Australian Synchrotron Development Plan
Project Submission Form

Section A: Summary and Proponent Details

Project Title

Dedicated High-throughput micro-CT beamline on Bending magnet adjacent to IMBL

Spokesperson

Name	Sherry Mayo
Institution	CSIRO Materials Science and Technology
Email	Sherry.Mayo@csiro.au
Phone	+61-3-9902-9801

Executive Summary (approx. 100 words)

Micro-computed-tomography opens a window on the micro-scale three dimensional structure of a wide range of samples relevant to many areas of science.
We propose a micro-CT beamline for the Australian Synchrotron which will enable high-throughput & dynamic micro-CT down to submicron resolution and capable of data-collection times of under a second. It will operate in white/pink beam and broad-band monochromatic modes for high speed as well as narrow-band monochromatic modes for applications such as absorption-edge subtraction and high-accuracy quantitative tomography. It will also support a number of phase-contrast imaging techniques for greater sensitivity to subtle sample features. A key feature of the beamline will be speed of data collection, focusing both on applications where many sample are imaged, facilitated by automated sample exchange, and experiments where a single specimen is imaged many time to observe dynamic responses to temperature, pressure, strain or other changing environmental conditions.

Other proponents (add more rows if necessary)

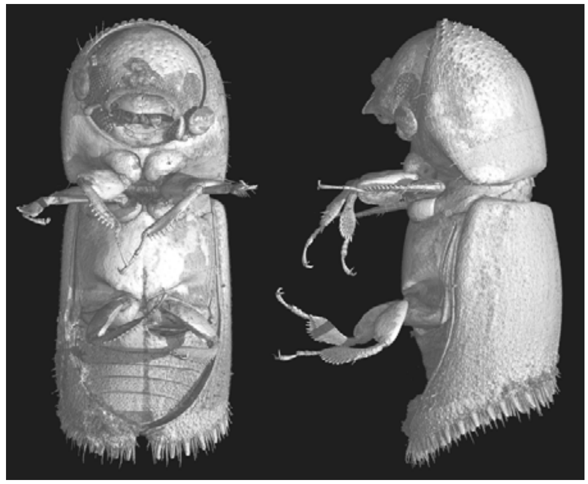
Listed below is a subset of the supporters, covering a diverse range of disciplines, and institutions. Over 90 people have expressed interest via either the mailing list or by private communication.

Name	Institution	Email address
Prof. Rob Lewis & colleagues	MCSS, Monash University	Rob.Lewis@sync.monash.edu.au
Mike Archer & Colleagues	UNSW	m.archer@unsw.edu.au
Allan Jones	University of Sydney	allan.jones@usyd.edu.au
Tim Senden & colleagues	ANU	Tim.Senden@anu.edu.au
Prof. Graham Jenkin	Monash Immunology and Stem Cell Laboratories	Graham.Jenkin@med.monash.edu.au
Marina Pervukhina	CSIRO Petroleum Resources, Kensington WA	Marina.Pervukhina@csiro.au
Andrew Peele & colleagues	Latrobe University	A.Peele@latrobe.edu.au
Kate Trinajstic	Curtin University	ktrinajs@bigpond.net.au

Prof. John Clements & David Thomas	Melbourne Dental School, University of Melbourne	johngc@unimelb.edu.au
Dr Ian Parkinson	Bone and Joint Research Laboratory, SA Pathology and Hanson Institute	Ian.Parkinson@health.sa.gov.au
Steve Knight and colleagues	Defence Science and technology Organisation	Steven.Knight@dsto.defence.gov.au
Assoc. Res. Prof. Bill Skinner	Ian Wark Research Institute University of South Australia	William.Skinner@unisa.edu.au
Prof. Peter Currie and Colleagues	Australian Regenerative Medicine Institute, Monash University	Peter.Currie@armi.monash.edu.au
Assoc Prof . Kate McGrath	Victoria University at Wellington, NZ	Kate.McGrath@vuw.ac.nz
Konstantin Pavlov	University of New England	konstantin.pavlov@une.edu.au

Dedicated micro-CT beamline on bending magnet adjacent to IMBL

Micro-computed-tomography opens a window on the micro-scale three-dimensional structure of a wide range of samples relevant to the life sciences, materials engineering, palaeontology and geology to name just a few. Synchrotron-based micro-CT featured notably in the recent SRI meeting where its application to palaeontology, including imaging insects in opaque amber and the fossil remains of soft tissue was highlighted in plenary and public lectures by Paul Tafforeau and Kate Trinajstic. Scientists who are already familiar with micro-CT in the lab are now turning to synchrotron micro-CT facilities to access a greater range of capabilities including higher resolution, phase-contrast, elementally sensitive techniques such as K-edge subtraction and high-speed data collection for observing dynamic processes in three-dimensions.



Miocene insect fossilised in opaque amber from Cape York (Paul Tafforeau, ESRF, Susan hand, UNSW)

We propose a micro-CT beamline for the Australian Synchrotron which will enable high-speed and high-throughput micro-CT capable of data-collection times of under a second. The field-of-view (FOV) and resolution will range from a few mm FOV at submicron resolution to larger fields of view up to a few cm at ~10 microns resolution. The beamline will support white/pink beam and broad-band monochromatic imaging modes for high-throughput, and narrow-band monochromatic modes for applications such as absorption edge subtraction and high-accuracy quantitative tomography. It will also support phase-contrast imaging modes such as in-line and DEI and will be able to accommodate environmental cells enabling dynamic CT studies of samples that change as a function of temperature, pressure, strain, pH or other modified environmental conditions.

There is already an active micro-CT community in Australia which has come together for two Australian workshops in the last two years. The community is growing due to the increased availability of laboratory micro-CT systems, and researchers are already using synchrotrons overseas for micro-CT studies which they can't accomplish in the lab. Access to a dedicated micro-CT beamline at the Australian Synchrotron would be an enormous boost to micro-CT based research across a wide range of science disciplines.

The community has already indicated strong interest in this beamline proposal with over 90 scientists expressing their support either by joining the mailing list or by contacting us privately. Potential applications from Australian & NZ researchers working in micro-CT include studies of the hierarchical structure of bone, fluids in porous geomaterials, corrosion in metals, fossil insects in amber, analysis of networks in radiolaria, & studies of the effects of medicines & genetics on bone health using animal models.

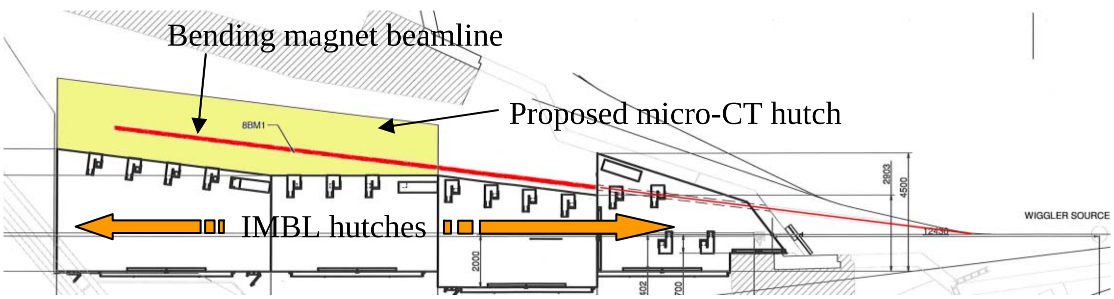
The beamline is envisaged to provide a complementary set of capabilities to the high-energy larger field-of-view capabilities of the IMBL which is the only other beamline capable of full-field CT at the synchrotron. It will focus on applications requiring higher resolution and lower x-ray energies (8-40keV) and will be particularly targeted at high-throughput and dynamic micro-CT applications.

B1: Description of Proposed Beamline/Development Project

The micro-CT beamline will cover an 8-40keV x-ray energy range with capability for white/pink-beam, high band-width quasi-monochromatic-beam using multilayer mirror monochromators and a highly monochromatic beam using standard Si monochromators. It will enable high-speed and high-throughput micro-CT capability with down to sub-second data-collection time, and with a field-of-view and resolution ranging from a few mm FOV at below 1 micron resolution to larger field of view up to a few cm at ~10 microns resolution.

The beamline will support white/pink beam and broad-band monochromatic imaging modes for high-throughput, and narrow-band monochromatic modes for applications such as absorption edge subtraction and high-accuracy quantitative tomography. It will also support phase-contrast imaging modes such as inline and DEI and will be able to accommodate environmental cells enabling dynamic CT studies of samples that change as a function of temperature, pressure, strain or other modified environmental conditions.

The beamline will take advantage of the fact that the hutches for the IMBL beamline were built with the possibility of adding an adjacent micro-CT beamline at a later date meaning that there is room in the IMBL optics hutch to accommodate the bending magnet beam and the external walls of the existing and planned IMBL hutches would provide part of the hutch walls for the proposed beamline.



Sketch of beamline location relative to IMBL

Beamline Specifications

Source:	Bending magnet 1.3T (possible future upgrade to ~ 2T superbend)
Energy Range:	8-40keV
Available modes:	White/pink beam, Multilayer mirror monochromation (2-3% bandwidth), Si monochromators
CT collection time:	Down to sub second CT datasets for broad-band monochromatic/white-beam

Robotic sample exchange for high-throughput studies.
Field of view/resolution from 2x2mm/<1micron to 2x 30+mm/10micron.

Capabilities

- High throughput micro-CT using white beam or high-bandwidth monochromatic beam with down to subsecond data collection time and automated sample exchange.
- Dynamic CT studies of samples that change as a function of temperature, pressure, strain, time etc.
- High-accuracy quantitative monochromatic micro-CT using beam from Si monochromators to remove beam hardening and enable tuning to absorption edges.
- Hi-speed 2D x-ray imaging of dynamic processes.
- Potential phase-contrast imaging modes: in-line, diffraction-enhanced, grating-based
- Topography and region-of-interest/limited-angle CT of larger samples using special reconstruction techniques

Synergies and Complementarities with existing facilities at the synchrotron and nearby

IMBL

The beamline is envisaged to provide a complementary set of capabilities to the IMBL which is the only other beamline capable of full-field micro-CT at the synchrotron. It will focus on applications requiring higher resolution and lower x-ray energies and will be particularly targeted at applications where collecting many datasets in a short time-frame is required, whether for statistical analysis of many samples or observations of a single system that is changing over time or subject to a controlled environment.

The IMBL is anticipated to be in great demand for a wide range of clinical and other applications requiring its high-energy, high-coherence and large-size beam. The dedicated micro-CT beamline will enable the IMBL to be reserved for those micro-CT projects where its specific properties are required and will provide a more suitable beamline for the significant demand for micro-CT at lower energies, but which cannot be satisfied with lab-based systems. It is also possible that the micro CT beamline could share some equipment used for micro-CT on the IMBL such as DEI phase-contrast and grating-based phase-contrast assemblies, environmental cells, strain stages and so forth.

NeAT Project

The micro-CT beamline will be able to capitalise on high speed CT reconstruction software being developed for the synchrotron's MASSIVE cluster under the NeAT project to develop a Remote CT Reconstruction Service. This will be particularly valuable for high-throughput work in providing real time feedback to users on how their data collection is progressing, thus enabling a more efficient use of beam time.

Nanofabrication facility

This facility under construction adjacent to the synchrotron will have the capacity to fabricate gratings and optical elements such as multi-layer-mirrors and zone plates. Taking advantage of these facilities it will be possible to advance the capacities of the beamline and experiment with new configurations such as new types of multi-layer mirrors, gratings for grating-based phase contrast, and even hard x-ray zone plates.

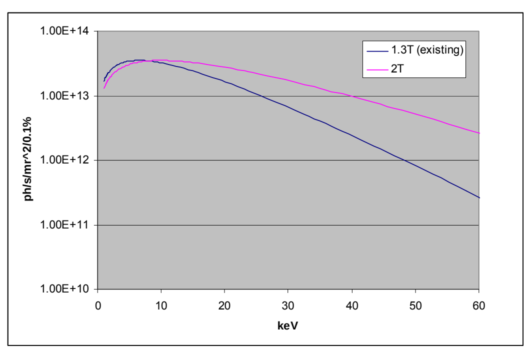
Local X-ray imaging/detector community

There is also a strong scientific community around Melbourne in the areas of x-ray imaging techniques – especially phase-contrast methods, and detector development. This user community could well contribute to the enhancement of the beamline, as well as benefitting from it.

Future upgrade possibilities

Superbend magnet

The radiation of the current bending magnet has a critical energy of around 8keV which means that flux towards the upper end of the target energy range at 40keV is significantly reduced compared to the flux at the lower end of the range.



Relative flux vs. energy for the existing 1.3T bending magnet and a 2T superbend.

A potential upgrade would be to replace the bending magnet with a 2T superbend with an Ec of ~ 12keV. This would boost the flux at the upper end of the targeted energy range by a factor of 4 and would also offer the possibility of expanding the upper energy range usable for experiments (with corresponding multi-layer mirror and mono upgrades) to 50keV, considerably expanding the range of applications to cover larger samples and denser materials (See figure).

Focusing Optics for Nanotomography

A further potential upgrade is to capitalise on constantly improving hard x-ray focusing optics to enhance the resolution and capabilities of the beamline. One such option would be to use refractive-diffractive optics to produce a secondary focus with of order 100 nm focal spot size and then use this for projection imaging with substantial magnification. Another possibility would be using a hard x-ray condenser and a high resolution hard x-ray objective such as a hard x-ray zone plate for nano-scale imaging and tomography.

Hyperspectral Imaging

New development in 2D energy-resolving detectors offer the possibility of multi- energy data sets simultaneously combined with appropriate data analysis methods.

B2: Applications and Potential Outcomes to Australian Scientific Community

Listed below is a compilation of potential applications for a micro-CT beamline for Australian researchers already using micro-CT and who would greatly benefit from a synchrotron micro-CT facility. In some cases these applications are already being carried out at overseas synchrotron facilities, in other cases the synchrotron would offer vastly extended possibilities over what is currently possible for these researchers in the lab.

Bio-sciences
Hierarchical studies of bone structure (Prof. John Clement, David Thomas Melbourne Dental School, University of Melbourne) To better understand and combat osteoporotic fractures, it is vital that we achieve a more complete understanding of the differences in bone architecture that exist between healthy adults and the elderly who are at risk of fracture. A hierarchical analysis, utilizing a range of imaging is essential for understanding of age-dependent change in bone architecture. Clinical CT imaging can readily provide quantitative data on the gross anatomy of long bones but at the scale of the internal pore structure, of the order of 10s of micrometres, and at the scale of the bone-forming and –resorbing cells it cannot resolve the necessary detail. This is where high throughput synchrotron micro-CT using phase-contrast and monochromatic beams can provide radically new information in large quantities in a relatively short time. Our ultimate objective will be to better characterize age-dependent change in bone architecture at the proximal femur and determine its relation to hip fracture.
Statistical studies of mouse-models on effects of medication on bone health (Damian Myers, Dept of Medicine, University of Melbourne). Medications such as valproate used to treat epilepsy are known or suspected to have deleterious effects on bone growth and health, causing significant problems for patients who take them throughout their lives. A number of researchers around Australia are using mouse models to assess the effect of various medications on bone-health and micro-CT of the mouse tibia is one promising way to assess this accurately. Synchrotron studies would enable micro-CT of a large number of similar samples enabling high quality statistical information to be obtained.

Micro CT for determining age at death from the micro-structure of teeth (Prof. John Clement, David Thomas, Melbourne Dental School, University of Melbourne). In the context of establishing the identity of unknown deceased individuals Professor John Clement has made several attempts to develop a method for determining age at death from the micro-structure of teeth. Existing methods require the preparation of thin sections and are known to be inaccurate, likely due to the use of two-dimensional methods to measure what is clearly a three-dimensional effect. Attempts to use laboratory micro-CT to map the surface of secondary mineralisation were unsuccessful due to limited spatial resolution & beam-hardening effects encountered using a laboratory machine. Both these problems are eliminated by the use of synchrotron-radiation micro-CT and, in addition, the high throughput of samples would allow adequate sampling of the population at a range of ages. (NB Paul Tafforeau's experiments with fossil teeth at ESRF suggest a good likelihood of success)
Imaging stem cells and their derivatives in mammalian tissues, Professor Graham Jenkin and colleagues, Monash Immunology and Stem Cell laboratories We aim to develop x-ray imaging methods which will reveal the position of single cells within the body of a live animal. In particular we wish to image stem cells that have been designed to treat disease and make repairs to the body both in their native form and after differentiation in vitro and in vivo into specific cell types. Studies of the distribution of therapeutic cells enabled by our new methods, will greatly assist research into adapting such cells to repair damaged tissue. In particular Monash Immunology and Stem Cell Laboratories (MISCL) and Monash Institute for Medical Research (MIMR) have developed means to turn certain easily obtained human cells into those suitable for repairing damaged lung tissue.
X-ray CT on embryonic specimens to investigate anatomy. (Prof. Peter Currie, Rob Bryson-Richardson, ARMI, Monash University) In vivo imaging of zebrafish embryos as well as other species is very valuable for the understanding of anatomy and its development. Imaging at a micro-CT beamline would include imaging of unlabelled samples, those using contrast agents as well as embryos specifically labelled with gold antibodies.
Understanding the mechanisms of tooth decay Dr. Nathan Cochrane, Prof Eric Reynolds (The University of Melbourne) Tooth decay is a widespread worldwide public health problem that ideally would be managed with non-invasive treatments that biochemically reverse the disease process. Enamel and dentine are hierarchical structures of organised organic and inorganic material. The behaviour of the inorganic crystals in the enamel and dentine at micrometer resolution are of importance in understanding the processes of demineralisation (progression of tooth decay) and remineralisation (the chemical process of non-invasively reversing tooth decay). Accurately mapping the mineral density changes in three dimensions (made possible by a monochromatic source) would progress our knowledge of the tooth decay process and means of reversing
Geomaterials
Real-time 3D studies of Thermal expansion and Fluid-Rock interactions at temperature and pressure (Florian Fusseis, University of Western Australia) Ongoing work at 2BM at the Advanced Photon Source with Francesco de Carlo includes the study of thermal expansion in granites in real-time. In future this approach will be taken a lot further by designing and constructing an X-ray transparent deformation cell, to study fluid-rock interaction in 3D in real time. This work would certainly benefit from access to local synchrotron high-speed micro-CT facilities.
Imaging Fluid Inclusions in Minerals (Dr Keyu Liu, CSIRO Petroleum, Kensington, WA) CSIRO Petroleum are interested in imaging fluid inclusions and associated mineralisation and bitumen trapped in minerals. The investigation is to study the fluid inclusion trapping mechanisms and their spatial distribution within minerals (carbonate, quartz, fluorite etc.). We would require the sub-micron resolution CT imaging capability for our research. [Some synchrotron work already carried out using the Chicago Synchrotron through Dr Rob Hough.]

Study of three-dimensional morphology of magmatic sulfides (Stephen Barnes, CSIRO Exploration and Mining, Bentley, WA)
Magmatic sulfides are the solidification products of magmatic sulfide liquids, which are found in association with many types of mantle-derived magma. They are important repositories for the highly chalcophile elements in the Earth's crust and mantle as well as the major source of nickel and the platinum group elements. Three dimensional information on the structure of these materials is used to shed light on ore formation and sulfide melt migration.

Mineral mapping in 3D (The ANU/UNSW XCT Group)
The diagenesis of oil-bearing carbonate rocks is a complex process of remineralisation, gain and lose of microporosity and importantly changes in wettability. Tomographic descriptions of rock fabric, in particular with respect to connected porosity, are greatly aided by the explicit identification of mineralogy. In the case of carbonates the differentiation of calcium and magnesium rich minerals is key and the application of energy-tuned micro-tomography would be a powerful tool in this field.

Rock microstructure data for numerical simulations – Marina Pervukhina (CSIRO Petroleum)
In geoscience microtomograms are used for description of mechanical behaviour of materials under stress, detection of fracture and localized deformation, clarification of pore saturation, etc., and most of all, microstructure characterization with a resolution down to less than 1 μm. The high-resolution 3D CT images are then used in numerical simulations of microstructure-related physical processes, e.g., flow and diffusion, elastic and electrical wave propagation, residual fluid saturation, etc. This is of practical importance to a number of fields including pure and applied geophysics, civil engineering, geochemistry, as well as geo-environmental sciences. In particular, we expect that in the nearest future 3D CT image-based numerical simulations will have a significant impact on oil and gas exploration and production, mineral ore grade identification and processing, subsurface pollutant transport and mitigation as well as underground storage and monitoring of CO_2.

Palaeontology

Studies of insects in opaque amber (Prof. Mike Archer, Dr Sue Hand, Henk Godthelp UNSW, & Dr Allan Jones, U. Sydney)
Australia's first fossil-rich amber was discovered in 2003 in Cape York, far north Queensland. Study of translucent samples indicates 20% have multiple inclusions such as insects, spiders, feathers, hair, plants, and fungi. Many of the samples are, however, opaque and cannot be studied using optical methods. Propagation-based micro-CT already carried out at ESRF has revealed high quality preservation of the fossils and has provided vastly more detailed biological and taxonomic data on these specimens for many of which this is their first fossil record. Access to such facilities within Australia would be a great boost to this work which is already benefitting from use of overseas synchrotron facilities.

Morphology of the narial chamber of sympatric, extinct nasal-ultrasound-emitting hipposiderid bats (Prof. Mike Archer, Dr Sue Hand & Henk Godthelp UNSW and Paul Tafforeau ESRF)
Discovery of perfect skulls of up to 8 sympatric species of hipposiderid or leaf-nosed bats from Oligocene and Miocene deposits in Riversleigh provides a unique opportunity to examine how these bats are modulating ultrasound to differentiate prey-hunting strategies. The internal structure/function of the narial chamber is very complex and poorly understood even in modern hipposiderids. Documentation and acoustic interpretation of these sound-modulating chambers could provide new insights into how animals have evolved innovative ways to use sound to better interpret their environments and compete more effectively for resources. The Australian synchrotron could provide the basis for this study which has already been 'proof-tested' using the ESRF in Grenoble, France.

3D morphology of teeth in modern and Pleistocene Australian mammals (Alistair Evans, Monash University)
High quality 3D data of the teeth and jaws of both modern and ancient mammals gives great insight into morphology and function such as jaw and tooth movement during feeding. Such studies can be used for palaeodietary reconstruction of Pleistocene mammals. High-throughput phase-contrast imaging of mammalian teeth would greatly improve the quality of data available for such studies.

Evolution of anatomy in the first land animals (Catherine Boisvert, ARMI, Monash University)
The evolution of anatomy in the first land animals can be inferred from the study of the larval and adult anatomy of fish and salamanders together with that of their fossil forebears. High resolution Micro-CT incorporating techniques such as phase-contrast which enhances sensitivity are ideal tools for this type of study.

Evolutionary origin of tooth development. (Kate Trinajstic, Curtin University, WA)
Establishing the evolutionary origin of tooth development can be achieved by surveying the dental developmental systems of fossil fish obtaining micro-CT of the denticles, teeth and jaws of each fossil fish group. From this virtual dissection we can show the growth history and comparison across ontogenetic stages to account for remodelling.
Micro-CT is needed to look at bone histology in fossils because CT is non destructive. It shows spaces very well and so we can trace sensory systems and the path of vessels and the lateral line usually obscured by bone. CT is particularly good at showing cavities in the head so the brain cavity, sinuses and the path of vessels and nerves can be determined. From this virtual endocasts can be produced. Fossils often collapse in on themselves and CT allows us to virtually remove overlying and obscuring features without destroying the fossil. (see also section B3).

Paleo-histology histology of preserved soft and boney tissue; (ANU, Curtin University, Museum Victoria)
Australia hosts some of the best examples of fossil soft tissue preservation in the world. Recent discoveries of connective tissue, muscle and even several fossilized fish embryos over 380 million years old would benefit from sub-micron histological investigation. The screening of tissue samples requires high throughput as well as high precision, two features offered by this new beamline proposal

Materials (synthetic and natural)

Systematic Studies of corrosion in small metal samples (Steven Knight, Maria Salagaras, & Tony Trueman, Corrosion Management Group, Defence Science & Technology Organisation)
Micro-CT can be used in studying how localised sub-surface corrosion develops in aluminium alloys used on aircraft and marine platforms. High throughput micro-CT available at a synchrotron beamline would allow us to better study the initiation and propagation of corrosion with respect to time and environmental conditions.

3D connectivity of porous biominerals including formanifera (Assoc Prof Kate McGrath, Assoc prof. Victoria University of Wellington, New Zealand)
Many biominerals are believed to serve a role beyond merely protection, such as, directing or focussing light and delivering nutrients. In order to probe these functions of the biominerals it is necessary to build up 3D mappings of the pore network to allow robust computer renditions of the skeletal forms to be generated enabling robust modelling of light paths and micro and nanofluidic characterisation to be performed. High resolution and high throughput CT would be of great benefit to these studies

Statistical information on wood microstructure from high-throughput micro-CT (Rob Evans, Sherry Mayo CSIRO Materials Science and Engineering) High speed methods of wood analysis based on x-ray diffraction and optical analysis have been developed at CSIRO in the form of the Silviscan instrument. Knowledge of the microstructure in three dimensions is highly valuable for validating and understanding the limitations of Silviscan analyses. High-throughput micro-CT would enable a statistically valid sample of datasets from a larger number of wood samples to be acquired, providing a much more rigorous basis for validation and comparison with data obtained from Silviscan.
Dental materials for the restoration of teeth. Dr Joseph Palamara, Melbourne Dental School • Investigation of the presence, propagation and size of cracks/voids within dental materials and at the bonded interface of restored teeth. • Dynamic/static effects of loading restored teeth and their longevity as a function of thermal and mechanical fatigue. • Wear studies on the surface of teeth as it relates to strain upon loading. • De-mineralization and re-mineralization of enamel and dentin and the protective effect of materials (fluoride etc) • Fluid flow through dentin and the ability of materials to seal. • Stability of crown and implants as a function of supporting hard tissue.
Study of particulate materials. Bill Skinner & colleagues, Ian Wark Research Institute University of South Australia • 3D mineralogy of particle assemblages, correlated with 2D QEMSCAN liberation analysis of sections (Skinner, Grano, Zanin) • Particle aggregate morphology and pore structures. Aggregation and particle growth in real time using immobilised seed particles (Addai-Mensah, Skinner). • Fluid flow and distribution in microporous materials (Ralston, Propescu, Sedev) • Bubble-particle interactions (Ralston, Grano) • 3D tomography of particles in flowlines (Grano, Ralston, Skinner) • Particulate pharmaceuticals in tissues and airway surface layers (Prestidge, Barnes, Skinner) • Metalloid particles in plant tissues and in the rhizosphere (Lombi, Kempson, Skinner)
Dynamic Studies of hydration – Will Gates Civil Engineering Monash University Geosynthetic Clay Liners (GCLs) are engineered products used extensively in lining and containment operations for the waste management and mining sectors. Bentonite, in is the most common raw material providing primary sealing action used in geosynthetic clay liners. Real-time hydration/dehydration, swelling and consolidation in bentonite liners to get a more accurate measure of porosity and pore connectivity and distribution.
Fundamental studies of CT methods
Fundamental Studies of CT methods (Imants Svalbe, Monash University) To test optimal CT algorithms requires very high quality data CT data acquired at translates and angles that optimally match those given in theory by exact, discrete projection formulations, such as the finite Radon transform. A dedicated micro-CT beamline offers the ability to acquire high quality data with closely controlled experimental conditions.
Data Constrained Modelling (Sam Yang, CSIRO Materials Science and Engineering) We are developing methods for model the 3D composition of complex materials from combined limited datasets including tomographic datasets acquired at different energies. In developing these methods, high quality micro-CT datasets of a number of difference samples acquired at a range of energies are required. This is difficult to achieve in the lab and would greatly benefit from access to a micro-CT beamline.

B3: Match to Selection Criteria.:

- ***Meet the demands of an identified group of researchers for new techniques***

This is largely addressed in sections B2 and B4. In summary there is an active and growing micro-CT community in Australia & New Zealand using lab-based systems and overseas synchrotrons. They are well positioned to take advantage of the proposed beamline should it become available as can be seen from the list of potential applications supplied by supporters of the beamline in section B2.

- ***Take advantage of the existing third generation light source***

A reasonable idea of what can be achieved at this beamline can be judged by comparison with the similar TOMCAT beamline at the third generation light source SLS. As reported by Rajmund Mokso at SRI 09 this beamline has already achieved sub-second data collection using broadband monochromatic beam from multilayer mirrors and they expect to achieve significantly greater speeds when white-beam data collection is implemented. Phase-contrast and other imaging modes have also been successfully used at this beamline.

TOMCAT is on a superbend on the 2.4GeV SLS ring which has a critical energy of 11keV. A standard bend on the 3GeV Australian Synchrotron would have a critical energy of 8keV and should have comparable flux in the lower half of the proposed energy range and somewhat lower flux in the upper half of the range. Based on what has already been achieved at TOMCAT, sub-second micro-CT should definitely be feasible on a bending magnet at the Australian Synchrotron. The source size in the bends should also make it possible to achieve propagation-based contrast without too much difficulty.

- ***Will position Australasian scientists at the leading edge of their field***

Synchrotron micro-CT has the potential to impact on scientific endeavour in a wide variety of fields. This can be illustrated with a few examples.

Some of the ground-breaking work made possible in the paleontological field by synchrotron micro-CT was highlighted in plenary and public lectures during the recent SRI 09 meeting by Paul Tafforeau of ESRF and Kate Trinajstic. Australian palaeontologists such as Kate and Mike Archer are already taking advantage of the facilities developed at ESRF to carry out widely recognised work in this field which also capitalises on Australia's unique fossil record.

Kate outlines how her work benefits from using the synchrotron:

> *'Fossils illuminate parts of vertebrate morphology that are not represented by living forms. However, fossils are very fragile and rare and there is conflict between obtaining significant morphological information and the conservation of the fossil.*
>
> *Synchrotron micro-CT overcomes this limitation by providing the ability to image the microstructure of the fossil bone three dimensionally and non destructively. It is capable of imaging histological details such as Sharpey's fibres (where muscles attach to bone) and arrested growth surfaces that lie entirely within solid bone at sub micron levels. This is allowing the reconstruction of soft tissues and growth patterns with an accuracy never realised before.'*

Australian palaeontologists would benefit greatly from local facilities to carry out these studies.

Geoscience is very important to Australia due to the larger concentration of mineral resources found in this country. Some of the critical questions in this field include the nature of deformation and flow processes in rocks at high temperatures and pressures and the behaviour of fluids in these porous materials. Perth-based scientist Florian Fusseis (see section B2) is already developing new tools for taking advantage of synchrotron micro-CT to answer some of these questions in collaboration with Francesco de Carlo at the Advanced Photon Source. Micro-CT in the geosciences area is starting from a strong base of excellent work already done in the lab by groups around Australia.

Materials Science is a field which is already making great use of micro-CT. Bill Skinner is from the Ian Wark Institute which includes the Special Research Centre for Particle and Material Interfaces. Bill writes:

> *Though 70+% in the soft X-ray area, I (and my colleagues here at the Ian Wark Research Institute) have been lamenting the lack of access to a good, practical and robust CT beamline. The prospect of dynamic imaging (< second/frame) is very exciting*

Bill and his colleagues outline the range of research where synchrotron micro-CT is of interest to them in section B2 above.

There is a great strength in the area of biomedical science within Australia with a significant concentration of researchers in SE Australia. It is interest from such researchers that played a major role in the establishment of the IMBL at the Australian Synchrotron. A great deal of work on bone health and anatomy is done using mouse and other small animal models together with studies of human bone on the microscopic scale. A high-throughput micro-CT beamline would be a great asset to this area of research by enabling a larger number of samples to be analysed making more statistically rigorous studies possible. The phase-contrast modes available on the beamline will also be of great benefit for the study of soft tissue features.

- ***Can be demonstrated to be feasibly constructed within a 3 year timeframe***

This type of micro-CT beamline has a relatively simple design. The beamline is located on a bending magnet so does not require procurement and installation of an insertion device. The major optics are silicon and multilayer-mirror monochromators, both of which can be sourced with relative ease.

The major end station components required for tomography are a high precision rotation stage and a high speed detector. Readily available air-bearing stages provide sufficient stability for submicron resolution. Detectors typically used for synchrotron micro-CT are based on scintillators optically coupled to CCDs. However in this case replacing the CCD with CMOS-based technology may provide better results for high speed acquisition, and a prototype of such a detector (manufactured by PCO) is in successful operation on TOMCAT.

For high throughput work robotic sample exchange is essential and this has been implemented on a number of other types of beamlines around the world including, the protein crystallography beamlines on the Australian Synchrotron. Additional desirable components include gratings for grating-based phase-contrast and analyser crystals for DEI are all readily available, and it may even be possible to share some such components with IMBL.

Nothing in the design or required components for this beamline should present major difficulties for sourcing and construction. Getting the best performance out of the beamline will depend instead on effective integration of all these components.

Experience with the first experiments on IMBL suggests that basic operation with white-beam tomography including inline phase-contrast should be possible at a very early stage provided a suitable detector and stage are available. Additional modes of operation can be introduced in a staged way as the necessary components come online.

B4: Potential Users

Micro-CT is a rapidly growing analytical technique with a growing community in Australia & New Zealand due to the increasing availability of lab-based micro-CT systems. Such lab systems typically enable micro-CT with resolution down to a few microns and data collection times of a few hours. Each such lab system is typically a collective resource supporting a significant number of users and operated by a micro-CT specialist. The community is a growing one and came together for two national workshops in the last two years.

A synchrotron light source offers the possibility of a range of micro-CT capabilities not possible in the lab. This includes applications requiring high-throughput, time-resolved micro-CT/imaging, phase-contrast or a monochromatic beam for quantitative work and elemental sensitivity. The flexibility of a synchrotron beamline environment also offers the possibility of environmental cells and stages for dynamic studies of changing systems. It would give the users of lab-based systems an invaluable set of additional capabilities.

The potential user community consists of a mixture of experienced micro-CT scientists who in many cases already make use of overseas micro-CT beamlines, together with a growing number of scientists who in recent years have added micro-CT to their suite of characterisation tools and are finding they have particular applications which cannot be satisfactorily carried out in the lab. The expert users who generally also run the lab-based systems would be an invaluable resource in directing their users/collaborators to the synchrotron when their experimental requirements warrant it.

There are also a number of potential users who would not think of using the synchrotron but who would likely become very interested as they see what their colleagues in the field are using it for. For example, a group of taxonomists contacted in the course of developing this proposal did not even know what a synchrotron was and have just started out using a lab micro-CT system. They are daunted by the sheer quantity of samples they have for analysis and were very excited by the possibilities that high-throughput micro-CT might offer them.

Experience at overseas synchrotrons clearly indicates that micro-CT in all its forms is a rapidly growing area of activity worldwide. This coupled with the existing potential user base make a strong case for building a dedicated CT beamline at the Australian Synchrotron. This is also indicated by the level of interest already achieved for this beamline - over 90 people either joined the mailing list or contacted us privately to indicate their support.

Other Supporters

Adrian Sheppard (adrian.sheppard@anu.edu.au)	Marina Pervukhina (marina.pervukhina@csiro.au)
Akira Otsuki (akira.otsuki@unisa.edu.au)	Mark Pownceby (mark.pownceby@csiro.au)
Alistair Evans (alistair.evans@sci.monash.edu.au)	Martin de Jonge (Martin.deJonge@synchrotron.org.au)
Allan Jones (allanj@emu.usyd.edu.au)	Martin Lackmann (Martin.Lackmann@med.monash.edu.au)
Andrew Bunger (andrew.bunger@csiro.au)	Michael Cheah (cheah@anbf2.kek.jp)
Andrew Kingston (andrew.kingston@anu.edu.au)	pascal vallotton (pascal.vallotton@csiro.au)
Andrew Peele (a.peele@latrobe.edu.au)	Peter Currie (peter.currie@armi.monash.edu.au)
Andrew Stevenson (andrew.stevenson@csiro.au)	Philip Heraud (phil.heraud@med.monash.edu.au)
Benedicta Arhatari (b.arhatari@latrobe.edu.au)	Richard Garrett (garrett@ansto.gov.au)
Bill Skinner (bill.skinner@unisa.edu.au)	Rob Lewis (rob.lewis@sync.monash.edu.au)
Catherine Boisvert (catherine.boisvert@armi.monash.edu.au)	Robert Bryson-Richardson (robert.bryson-richardson@armi.monash.edu.au)
Chris Ryan (chris.ryan@csiro.au)	Robert Hough (robert.hough@csiro.au)
Chris Sobey (chris.sobey@med.monash.edu.au)	S H Lau (shlau@xradia.com)
Christopher Hall (chris.hall@sync.monash.edu.au)	Sherry Mayo (Sherry.Mayo@csiro.au)
Cordelia Selomulya (cordelia.selomulya@eng.monash.edu.au)	Stephen Cody (stephen.cody@med.monash.edu.au)
David McLellan (wisdom_management@bigpond.com)	Steve Barnes (steve.barnes@csiro.au)
David Paganin (david.paganin@sci.monash.edu.au)	Steven Knight (steven.knight@dsto.defence.gov.au)
David Thomas (cdthomas@unimelb.edu.au)	Tim Gureyev (Tim.Gureyev@csiro.au)
David Tokell (David.Tokell@synchrotron.org.au)	Tim Senden (tim.senden@anu.edu.au)
Eric Reynolds (e.reynolds@unimelb.edu.au)	Vicki Chen (v.chen@unsw.edu.au)
Florian Fusseis (florianfusseis@me.com)	Will Gates (will.gates@eng.monash.edu.au)
Gareth Moorhead (gareth.moorhead@csiro.au)	Wojciech Kwiatek (wojciech.kwiatek@ifj.edu.pl)
Garry Foran (garry.foran@gmail.com)	Xun Bian (xun.bian@postgrads.unisa.edu.au)
Gary Delaney (gary.delaney@csiro.au)	Yanju Liu (Yanju.Liu@postgrads.unisa.edu.au)
George Simon (george.simon@eng.monash.edu.au)	Zbigniew Stachura (Zbigniew.Stachura@ifj.edu.pl)
Glenn Walker (gdwalker@unimelb.edu.au)	Zhonghua Sun (z.sun@curtin.edu.au)
Graham Jenkin (graham.jenkin@med.monash.edu.au)	Robert Evans (Robert.Evans@csiro.au)
Hua Li (liyhy034@students.unisa.edu.au)	Nathan Cochrane
Iain Young (iain.young@une.edu.au)	David Jones (David.Jones@sci.monash.edu.au)
Ian Gentle (Ian.Gentle@synchrotron.org.au)	Karl Whittle (karl.whittle@ansto.gov.au)
Ian Harper (Ian.Harper@med.monash.edu.au)	Marjorie Valix (mvalix@usyd.edu.au)
Ian Parkinson (ian.parkinson@health.sa.gov.au)	Damian Myers (damianem@unimelb.edu.au)
Imants Svalbe (imants.svalbe@sci.monash.edu.au)	Karen Siu (karen.siu@sync.monash.edu.au)
Jacqui Hislop-Jambrich (jacquihj@gmail.com)	Steve Wilkins (steve.wilkins@csiro.au)
James Pearson (james.pearson@med.monash.edu.au)	Glenn Davis (sales@flo.com.au)
Janusz Lekki (Janusz.Lekki@ifj.edu.pl)	Rosyln Gleadow (ros.gleadow@sci.monash.edu.au)
Jeffrey Crosbie (Jeff.Crosbie@med.monash.edu.au)	
John Gillam (john.gillam@sci.monash.edu.au)	**Other supporters not on list**
John Terlet (john.terlet@adelaide.edu.au)	Peter van der Heide [p.vanderheide@uq.edu.au]
Josef Uher (josef.uher@csiro.au)	Mike Archer

Joseph Palamara (palamara@unimelb.edu.au)	Kate McGrath
Julio Soria (julio.soria@eng.monash.edu.au)	John Clement
Katherine Trinajstic (k.trinajstic@curtin.edu.au)	Susie Nilsson
Keyu Liu (Keyu.Liu@csiro.au)	Dr Joseph Palamara
Konstantin Pavlov (konstantin.pavlov@une.edu.au)	Ben Clennell
Lars Thomsen (Lars.Thomsen@synchrotron.org.au)	Damian Dowling
Malgorzata Lekka (Malgorzata.Lekka@ifj.edu.pl)	
Maria Forsyth (maria.forsyth@eng.monash.edu.au)	
Marian Cholewa (Marian.Cholewa@sync.monash.edu.au)	