimize attendance and accessibility, the event was hosted at the Cyprus Institute in connection with the major regional conference on Archaeological Sciences, the 2nd International Congress on Archaeological Sciences in the Eastern Mediterranean and Middle East (ICAS EMME2), enabling regional and international reach for the BEATS events.

Invited speakers for the user community building event included Giorgio Paolucci (SESAME), Kirsi O. Lorentz (Cyprus Institute), Gihan Kamel (SESAME), Belal Gharaibeh (University of Jordan), Simone Lemmers (Cyprus Institute), and Ali Metin Buyukkarakaya (Hacettepe University, Ankara). The total registered participant number was 34. In the framework of ICAS EMME2 on 12th November, with approximately 100 participants, a further special session on BEATS and SR in Cultural Heritage and Archaeology was organized, where the participants of the BEATS User Community building event delivered talks.

During the community building event, focused discussions were held regarding the status of BEATS and SESAME, SXCT and other synchrotron radiation (SR) techniques and potential science applications, the BEATS tomography beamline design and construction and BEATS synergies with the BioMERA (Platform for Biosciences and Human Health in Cyprus: MicroCT Enabled and Synchrotron Radiation Enabled Analyses) facility in Cyprus. Invited participants from Italy, Jordan, Turkey and Cyprus covered topics related to SESAME status, BEATS tomography beamline status and its technical specifications, multimodal data acquisition, and highlights of micro-tomography applications in the SESAME and EMME region (Eastern Mediterranean and the Middle East).

BioMERA and BEATS networking event was held in the afternoon of 11th Nov 2019, with Cypriot partners present from Health, Pharma, Geology, Cultural Heritage, and Environment domains, including academic institutions, governmental organisations, and industry. After the BEATS-BioMERA meeting, the formal part of the day was concluded with the public Colloquium talk by Prof. Esen Ercan Alp (Argonne National Laboratory (ANL), Illinois, USA), titled: *Synchrotron X-rays and lattice dynamics: Implications in chemistry, geology and physics*. During the talk, Prof Alp reviewed key issues addressed by nuclear resonant scattering methods in geophysics and geochemistry such as velocity of sound of earth-bound minerals, iron valence and isotope fractionation in core-mantle boundary under high pressure, in the context of Synchrotron Radiation. The colloquium was followed by a reception where the audience was able to meet and speak with Prof. Alp. A BEATS networking dinner followed where both senior researchers, and early career researchers had the chance to discuss their work with the invited speakers of the BEATS User Community building event.

On the 12th of November, a BEATS and SR session took place within the ICAS EMME2 conference on archaeological sciences. This session was entirely devoted to Synchrotron radiation in Archaeology and Cultural Heritage. The talks during this session explored SXCT applications in Archaeology and Cultural Heritage, as well as informed those delegates of the conference not yet familiar or experienced with the concept of Synchrotron radiation to understand the wide range of application possibilities, including tomography, XRF, and FTIR, and how these could benefit their field of interest.

Between 13th and 15th of November the team involved in the organization of the BEATS User Community building event ran a series of follow-up and satellite events focused on building the User Community for BEATS. These activities included mentoring sessions for individual researchers to obtain feedback and answer questions regarding their field of interest and opportunities to move their research forward with SXCT techniques, assistance with beamtime proposal writing in the form of 'surgery sessions' and networking opportunities for both experienced and early career researchers.

The following section includes the programmes for the different components of the Cyprus edition of the BEATS User Community Building event. The programme section is followed by photographs from the various event components.

BEATS:

Beamline for Tomography at SESAME (EU H2020)

User Community Building Event

11-12th November 2019

The Cyprus Institute, Nicosia

The Cyprus Institute – Guy Ourisson Building, Seminar Room, 1st Floor, Athalassa Campus

Come discover how synchrotron radiation microCT can advance your research on any material samples

Open to all researchers and industry representatives

For better organization, please register your participation by emailing sciencecaseBEATS@cyi.ac.cy,

9:30 – 9:40	Welcome and introduction	K.O. Lorentz, Vice-Chair of BEATS Steering Committee
9:40 – 10:00	SESAME status, BEATS tomography beamline, and its technical specifications	G. Paolucci, SESAME Scientific Director
10:00-10:20	From the laboratory to the synchrotron: BEATS tomography beamline at SESAME, and BioMERA microCT facility in Cyprus	K.O. Lorentz
10:40-11:00	Multimodal data acquisition: Other synchrotron radiation techniques and their interfaces with SR tomography	G. Kamel, SESAME Synchrotron IR Beamline Scientist
11:00 – 11:30	*Coffee break*	
11:30 – 11:50	Highlights of micro-tomography applications for Jordan's SESAME users	B. Gharaibeh, University of Jordan
11:50-12:10	Dental histology and SR tomography: Possibilities in the context of BEATS	S. Lemmers, K.O. Lorentz, The Cyprus Institute
12:10-12:30	Potential for SR tomography applications for the bioarchaeology of Anatolia: Skeletal pathologies, dental histology, and ancient skin remains	A. Buyukkarakaya, S. Lemmers, S. Kayalp & K.O. Lorentz, Hacettepe University and The Cyprus Institute
12:30-12:45	Discussion and closing remarks	

https://beats.esrf.fr/

https://www.cyi.ac.cy/index.php/component/k2/beamline-for-tomography-at-sesame-eu-h2020-user-community-building-event

Colloquium talk by Ercan Alp followed by BEATS networking reception

Colloquium: Synchrotron X-rays and lattice dynamics: Implications in chemistry, geology and physics

Event Details:

Date: Monday 11 November 2019

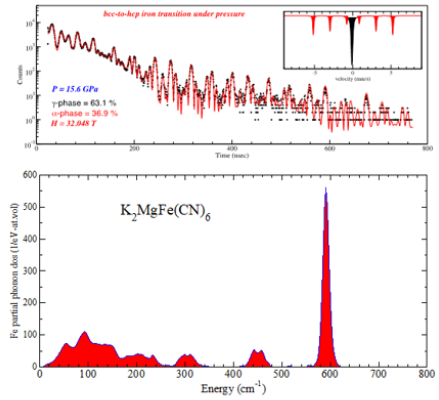
Time: Starts: 16:30

Venue: The Cyprus Institute – Guy Ourisson Building, Seminar Room, 1st Floor, Athalassa Campus

Speaker: Prof. Esen Ercan Alp, Argonne National Laboratory (ANL), Illinois, USA

Abstract

It's been almost 45 years since the idea of using a synchrotron source to excite the Mossbauer isotopes was proposed. Since then significant progress has been made in developing the methodology, instrumentation and data analysis. Application areas are extended into wide range of scientific disciplines. In this talk, I will review the key issues addressed by nuclear resonant scattering methods in geophysics and geochemistry such as velocity of sound of earth-bound minerals, iron valence and isotope fractionation in core-mantle boundary under high pressure. Similarly, determination of possible pathways related to the functions of iron-containing biological systems or catalysts will be discussed. The extension of the method to more than a dozen isotopes provides a wide-ranging tool to study the interplay between magnetism and superconductivity in new quantum materials like pnictides. This presentation will review modern applications, and provide a perspective view.



(*) In collaboration with J. Zhao, T. Toellner, M. Hu, and W. Bi.

Work supported by US DOE Office of Science under contract DE-AC02-06CH11357 and by Consortium for Materials Properties Research in Earth Sciences (COMPRES), the National Science Foundation (NSF) through Grant No. DMR-1104742.

About The Speaker

Esen Ercan Alp is a senior physicist and Argonne Distinguished Fellow in the X-ray Science division at Argonne National Laboratory. His research has focused on the development of nuclear resonance scattering techniques and applying them to problems in condensed matter physics, geophysics and biochemistry.

He joined Argonne as a postdoctoral associate in the Materials Science division, and subsequently became assistant physicist in the X-ray Scattering group. Dr Alp moved to the Advanced Photon Source (APS) project in 1990 to lead the development of the 3-ID beamline for nuclear resonant and inelastic X-ray scattering. From 1999-2003 he was the group leader for the inelastic scattering group. During this time, he was responsible for the design and construction of a novel groundbreaking beamline for high-resolution inelastic scattering measurements at 30-ID.

His research has focused on the development of nuclear resonance scattering techniques and applying them to problems in condensed matter physics, geophysics and biochemistry. He has co-authored over 310 publications, which have been cited more than 9,200 times. He has been extensively involved in international scientific outreach efforts through the American Physical Society, including participation in the SESAME synchrotron project in Amman, Jordan. Dr Alp was recently named the 2019 winner of the IBAME Science Award, given every two years to one of the top Mössbauer spectroscopists world-wide. He received BSc and MSc degrees in metallurgy and materials science from Middle East Technical University in Ankara, Turkey, and a PhD in physics from Southern Illinois University, where his thesis focused on using Mössbauer spectroscopy to understand metallic glasses.

Session III Synchrotrons in Archaeology and CH-SESAME (GOB Building) (parallel session)

Chairs: Dr G. Paolucci, Dr K.O. Lorentz

14:00-14:30	**Keynote lecture**: *Cultural Heritage and Archaeological Research at SESAME Synchrotron*	Dr Giorgio Paolucci
14:30-14:50	***SSE1***: Synchrotron radiation enabled human bioarchaeology in the EMME region: SR-XRF, XANES and EXAFS data in exploring key archaeological questions	K. Lorentz
14:50-15:10	***SSE2***: SR-FTIR in Archaeological and Cultural Heritage Research at SESAME	G. Kamel
15:10-15:30	***SSE3***: Advantages and potential of SR phase contrast microCT enabled virtual dental histology in comparison with conventional dental histology	S. Lemmers, K. Lorentz
15:30-15:50	***SSE4***: Highlights of potential Synchrotron research applications at the University of Jordan: case studies from Cultural Heritage	B.M.Y. Gharaibeh, M. Arimat
15:50-16:10	Coffee break	

16:10-16:30	***SSE5***: STARCH: at the origins of starch food diet. SR-FTIR and SEM applied to Palaeolithic Grinding Stones from the Pontic area	G. Biranda, L. Vaccari, N. Cefarin, C. Cagnato, I. Pantushina, N. Skakun, C. Lubritto, G. Sorrentino, L. Longo
16:30-16:50	***SSE6***: SR-FTIR analyses of ancient hair remains from Anatolia	A. Buyukkarakaya, G. Kamel, S. Lemmers, K. Lorentz
16:50-17:10	***SSE7***: Comparison of synchrotron CT and laboratory based micro-CT with applications in heritage materials	K. Jakata
17:10-17:30	***SSE8***: SR microCT in identification of NNL: Distinguishing between stillborn and newborn infants	Y. Miyauchi, S. Lemmers, K. Lorentz

17:30 – 18:00	Synchrotron X-Ray Spectroscopy in archaeology and cultural heritage: Lessons learned	E. Alp

Photographs from the BEATS User Community Building Event in Cyprus and satellite activities

BEATS User Community Building Event group photo: Delegates from academia, governmental organizations, and industry; domains covered include Cultural Heritage and Archaeology; Health; Pharma; Geology; Environment; Materials Science; Architecture; Energy

Giorgio Paolucci, SESAME
(Scientific Director of SESAME)

Kirsi Lorentz, The Cyprus Institute
(BEATS SC Vice-Chair; BEATS WP2 T1)

Gihan Kamel, SESAME
(Beamline Scientist)

Belal Gharaibeh, University of Jordan
(regional user)

Report on BEATS User community building event in Jordan

30th November and 1st December 2019 at SESAME (Allan, Jordan)

On the 30th of November and 1st of December 2019, the BEATS User community building event took place at SESAME, in order to strengthen the future BEATS user community in Jordan.

The event consisted of a series of talks and discussions, to allow for informing, networking, mentoring and discussing future possibilities in the framework of SXCT in the EMME region and Jordan specifically. The event was open to both researchers as well as representatives from the industrial section. The goal of this BEATS community building event was to inform the audience about how SXCT can advance the research on any material samples, fostering the creating a strong user community among Jordanian research and industrial representatives across domains. The user community building event was purposefully built into the 17th SESAME user meeting which was held at SESAME, to optimize attendance and accessibility to the event, enabling an additional number of researchers, students, industrial representatives and senior scholars to attend the BEATS talks and discussions, in order to strengthen the userbase of BEATS. The context of the annual SESAME user meeting, which brings together scientists from the region and world experts in the various fields of synchrotron applications, provided an ideal platform for information exchange and discussions of ongoing collaborative efforts within the community. This therefore was a great opportunity to inform and strengthen the future user base for BEATS, with 81 delegates of which 60 were regional users.

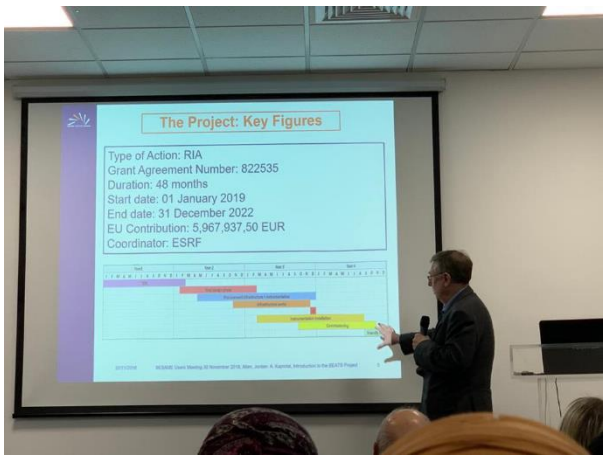
Invited speakers included Axel Kaprolat (ESRF, BEATS Project Coordinator), Alexander Rack (ESRF, BEATS Tomography expert), and Kirsi O. Lorentz (The Cyprus Institute, BEATS SC Vice-Chair; BEATS WP2 T1 Leader). During the user community building event expert talks were delivered, focused discussions were held regarding the status of BEATS, beamline design and construction, and scientific application possibilities, strengthened by talks from and discussions with various experts in the field. The events on the 30th of November were followed by a tour of SESAME, where the user community was given the opportunity to see the operational beamlines, as well as get an insight into the construction of the tomography beamline, and meet the BEATS Beamline Scientist.

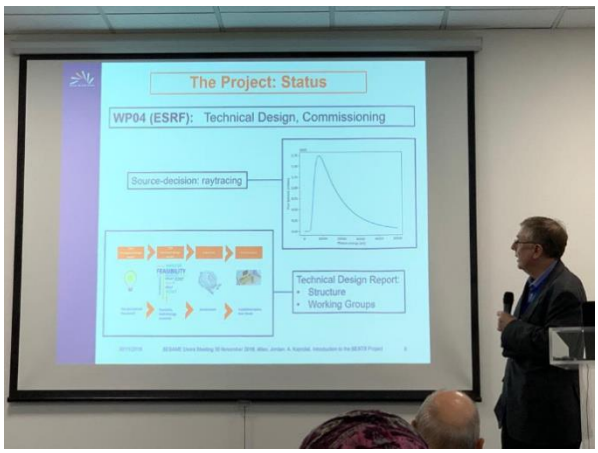
During the second day, individual mentoring sessions were organized where regional and aspiring users had the opportunity to discuss their research ideas and proposals with experts, and receive feedback on previously conducted and presented research projects, and gain inspiration for future research potential. Furthermore, a 'future BEATS user' survey was conducted, both online and in hard-copy, to gauge the interest, needs, and application possibilities for BEATS within the region.

BEATS activities during the 17th SESAME User Meeting & ESUO Regional Meeting 2019

1st Day: Saturday, November 30th, 2019	
BEATS Talks	
BEATS Tomography beamline	Axel Kaprolat (ESRF, BEATS Project Coordinator), Alexander Rack (ESRF, BEATS Tomography expert) and Kirsi O. Lorentz (The Cyprus Institute, BEATS SC Vice-Chair, WP2 T1 Leader)
BEATS scientific case: involving SESAME User Community	Axel Kaprolat (ESRF, BEATS Project Coordinator), Giorgio Paolucci (SESAME Scientific Director) and Kirsi O. Lorentz (The Cyprus Institute, BEATS SC Vice-Chair, WP2 T1 Leader)
Q & A	
User Talks	
Tour of SESAME	
2nd Day: Sunday, December 1st, 2019	
• BEATS individual mentoring sessions • BEATS future user online survey	

Photographs from the BEATS User Community Building Event in Jordan





Dr Axel Kaprolat (ESRF), BEATS project Coordinator presenting BEATS project status

Professor Esen Ercan Alp (Argonne National Laboratory; Chair of SESAME SAC)

Dr Hanan Sa'adeh, Jordan University (SESAME SUC Representative for Jordan)

SESAME beamline scientists with BEATS and OpenSESAME contributors. From left to right: Ahmed Refaat, Messaoud Harfouche, Mahmoud Adbellatief, Kirsi Lorentz, Gihan Kamel, Greta Facile, Gianluca Iori (BEATS Beamline Scientist).

SESAME SUC Members Dr Hanan Sa'adeh (SESAME SUC Member for Jordan) and Dr Amir Rozatian (SESAME SUC Member for Iran) with Dr Kirsi Lorentz from BEATS.

Report on BEATS User Community Building Session

at the 45th International Nathiagali Summer Collage (INSC), Pakistan

21 July 2020, 45th INSC online, Pakistan

On the 21st of July 2020 the BEATS User Community Building Session took place at the 45th International Nathiagali Summer College (INSC), in order so strengthen the future BEATS user community in Pakistan. The event consisted of a series of talks, a panel discussion, and a question and answer session with the INSC participants, to enable information flow, networking, mentoring and discussing future possibilities in the framework of BEATS and SXCT, to benefit researchers and enterprise in Pakistan. The talks aimed to inform and engage young researchers with the BEATS tomography beamline, its construction and operation, SXCT applications, and how to become a future user. The event was open to both researchers as well as representatives from the industrial sector. The goal of this BEATS event was to inform the audience about how SXCT can advance research on any material samples, fostering the creation of a strong user community among research and industrial representatives across domains in Pakistan. The context of this online event, the INSC, which brought together scientists from the region, and world-renowned experts in the various fields of synchrotron applications, provided an ideal platform for information exchange and discussions of ongoing collaborative efforts within the community, and future potential in BEATS science application domains. INSC therefore provided a great opportunity to inform and strengthen the future user base for BEATS in Pakistan.

BEATS speakers included Axel Kaprolat (ESRF, BEATS Project Coordinator), Kirsi O. Lorentz (The Cyprus Institute, BEATS SC Vice-Chair; BEATS WP2 T1 Leader), Andrea Lausi (Scientific Director of SESAME) and Gianluca Iori (Beamline Scientist at SESAME). During this user community building event expert talks were delivered, followed by a panel discussion, and a question and answer session with the INSC audience, with focused discussions regarding the status of BEATS, beamline design and construction, scientific application possibilities, and how to become a BEATS user. Interaction live with the audience took place both through the online platform with video and sound, as well as text based interaction on the messaging platform of the videoconference software of INSC. Several new contacts to future BEATS users in Pakistan were established thanks to the

above efforts. The main expressions of interest received during the event itself are outlined in the below table.

New contacts established at the INSC BEATS User Community Building Session

(NB. These are additional to any prior BEATS contacts from Pakistan)

Organisation	Research Domain	BEATS Science Case domain
Forman Christian College University	X-ray microtomography, Neutron Imaging Material Science, Nanotechnology, Nuclear Physics, Experimental Physics	Material Science
Allama Iqbal Open University	Material Science	Material Science
Department of Physics, University of Karachi	Computer Physics, Condensed Matter Physics, Solid State Physics, Material Science, Cultural Heritage	Material Science, Cultural Heritage
Dr. Panjawni Center for Molecular Medicine and Drug Research, University of Karachi	Biotechnology, Structural Biology, Molecular Medicine	Biology
Microwave Devices Group (MDG)" at LINAC project, PINSTECH, Islamabad	Microwave Engineering, Microwave Devices, Microwave and Millimeter Wave Technology	Engineering
International Islamic University	Experimental Physics; Condense matter physics	Other

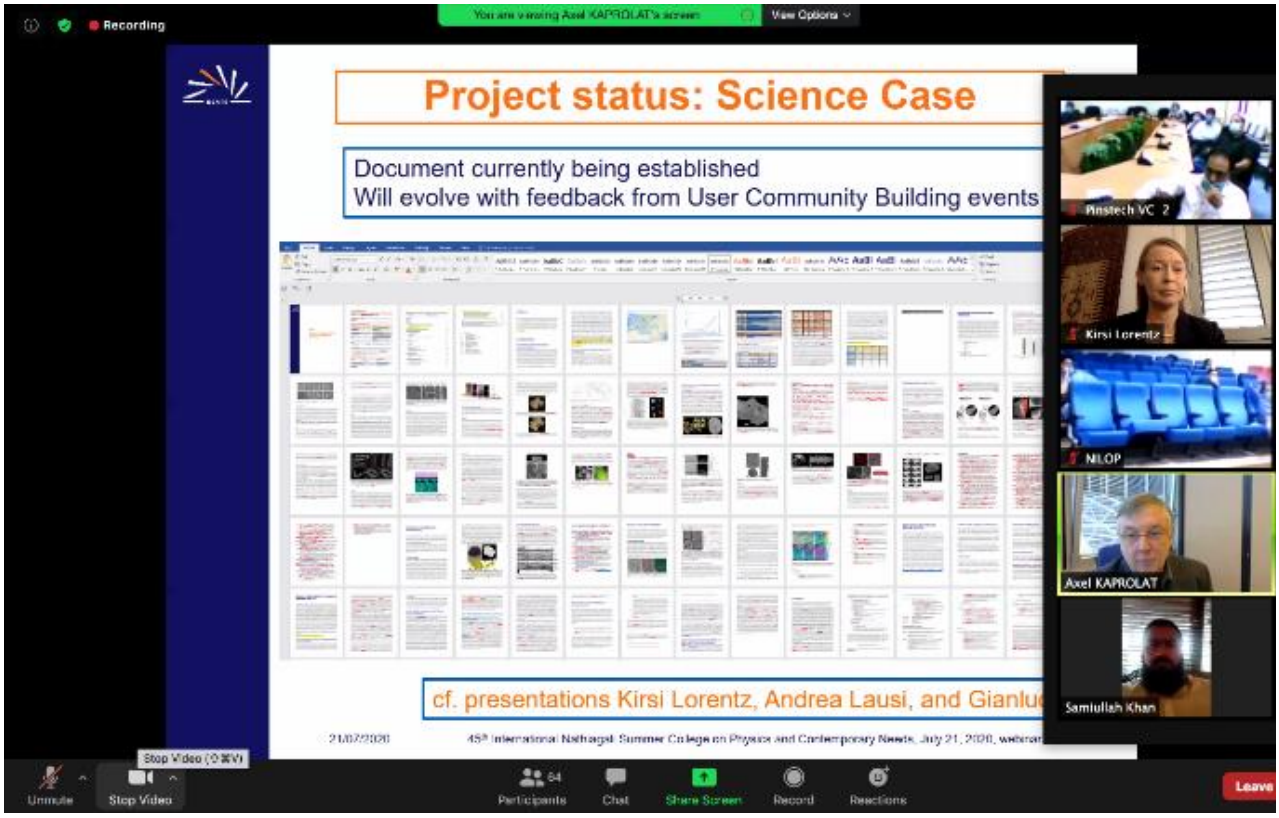
Programme of the BEATS User Community Building Session

Speakers - 45th Intl. Nathiagali Summer College (Webinars)

Activity - I: Applications of Synchrotron Radiations (20th - 21st July, 2020)

Date	Time	Title	Country	Title
Building the user community for BEATS (Beamline for Tomography at SESAME)				
21-07-2020	10:15 - 13:00	Axel Kaprolat	France	The BEATS tomography beamline project: Structure and Spirit
		Andrea Lausi	Jordan	BEATS and the phase 1 beamlines of SESAME
		Gianluca Iori	Jordan	BEATS tomography beamline: design, construction, operation and possibilities
		Kirsi Lorentz	Cyprus	SR-microCT (SXCT) at BEATS tomography beamline at SESAME Synchrotron: Science applications and how you can become a future user

Photographs from the BEATS Session at the 45th International Nathiagali Summer Collage (INSC), Pakistan

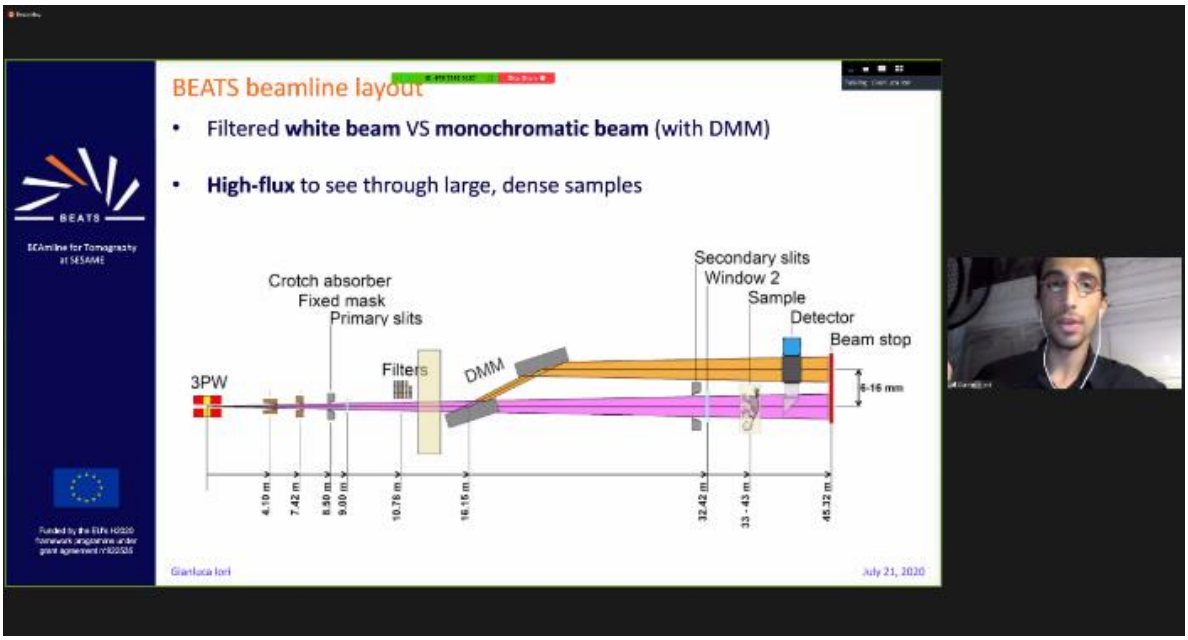


Presentation by Axel Kaprolat (ESRF, BEATS Project Coordinator):

The BEATS Tomography Beamline Project: Structure and Spirit

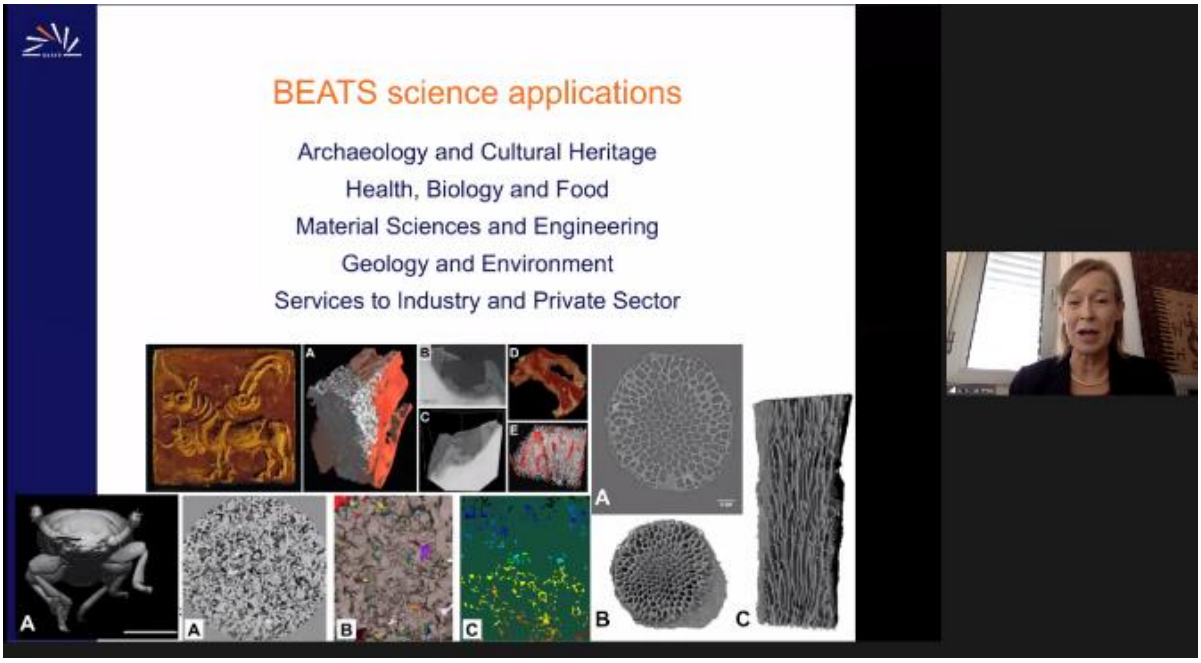
Presentation by Andrea Lausi (Scientific Director of SESAME):

BEATS and the phase 1 beamlines of SESAME

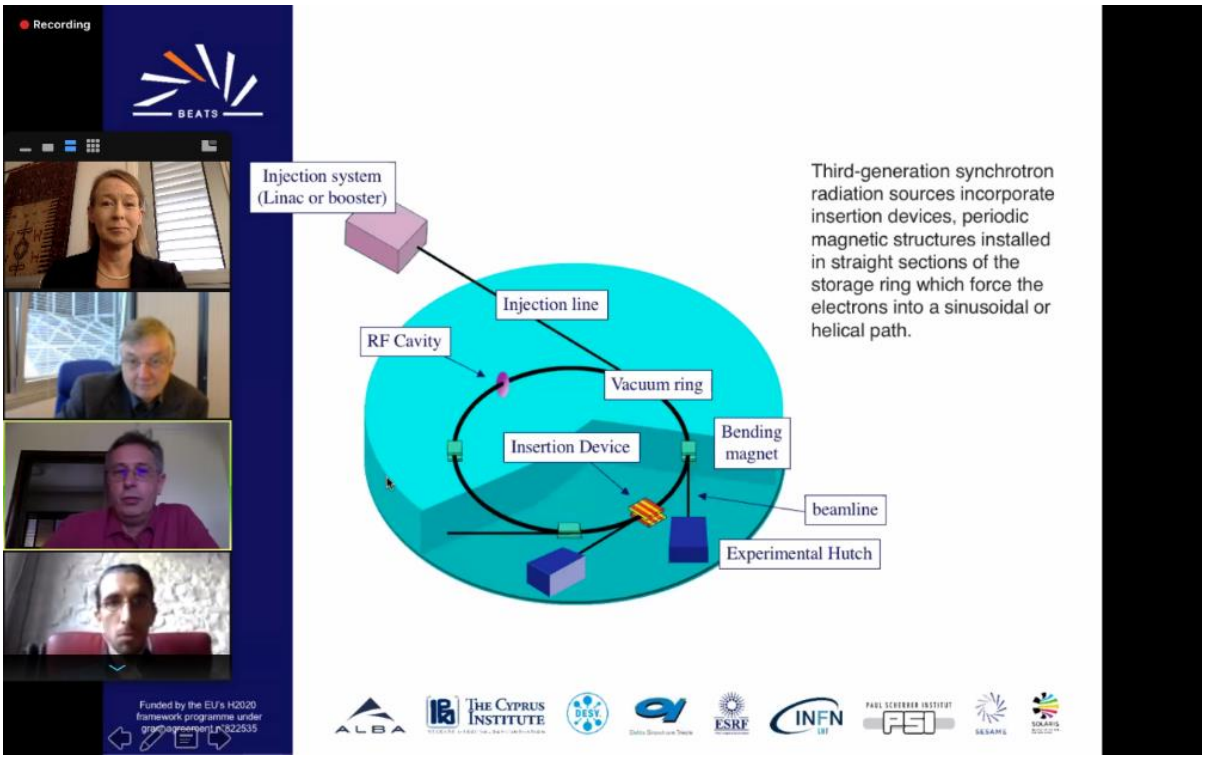


Presentation by Gianluca Lori' (BEATS Beamline Scientist):

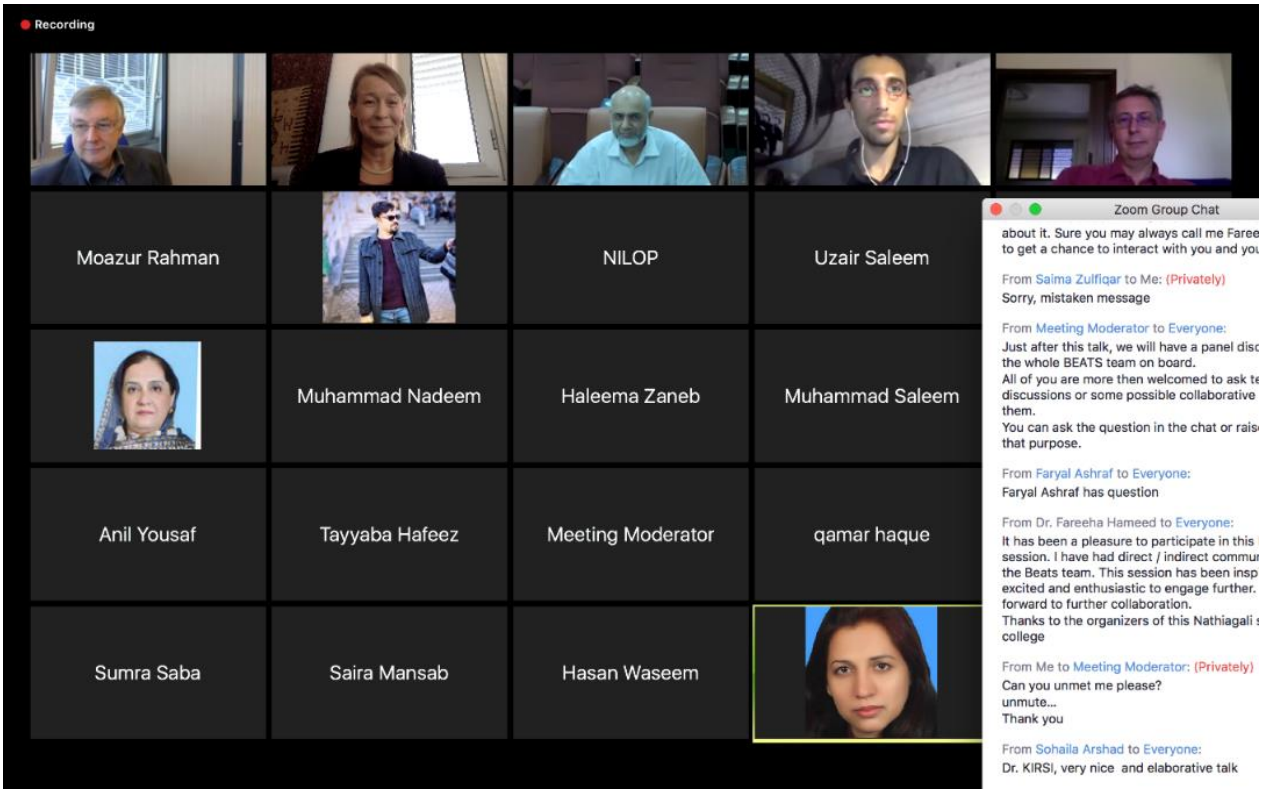
BEATS Tomography Beamline: Design, Construction, Operation and Possibilities



Presentation by Kirsi Lorentz (The Cyprus Institute, BEATS SC Vice-Chair; BEATS WP2 T1 Leader): SXCT at BEATS tomography beamline at SESAME Synchrotron: Science applications and how you can become a future user



BEATS speakers at INSC



BEATS panel discussion and Q&A at INSC

ANNEX 2: Organisations from SESAME members with interest in SXCT

NB. The following tables should be seen as work in progress, as the BEATS User Community Building activities continuously influence and develop the interested users landscape as the BEATS project progresses. The tables below should be taken as a snapshot of the situation at the time of writing this report, influenced by the so far completed BEATS User Community Building events (Cyprus, Jordan), and other user community building efforts within the first 18 months of the project.

Cultural Heritage and Archaeology: Organisations already (A) or prospective (P) SXCT users

SESAME Member	Organisation	Organisation type	Status
Cyprus	The Cyprus Institute	Academic	A
Cyprus	Department of Antiquities	Governmental	A
Cyprus	University of Cyprus	Academic	P
Cyprus	Medochemie	Enterprise	P
Cyprus	Church of Cyprus	Other	P
Cyprus	A.G. Leventis Gallery	Enterprise	P
Cyprus	Bank of Cyprus Cultural Foundation	Other/Enterprise	P
Cyprus	Leventis Museum	Other/Enterprise	P
Egypt	Cairo Egyptian Museum	Academic	A
Egypt	American University in Cairo, Department of Sociology, Egyptology, and Anthropology	Academic	A
Egypt	Zewail City of Science and Technology	Academic	P
Egypt	NCR Egypt	Enterprise	P
Egypt	Egyptian Cultural Heritage Organisation	Academic	P
Egypt	Center for Conservation and Preservation of Islamic Architectural Heritage	Academic	P
Egypt	American University of Cairo, Department of Political Science and Sociology, Anthropology, Psychology and Egyptology	Academic	P
Egypt	Cairo University, Faculty of Archaeology	Academic	P
Egypt	Ministry of Antiquities	Governmental	P
Iran	University of Isfahan	Academic	P
Iran	Research Institute of Cultural Heritage	Academic	P
Iran	Iranian Center for Archaeological Research (ICAR)	Academic	P
Iran	University of Tehran, Institute of Archaeology	Academic	P
Iran	Ministry of Cultural Heritage, Tourism and Handicrafts	Governmental	P
Israel	Tel Aviv University, Department of Anatomy and Anthropology of the Sackler Faculty of Medicine	Academic	A
Israel	Hebrew University of Jerusalem	Academic	A

Israel	Bar-Ilan University, Department of Land of Israel Studies and Archaeology	Academic	P
Israel	Ben Gurion University, Department of Bible, Archaeology and Ancient Near Eastern Studies	Academic	P
Israel	Tel Aviv University, Department of Archaeology and Ancient Near Eastern Cultures	Academic	P
Israel	University of Haifa, Department of Archaeology	Academic	P
Israel	Israel Antiquities Authority	Governmental	P
Jordan	University of Jordan	Academic	P
Jordan	Jordan Museum	Governmental	P
Jordan	Yarmouk University, Department of Archaeology	Academic	P
Jordan	Department of Antiquities	Governmental	P
Pakistan	Department of Archaeology and Museums, Government of Pakistan	Governmental	A
Pakistan	Pakistan Institute of Nuclear Science and Technology, Chemistry Division, Directorate of Science	Academic	P
Pakistan	National Institute of Historical & Cultural Research	Academic	P
Pakistan	Punjab University, Department of Archaeology	Academic	P
Pakistan	National Heritage & Culture Division, Government of Pakistan	Governmental	P
Palestine	Bethlehem University, Department of Humanities	Academic	P
Palestine	Birzeit University, Department of History and Archaeology	Academic	P
Palestine	Palestinian Authority's Ministry of Tourism and Antiquity	Governmental	P
Turkey	Çanakkale Onsekiz Mart University, Faculty of Arts includes Archaeology and Art, Heritage	Academic	P
Turkey	The European Union-Turkey Anatolian Archeology and Cultural Heritage Institute	Academic	P
Turkey	Hacettepe University, Department of Anthropology	Academic	P
Turkey	Istanbul University, Faculty of Letters	Academic	P
Turkey	Koç University, Research Center for Anatolian Civilizations, Suna & İnan Kıraç Research Centre for Mediterranean Civilizations	Academic	P
Turkey	Republic of Turkey Ministry of Culture and Tourism	Governmental	P

Health, Biology and Food: Organisations already active (A) or prospective (P) SXCT users

SESAME Member	Organisation	Organisation type	Status
Cyprus	Cyprus Institute of Neurology and Genetics	Academic	A
Cyprus	Medochemie	Enterprise	P
Cyprus	Bank of Cyprus Oncology Center (BOCOC), University of Cyprus	Academic	P
Cyprus	European University Cyprus	Academic	P
Cyprus	Pathology Department of Nicosia General Hospital	Governmental	P
Cyprus	University of Nicosia	Academic	P
Egypt	Benha University Banhā, Egypt	Academic	P
Israel	Weizmann Institute of Science	Academic	A
Israel	The Hebrew University of Jerusalem	Academic	A
Israel	Technion - Israel Institute of Technology	Academic	A
Pakistan	Dr. Panjawni Center for Molecular Medicine and Drug Research, University of Karachi	Academic	P

Material Science and Engineering: Organisations already active (A) or prospective (P) SXCT users

SESAME Member	Organisation	Organisation type	Status
Iran	Babol Noshirvani University of Technology, Iran	Academic	A
Israel	Ben-Gurion University of the Negev	Academic	A
Israel	Technion - Israel Institute of Technology	Academic	A
Jordan	University of Jordan, Department of Industrial Engineering	Academic	P
Jordan	Mu'tah University, Karak City, Jordan	Academic	A
Pakistan	Pakistan Institute of Nuclear Science and Technology, P. O. Nilore, Islamabad, Pakistan	Governmental	A
Pakistan	Department of Physics, University of Karachi	Academic	P
Pakistan	Allama Iqbal Open University	Academic	P
Pakistan	Forman Christian College	Academic	P

Pakistan	International Islamic University	Academic	P
Turkey	Innovative Technologies Ermaksan	Enterprise	A
Turkey	Mekatronik Sistemler Mühendisliği, Turkish-German University	Academic	A

Geology and Environment: Organisations already active (A) or prospective (P) SXCT users

SESAME Member	Organisation	Organisation type	Status
Cyprus	Cyprus Geological Survey	Governmental	P
Cyprus	Marine & Carbon Lab, Department of Engineering, University of Nicosia	Academic	P
Egypt	The American University in Cairo	Academic	P
Egypt	Cairo University, Department of Geology, Faculty of Science	Academic	P
Egypt	Al Azhar University, Geology Department, Faculty of Science	Academic	P
Egypt	Exploration Department, Egyptian Petroleum Research Institute	Governmental	P
Iran	University of Tehran , School of Chemical Engineering and Institute of Petroleum Engineering	Academic	P
Israel	Geological Survey of Israel	Governmental	P
Jordan	Mu'tah University, Karak City, Jordan	Academic	A
Jordan	Al al-Bayt University, Department of Applied Earth and Environmental Sciences, Al Mafraq	Academic	P
Jordan	Al-Hussein Bin Talal University, Faculty of Engineering	Academic	P
Jordan	Tafila Technical University, Faculty of Engineering, Tafila	Academic	P
Jordan	Jordan Oil Shale Energy Company	Enterprise	P
Jordan	Karak International Oil	Enterprise	P
Jordan	Eesti Energia (office in Amman)	Enterprise	P
Palestine	Hebron university	Academic	P
Turkey	Middle East Technical University, Department of Mining Eng. & Department of Petroleum and Natural Gas Eng.	Academic	P