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ABOUT CXS

The Australian Research Council (ARC) Centre of Excellence for Coherent X-ray Science (CXS) brings together leading Australian researchers in the fields of X-ray physics; the design and use of synchrotron radiation sources; and the preparation, manipulation and characterisation of biological samples.

Its aim is to open a new frontier in biotechnology – the non-crystallographic structural determination of membrane proteins. These proteins mediate the activity of pharmaceuticals in human medical therapies. Their structures, however, are still mostly unknown because they do not form crystals suitable for analysis using the conventional crystallographic techniques that have driven almost all the progress in structural biology. A breakthrough in this area would revolutionise rational drug design through the insight gained into the function of membrane proteins. This would have far-reaching consequences for the pharmaceutical industry. CXS's research is driven by its access to existing third-generation synchrotron light sources and to the Australian Synchrotron. We are also exploring the application to imaging problems of short wavelength high-harmonic generation sources and free-electron X-ray lasers that are under development worldwide.

When combined with non-crystallographic diffractive imaging techniques, the brightness and intensity of these sources gives us the opportunity to take snapshots of biomolecules. We are exploring the fundamental issues in the use of these light sources, including the nature of the interaction between intense coherent X-rays and electronic matter. The efficiency of diffraction processes in these highly coupled light-matter systems, the detection of the scattered light, the preparation and handling of suitable biological samples, the management of radiation damage throughout the interaction, and the design of algorithms to extract structural information from diffraction data is also under exploration.

It is an ambitious interdisciplinary program of research.



DIRECTOR'S REPORT

2011 has been another tremendous year for CXS, as well as a year of change, development and challenges.

CXS is, at its heart, a program that is committed to the promotion of interdisciplinary science. We stated from the outset that we would succeed or fail by the degree to which we can work collectively across disciplinary and institutional boundaries. The development of activities across boundaries, which often seem like barriers, takes time and commitment. I am delighted to see that, as is reflected in the 2011 Annual Report, we continue to develop and improve the cross-disciplinary integration of CXS. I think we can safely say that we are succeeding.

There are a wide range of scientific highlights that are discussed in this report. To my mind, the goal of a Centre of Excellence should be to produce the best possible science and this is perhaps best measured by the quality of the journals in which our work is published. The evidence of our continued improvement by this metric is compelling, including the publication of three papers in the *Nature* stable in 2011.

CXS staff continue to be recognised for their excellence. It was pleasing to see recognition for Alex Maier's work - amongst that of many others - through the presentation of the Khwarizmi International Award; the La Trobe University Deputy Vice-Chancellor's Excellence in Research Award for a mid-career researcher; and as a runner-up in the Eureka Prize People's Choice Award. Our Deputy Director, Leann Tilley, won the 2011 Beckman Coulter Discovery Science award from the Australian Society for Biochemistry and Molecular Biology and

in 2011 it was announced that Harry Quiney, leader of the Theory and Modelling Program, had been awarded the 2010 David Syme Research Prize.

2011 saw us continue with our annual workshops and they get better every year. These meetings are truly exceptional and we are able to attract leading researchers from across the world to share their expertise and mix with staff and students in a relaxed and informal atmosphere. This year we combined the workshops with our annual advisory committee meetings. The Scientific Advisory Committee (SAC) continued to provide insightful guidance on the way forward for us. We also held a workshop on the evolution of ideas for the continuation of CXS beyond our current term. This was very lively meeting that has established the basis for more development and team building over 2012.

An important piece of advice from SAC was for us to continue growing our relationship with the international X-ray free electron laser community. To this end, among a number of other activities and workshops, we co-hosted a wonderful workshop in Cairns with our Japanese colleagues to discuss the opportunities made possible by the successful operation of the SACLA X-ray free electron laser at the SPring8 site. We hope that this meeting will contribute to a deeper relationship with our northern colleagues.

The outreach program that CXS jointly operates with Santa Maria College, Northcote, *Growing Tall Poppies*, continues to develop and thrive. We are delighted that it is having a significant impact on the number of girls retained in the study of physics. This is precisely the goal of the project and we will explore how we may broaden the impact of the approach to enthuse the next generation of scientists.

Changes at Monash University have also had a serious impact on CXS and I am sorry to report that we will lose the contribution of Andrei Nikulin at the beginning of 2012. We are exploring options in the wake of this development, but we wish Andrei the very best for his future career.

It is a cliché, but CXS is primarily about people and relationships. We are always delighted to see our members thrive and the appointment of Harry Quiney and Brian Abbey to continuing positions (at the University of Melbourne and La Trobe University respectively) was a tremendous endorsement of the quality of our people and the work we do. Leann Tilley's excellence was recognised by her move to the University of Melbourne. La Trobe's loss is the University of Melbourne's gain. Dave Kielinski, leader of the Attosecond Science Program was promoted to Professor at Griffith University.

Andrew Peele has continued his secondment as Head of Science to the Australian Synchrotron and I took up a part-time role as Director of the Australian Synchrotron. These external appointments are testament to the esteem in which CXS scientific leadership is held, but of course also lead to significant challenges. In particular, I am indebted to Harry Quiney for stepping up to the role of Assistant Director to ensure that the managing node of CXS continues with leadership of the highest quality.

It has been a terrific year. 2012 is shaping up to be even better.



PROFESSOR KEITH NUGENT
DIRECTOR

ASSISTANT DIRECTOR'S REPORT

It has been an honour and a privilege to serve as the CXS Assistant Director during 2011. CXS is particularly fortunate to have such a dedicated and enthusiastic Executive Committee that has made my duties so easy and enjoyable.

During this year our Director was seconded to other important tasks with the Australian Synchrotron. This facility has always played an important role in our goal to contribute to Australia's established position as a global leader in all aspects of X-ray science. While Keith has been diverted from his research in 2011, it is nevertheless appropriate that he has spent much of the year dedicated to the goal of ensuring that the Synchrotron will continue to benefit the entire scientific community. I am delighted to have been given the opportunity to make a modest contribution towards these wider goals by taking on the position of CXS Assistant Director during 2011. I am personally indebted to the wise counsel of Bonnie Wallace and Steve Lane of our Scientific Advisory Committee, whose international perspectives on CXS are helping us all look forward to the future with renewed energy and confidence. I have also very much enjoyed assisting the Deputy Director, Leann Tilley, in driving forward the CXS science program and in finding new and surprising ways in which physicists and biologists can work together.

The year 2011 was marked by a number of significant changes in CXS. Most of these reflect the esteem in which our interdisciplinary collaboration and its

membership are already held and point towards an even brighter scientific future. The Director has already reported the outstanding achievements of CXS members and the year's events; I would like to record my own thanks to the many collaborators who helped to develop and promote our inter-disciplinary research program in 2011.

A high point of the year was the CXS Annual Workshop, which was again held in Bio21 and attracted a truly stellar list of local and international speakers. At the conclusion of this meeting we took the opportunity to gather these experts together to elicit their opinions on the progress and scientific direction of CXS, with a view to identifying future opportunities. This round-table Meeting identified a number of exciting new research prospects for us to explore and was the first step towards our efforts to identify new interdisciplinary research targets that might form the basis of future collaborations. This initiative has already attracted significant support and I look forward to coordinating our next forward planning workshop in May 2012 to develop specific proposals for our future growth.

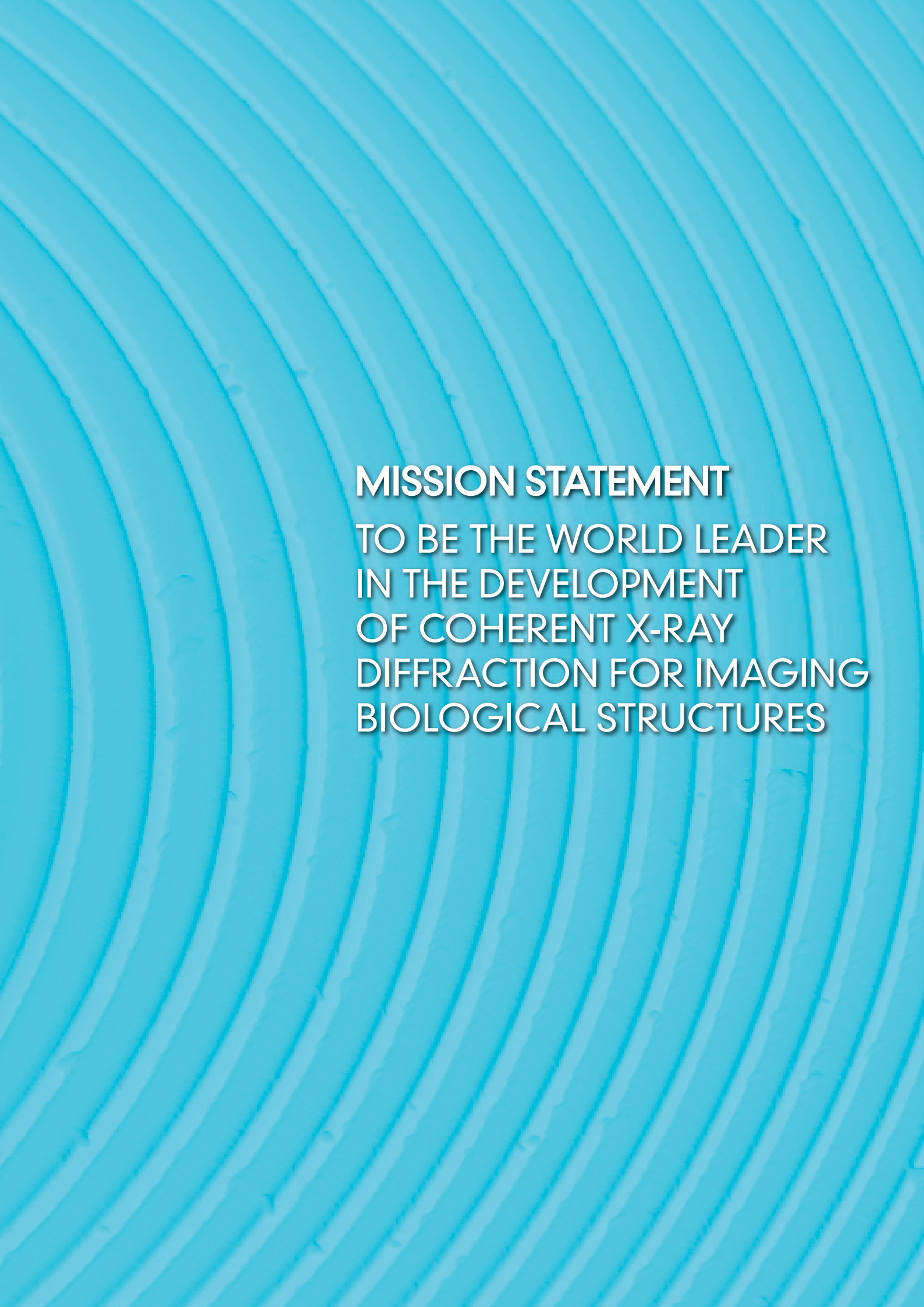
A particular highlight for me was the award to CXS of beam time at the Linac Coherent Light Source (LCLS) X-ray free-electron laser facility in California. A principal goal of CXS has been to perform structural studies of bio molecular systems at LCLS, the European X-Ray Free-Electron Laser (XFEL) or with our Japanese collaborators at SPring-8 Angstrom Compact Free Electron Laser (SACLA). The success of our application in this highly competitive process represents a tangible and pleasing outcome of the wide-ranging and complex interdisciplinary research that we have conducted over the past seven years

towards precisely this outcome. It reflects the very high international standing of CXS research in this emerging field of research.

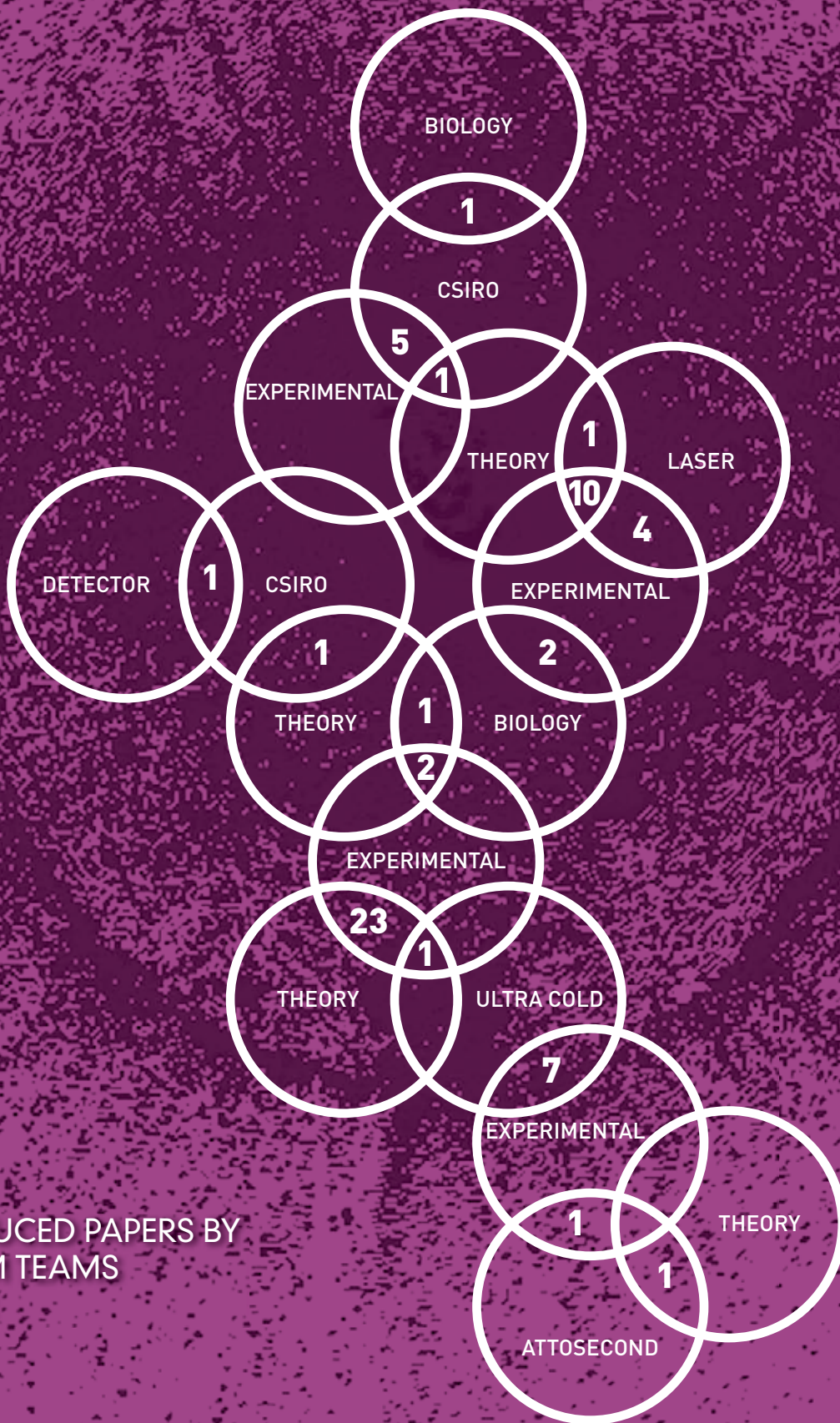
It has been a splendid year. I would like to thank you all for your support and for the collegial manner in which we have pursued our ambitions to make a significant impact at the intersection of physics, chemistry and biology. I look forward, with confidence, to an even more splendid 2012.



HARRY QUINEY
ASSISTANT DIRECTOR



MISSION STATEMENT
TO BE THE WORLD LEADER
IN THE DEVELOPMENT
OF COHERENT X-RAY
DIFFRACTION FOR IMAGING
BIOLOGICAL STRUCTURES



CO-PRODUCED PAPERS BY
PROGRAM TEAMS
2005 – 2011



RESEARCH PROGRAMS

ATTOSECOND SCIENCES PROGRAM

The Attosecond Science program in CXS, which began collaborating with CXS in June 2009, offers new opportunities for coherent X-ray science that are unique within Australia. The new and rapidly expanding field of attosecond science is based on recent revolutionary developments in ultrafast optics that resulted in the award of the Nobel Prize in 2005.

It is now possible to generate high-energy infrared light pulses consisting of only a few cycles of the electric field and to control the optical electric field waveform within the light pulses. Such optical pulses have been used to generate isolated soft X-ray bursts with durations below 100 attosecond ($1 \text{ as} = 10^{-18} \text{ s}$). They can also provide information on atomic and molecular dynamics on the attosecond timescale and have been used to map the electronic structure of molecules. The Australian Attosecond Science Facility (AASF) is the unique tool in Australia for attosecond science investigations. The facility is directed by A/Prof Kielinski, leader of the CXS Attosecond Science program as of January 2010. The heart of the facility is a laser source providing 6 fs, 300 μJ , phase-stabilized laser pulses, commissioned in 2007 through an ARC LIEF grant.

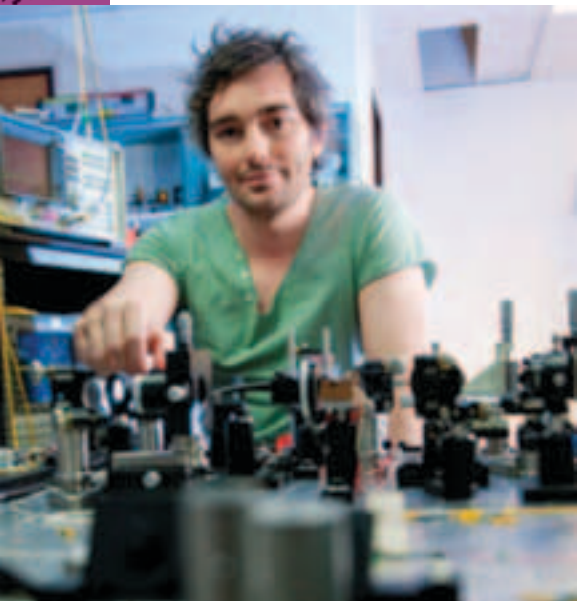
In 2009, the AASF experimental group began a close collaboration with the CXS Theory and Modeling group on the response of atomic hydrogen to strong few-cycle laser pulses. Atomic and molecular dynamics in strong optical fields plays a crucial role in many CXS activities, from the Biological Sciences program's goal of molecular structure retrieval from single-molecule X-ray diffraction to the high-harmonic generation work of the Short Wavelength Laser Source program. However, theory and experiment in this area rarely give quantitative agreement. As the only attosecond science group with access to atomic hydrogen, the AASF group has a unique opportunity to benchmark strong-field theories with the help of the Theory and Modeling group.

As part of CXS, the AASF group will also pursue the generation of isolated attosecond X-ray pulses, which have already proved useful as tools for probing electronic structure of atoms, molecules, and surfaces. Currently only four research groups in the world have this capability. Isolated attosecond pulses can help unravel the problem of nonlinear X-ray backaction on molecular diffraction imaging, a key step in realising CXS goals in biomolecular structure determination. Modelling of back-action during the long X-ray pulses from synchrotrons and free-electron lasers (FELs) requires simultaneous incorporation of several mutually interacting many-body effects, a highly challenging task. In contrast, attosecond pulses provide a window into the short-time dynamics, effectively decoupling the many-body effects. Attosecond interactions can also selectively incorporate or exclude particular processes. Although the total energy delivered in an attosecond pulse is much lower than that expected at a FEL, the peak X-ray intensity can be nearly as high because of the short pulse duration.

GOALS

The goals of the Attosecond Science program are twofold:

1. We will generate isolated attosecond pulses of XUV light for time-resolved X-ray science. Such pulses are presently the unique means of access to attosecond dynamics and are currently available at only four laser facilities worldwide. We anticipate that XUV pulses of duration <500



PhD graduate Michael Pullen adjusts an optical setup.

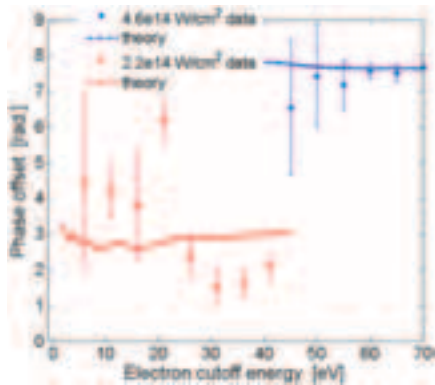
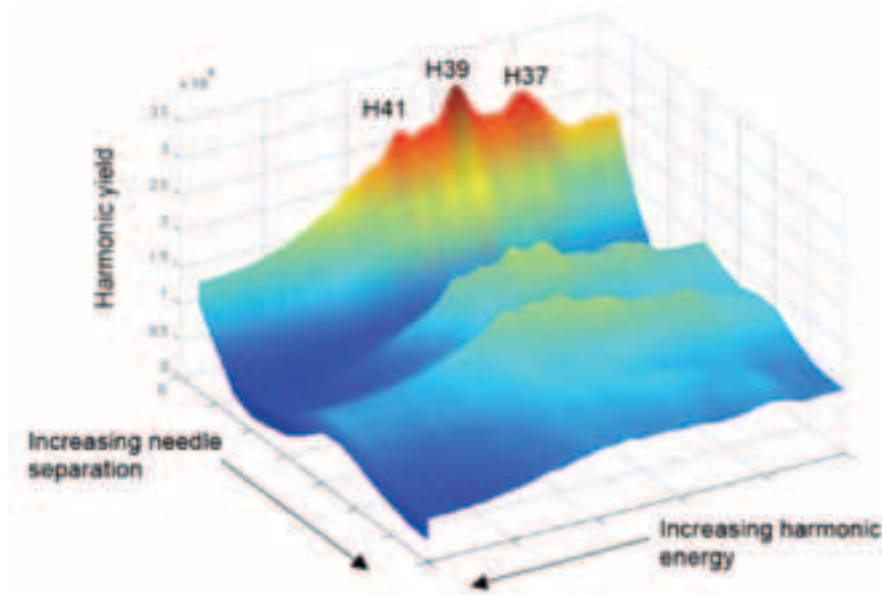


Figure 1. Measurement of laser carrier-envelope phase with atomic hydrogen. Good agreement with theory is obtained at high laser intensity. At lower intensities some differences remain to be resolved.



as and peak intensities of 100 GW/cm², with wavelength in the 10-20 nm range, will be achievable in the next two years. Isolated attosecond pulses have already proved useful as tools for probing electronic structure of atoms, molecules, and surfaces. We will extend these studies to specific chemical and biological applications of interest to CXS members. Because attosecond science is so new, basic experimental methods are still under development. Close collaboration between our group and end-users in CXS will prove essential in realising the promise of attosecond science and new methods will be rapidly taken up worldwide. We have already generated XUV radiation at wavelengths as short as 30 nm by focusing the AASF laser through an argon gas jet and are preparing to investigate the temporal properties of the XUV light. Nonlinear X-ray processes in helium gas have been observed in other laboratories with isolated attosecond pulses and will be readily observed for the much larger dipole moments of chemical and biological samples. Generalising commonly used ultrafast pump-probe techniques to the attosecond domain will eventually enable us to evaluate the full dynamic structure factor of chemical and biological samples under X-ray irradiation for detailed comparisons with backaction models.

2. We will investigate the effects of atomic structure on strong-field interactions through quantum control of the ultracold metastable neon atoms currently generated in our laboratory. HHG data

on the exotic electronic structure of metastable neon will be critically sensitive to poorly-understood atomic physics effects in HHG. Quantum state control of the atoms involved in HHG isolates specific atomic processes for detailed tests of theoretical HHG models. The novel computational techniques of the CXS Theory and Modeling group will transform our data into optimised designs for HHG-based X-ray sources of specific spectral and temporal characteristics. The Short Wavelength Laser Source program can take advantage of these designs for their XUV imaging source, tailoring the XUV source to their particular goals.

The single-atom dipole response to a strong IR field is a crucial input for optimisation of HHG sources. A recent experiment has shown that interference between the dipole amplitudes of different atomic species in a mixture of gases can boost HHG by over three orders of magnitude. However, the standard theory of HHG is inadequate for describing atomic structure effects and numerical predictions of the HHG spectrum vary by a factor of 2 according to the exact methods used. The CXS Theory and Modeling group has developed a new theory of atomic HHG based on free-field atomic states. Our current experiment examines ionisation of atomic hydrogen with few-cycle laser pulses, and we are now working with the CXS Theory and Modeling Group to interpret these results. Because the hydrogen atom is so simple, subsequent HHG studies in hydrogen will be an excellent benchmark for HHG modeling.

CARRIER-ENVELOPE PHASE EFFECTS IN PHOTOIONISATION OF ATOMIC HYDROGEN

Attosecond science promises to revolutionize our understanding of the electronic dynamics of matter, but relies on the control of highly nonlinear light-matter interactions driven by few-cycle laser pulses. In this regime, retrieving useful measurements from experimental data requires complex, nonlinear numerical simulations. Only qualitative agreement between experiment and simulation is generally obtained, so that calibration and control of experiments remains difficult.

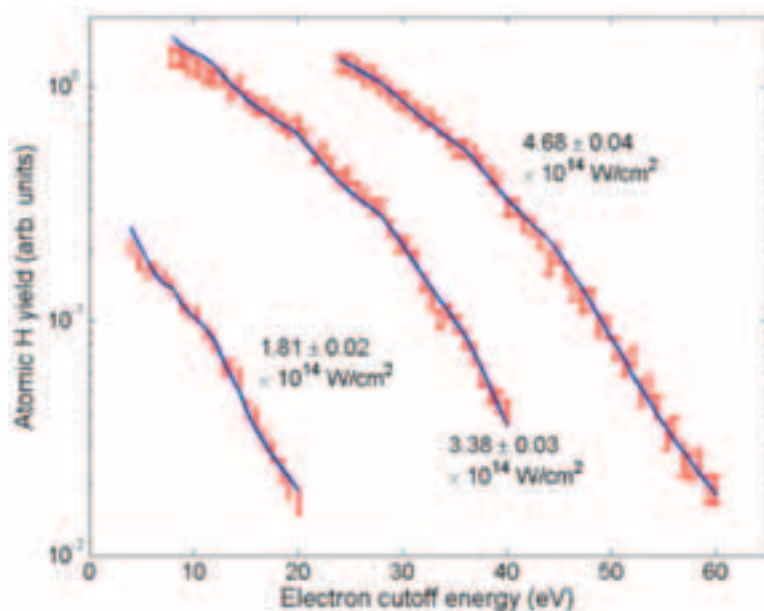
The Attosecond Science program uses atomic hydrogen to obtain accurate and precise reference data that can be used to test the predictions of the Theory and Modeling group and for ready calibration of attosecond science experiments in laboratories around the world. Only atomic hydrogen can be simulated theoretically from first principles in this regime, so hydrogen provides a unique benchmark for accurate attosecond science measurements. The Attosecond Science program is the only group in the world to combine attosecond laser technology with atomic hydrogen. Last year, we achieved a remarkable degree of quantitative agreement between experiment and theory in the laser interaction regime relevant to attosecond science.

In 2011 we extended this success to observe laser carrier-envelope phase effects in the photoionisation of hydrogen. This laser



Left: Figure 2. Dual XUV generation at variable time delay with phase-stabilised IR pulses. The appearance of a featureless high-energy continuum (left of H41) at a particular laser phase indicates the generation of pairs of attosecond pulses.

Right: Figure 3. Calibration of strong laser intensities using photoionisation of atomic hydrogen. Data (red bars) agrees perfectly with first-principles theory calculations (blue lines), enabling us to infer the intensity with 1% accuracy.



phase is the “clock” for attosecond time resolution and is often measured using photoionisation of noble gases. However, there is a time delay for the electron to escape from the atom, and the size of the time delay depends on the exact atomic structure. This time delay cannot be independently measured, and theory is unable to predict it except for hydrogen, so it is currently not possible to make an absolutely accurate measurement of the “clock” timing. By comparing our data on hydrogen to theoretical predictions (Fig. 1), we provide a unique benchmark for timing measurements in attosecond science. This year, we plan to use the hydrogen data to calibrate this time delay for the noble gas species used in other experiments worldwide, transferring our absolute accuracy to those experiments.

ATTOSECOND PULSE PAIRS WITH TUNABLE DELAY

When an atom is exposed to an electric field in which the field strength approaches the Coulomb binding energy of the outer electrons, an electron can be freed from the atom and accelerated in the laser field. High-order harmonic generation occurs when the free electron recombines with its parent ion, resulting in the emission of an extreme ultraviolet (XUV) photon with energy determined by the trajectory of the electron in the accelerating electric field. When the laser pulse is only a few optical cycles long and the laser carrier-envelope phase is stabilised, it is possible to create an isolated XUV pulse of attosecond duration by gating the emission. Such isolated attosecond pulses are now widely

used to study physical, chemical, and biological phenomena.

Our laser system is the only one in Australia with the requisite degree of control to achieve attosecond XUV pulses. Last year we developed a new kind of XUV interferometer that generates XUV light in two gas jets, one placed after the other. The laser phase shifts during propagation, inducing delay in the XUV emission time, and we obtained <100 zeptosecond timing resolution for the XUV delay time. This year, we verified that our XUV interferometer preserves the spectral signature of attosecond pulse generation, namely the appearance of a featureless continuum at high photon energy that depends strongly on laser phase (Fig. 2). This data indicates that we are generating pairs of attosecond pulses with variable time delay and zeptosecond timing resolution.

ATTOSECOND SCIENCES PROGRAM CASE STUDY

RECORD ACCURACY IN MEASUREMENT OF LASER INTENSITY

Our laser pulses attain such high intensity that they destroy any and all matter when tightly focused. Usually one would use a physical detector to measure laser intensity, but in our case it would vaporise. This year we found that the ionisation of atomic hydrogen can serve as the best intensity meter available for strong laser pulses. The energy of electrons emitted from the atoms depends strongly on the laser intensity. Since hydrogen is uniquely

well understood theoretically, comparing our measurements of electron energy with theoretical simulations let us infer the intensity to within 1% (Fig. 3). This is three times more accurate than the previous standard, which also required much more sophisticated detection apparatus. The availability of “first principles” simulations is crucial to this result. Trying the comparison with any approximation in the theory threw off the results so much that they became inconsistent with independent cross-checks on the pulse energy and size of the laser spot.



BIOLOGICAL SCIENCES PROGRAM

Methods for imaging cellular architecture and, ultimately, macromolecular complexes and individual proteins, within a cellular environment are important goals for cell and molecular biology. The Biological Sciences Program involves the participation of biochemists, structural biologists and cell biologists who are undertaking specific research in the biomedical area. As part of work undertaken within CXS, Biological Sciences Program members collaborate closely with members of the Experimental Physics Program (EPP) in the development and implementation of novel imaging techniques to provide new insights into the structures of cells and cellular compartments. Members of this program also interact with members of the Structure Determination Methods Program and the Theory and Modelling Program to optimize techniques to determining the structures of membrane proteins and other components of biological interest.

The groups within this program conduct world-class research in the following areas:

MALARIA AND REMODELLING OF THE RED BLOOD CELL

The most deadly of the human malaria parasites, *Plasmodium falciparum*, invades red blood cells and initiates a remarkable series of morphological rearrangements. The mature red blood cell (RBCs) is effectively a floating sack comprising a membrane that encloses the oxygen-transporting protein, haemoglobin. Unlike other cells, RBCs have no nucleus and cannot make or traffic proteins. In order to colonize and remodel the red blood cell, the parasite generates a series of novel structures that are involved in the export of virulence proteins to the surface of the host cell. These include extensions of the parasite's vacuolar membrane, known as the tubulovesicular network, and structures referred to as Maurer's clefts. These membrane structures play an important role in the trafficking of virulence proteins to the host cell surface, however their ultrastructure is only partly defined and there is on-going debate regarding their origin, organization and connectivity. Parasite endocytic processes are also poorly understood. The parasite consumes host haemoglobin in order to support its own growth. Packets of hemoglobin are transferred from the host cell cytoplasm to a parasite digestive vacuole for hemoglobin digestion and heme detoxification however the precise mechanism for uptake is debated. One of the aims of CXS is to

image these compartments and to develop an understanding of their function and the way in which they are formed. Such research can lead to new avenues for drug and vaccine design to combat the serious problem of malaria.

MITOCHONDRIA: UNDERSTANDING THE POWERHOUSE AND THE POISON CUPBOARD

Mitochondria are the generators within our cells, synthesizing chemical energy in the form of the molecule ATP. They also act as poison cupboards, releasing certain proteins that kill cells as part of programmed cell death if the mitochondrial outer membrane is opened. Defects in mitochondria cause energy-generation disorders and are also implicated in other diseases, including Parkinson's disease and Alzheimer's disease. In addition, efforts to activate the machinery involved in mitochondrial permeabilization can act as anti-cancer agents. Work within the CXS seeks to understand some of the events involved in remodeling mitochondrial membranes during disease and to provide potential new insights into the formation of pores that lead to cell death. In addition, work is being undertaken to provide insights into the structure of mitochondrial membrane proteins and their complexes.

GOALS:

- Prepare and optimize cellular samples for use as test-beds for X-ray coherent diffraction imaging and for other pioneering imaging techniques.



Cryo X-ray Tomogram Image of a Sexual Stage Malaria Parasite. Image provided by Dr Eric Hanssen.



- Use X-ray imaging and other imaging modalities to gain novel insights into cellular architecture and function.
- Prepare samples of soluble and membrane proteins and determine their structural characteristics using both conventional and novel X-ray-based approaches.

ACHIEVEMENTS

An important human pathogen, the malaria parasite *Plasmodium falciparum*, has been imaged using a range of X-ray microscopy methods, and the data have been correlated with other imaging modalities. In particular, the group has performed pioneering work in the development of whole cell electron tomography, cryo X-ray tomography and super-resolution fluorescence imaging.

IMAGING INSIDE CELLS

We have developed three high end imaging methods. Cryo transmission x-ray microscopy in the “water window” of photon energies is a method that exploits the natural contrast of biological samples. Three-dimensional structured illumination microscopy provides resolution beyond the optical diffraction limit and permits analysis of fluorescently labeled features in whole cells. Immunoelectron tomography offers the possibility of high resolution imaging of individual ultrastructural features in a cellular context. Combined with serial sectioning and immunogold labeling, this technique permits precise mapping of whole cell architecture.

We have used cryo transmission x-ray microscopy to make a survey of the cellular features of *P. falciparum*. Absorption of soft

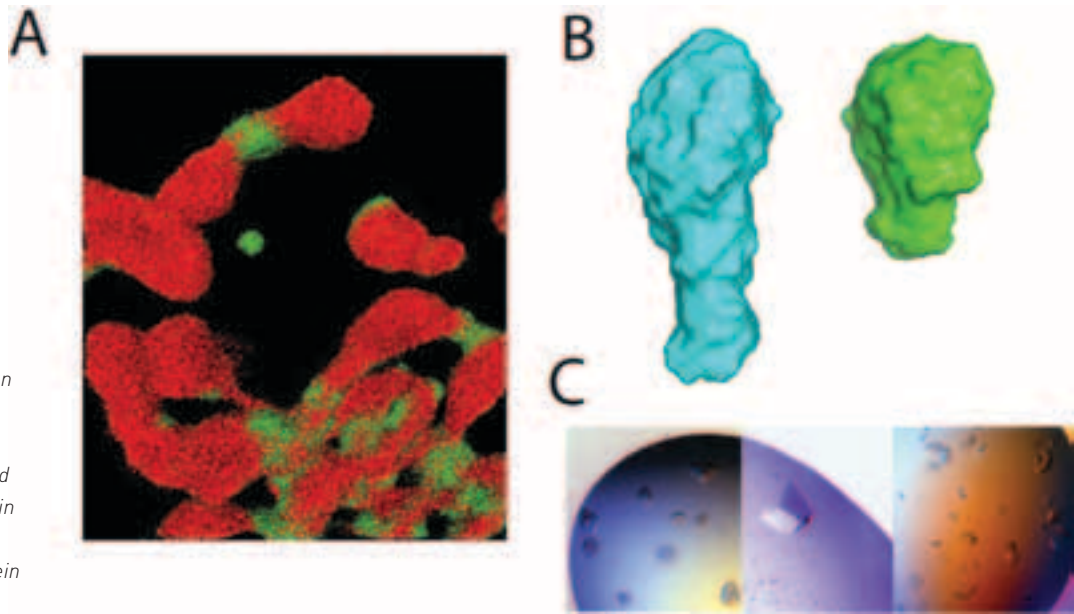
x-rays by protein adheres to Beer-Lambert’s law permitting a quantitation of protein concentrations in different compartments. Probing the parasite’s digestive apparatus revealed invaginations, consistent with phagocytic structures, and independent endocytic vesicles in the parasite cytoplasm that appear to play a role in hemoglobin uptake. We have shown that hemoglobin digestion and parasite growth are tightly coordinated in both asexual and sexual stage *P. falciparum*; this permits an increase in parasite volume without causing premature host cell lysis. Tip Enhanced Raman Scattering (TERS) was used to interrogate hemozoin crystals within a sectioned infected erythrocyte. The observation that haemoglobin digestion is initiated in ring stage parasites led to insights into the likely mode of action of the important antimalarial drug, artemisinin.

Malaria parasites develop within human erythrocytes. As it grows the parasite establishes a membrane network outside its own limiting membrane in the cytoplasm of its host cell. These membrane structures play an important role in the trafficking of virulence proteins to the host cell surface. While the exomembrane system of *P. falciparum* has been well studied almost nothing is known of the other major human malaria pathogen *P. vivax*, or its close monkey malaria relation, *P. cynomolgi*. We used serial section electron tomography to study the caveolar-vesicular complexes of *P. cynomolgi*.

Super-Resolution microscopy (3D-SIM), which gives an 8-fold increase in volume resolution, was used to follow the genesis and organisation of the malaria parasite invasion apparatus. Host cell invasion is powered

by an actin/myosin motor complex that is linked to an inner membrane complex (IMC). We showed that the IMC originates from the endoplasmic reticulum, redistributes to apical caps during the formation of daughter cells, then extends around the merozoite surface in the final stages of schizogony.

Mitochondria are dynamic organelles that undergo fission and fusion events and they traffic along cytoskeletal elements. The appearance of the mitochondrial network differs between cell types and is directly related to cellular function. Examples include the wrapping of fused mitochondria around the base of the sperm flagellum, positioning of mitochondria for spine and synapse formation in neurons and for facilitating immune signaling. Genes involved in directly regulating mitochondrial dynamics and turnover have been linked to peripheral and optic neuropathies while defects in mitochondrial dynamics have been implicated in more common disease including, Parkinson’s and Huntington’s diseases. Understanding how mitochondrial fission and fusion is regulated is essential for therapeutic targeting of mitochondria. We have used novel super-resolution approaches based on fluorescence resonance energy transfer to image mitochondria and their remodeling within cells. This so-called SURF technique is being employed to investigate patches on the mitochondrial surface that are sites of mitochondrial division. FRET techniques have also been utilized to understand the interactions between mitochondrial morphology components, providing new insights into how they act.



Structural characterization of MiD51, a membrane receptor for mitochondrial fission.
A: Fluorescence imaging of MiD51-GFP (green) at distinct patches and constriction sites of mitochondria (red) in ovarian cancer cells. **B:** Molecular envelope reconstructions of the MiD receptor with (left) and without (right) a flexible domain following SAXS analysis. **C:** Crystal forms of the MiD protein lacking the flexible linker.

STRUCTURAL AND BIOCHEMICAL STUDIES OF MEMBRANE PROTEINS

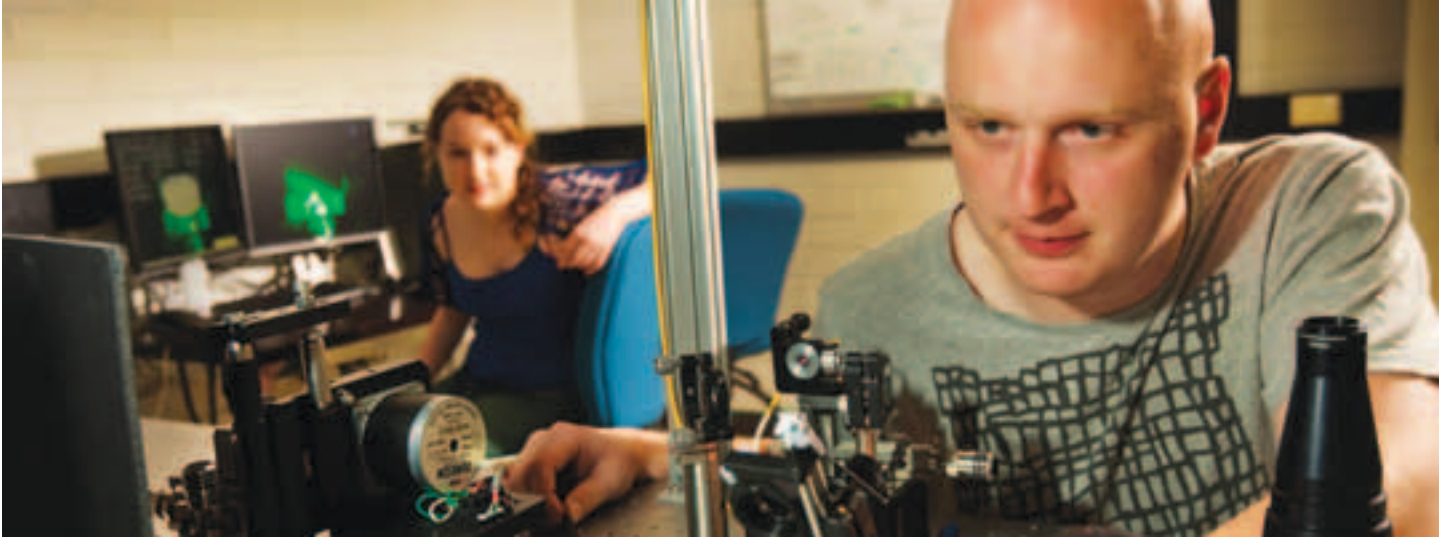
The group has optimised the expression and purification of a number of mitochondrial proteins involved in the assembly of the first mitochondrial generator, Complex I. One such protein, CIA30, has been purified. Using FRET studies, we established that CIA30 tightly associates with another mitochondrial membrane protein termed Ecsit. Recombinant expression trials revealed that they can be purified together in complex. These proteins are now being used in crystallisation trials for conventional protein structure determination and can be used as future test beds with complex I assemblies in novel X-ray approaches. We have also investigated the nature of a mutation in the protein Tom40 – the universal entry gate into mitochondria. This mutation leads to heart defects and death early in life. We have found that the mutation in Tom40 results in the destabilisation of the membrane protein complex with specific receptor subunits dissociating. The effect of this mutation on mitochondrial function is currently under investigation. In association with this, the Tom40 protein was purified for structural analysis. We are currently attempting refolding assays to obtain Tom40 in its folded, membrane-integrated form.

BIOLOGICAL SCIENCE PROGRAM CASE STUDY

UNDERSTANDING HOW MITOCHONDRIAL MEMBRANE DIVIDE

We identified two mitochondrial outer membrane proteins that we termed MiD49 and MiD51 [mitochondrial dynamics proteins of 49 and 51 kDa], that induce morphological changes to the mitochondrial network following their overexpression or knockdown. Characterization of these proteins revealed that they are novel mediators of mitochondrial fission that participate in the recruitment and action of Drp1 at the mitochondrial surface. Overexpression of MiD49/51 resulted in the appearance of highly fused mitochondria. However, under low level MiD49/51 expression, mitochondrial morphology was relatively normal and MiD49/51 formed foci and rings around mitochondria similar to Drp1. Indeed, we found that MiD49/51 expression led to recruitment of virtually all cytosolic Drp1 to mitochondria. Live cell imaging shortly after induction of MiD49 or MiD51 expression revealed that Drp1 was initially recruited to mitochondria and could execute mitochondrial fission. At later stages, mitochondria became fused and we suggested that Drp1 became sequestered at mitochondria in a way in which it could not properly assemble into functional scission complexes, thereby blocking fission and shifting the balance towards fusion. Using FRET studies, we could confirm an interaction between MiD49 and MiD51 with each other and with Drp1.

We have expressed and purified different domains of MiD proteins and performed Small angle X-ray scattering (SAXS) at the Australian Synchrotron. An area of flexibility was confirmed and following its removal from the proteins, a number of different crystal forms were generated. These crystals will be tested for their diffraction ability using the MX beamline at the Australian Synchrotron. The structure of these proteins will provide novel insights into how they function at a molecular level in mitochondrial fission.



EXPERIMENTAL METHODS PROGRAM

The Experimental Methods Program (EMP) develops imaging methods using coherent and partially coherent light sources. The research profile of EMP includes the design of experimental systems, sample handling and nanofabrication techniques, tomographic imaging of three-dimensional objects, the detailed characterization of radiation sources and the development of novel imaging methodologies using diffraction data.

The EMP group has members based at La Trobe University, the University of Melbourne and Monash University. Through its broad spectrum of members and activities, the EMP has standing research activities with most of the other programs in CXS:

- Biological Sciences Program (BSP) – this is a fundamental CXS interaction. The work of the EMP is to image biological samples in three-dimensions. This basic work is assisted also by the Theory and Modelling Program in analysing imaging data obtained from biological samples. EMP and BSP researchers regularly work together to develop methods for imaging and specimen preparation. To further facilitate the mutual translation of physics and biology BSP staff attend EMP experiments at overseas facilities, which has led to the exploration by BSP

of access to other imaging techniques and facilities around the world.

- Theory and Modelling Program (TMP) – TMP and EMP regularly cross fertilize. EMP provides experimental data that TMP can apply new methods of analysis to and TMP provides new directions for the experimental work. Members of TMP are co-located at the University of Melbourne with several of the EMP group so that interaction is frequent.
- Short Wavelength Laser Source Program (SWLSP) – the SWLSP provides a novel source of coherent photons at wavelengths approaching X-ray. Again, with strong interaction from TMP, the EMP and SWLSP have a standing experimental activity based around pursuing the limits of imaging with these sources.
- Ultra-Cold Plasma Source Program (UCP) – the UCP was formed within CXS to exploit techniques developed by EMP and TMP to demonstrate imaging using a bright coherent source of high-energy electrons. Again with membership based at the University of Melbourne UCP and EMP have a high degree of interaction. Each Program benefits from the membership of past members of the other.
- Structure Determination Methods Program (SDMP) – the SDMP are partners in an effort aimed at understanding electronic and structural damage to biomolecules induced by femtosecond X-ray free electron laser pulses. Experimental tests of damage models developed by the TMP are an important step toward determining biomolecular structures from diffraction experiments.

ACHIEVEMENTS

2011 saw an intensive program of experiments using our laboratory facilities, synchrotron light sources in six countries and the first hard X-ray Free Electron Laser (XFEL). These experiments encompass a broad range of 2D and 3D imaging methods over a wide X-ray energy range, including, for the first time, water-window biological diffractive imaging. A unifying theme in our research during 2011 has been the consolidation of methods in imaging and coherence to enable more robust, sensitive and efficient three-dimensional imaging. We have also advanced our experimental capabilities with the Imaging ENDstation (FRIEND) that is being commissioned at the Advanced Photon Source in Chicago.

In addition to our stated program goals the EMP continued to explore new methods in imaging and coherence. Some of the key results achieved in 2011 include:

- Extending Fresnel Coherent Diffractive image to the water window, a low energy regime optimal for biological imaging
- Tomographic FCDI reconstructions of whole red blood cells at multiple stages in the *P. Falciparum* parasite lifecycle
- Methods based on the understanding of the role of partial coherence in image formation were extended to demonstrate coherent diffractive imaging with, simultaneously, partial temporal and partial temporal coherence (polychromaticity).
- Demonstration of new methods in phase imaging and tomography with polychromatic X-ray sources

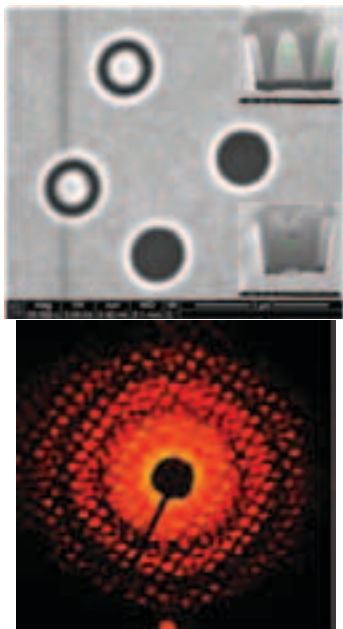


Fig. E. (upper) Microfabricated ensembles of model molecules were used to explore with synchrotron light whether models for electronic damage due to XFEL pulses can be included in the analysis of diffraction data (lower).

the molecule interacts with light as the pulse passes through it. The theoretical foundations for including the effects of electronic damage in the treatment of XFEL diffraction data have been laid by the Theory and Modelling Group (TMP) of CXS. Together with the TMP and Structure Determinations and Modelling Program, the EMP has been developing methods to deal with the abundant data we expect to obtain. Meanwhile the EMP has been developing solutions to meet a multitude of new experimental challenges that arise from the exceptionally intense X-ray pulses that will be used to probe many thousand of lysozyme nanocrystals and fullerenes (Fig. D). In the leadup to XFEL experiments we have undertaken experimental tests with synchrotron light of electronic damage in microfabricated model systems that imitate ensembles of undamaged and damaged molecules (Fig E). The LCLS experiments are scheduled for April 2012.

IMAGING ENDSTATION DEVELOPMENTS

The FResnel Imaging ENDstation (FRIEND) is a custom designed experimental that was commissioned at the Advanced Photon Source (APS) in Chicago under a partnership arrangement. In 2011 the APS extended the agreement in recognition of the quality of the research it enabled over a period of several years. During that time the endstation has been thoroughly characterised and shown to be extremely stable and highly versatile. The relative optics-to-sample displacement is stable to within 5 nm/hour which, together with its in-vacuum operation, allows for long exposure times, high signal-to-noise and large dynamic range two-dimensional intensity measurements to be acquired. The

instrument now has twenty axes of motion, all housed within a vacuum chamber, for positioning optics, specimens and detectors in various geometries to accommodate three common implementations of diffractive imaging; plane wave illumination; scanning focused (ptychographic) and defocused-probe (Fresnel diffractive imaging). The strength of FRIEND lies in its stability and in-vacuum operation which allow for long exposure times, high signal-to-noise and large dynamic range two-dimensional intensity measurements to be acquired.

In 2011 CXS used FRIEND to undertake unique experiments that combine ptychographic, phase-diverse and tomographic methods with Fresnel coherent diffractive imaging. Unique experiments using polychromatic X-rays with a controlled degree of partial coherence were also undertaken in an effort to accelerate data tomographic data acquisition. This work has thrown up new challenges in data acquisition and processing that must be addressed with new detector technologies and high performance computing. To this end we have embraced a new collaboration with the APS and the Lawrence Berkeley National Laboratory to study fast soft X-ray detectors using FRIEND. We have also commissioned a three-dimensional nanometrology system that will soon be installed on FRIEND to provide measurements of the displacement between the sample and the X-ray optics to nanometre precision. This system will provide feedback for real-time dynamic stabilization and essential input to ptychographic and tomographic reconstruction algorithms that, until now, have required computationally expensive corrective algorithms.

We are on track to being FRIEND back to Australia in 2012 after the partnership agreement with APS is concluded and construction of a dedicated branch on the soft X-ray beamline at the Australian Synchrotron is completed.

FROM SYNCHROTRON TO LAB

By exploring the role of partial coherence in synchrotron X-ray sources we have gained new insight into how the role of conventional laboratory X-ray sources can be expanded. This is illustrated by the following achievements.

X-RAY VISION TO REVEAL NANOPARTICLES

In 2011, research led by Dr Daniele Pelliccia established statistical techniques for non-destructive analysis of buried nanoparticles. X-ray diffraction patterns obtained from polydisperse nanoparticle mixtures are made up of incoherent superposition of the scattering pattern of the individual nanoparticles. The group's work showed that phase retrieval algorithms can be applied to such patterns to yield a real space image containing statistical information about the nanoparticle mixture. A key feature of the experimental setup is that the data are collected in momentum transfer (angular) space and is not susceptible to movement of the sample. Moreover, the method can be implemented with conventional laboratory X-ray sources, because the required coherence is of the order of the nanoparticle size.

SPLITTING THE DIFFERENCE

In conventional X-ray absorption contrast

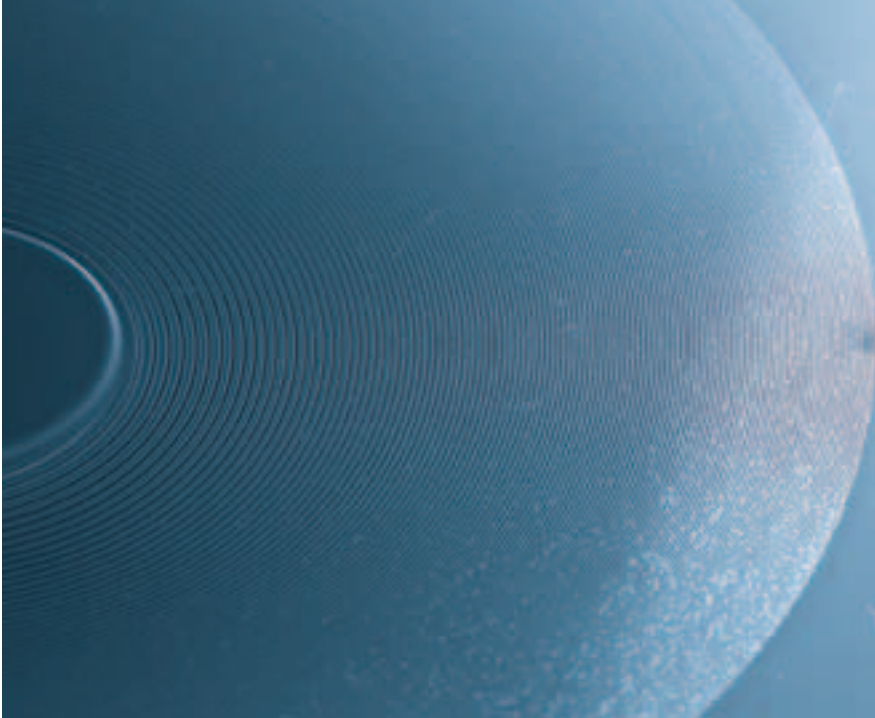


Fig. XXX Fresnel Zone Plate optic fabricated for water window FCDI experiments (Eugeniu Balaur).

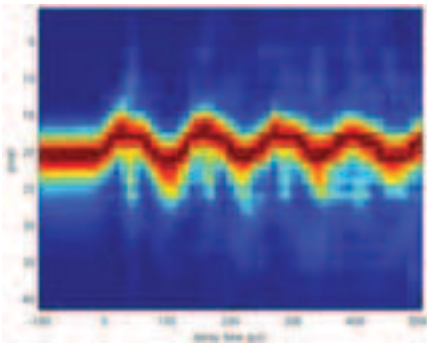
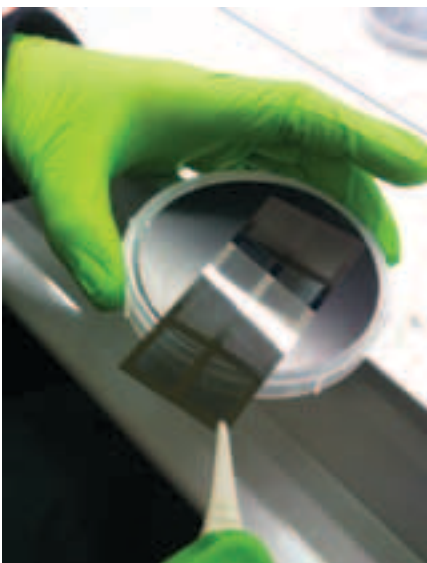


Fig. D: XFEL data showing the oscillations of the lattice constant within a nanocrystal as a function of the time-delay between excitation and measurement, ("pump and probe"). Reproduced with permission from Prof. Ian Robinson, UCL.



tomography, low density structures can present a problem, particularly when their absorption properties hardly differ from that of the surrounding medium. Our developments in phase retrieval tomography, led by Dr Benedicta Arhatari, make it possible to resolve structures with small differences in density within a highly absorbing sample, revealing complex 3D structures that could be studied by previous methods. The phase-retrieval step is included before carrying out standard filtered back-projection tomographic reconstructions. Exquisite detail in three-dimensional images of cortical bone reveals secondary osteon structures and their relationship to surrounding tissue (Fig D).

EVERY PHOTON COUNTS

We have shown that by careful characterisation of synchrotron X-ray sources we extend phase retrieval methods developed for far-field imaging (CDI) to partially spatially coherent and polychromatic sources. In a similar vein, we have performed simulations, experiment and analytical work to analyse models of coherence and polychromaticity applied to general imaging. We have recently shown that these ideas can be even be adapted to near field imaging using laboratory X-ray sources which should allow efficient use of all the light they produce. To explore this further we have commissioned a nanofocus X-ray source and customised high resolution X-ray camera.

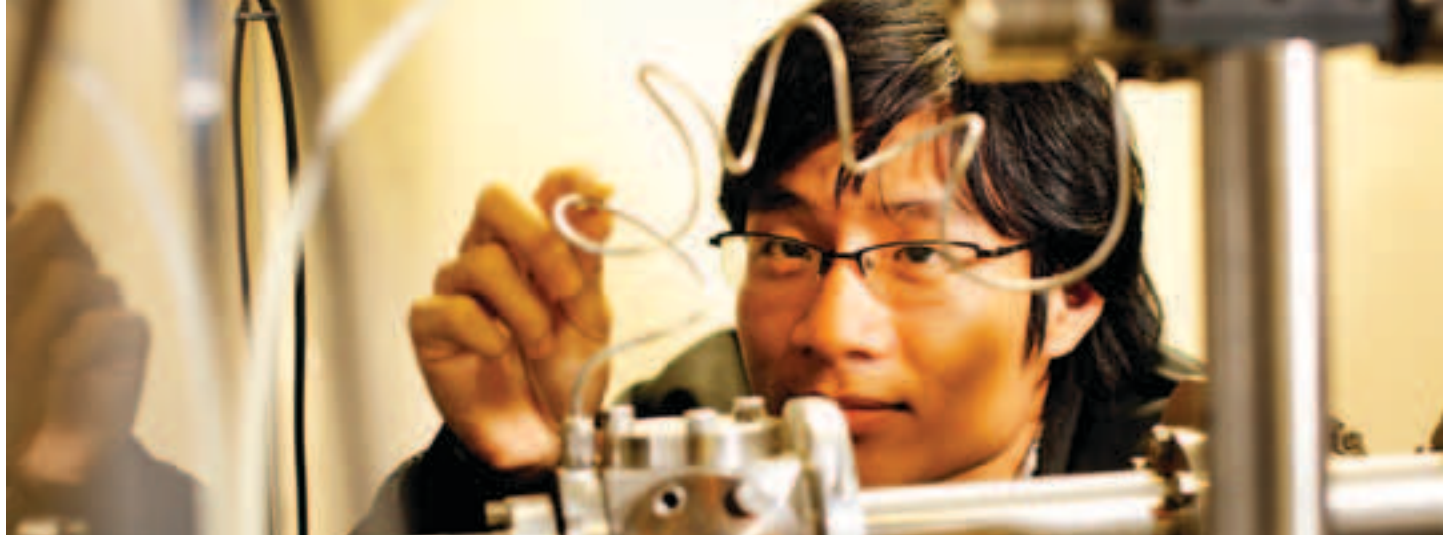
CASE STUDY

SOFTENING THE IMAGE OF FCDI

Knowledge of the biology of living cells starts with imaging. Despite tremendous progress in super-resolution light microscopy at visible wavelengths and in cryogenic electron microscopy, there exists a strong demand for a microscopy that provides higher resolution information on thick hydrated cells without requiring elaborate specimen preparation. Soft X-ray coherent diffractive microscopy uniquely fits this bill. In 2011 the EMP started to explore Fresnel Coherent Diffractive Imaging in an X-ray energy regime known as the water-window that is ideally suited to frozen hydrated cellular imaging. Natural contrast is enhanced at these energies because essentially transparent but nitrogen and carbon are strongly absorbing. To perform the first water window FCDI imaging of biological samples we worked with scientists at TwinMic beamline of the ELETTRA synchrotron in Italy. It was necessary to design and fabricate X-ray optics suitable for the energy and geometric constraints of the instrumentation (Fig. XXX).

Images were obtained with spatial resolution around 60 nm, with a strong indication that this could be substantially improved using alternate cell preparation protocols and higher performance detector. This gives us reason for an optimistic outlook for window FCDI as a method that can help to answer questions that no other imaging technique can. It promises to be a mainstay of research with FRIEND at the Australian Synchrotron where a dedicated beamline will be optimised to deliver coherent flux in the water window.





SHORT WAVELENGTH LASER SOURCE PROGRAM

The Short Wavelength Laser Source Program has investigated the generation of extreme ultraviolet (XUV) and soft X-ray pulses by high harmonic generation (HHG) and applied these sources in atomic and molecular spectroscopy, condensed matter physics, and imaging on the micron- and submicron-scale. These compact (table-top) femtosecond pulsed sources will complement imaging studies using X-ray free-electron laser (XFEL) sources currently under development at large international facilities.

By their nature, HHG sources produce a laser-like beam that consists of a number of harmonic orders. Therefore, a harmonic source with just a few intense orders (ideally a single harmonic order) may be advantageous for many applications because they can be used directly without additional spectral selection optics.

The high harmonic generation process can be explained in terms of a semi-classical three-step model. In this model, under interaction of a strong laser field the active electrons first tunnel through the potential barrier, are then accelerated in the first half of the optical cycle of the laser field, and then are pulled back and finally recombine with parent ions to emit high-energy photons in the second half of the cycle. The electronic acceleration processes and the variation of the molecular or atomic ground

state throughout the interaction with the driving laser field play important roles in quantum systems and need to be studied in more detail.

Unlike atoms, molecules are not spatially isotropic systems. For randomly aligned molecules, their HHG spectrum has been shown to have characteristics similar to that produced by atoms, but for aligned molecules, which can be realized by using another laser field, the HHG is influenced by the angle between the molecular frame and the polarization vector of the femtosecond laser field. An investigation to clarify the roles of intramolecular quantum processes in field-free aligned molecules is highly desirable, in order to obtain an improved understanding of the underlying physics which is the basis of future applications.

Due to the low efficiency of the HHG process, phase-matched propagation of the fundamental and harmonic radiation throughout a macroscopic sample is required to obtain a measurable signal. The degree of phase-matching depends on the harmonic order and several experimental parameters, including the focusing characteristics of the laser beam, the absorption coefficient of the target gas at the harmonic frequencies, the ionization fraction of the gas and the difference in the refractive index at the fundamental and harmonic wavelengths. We have been investigating ways of optimizing the phase matching.

The high harmonic spectrum and intensity contains information about the electronic structure of the atom or molecule and other quantum processes involving the free and bound electrons. Studies of the process of high harmonic generation provide a better understanding of the microscopic

and macroscopic process and may lead to additional information about the electronic structure of the atom or molecule.

ACHIEVEMENTS

One avenue for pushing into the "water window" wavelengths for radiation achievable via High Harmonic Generation is to use longer wavelength laser pulses to interact with the respective gases. In order to achieve infrared femtosecond pulses, we have developed an IR optical parametric amplifier.

HIGH POWER OPTICAL PARAMETRIC AMPLIFICATION (OPA)

A collinear high power OPA scheme has been implemented using 8 mJ pulses of 30 fs duration and centred at 810 nm from our high energy Titanium:sapphire laser/amplifier system as the pump source. 2.5 mJ laser pulses from this OPA source are used to pump a commercial OPA, which is designed with a two-stage configuration seeded by a white light continuum (Quantronix, Palitra). The remaining 5.5 mJ is used to pump the power amplifier stage of the OPA. Type II crystals, cut at $\theta = 42^\circ$ in the x-z principal plane ($\phi = 0$) for ordinary \rightarrow extraordinary interaction, are used in all subsequent stages. The advantages of using type-II interaction are related to the possibility to tune, even close to degeneracy, at almost constant bandwidth for the signal and idler of the OPA. The maximum total conversion efficiency (signal and idler) for the power amplifier stage is about 60%. An OPA output pulse \sim 2.5 mJ with a pulse duration of about 40 fs at 1400 nm has been obtained.

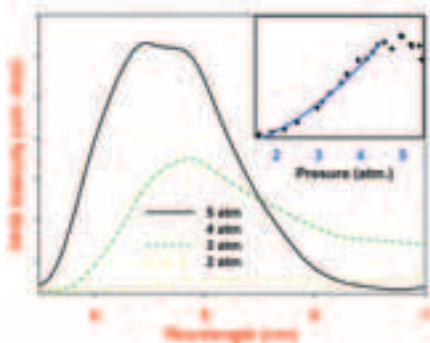


Figure 1: XUV HHG spectra from He at different gas pressures. The inset shows the harmonic yield versus the gas pressure: the dots show the experimental data and the line represents the best fit with P^2 , where P is the gas pressure.

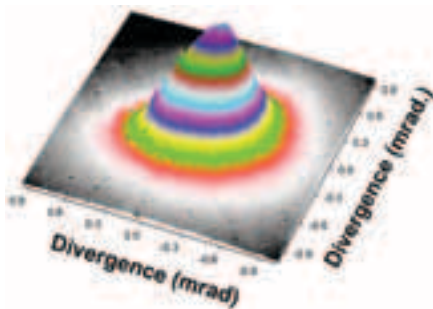


Figure 2: Beam profile of high order harmonic radiation at a distance of 1500 mm from the source.

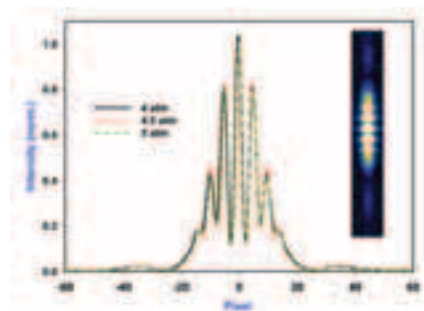


Figure 3: Interference fringes from the Young's double slit. The YDS device consists of two parallel slits of $4 \mu\text{m}$ width, $100 \mu\text{m}$ high and separated by $20 \mu\text{m}$. The CCD is located 800 mm from the slit. The inset shows the CCD image.

GENERATION OF HARMONIC RADIATION IN WATER WINDOW REGION ($\sim 4.3\text{nm}$)

The IR pulses at 1400 nm are focussed by a lens with a focal length of 300 mm into a 250 mm long gas cell with a glass window at the entrance and a $200 \mu\text{m}$ pinhole at the exit. We use helium (He) gas for generation of high photon energy because of its high ionization energy and it has been shown in theoretical calculations that it is possible to obtain true phase matching for the generation of radiation in the water window region using 1400 nm radiation. Very high gas pressure (up to 5.5 atm) is used for generation of radiation around 4.3 nm.

Figure 1 shows an XUV spectrum emitted from He at different pressures. The bandwidth and beam profile of the radiation depend on the gas pressure, the focus position and the diameter of the fundamental beam. When the pressure is low ($< 2 \text{ atm}$) HHG radiation is observed at $\sim 5 \text{ nm}$ and the beam divergence is very large. HHG radiation above the carbon K-edge (4.4 nm) is obtained for a gas pressure $> 4 \text{ atm}$. The beam profile is remarkably improved for pressures $> 3 \text{ atm}$. The inset in Fig. 2 shows the total photon number in the generated spectral range around the water window region for different gas pressures P . The dots show the experimental data and the line shows a fit based on P^2 . At lower pressures ($P < 4 \text{ atm}$), the HHG signal increases quadratically with pressure as is expected for phase-matched HHG emission. The total photon flux around the maximum of the beam profile in the wavelength range of $4 - 5 \text{ nm}$ is $\sim 10^8 \text{ photon/cm}^2\text{s}$.

COHERENT PROPERTY OF THE WATER WINDOW SOURCE

Figure 2 shows the spatial profile of the high order harmonic beam at a distance of 1800 mm from the source. The beam divergence was measured to be 0.4 mrad (FWHM). As shown in this picture, the almost perfect Gaussian profile of the high order harmonic beam suggests that there is no density disturbance due to ionization in the interaction region.

To study the spatial coherence of the source in more detail, a Young's Double Slit (YDS) has been used. Figure 3 shows a clear interference pattern resulting from the YDS, which consists of two parallel slits $4 \mu\text{m}$ width, $100 \mu\text{m}$ high and separation $20 \mu\text{m}$. The fringe contrast is low (< 0.5) for $50 \mu\text{m}$ slit separation and very low < 0.1 for $75 \mu\text{m}$ slit separation (Fig. 4). From this observation we expect that the spatial coherence length of this source is $< 50 \mu\text{m}$.

To test the possibility of using the source in CDI applications we illuminated multiple pinholes on a Cu foil with high harmonic radiation in the water window region ($4 - 5 \text{ nm}$). The pinhole diameter is $3.5 \mu\text{m}$. The diffraction image (Fig. 5) was obtained with an exposure time of 30 min. The inset shows the corresponding scanning electron microscope image of the sample.

SUPER-RESOLUTION MICROSCOPY

Super-resolution optical microscopy is an attractive method of visualising features at resolution beyond the diffraction limit, and

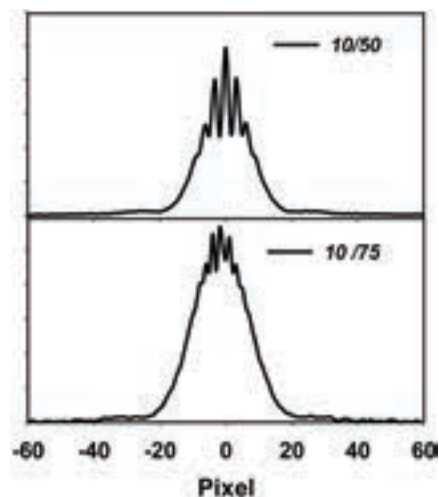


Figure 4: Interference fringes of two Young's double slits with slit separations of $50 \mu\text{m}$ and $75 \mu\text{m}$. The CCD is located 800 mm from the slit.

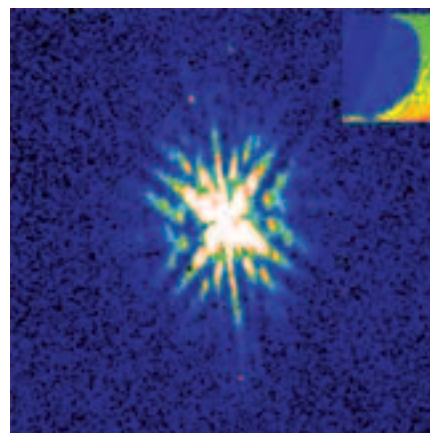


Figure 5: Diffraction image of a test sample illuminated by the XUV source around $4-5 \text{ nm}$.

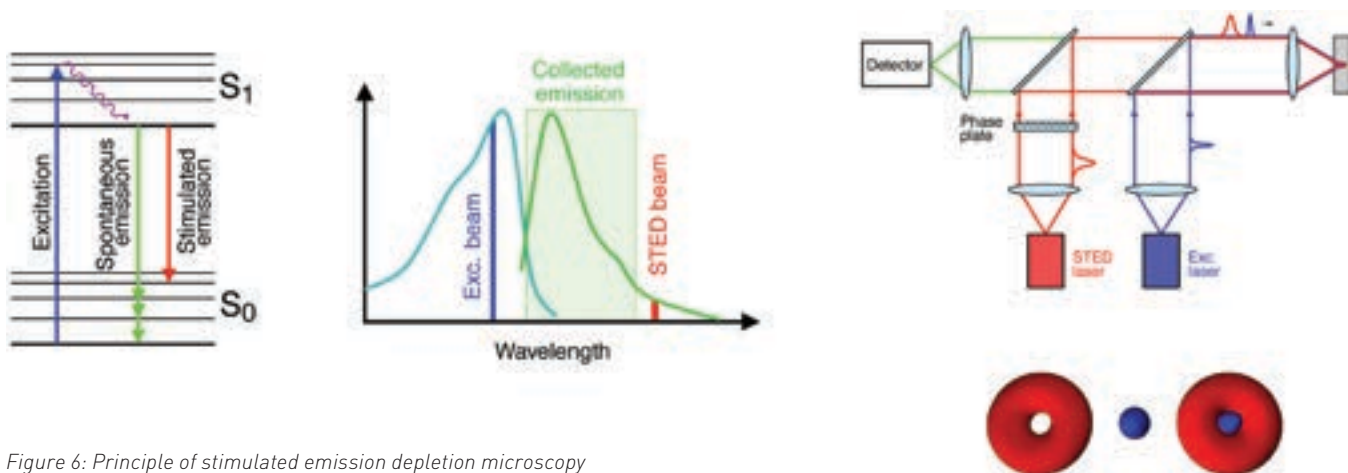


Figure 6: Principle of stimulated emission depletion microscopy

ultimately comparable to that achieved with other methods including CDI. Correlating optical images with CDI reconstructions on the tens of nanometres scale will provide additional information to that provided by one technique alone. The development of various modes of super-resolution optical microscopy continues within this program. The techniques we are developing include scanning near field optical microscopy (SNOM), structured illumination microscopy (SIM), photoactivated localisation microscopy (PALM), stochastic optical reconstruction microscopy (STORM) and stimulated emission depletion microscopy (STED). SNOM with transmission and emission capabilities, as well as a time-resolved fluorescence detection mode, has been established. We are working on developing more rapid acquisition of data in SIM using polarisation-encoded information.

We are also finalising construction of a STED system, the principle of which is shown in Fig. 6. Our system is based on a picosecond mode-locked super-continuum laser. The white light output of this laser is spectrally separated into an excitation beam and a stimulated emission depletion beam. The STED beam is then modified using a phase plate or spatial light modulator to produce an optical vortex (doughnut shaped beam). Both beams are then collinearly incident on the microscope objective, which focusses them to a common point. However, the emission from those molecules that interact with the STED beam is depleted, thus restricting the detected emission from just the "hole" of the doughnut, thus overcoming the diffraction limit. The microscope is then essentially a scanning confocal microscope that can achieve spatial resolution on the tens of nanometre scale.

These microscopes are being used to investigate a range of samples, including thin films of conjugated polymers used for organic photovoltaic devices.

SUPER-RESOLUTION OPTICAL MICROSCOPY CASE STUDY

Conjugated polymers are finding increased application in devices such as flexible thin displays, where their electro-luminescence properties are exploited, and in photovoltaic devices, where light-induced electron-hole pairs are harnessed to produce photo-current. The efficiency of these devices is dependent on the morphology (or structure) of the thin films, and various factors influence the morphology. Optical microscopy is a useful technique to

investigate morphological behaviour, but many of the features, and exciton diffusion lengths, in these polymer films occur on the tens of nanometre scale – beyond the diffraction limit of conventional optical microscopes.

We have applied structured illumination microscopy (SIM) to investigate the changes in film morphology as polymer films undergo annealing. The Figure XX shows a P3HT/PCBM film before and after annealing, where the dark areas are the electron accepting PCBM regions and the light areas correspond to luminescent polymer richer regions. These images can be correlated with atomic force microscope or CDI X-ray images to provide great detail about factors that influence the photophysics of the polymers.

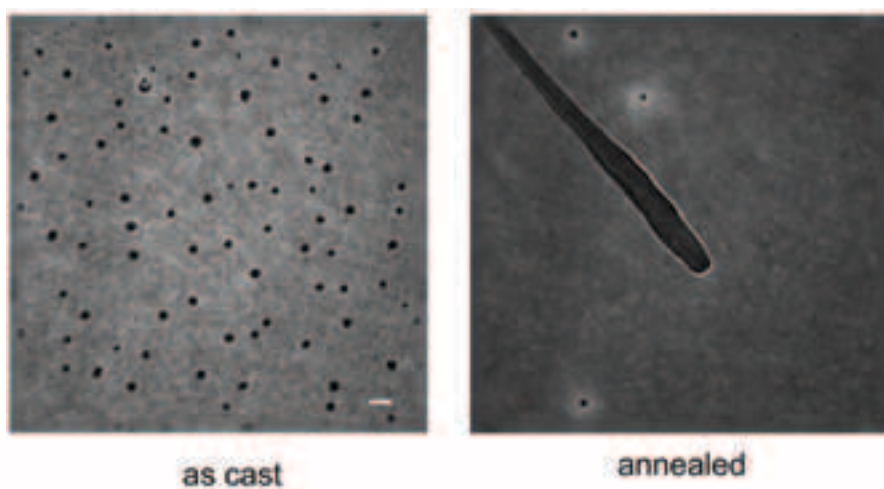


Figure XX. a P3HT/PCBM film before (as cast) and after annealing (annealed).

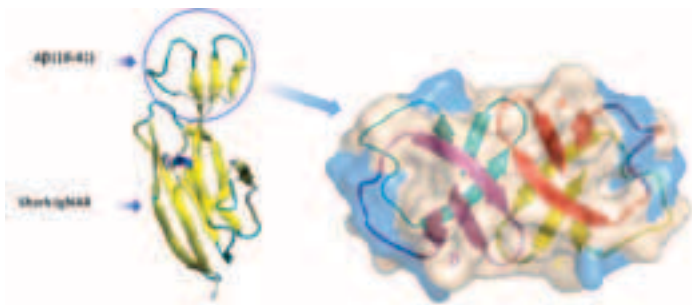


Figure 1. Crystal structures of Aβ-IgNAR and Aβ₁₈₋₄₁ tetramer.

STRUCTURE DETERMINATION METHODS PROGRAM

The Structure Determination Methods Program (SDP) consists of CSIRO researchers working broadly within the fields of X-ray and electron crystallography in collaboration with other CXS Centre members. Its main aim is to develop novel experimental techniques and data analysis methods for extracting structural information from 2-D crystals and 3-D nanocrystals, especially relating to the determination of the structure of the pharmaceutically very important class of proteins known as integral membrane proteins. This Program brings with it internationally recognised expertise in the preparation, purification, crystallization and handling of these samples.

The ongoing study of *purple membrane*, a naturally occurring 2-D crystal of the membrane protein *bacteriorhodopsin*, serves as a useful test case because there is high-resolution structural information available from 3-D X-ray crystallography and 2-D cryo-electron microscopy that can be used for comparison. A collaboration within CXS has helped link into expertise in developing and applying computer

programs for deconvoluting data for diffraction from 2-D crystal powders and led to alternative ways to explore the use of 2-D crystal samples in the context of different X-ray diffraction techniques.

Development has begun of novel experimental and related theoretical methods for the preparation and analysis of powder samples for integral membrane proteins. These techniques include preparation of and data collection from various 2-D crystal powders, a little-explored approach. They offer the exciting possibility of providing alternative and easier paths to the X-ray structure determination of this very important class of proteins that have mostly resisted efforts based on conventional 3-D single-crystal methods.

On the CSIRO Molecular & Health Technologies (CMHT) side, work has progressed on the preparation of a number of different types of powder samples of integral membrane proteins consisting of preferentially and randomly oriented 2-D crystal layers.

Work at CSIRO Materials Science and Engineering (CMSE) has been continuing on the development of analytical methods for structure determination using X-ray diffraction with two-dimensional (2-D) protein crystals in powder samples. The research can broadly be divided into three areas. The first is concerned with fitting 2-D powder diffraction data using a non-empirical approach based on a physical model of the scattering process. The second and third areas are closely linked: phase retrieval and refinement and structure determination. While these are separate

problems, they are generally best treated together. Structure determination in the 2-D crystal powder diffraction context amounts to reconstruction of a 2-D projection map of the electron density in the crystal. This can be viewed as a technique spanning coherent diffractive imaging and 3-D crystallography and is aimed at high-resolution 3-D structure determination. The advantage of the technique being developed here is that it does not require 3-D crystals, nor does it require 2-D crystals of the size needed for structure determination by electron diffraction.

ACHIEVEMENTS

- Lynn Liang has expressed and purified two butyrate GPCRs (GPR41 & GPR43) as part of her PhD project. She has entered both proteins into crystallisation trials and small angle x-ray scattering trials. She has characterised her GPCRs in two different lipid systems monoolein and Phytantriol and has shown their compatibility for crystallisation trails. These results are currently being written up for publication and her thesis will be submitted by 1st March.
- As part of the ongoing work cubic phase lipids we continue to publish results on the understanding the structural evolution of lipids in meso crystallisation and have published one article with two more being submitted. We have tracked the structural evolution of the monoolein bicontinuous cubic phase under in meso crystallogeneses conditions. Significantly, all measurements have been carried out in situ within a crystallisation plate reproducing the exact conditions during





Figure 2. The research team: (L-R) Prof. Colin Master, Dr Stewart Nuttall, Dr Victor Streltsov, and CSIRO CEO Dr Megan Clark at the 2011 CSIRO Awards ceremony.



Figure 3. The Amyloid Structure Team: (L-R) Dr Stewart Nuttall, Dr J. Varghese, Dr Victor Streltsov and Prof. Colin Master in the CSIRO X-ray Lab.

a crystallisation trial. We have discussed the implications of the observed structural changes with respect to the putative mechanism of protein crystal growth within a lipidic cubic phase. We suggest that, for in meso crystallisation, the components of the screen affect crystal growth both by influencing protein-protein interactions directly (in a similar manner to traditional soluble protein crystallisation trials) and indirectly, via changes to the structure of the underlying lipid matrix. In future work we aim to correlate these structural variations with crystallisation data so that we can determine the role of cubic phase symmetry during crystal growth.

- Victor Streltsov has completed a series of synchrotron X-ray Absorption (XAFS) experiments to analyse liquid samples of Fe(III) haem species and their complexes with antimalarial drugs in collaboration with Prof Timothy Egan and his PhD student David Kuter (University of Cape Town).
- Victor Streltsov has solved the first atomic resolution crystal structure of the A β amylogenic fragment (*J. Neuroscience* 2011, 31: 1419) (Figure 1). The structure suggests a novel paradigm for A β oligomer formation and potentially provides a system for the discovery of imaging or therapeutic reagents for AD. This achievement was recognized by CMSE divisional award and the CSIRO Medal and Award (see below).
- Victor Streltsov has also received a JSPS (Japanese Society for Promotion of Science) fellowship under the "JSPS

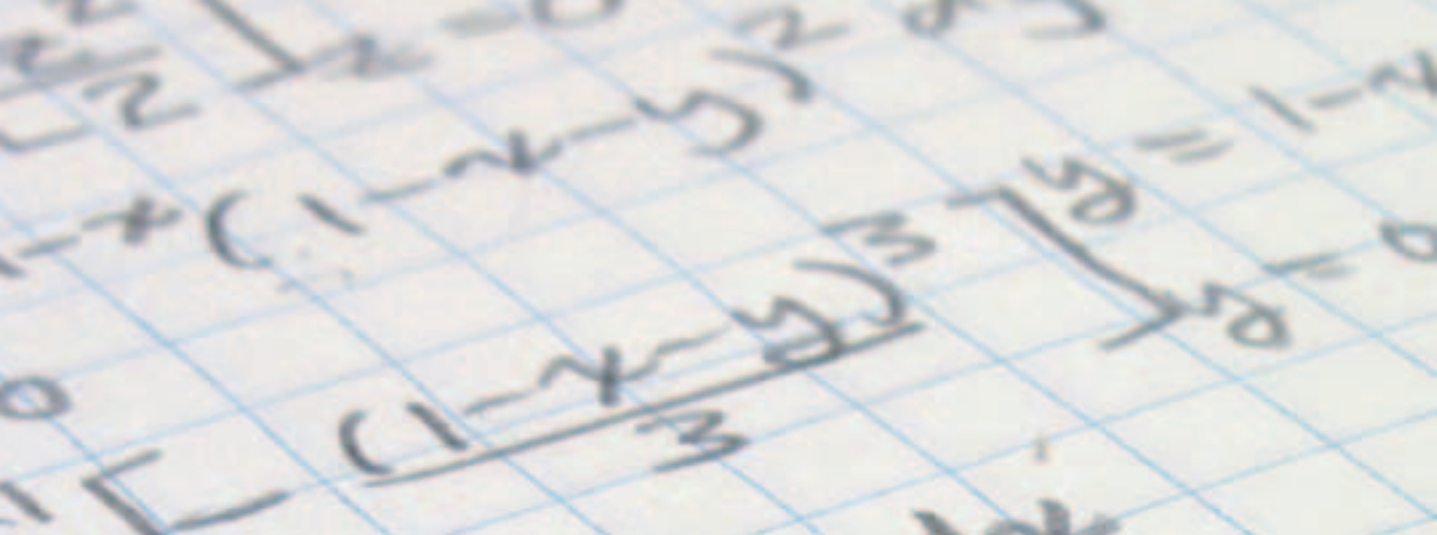
Invitation Fellowships Program for Research in Japan" to conduct research, attend seminars, give lectures etc in host institution (Nagoya Institute of Technology) for a period of 30 days in 2012.

- Connie Darmanin & Victor Streltsov have hosted a crystallisation/protein structure determination day for the Tall Poppy group of Santa Maria students.
- As part of the CXS team we are part of a successful application to attend the LCLS XFELS program to carryout radiation damage experiments on protein crystals and powdered samples.
- In collaboration with Brian Abbey (La Trobe University) we have designed a XFELS holder to encase Lysozyme crystals. The holder is currently in test phase.

STRUCTURE DETERMINATION PROGRAM CASE STUDY

The first atomic resolution crystal structure of the amyloid- β (A β) amylogenic fragment in Alzheimer's Disease (AD) was solved (Streltsov et al 2011 *J. Neuroscience*). The A β is a toxic protein that forms damaging plaques in the brain which are the hallmark of AD. The Amyloid Structure Team (see Fig. 2 and 3) was the first to successfully crystallize the part of A β that forms plaque in the brain by fusing it to a shark antibody (IgNAR, Fig.1) to prevent aggregation. This enabled a structure to be resolved to atomic resolution, providing an insight into the early molecular processes that occur in AD.

This discovery provides a starting point for discovering drugs which might be used to interfere with the accumulation of A β in AD. This achievement was recognized by the CSIRO Medal and structural studies were a major CSIRO contribution to the CRC for Mental Health awarded in 2011.



THEORY AND MODELLING PROGRAM

The Theory and Modelling Program (TMP) is responsible for developing the theoretical and computational physics needed to support the experimental programs in CXS. Our interests involve (i) the solution of inverse problems (ii) the characterization of partial spatial and temporal coherence in short wavelength light sources (iii) the relativistic formulation of molecular electronic structure and quantum electrodynamics (iv) the dynamical description of non-linear interactions between molecules and strong coherent fields (v) coherent energy transfer processes in biomolecules and (vi) the design of efficient computational algorithms.

Goals: The Theory and Modelling Program collaborates closely with all of the other programs in the Centre, especially in identifying fruitful directions for the experimental programs to pursue and by supporting these activities with theoretical and computational tools. The key aims of TMP involve the development of:

- Image reconstruction algorithms for diffraction data obtained using

sources exhibiting partial spatial or temporal coherence.

- Quantum electrodynamical models of high-harmonic generation in atomic systems using visible and infra-red light sources and of the interaction of molecules with strong-field high-frequency X-ray free-electron laser (XFEL) sources.
- Non-interferometric phase recovery techniques in photon echo spectroscopy.

ACHIEVEMENTS

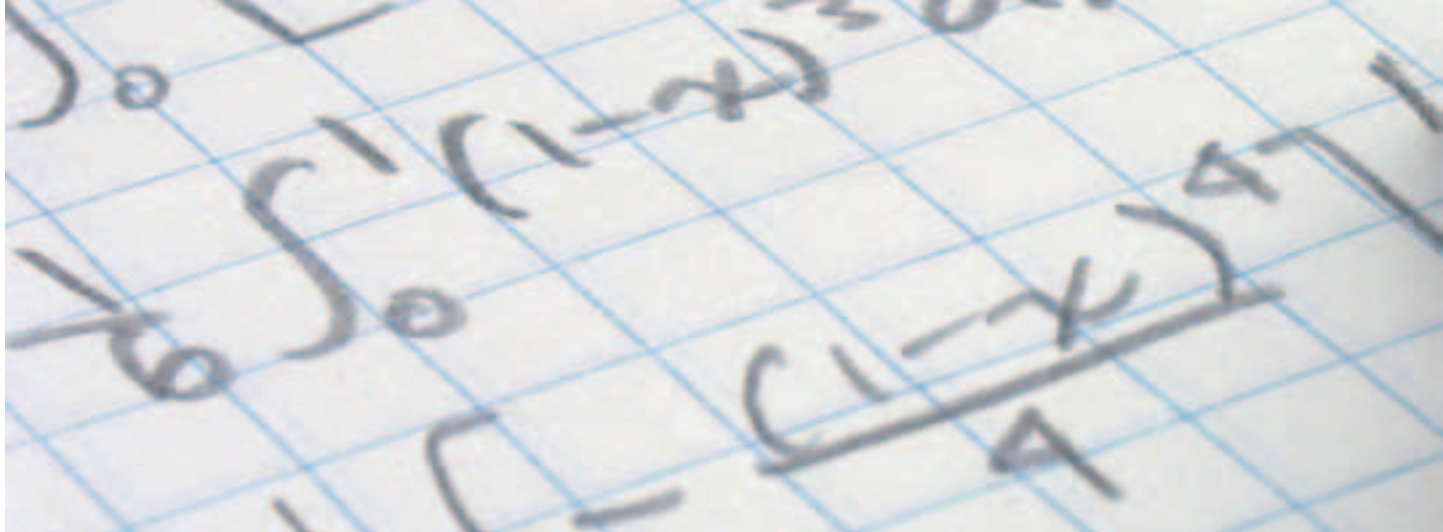
As one of the significant long-term outcomes of CXS, the theoretical basis of the imaging techniques that we have developed during the past few years was published in *Journal of Modern Optics* in 2010. The ideas contained in this article have formed a template for continuing research in CXS into the development of X-ray diffractive imaging applications. We have adopted an approach that is quite different to that of our international colleagues, in that our theoretical work is based on a partially coherent model of the optical sources that we employ in experiments. Initially, this approach was introduced to allow us to correct for small deviations from full spatial and temporal coherence in conventional diffractive imaging applications. We soon discovered, however, that casting the diffractive imaging problem within a more general theoretical approach allowed us to employ experimental configurations that deviate very significantly from the fully coherent ideal limit. The earliest application of this general approach was to the analysis of experimental diffraction data obtained from

the High-Harmonic source at Swinburne, which could be regarded as consisting of a small number of well-spaced, discrete frequency components, each exhibiting high spatial coherence.

The success of this study naturally prompted the question: "how far from the limits of full spatial and temporal coherence may we stray and still achieve high resolution diffractive imaging?" This question was addressed in a *Nature Photonics* article on "Broadband X-ray Imaging", in which it was demonstrated that one may employ a complete harmonic from a third-generation synchrotron without attenuating the output using a monochromator. The practical advantages of this insight are considerable, since it reduces the time required to collect diffraction data by almost two orders of magnitude, compared with observing the conventional structures regarding the tolerance of coherent diffractive imaging algorithms to spectral bandwidth. This approach is currently being extended to sources that are both spectrally broad and which exhibit partial spatial coherence.

The efforts of CXS, both theoretical and experimental, in developing practical approaches to diffractive X-ray imaging have been collected into a software package, which is now known as NADIA. The acronym is derived from *Nadia's Algorithms for Diffractive Imaging Applications* and includes a recursive reference to Nadia Davidson, who designed and developed the package using an inhomogeneous collection of software that had been circulating in CXS for some time. This package now includes most of the iterative algorithms that are widely used in





diffractive imaging community, including the Fresnel coherent diffractive imaging approach developed by CXS a few years ago. This software is under continuing development and, it is hoped, will be taken up as a standard at facilities that perform diffractive imaging experiments.

BIOMOLECULAR IMAGING USING XFEL SOURCES

One of the unexpected outcomes of our work in partially coherent imaging was the realization that the same general ideas could be adapted to model the effects of electronic and structural damage in biomolecular imaging experiments using fourth-generation X-ray Free-Electron Laser sources. This led to the publication of an article by Quiney and Nugent in *Nature Physics* on the electronic damage problem in biomolecular imaging and, ultimately, to the award of significant beamtime at LCLS in April 2012 to study this effect.

A theoretical analysis of the anticipated powder diffraction patterns from haemozoin, fullerene C_{60} and nanodiamond crystals to simulate upcoming XFEL experiments has been conducted. Considerations of crystal symmetry are made to simulate diffraction patterns for different energies, as well as several distances of the samples from a CCD detector. The ionization of samples resulting from XFEL irradiation is modeled for C_{60} crystals by variation of the fractional occupation of lattice sites by chemical species of sequential atomic number. Detailed studies are being performed of the effects of electronic damage on predicted diffraction patterns. A signature of damage may be the appearance of "forbidden reflections" due to the reduction in

symmetry caused by the electronic excitation processes; an attempt will be made to identify these signals in the upcoming experiments. The analysis work has been directed by Ruben Dilanian and Harry Quiney and conducted by the research students Evan Curwood, Rebecca Ryan and Sophie Williams.

PROTEIN CRYSTALLOGRAPHY

The recent development of the extremely bright X-ray free-electron laser (XFEL) sources has created an opportunity for the structure analysis of proteins which only form crystals less than 1 micron in size. However, the fact that proteins form crystals of the nanoscale size indicates that

their crystal structures are far from ideal. Structural imperfections play a significant role in formation of the diffraction pattern and should be taken into account during the structure analysis. We analyzed the interference phenomenon caused by such defects. The structural imperfections can be described in terms of a partial coherency of adjacent molecular clusters. This allows us to apply the modal expansion Coherent Diffraction Imaging (CDI) approach for the structure analysis of the protein nanocrystals. The Photosystem I protein molecule was used as a target for the structure reconstruction. The resulting images, Figure 1, clearly show structure details, including envelopes of Photosystem I protein molecules and transmembrane α -helices.

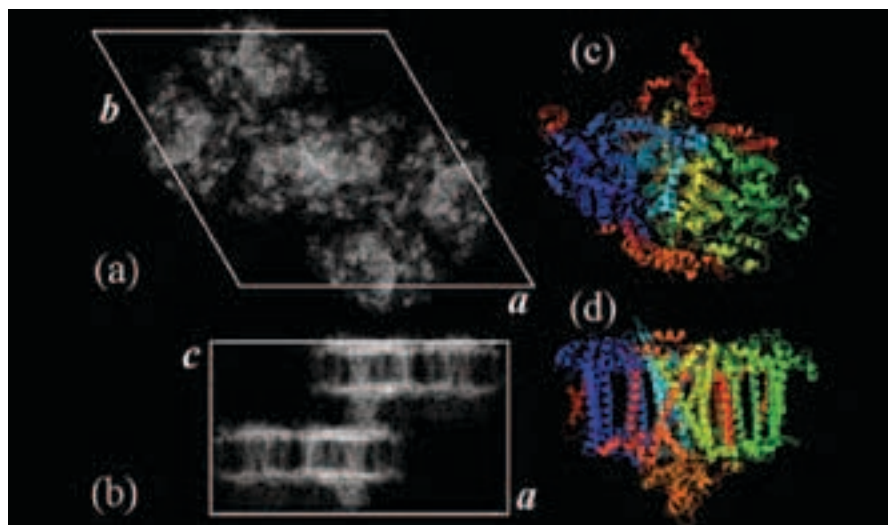
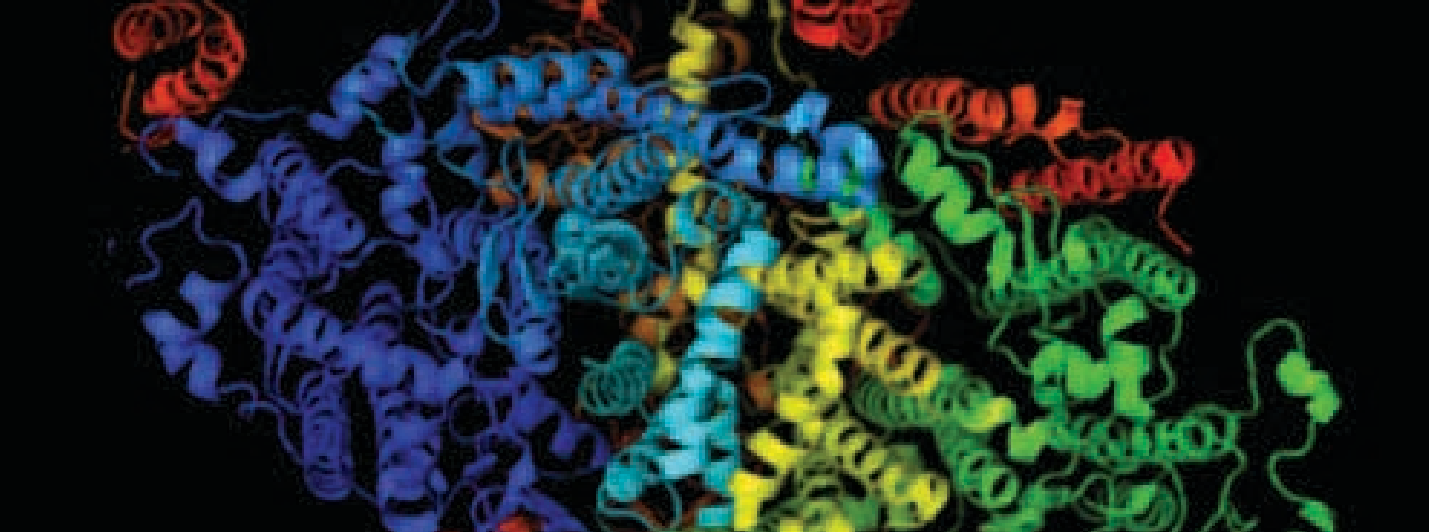


Figure 1. The projections of the electron density of the Photosystem I molecular cluster, reconstructed with resolution of 4.1 \AA by incorporating models of the structural imperfections: (a) **(ab)** crystallographic plane, (b) **(ac)** crystallographic plane, (c) and (d) the models of the Photosystem I molecule, **(ab)** and **(ac)** projections respectively.



OPTICAL MULTIDIMENSIONAL SPECTROSCOPY

Work continues in collaboration with Dr Jeff Davis (Swinburne) on developing analytical tools for multi-dimensional Fourier transform spectroscopy. Rather than rely on interferometry to determine the phase information contained in a four-wave mixing experiment, we have developed a scheme that utilizes ideas borrowed from the phase retrieval techniques that we use to recover images using diffraction patterns. These ideas have led to the development of a range of methods to examine what role, if any, quantum coherence phenomena may play in the efficient transport of energy in naturally-occurring light harvesting complexes. Recent applications of these techniques have been to carotenoids and to complexes extracted from marine algae.

ATTOSECOND PHYSICS

Theory and modelling is committed to supporting the experimental research at Griffith on attosecond physics and few-cycle interactions with electronic media. Our theoretical effort was slowed by the departure of Dansha Jiang, though we are all delighted that she has now given birth to a healthy baby. The strong-field modelling project has been taken up recently by Daniel Wells, who has just begun his PhD with the group. Daniel performed detailed calculations of the photoionization yield of atomic hydrogen subjected to an intense few-cycle pulse within a one-dimensional approximation during his MSc research in 2011. In 2012 he will develop a complete three-dimensional model within the velocity

form of the electronic dipole approximation. This scheme employs a novel approach to the solution of the propagation equations that promises increased efficiency and generality; it is planned to extend the treatment to include non-dipole and spin-dependent effects using a relativistic formalism based on the Dirac equation and quantum electrodynamics.

STRUCTURED ILLUMINATION MICROSCOPY

Simulation software has been developed by Dr Brendan Allman to support the development of Structured Illumination Microscope (SIM) by Trevor Smith and his team in the Short Wavelength Laser program. This development has been undertaken in IDL and currently exists in two versions,

- a code to fully simulate a SIM microscope, generating a theoretical SIM result and Moiré images from a given input image, in this case modelled on the UML microscope in Chemistry, and
- a code to take in theoretical or experimentally generated moiré images and produce a SIM result.

These codes are now operational and ready to be fully-formatted and documented into the CXS Software Interface. This now also includes documentation of Phase Diverse CDI code within the program.





ULTRA-COLD PLASMA SOURCE PROGRAM

The Ultra-Cold Plasma Source Program (UCP), formed within CXS in 2007, is developing an ultra-bright, coherent source of electrons for imaging of biologically relevant targets. By applying technical developments taken from the ultracold atom community, and the theoretical algorithms developed in the TMP program, we will enable a new approach to electron imaging. The enhanced probe-molecule interaction strength that a coherent electron source offers, combined with an improvement of four orders of magnitude in brightness over existing electron sources, will enable high-resolution imaging of biological targets with atomic scale resolution.

The most significant aspect of the UCP source and the basis of the dramatic enhancement in brightness that it promises is the origin of the electrons: they will be extracted from ultracold atoms, just a few millionths of a degree above absolute zero. The brightest conventional electron sources start with hot material, by blasting a target with a high-energy laser pulse. The hot electrons then expand like steam from a kettle, and are equally difficult to tame and control. Electrons extracted from ultracold

atoms can be accelerated and focused with unprecedented resolution. The comparison is like that of a conventional light bulb and a laser: we need laser-like coherence and brightness to image molecular structure with atomic resolution.

The UCP team has strong expertise with ultracold atom technology, with conventional optical imaging, and with electron optics. They are collaborating with the world-leading research group in this area, at the University of Eindhoven in The Netherlands. The project is strongly connected with the Centre's TMP program. We have jointly published work based on the Centre's imaging approaches for applications in characterising the cold atom cloud. We are now collaborating with the TMP group to employ their expertise on partially coherent x-ray sources for modeling our now-operational electron source. The theoretical formalism of partial coherence has not previously been applied to electron imaging, but recent development of new sources has made partial coherence highly relevant. Our modeling will be used to design the imaging component of our system, firstly to enable verification that the electron source is indeed coherent and bright, and secondly to enable imaging applications. In the longer term, collaboration with TMP will be essential to unravel electron-molecule interactions so that target structural information can be separated from the complexity of the diffraction data. The ultimate goal, the high-impact demonstration of electron diffraction from molecules, will require

close liaison with the Biological Sciences Program, to determine the optimum biological targets and the appropriate sample preparation strategies. Our initial collaboration with BSP has established two-dimensional crystals of bacteriorhodopsin as a promising target for the first experiments. Such inter-program collaborations, the envy of our colleagues at Eindhoven, are simply not available to other groups around the world and will allow the UCP team to rapidly achieve high-impact results across disciplines.

ACHIEVEMENTS

Electron microscopy has revolutionised science. The strong interaction with matter and short de Broglie wavelength of electrons has allowed the formation of exquisite images of the nanoscale world. X-ray imaging has also had a similarly transformative impact, though in a rather different way, x-rays being able to probe inside materials with high spatial resolution. The complementarity between the two approaches has together yielded great insights, which have underpinned many advances in medicine, biology, materials science and technology.

X-ray sources have continued to develop at an extraordinary rate and new x-ray laser sources are opening up new frontiers in ultrafast science (see Short Wavelength Laser Source Program). In many ways, electron sources have not kept pace. In 2011, the CXS Ultracold Plasma Source Program has demonstrated the extraordinary potential of a new high-coherence cold

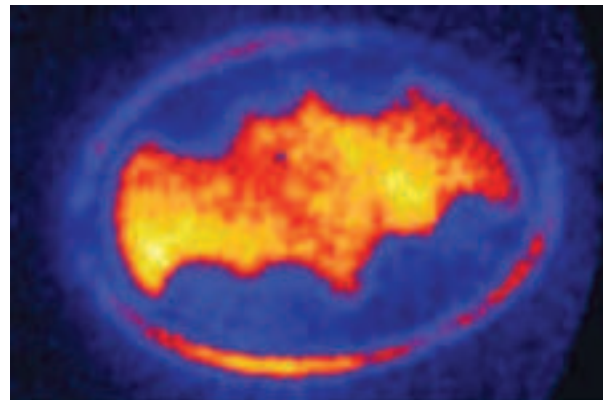
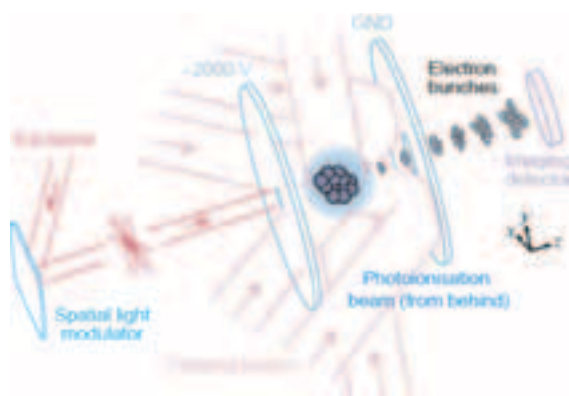


Fig 1: Arbitrarily shaped electron bunches from a cold atomic gas. a Selectively photoionising and accelerating the electrons from a laser-cooled rubidium cloud produces an electron bunch with a well-controlled distribution. b False colour image of the electrons after propagating 24cm. The extremely low temperature of the resulting electrons and the absence of space-charge effects enable it to retain its shape as it travels away from the gas. From Nature Physics 7 p785 (2011).

electron source (Fig. 1) which promises increases in brightness comparable to those seen with x-rays, with important consequences for electron coherent diffractive imaging (eCDI) at the nanoscale.

In our experiments, we first produced a cloud of about 10^9 cold atoms, suspended by laser light in an inhomogeneous magnetic field. Some of those atoms were selectively excited using laser beams shaped with a spatial light modulator – effectively a computer-controlled hologram. The cloud was then illuminated with another laser beam to ionise only the excited atoms, creating a shaped bunch of electrons. Because the atoms are essentially stationary, and the excitation and photoionisation lasers can be precisely tuned to the quantum levels of the cold atoms, the electrons are released with very little excess energy: they are very cold, about 10 degrees above absolute zero. We have for the first time shown that it is possible to make a pattern with electrons and see that pattern after the electrons have propagated a substantial distance (24cm) across free space. The ability to do so demonstrates the high spatial coherence of the new electron source, which translates to high resolution when the electrons are used for diffractive imaging.

Using a conventional electron source, diffractive imaging is inherently very slow, because the current must be low to avoid distortion caused by electron-electron repulsion. Electron bunches inherently expand due to the Coulomb repulsion between like charges. The ability to

arbitrarily shape an electron bunch allows formation of uniform density ellipsoidal bunches, which like any other electron bunch will expand due to Coulomb repulsion, but which have linear internal fields and thus can be refocused to reverse the Coulomb explosion. The cold atom electron source (CAES) is the only source with full 3D bunch shaping ability.

We have also shown that femtosecond laser pulses can be used in the photoionisation process to create extremely short bunches (150ps or less), which are still very cold despite the large energy spread of the femtosecond laser pulse. It has been shown by collaborators Luiten and Vredendregt at the Eindhoven University of Technology that short bunches can be further compressed to femtosecond durations with standard charged particle accelerator techniques. The combination of high spatial coherence and ultrashort bunch durations will enable a new approach to imaging critical processes at the nanoscale, for example chemically induced changes to nanocrystals of biomolecules.

The potential for this program of work was beautifully captured by Prof. John Spence during a discussion at the 2011 CXS International Workshop. Prof. Spence is a world-leader in both electron and x-ray imaging at the atomic scale and he described our new electron source as a “mini-XFEL” (x-ray free electron laser) because of its potential to image at atomic resolution and sub-picosecond timescales.

ULTRA-COLD PLASMA SOURCE PROGRAM CASE STUDY

High spatial coherence is critical for coherent diffractive imaging (CDI). Traditional electron sources have very poor spatial coherence, though the coherence can be increased by allowing the electron beam to expand – at the price of reducing the current and therefore increasing the imaging time. That lack of coherence has prevented useful application of CDI techniques, such as those developed by CXS for innovative x-ray imaging, with electrons. Using the latest generation of aberration-corrected microscope, Dr. Corey Putkunz of the UPSP group has been able demonstrate electron CDI with atomic resolution for the first time, using a ptychographic approach (Fig. 2). The proof-of-principle demonstration suggests that with sufficiently bright electron sources, such as the novel CXS cold atom electron source, high speed diffractive imaging of nanoscale processes will be possible.



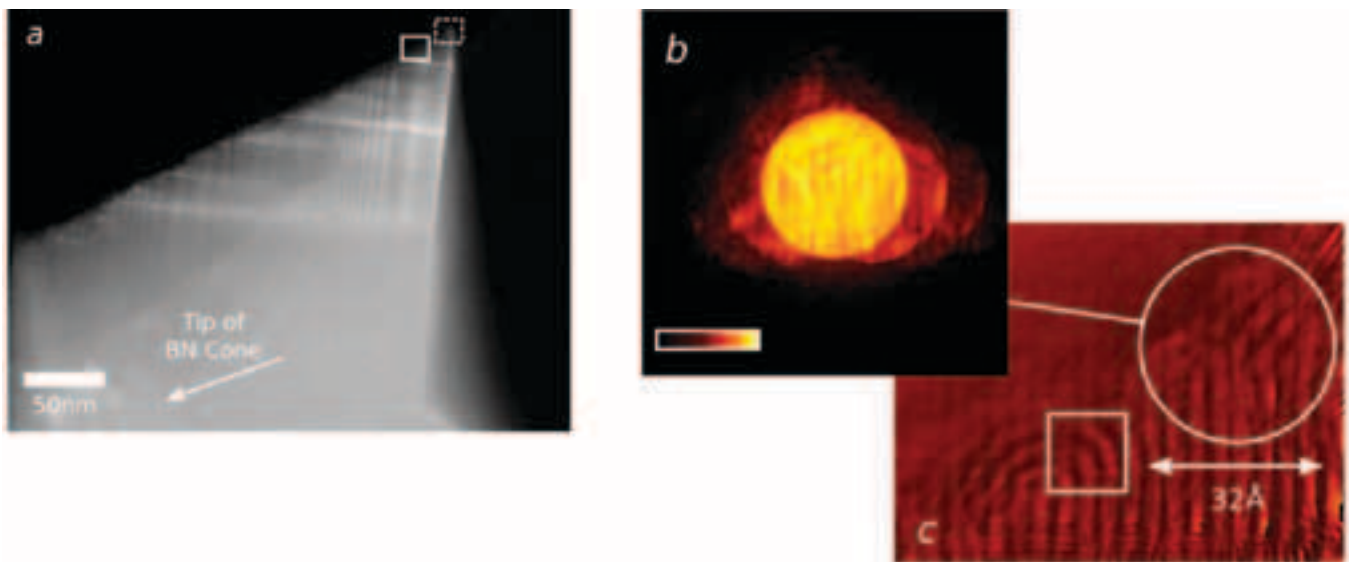
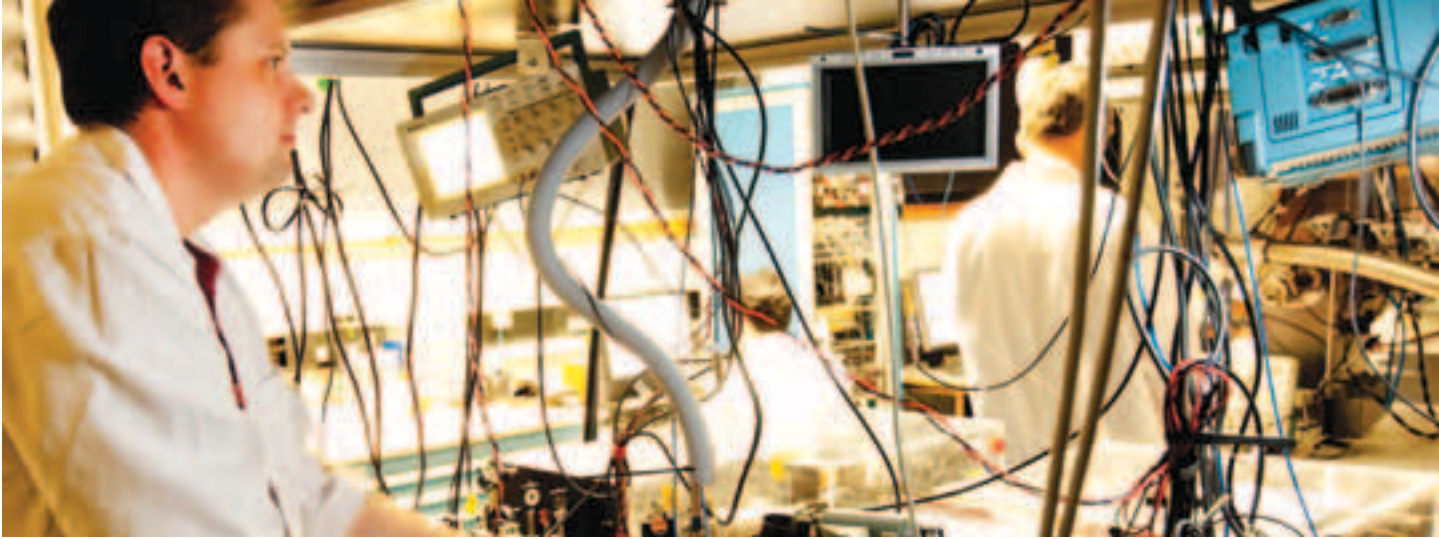
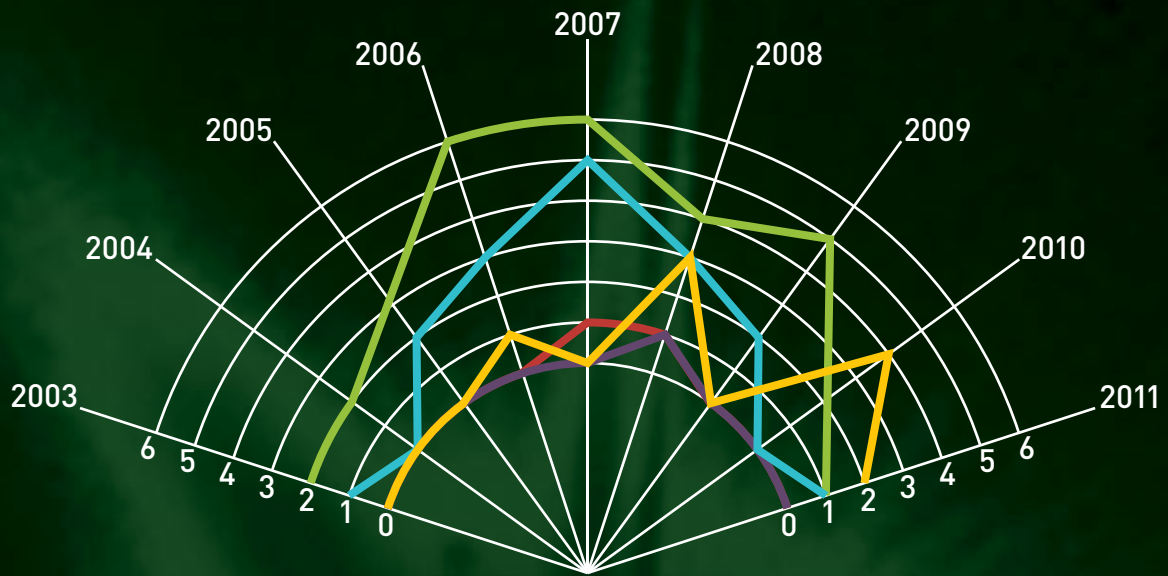
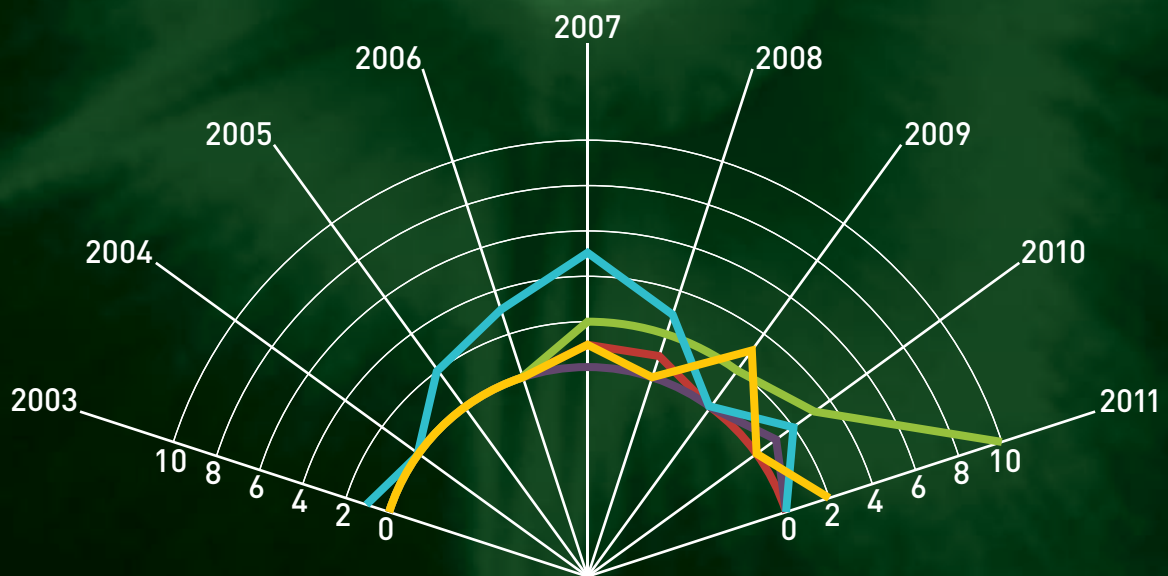


Fig 2: Electron coherent diffractive imaging of a boron nitride cone, acquired using an FEI Titan transmission electron microscope at 300keV. **a** Annular dark field image; **b** Diffraction disc (log scale), with microscope probe over-focussed; **c** Recovered phase map extracted from multiple overlapping diffraction disc images, showing individual atom columns. From Physical Review Letters **108** 073901 (2011).



STUDENT RECRUITMENT 2003 – 2011

- PhD
- Hon
- MSc
- Mphil
- Pgrad Dip

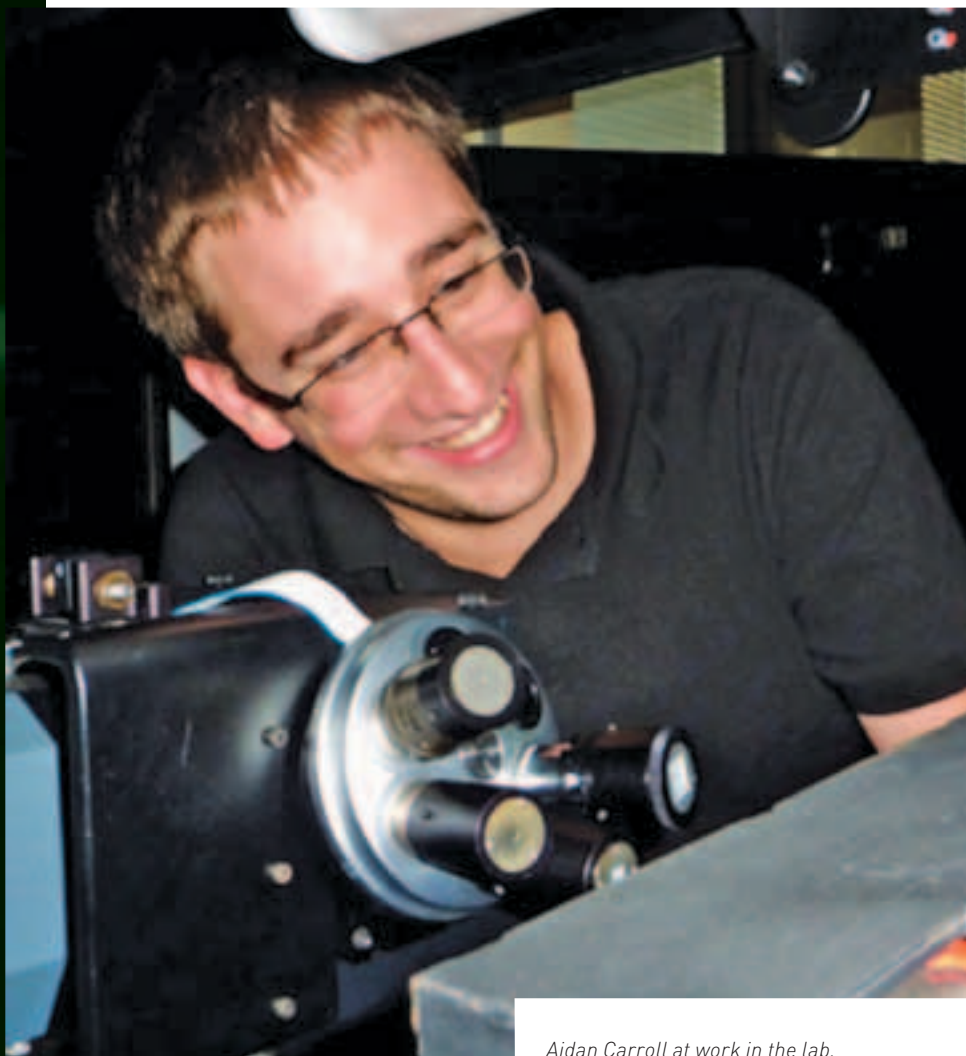


STUDENT COMPLETION 2003 – 2011

- PhD
- Hon
- MSc
- Mphil
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STUDENT LIFE @ CXS

EXPANDING HORIZONS



Aidan Carroll at work in the lab.

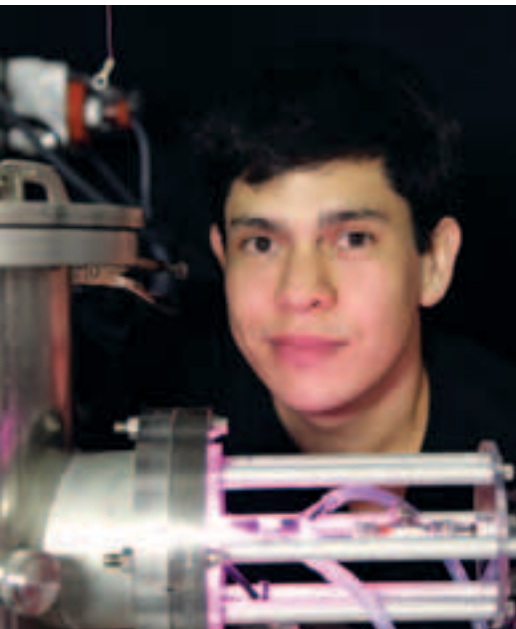
AIDAN CARROLL, EXPERIMENTAL METHODS PROGRAM

LA TROBE UNIVERSITY

I was fortunate enough to join CXS in late 2009 as an Honours student and continued on as a PhD student in 2011 in the Experimental Methods Program. During the past year, my work has centred on adapting imaging techniques currently used at synchrotron facilities to conventional laboratory sources. As such, I am developing a near field broadband phase contrast algorithm using iterative techniques.

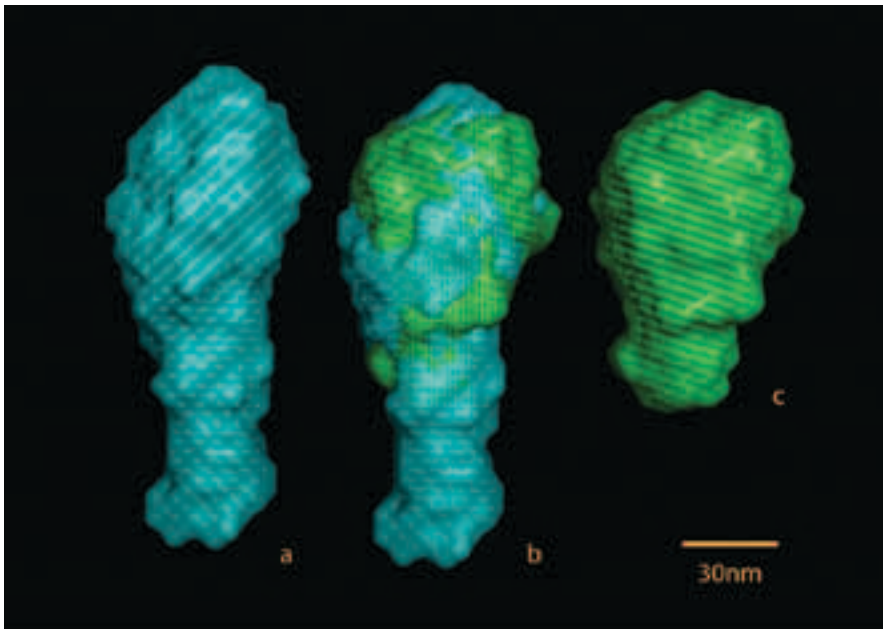
People in the outside world ask what I do as a student or what the Experimental Methods Program actually is. My standard response is, "I get to build and play with some awesome toys", and 2011 was no different. I had the opportunity to help build the new Nano-Focus source at La Trobe University and got to participate in experiments at Elettra (Italy), the APS (USA) and the AS (Australia). These were great education experiences, as they covered a wide range of areas of research ranging from coherence studies to biological and material imaging. Giving a talk about my research at the Australian Synchrotron user meeting was a highlight for the year.

Being a member of CXS has offered me opportunities and opened doors, always within a rich learning environment. I am grateful for the remarkable collaboration within the Experimental Methods Program and across CXS and throughout the x-ray community in general.



Left: William Wallace working with the atomic hydrogen source.

Right: Small angle X-ray scattering (SAXS) analysis of mMiD49^{ΔNA} and mMiD49^{ΔNB}



WILLIAM WALLACE, ATTOSECOND SCIENCE PROGRAM

GRIFFITH UNIVERSITY

For the past three years I have been undertaking my PhD research in the Attosecond Science Program of CXS under the supervision of Dave Kielpinski and Robert Sang. The core focus of my research is on the photoionisation of atomic hydrogen when exposed to ultrashort laser pulses.

As a member of CXS I have had the opportunity to attend a number of conferences and workshops. My personal highlight of 2011 was being able to present work from the hydrogen experiment at the International Conference on Photonic, Electronic and Atomic Collisions in Northern Ireland. Some other enjoyable experiences from last year were the 'Talking Backwards' and the CXS Annual workshop. The former provided the chance to interact with researchers from other disciplines in a fun and relaxed atmosphere and the latter a chance to learn from international speakers with expertise across a broad range of topics.

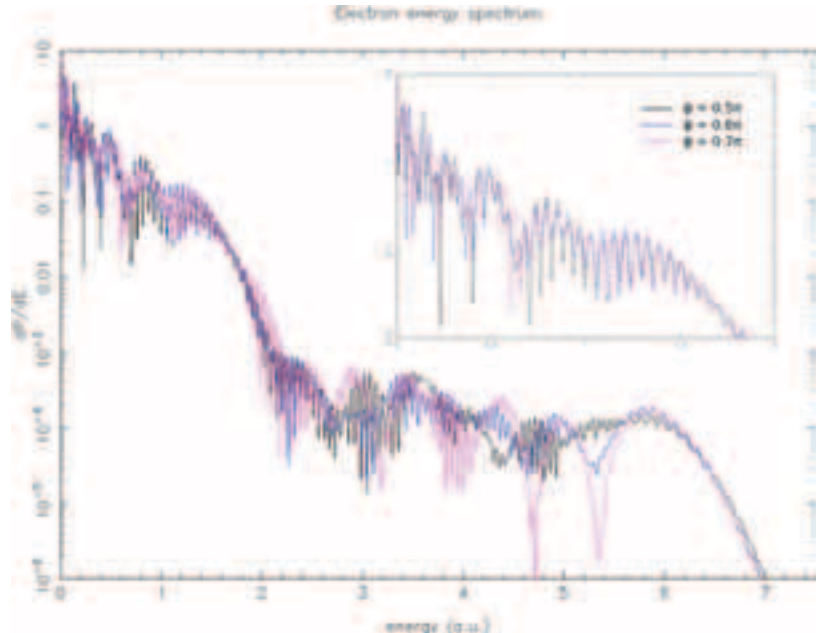
Support from CXS has also led to personal growth, with new friendships, a broader professional network and increased knowledge allowing me to develop further as a research scientist.

VIVIANE RICHTER, BIOLOGICAL SCIENCES PROGRAM

LA TROBE UNIVERSITY

I joined CXS in 2010 as a PhD student, working on a structural project focussing on mitochondrial outer membrane-tethered proteins involved in mitochondrial morphology. Being part of this organisation has given me excellent opportunities to learn from and network with leaders in the field of X-ray sciences, through various workshops and meetings, where I have received feedback and ideas on possible directions in my project. Coming from a pharmacology and chemistry context, I have appreciated the exposure to forefront techniques in physics and more significantly, their application to biological questions. It is apparent how different the backgrounds of biologists and physicists are, but also how much room there is for overlap and collaboration. Being part of CXS early in my scientific career has encouraged me to think in a broader context about my own project and how work in our lab may benefit from an integrated approach.





NAYLYN GAFFNEY, SHORT WAVELENGTH LASER SOURCE PROGRAM

SWINBURNE UNIVERSITY OF TECHNOLOGY

I started my PhD at the beginning of 2011 with the SWLP and my experiences with CXS have been great. My project addresses the improvement of the HHG source for CDI and I have found that the ability to tap into the collective knowledge of CXS to be invaluable to my understanding of the challenges that I face.

I have found that there is a great sense of community within CXS, which has given me the opportunity to interact with researchers and students beyond my research group. I have particularly enjoyed the CXS workshops for the exposure that they provide to work which I otherwise would most likely not encounter. In 2011 I attended a number of CXS workshops, with the highlights being the international guests at the annual workshop and the different perspectives provided by the Talking Backwards workshop.

DANIEL WELLS, THEORY AND MODELLING PROGRAM

UNIVERSITY OF MELBOURNE

I joined CXS in 2010 as a Masters student working in the theory and modelling group at the University of Melbourne, under the supervision of Harry Quiney. While I've been a student here I have benefited greatly from the expertise of other CXS members and I am grateful to the CXS for providing a thoroughly enjoyable and welcoming environment.

My Masters project involved modelling the interaction of atoms with intense laser pulses, which is closely related to experimental work studying above threshold ionisation of hydrogen atoms performed by the attosecond science group at Griffith University. In July 2011, I was fortunate enough to attend the Attosecond Science Workshop hosted by Griffith, which allowed me to meet with other physicists in the CXS.

As a student in the CXS I have had invaluable opportunities to attend conferences and learn from experts. One of the highlights of my time at the centre was a trip to Cairns for the XFEL workshop in 2011, where I presented a poster. Having only studied physics in undergraduate science I have found it particularly rewarding to be exposed to the different branches of science and skill sets that make up CXS.

I began a PhD with CXS in 2012, and am looking forward to continuing my work with the centre into the future.

Left: Swinburne University Optics Lab.

WHERE ARE THEY NOW?

	CXS Node	Where are they now
Brian Abbey	University of Melbourne	Postdoc Research Fellow, Swinburne University, Australia
Amanda Aloia	La Trobe University	Australian Nanotechnology Network, Australia
Abhishek Awasthi	La Trobe University	Transition and Student Engagement Officer, La Trobe University, Australia
Michael Baker	La Trobe University	Cologne, Germany
Simon Bell	University of Melbourne	Postdoc Research Fellow, Tubingen, Germany
Jenny Carmichael	La Trobe University	Self employed, JC Protein Modelling, Melbourne, Australia
Jihun Cha	Griffith University	Working in Korea
Cherrine Chan	La Trobe University	Research Assistant, NCRIS Biologics, Australian Institute of Bioengineering and Nanotechnology, Australia
Jesse Clark	La Trobe University	Centre for Nanotechnology, Imperial College, London
Nadia Davidson	University of Melbourne	Children's Hospital, Melbourne, Australia
Samantha Deed	La Trobe University	Parenthood
Emma Duglas	La Trobe University	PA, Dept Biochemistry, La Trobe University
Sam Flewett	University of Melbourne	Technical University, Berlin, Germany
Chris Hall	Monash University	Beamline Scientist, Australian Synchrotron
Eric Hanssen	La Trobe University	Bio21 Institute, University of Melbourne, Australia
Martijn Jasperse	University of Melbourne	Bose-Einstein Condensation Research Group, Monash University, Australia
Dansha Jiang	University of Melbourne	Parenthood, USA
Michael Jones	La Trobe University	Super Science Research Fellow, La Trobe University, Australia
Mark Junker	University of Melbourne	Postdoc Research Fellow, La Trobe University, Australia
Lisa Lansfield	University of Melbourne	Royal Melbourne Hospital, Australia
Craig Lincoln	University of Melbourne	Postdoc Research Fellow, Imperial College, London
Alex Lowdin	La Trobe University	Technical Assistant, La Trobe University, Australia
Bohumil Maco	La Trobe University	Postdoc Research Fellow, The Educational Institute, Switzerland
Adrian Mancuso	University of Melbourne	Group Leader, Instrument - SPB, European XFEL, Germany
Lachlan McKimmie	University of Melbourne	Technician, Coherent Scientific, Australia
Ted McMurchie	CSIRO	Fuels from Food Waste, University of Adelaide, Australia
Stephen Mudie	CSIRO	Australian Synchrotron
Laura Osellame	La Trobe University	UCL Research Department, University College London
Mark Pfeifer	La Trobe University	Cornell University, New York, USA
Olena Ponomarenko	University of Melbourne	Teaching Assistant, University of Saskatchewan, Canada
Michael Pullen	Griffith University	Research Fellow, Griffith University, Australia
Corey Putkunz	La Trobe University	Postdoc Research Fellow, University of Melbourne, Australia
Alin Rai	La Trobe University	Technical Assistant, La Trobe University, Australia
Sebastian Saliba	University of Melbourne	Portland, USA
David Sheludko	University of Melbourne	Research Associate, University of Melbourne, Australia
Danielle Smith	La Trobe	Postdoc Research Fellow, UK
Sven Teichmann	Swinburne University	Postdoc Research Fellow, Swinburne University
David Vine	University of Melbourne	Advanced Photon Source, Chicago, USA
Kaushal Vora	La Trobe University	Processing Engineer, Australian National University
Lachlan Whitehead	University of Melbourne	Technical Assistant, Phillips Ormonde Fitzpatrick, Melbourne, Australia
Garth Williams	University of Melbourne	National Accelerator Laboratory, Stanford University, USA
Jeff Yeoman	La Trobe University	Associate Lecturer, Molecular Sciences, La Trobe University, Australia
Rotha Yu	University of Melbourne	School of Physics, Monash University, Australia

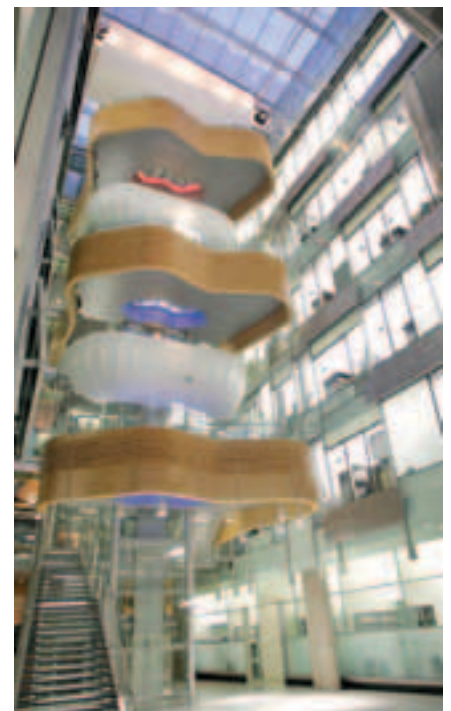
BIOLOGICAL SCIENCE PROGRAM @ BIO21

Leann Tilley has taken up a position as a Professor of Biochemistry and Molecular Biology, in the Bio21 Molecular Science and Biotechnology Institute at the University of Melbourne. This move offers excellent opportunities to expand the scope and activities of the Biology Program of CXS by embedding the work of Prof. Tilley's team within the excellent research environment of the Bio21 Institute. The Institute operates a large array of platform technologies including an outstanding electron microscopy capability, as well as light microscopy, metabolomics, mass spectrometry and NMR.

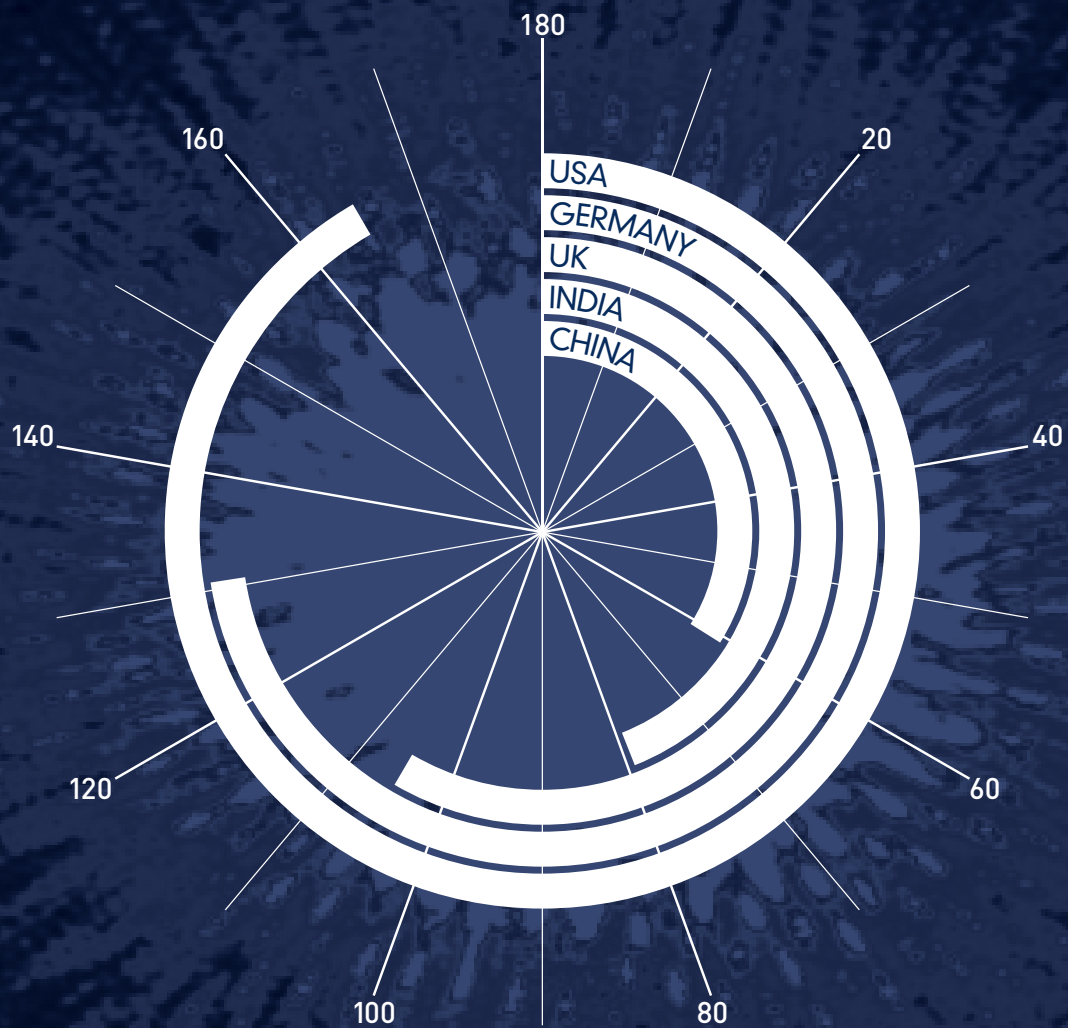
In 2011 Leann led an ARC LIEF application, supported by the University of Melbourne, La Trobe University, Monash University the Walter and Eliza Hall Institute and CXS, that successfully sought funds (total of \$1.12M from the ARC and partner institutions) to set up a Cellular Nanomaging Facility. As part of this Facility in 2012. Professor Tilley will commission a 3D-Structured Illumination Microscope at the Bio21 Institute. The OMX BLAZE™ system will enable live cell super-resolution imaging with an 8-fold increase in volume resolution. This will expand the CXS's pioneering efforts in the area of super-resolution optical microscopy and will increase collaborations with A/Prof Trevor Smith (Short Wavelength Lasers Program).

The Bio21 Institute houses one of only two Tecnai F30 EMs in Australia, providing 3D electron tomography capability. As part of the work of the CXS Biology Program, Prof Tilley and Dr Eric Hanssen have pioneered multi-section electron tomography and cryo-electron microscopy of malaria parasites. She is working with Dr Harry Quiney (Theory Program) to develop novel methods for analysing electron tomography data.

Leann's group is also working with members of the Experimental Program to develop methods for application of X-ray microscopy to malaria parasites. This involves experiments conducted at the Australian Synchrotron; the Advanced Photon Source, Argonne, Illinois; the Advanced Light Source, Berkeley, CA; and at the Elettra Synchrotron Light Source, Trieste, Italy. The move to the Bio21 Institute provides the opportunity to develop methods for directly correlating data from X-ray microscopy methods with data from high-end electron and optical microscopy modalities.



Bio21 Foyer.



TOP 5 INTERNATIONAL VISITOR COUNTRIES 2011

The collection of CXS website data commenced in late 2010, therefore no data is available prior to that time.



CXS MANAGEMENT & GOVERNANCE

CXS is a collaborative research program between the University of Melbourne, La Trobe University, Monash University, Swinburne University of Technology, Griffith University and CSIRO, funded under the Australian Research Council (ARC) Centre of Excellence program and the Victorian Government's Science, Technology and Innovation (STI) Initiative.

As Lead Administering node, the University of Melbourne manages the grants and distributes funds in accordance with the signed agreements. These agreements cover CXS management, collaboration and intellectual property arrangements.

All collaborating organisations are represented on the CXS Board. Commercial expertise is represented on the CXS Intellectual Property Committee and Sub Committee. A Scientific Advisory Board and a General Advisory Board have been established and meet annually.

CENTRE MANAGEMENT

The CXS Management team and its Executive Committee are responsible for administration as it pertains to centre policy, performance, financial matters, research output, research training and professional education of members, partnerships, national and international liaison, commercialisation and outreach.

The management team is:

PROFESSOR KEITH NUGENT
Director of Research

PROFESSOR LEANN TILLEY
Deputy Director of Research

DR HARRY QUINEY
Assistant Director of Research

MS TANIA SMITH
Chief Operating Officer

EXECUTIVE COMMITTEE

During 2011, the administration of CXS was overseen by the Executive Committee, which comprises:

MS ROSSLYN BALL
Executive Officer to Committee

ASSOCIATE PROFESSOR DAVID KIELPINSKI
Attosecond Science Group Leader

PROFESSOR KEITH NUGENT
Research Director

DR GRANT VAN RIESSEN
Experimental Methods Group Leader

DR HARRY QUINEY
Theory and Modelling Group Leader

ASSOCIATE PROFESSOR MIKE RYAN
Biological Sciences Group Leader

ASSOCIATE PROFESSOR ROBERT SCHOLTEN
Ultra Cold Plasma Source Group Leader

MS TANIA SMITH
CXs Chief Operating Officer

ASSOCIATE PROFESSOR TREVOR SMITH
Short Wavelength Laser Source Group Member

PROFESSOR LEANN TILLEY
Deputy Research Director

DR VICTOR STRELTSOV
Structure Determination Methods
Group Leader

PROFESSOR LAP VAN DAO
Short Wavelength Laser Source Group Leader

ADVISORY BOARD

The CXS Advisory Board met in October 2011 at the University of Melbourne CXS Office. The meeting focussed on the recommendations of the CXS Scientific Advisory Board and discussed matters relating to the long-term future of CXS, industry and community outreach, and the leadership of the Centre leading into 2012.

CXS would like to thank Anita Hill, Matthew Bailes and Gerry Roe for their contribution to this year's meeting. We would also like to thank Stephen Lane for taking the Chair's position this year.

MR DAVID KRENUS (CHAIR)
Chief Executive Officer Cyclotek

PROFESSOR JAMES MCCLUSKEY
Deputy Vice Chancellor (Research)
The University of Melbourne, or nominee

DR CAL DRUMMOND
Chief of CSIRO Materials Science and Engineering

PROFESSOR ANDREW FLITMAN
Pro Vice-Chancellor (Research) Swinburne University of Technology, or nominee

PROFESSOR JOHN HELLIWELL
Professor of Structural Chemistry
University of Manchester

PROFESSOR TIM BROWN
Deputy Vice Chancellor (Research)
La Trobe University, or nominee

DR STEPHEN LANE
Chief Science Officer
NSF Centre for Biophotonic, Science & Technology, UC Davis

PROFESSOR EDWINA CORNISH
Deputy Vice Chancellor (Research)
Monash University, or nominee

PROFESSOR BONNIE WALLACE
Professor of Crystallography
Birkbeck College

BRUCE WHAN
Chairman of INNOVIC
(Victorian Innovation Centre Ltd) & Director
Swinburne Knowledge

SCIENTIFIC ADVISORY BOARD

PROFESSOR JOHN HELLIWELL (CHAIR)
Professor of Structural Chemistry
University of Manchester

DR STEPHEN LANE
Chief Science Officer
NSF Centre for Biophotonic, Science & Technology, UC Davis

PROFESSOR KEITH NUGENT
CXS Director of Research
University of Melbourne

PROFESSOR LEANN TILLEY
CXS Deputy Director of Research
LaTrobe University

PROFESSOR BONNIE WALLACE
Professor of Crystallography
Birkbeck College

PROFESSIONAL STAFF

ROSSLYN BALL
PA to Director & Administrator,
University of Melbourne

TANIA CURRUBBA
Finance and Administrative Officer,
University of Melbourne

NICOLE ANDERSON
Administration Assistant, University
of Melbourne

FABIENNE PERANI
PA to Deputy Director & Administrator,
La Trobe University

TATIANA TCHERNOVA
Administrator, Swinburne University

RESEARCH TEAMS

ATTOSECOND SCIENCE PROGRAM

JAMES CALVERT
PhD Student, Griffith University

AIDAN JESSEN
PhD Student, Griffith University

MALCOLM KELSON
Technical Officer, Griffith University

PROFESSOR DAVE KIELPINSKI
Program Leader, Griffith University

DANE LABAN
PhD Student, Griffith University

ASSOCIATE PROFESSOR ROBERT SANG
Research Fellow, Griffith University

WILLIAM WALLACE
PhD Student, Griffith University

HAN XU
PhD Student, Griffith University

BIOLOGICAL SCIENCES PROGRAM

STEPHEN BATIOVIC
PhD Student, University of Melbourne

MARIA CRESPO
PhD Student, University of Melbourne

MEGAN DEARNLEY
PhD Student, La Trobe University

SAMANTHA DEED
Research Assistant, La Trobe University

DR MATTHEW DIXON
Research Fellow, La Trobe University

KIRSTIN EGLASS
PhD Student, La Trobe University

LUKE FORMOSA
PhD Student, La Trobe University

SARAH FRANKLAND
PhD, University of Melbourne

DR JACQUI GULBIS
Structural Biology Division, WEHI

DR ERIC HANSEN
Affiliate Research, University of Melbourne

DR NICK KLONIS
Associate Researcher, La Trobe University

LYNN LIANG
PhD Student, La Trobe University

HEATHER LEWIS
PhD Student, University of Melbourne

ALEX LOWDIN
PhD Student, La Trobe University

DR ALEX MAIER
Research Fellow, La Trobe University

MAURO MAIORCA
MSC Student, La Trobe University

DR PAUL MCMILLAN
Research Fellow, La Trobe University

DR CAROLIE MILLET
Research Fellow, University of Melbourne

VED MOOGA
MSc Student, La Trobe University

THANH NGOC NGUYEN
Honours Student, La Trobe University





MR ALIN RAI
Technical Assistant, La Trobe University

VIVIANE RICHTER
PhD Student, La Trobe University

PROFESSOR MIKE RYAN
Program Leader, La Trobe University

JESSE RUDD-SCHMIDT
PhD Student, University of Melbourne

CHE STAFFORD
PhD Student, University of Melbourne

DR DIANA STOJANOVSKI
Affiliate Research, La Trobe University

SILVIA TEGUH
PhD Student, University of Melbourne

PROFESSOR LEANN TILLEY
CXs Deputy Director, La Trobe University

JEFF YEOMAN
PhD Student, La Trobe University

EXPERIMENTAL METHODS PROGRAM

DR BRIAN ABBEY
Research Fellow, University of Melbourne

REEM AL AMOUDI
PhD Student, La Trobe University

DR BENEDICTA ARHATARI
Research Fellow, La Trobe University

NOR AZAH ABDUL AZIZ
PhD Student, University of Melbourne

DR EUGENIU BALAU
Research Fellow, La Trobe University

GUIDO CADENAZZI
PhD Student, University of Melbourne

AIDAN CARROLL
Honours, La Trobe University

ALBERTO CERESER
PhD Student, La Trobe University

DR BO CHEN
Research Fellow, University of Melbourne

HANNAH COUGHLIN
PhD Student, La Trobe University

EVAN CURWOOD
PhD Student, University of Melbourne

CHANDNI DOSHI
PhD Student, La Trobe University

CLARE HENDERSON
PhD Student, University of Melbourne

DR MICHAEL JONES
Research Fellow, La Trobe University

DR MARK JUNKER
Research Fellow, La Trobe University

HENRY KIRKWOOD
MSc Student, University of Melbourne

MAC BA LUU
MSc Student, La Trobe University

ASSOCIATE PROFESSOR ANDREI NIKULIN
Research Fellow, Monash University

DR ROBERT NORMAN

Research Fellow, La Trobe University

PROFESSOR KEITH NUGENT
CXs Director, University of Melbourne

DR DANIELE PELLICCIA
Research Fellow, Monash University

ISAAC PETERSON
Honours Student, University of Melbourne

ASSOCIATE PROFESSOR ANDREW PEELE
Program Leader, La Trobe University

THANH BAO PHAM
PhD Student, La Trobe University

NICK PHILIPS
PhD Student, La Trobe University

STEPHANIE PRADIER
PhD Student, La Trobe University

DR GRANT VAN RIESEN
Research Fellow, La Trobe University

REBECCA RYAN
MSc Student, University of Melbourne

DR CHANH TRAN
Research Fellow, La Trobe University

GIANG TRAN-NHAN
PhD Student, La Trobe University

ANGELA TORRANCE
PhD Student, University of Melbourne

SOPHIE WILLIAMS
PhD Student, University of Melbourne

LACHLAN WHITEHEAD
PhD Student, University of Melbourne



SHORT WAVELENGTH LASER SOURCE PROGRAM

EVELYN CANNON

PhD Student Swinburne University

DR JEFFREY DAVIS

Research Associate, Swinburne University

BA KHONG DINH

PhD Student, Swinburne University

ANTOINE DUROUIL

Research Fellow, Swinburne University

DR WILFRED FULLAGAR

Research Fellow, Monash University

NAYLYN GAFFNEY

PhD Student, Swinburne University

CHRISTOPHER HALL

Research Fellow, Swinburne University

PROFESSOR PETER HANNAFORD

CAOUS, Swinburne University

DR LIISA HIRVONEN

Research Fellow, University of Melbourne

VU HOANG LE

PhD Student, Swinburne University

LACHLAN MCKIMMIE

Research Assistant, University of Melbourne

BEN MORRISON

PhD Student, University of Melbourne

MICHAEL PULLEN

Research Fellow, Swinburne University

DARREN SMITH

PhD Student, Swinburne University

ASSOCIATE PROFESSOR TREVOR SMITH

Chemistry, University of Melbourne

PROFESSOR LAP VAN DAO

Program Leader, Swinburne University

STRUCTURE DETERMINATION METHODS PROGRAM

DR MATTEO ALTISSIMO

CSIRO, Clayton

DR CONNIE DARMANIN

CSIRO, Parkville

PROFESSOR CAL DRUMMOND

Membrane Chemistry, CSIRO, Parkville

DR TIM GUREYEV

CSIRO, Clayton

LYNN LIANG

PhD Student, La Trobe University

DR PETER LYNCH

CSIRO, Clayton

DR SHERRY MAYO

CSIRO, Clayton

DR DAMIAN E. MYERS

University of Melbourne

DR YAKOV NESTERETS

CSIRO, Clayton

DAVID PARRY

CSIRO, Clayton

DR ANDRE POGANY

CSIRO, Clayton

DR ANDREW STEVENSON

CSIRO, Clayton

DR VICTOR STRELTSOV

Group Leader – CSIRO, Clayton

DR JOSE VARGHESE

Group Leader, CSIRO, Parkville

DR JANELLE WILLIAMS

CSIRO, Parkville

THEORY AND MODELLING PROGRAM

DR BRENDAN ALLMAN

Programmer, University of Melbourne

NADIA DAVIDSON

Programmer, University of Melbourne

DR RUBEN DILANIAN

Research Fellow, University of Melbourne

DR DANSHA JIANG

Research Fellow, University of Melbourne

DR HARRY QUINEY

Program Leader, University of Melbourne

DANIEL WELLS

MSc Student, University of Melbourne





ORGANISATIONAL CHART AS OF JUNE 2011

ULTRACOLD PLASMA SOURCE PROGRAM

GABRIELLE FEJES

MSc Student, University of Melbourne

ANDREW MCCULLOCH

PhD Student, University of Melbourne

DENE MURPHY

PhD Student, University of Melbourne

DR COREY PUTKUNZ

Research Fellow, University of Melbourne

ASSOCIATE PROFESSOR ROB SCHOLTEN

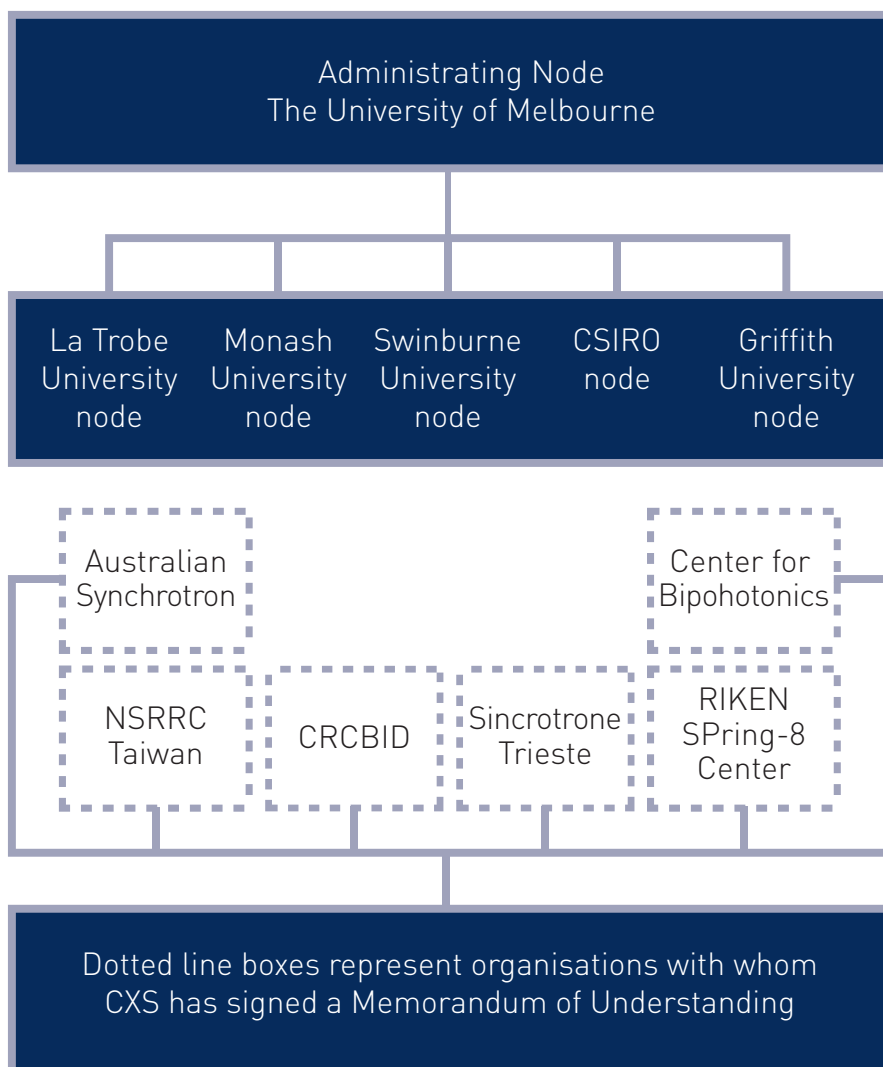
Program Leader, University of Melbourne

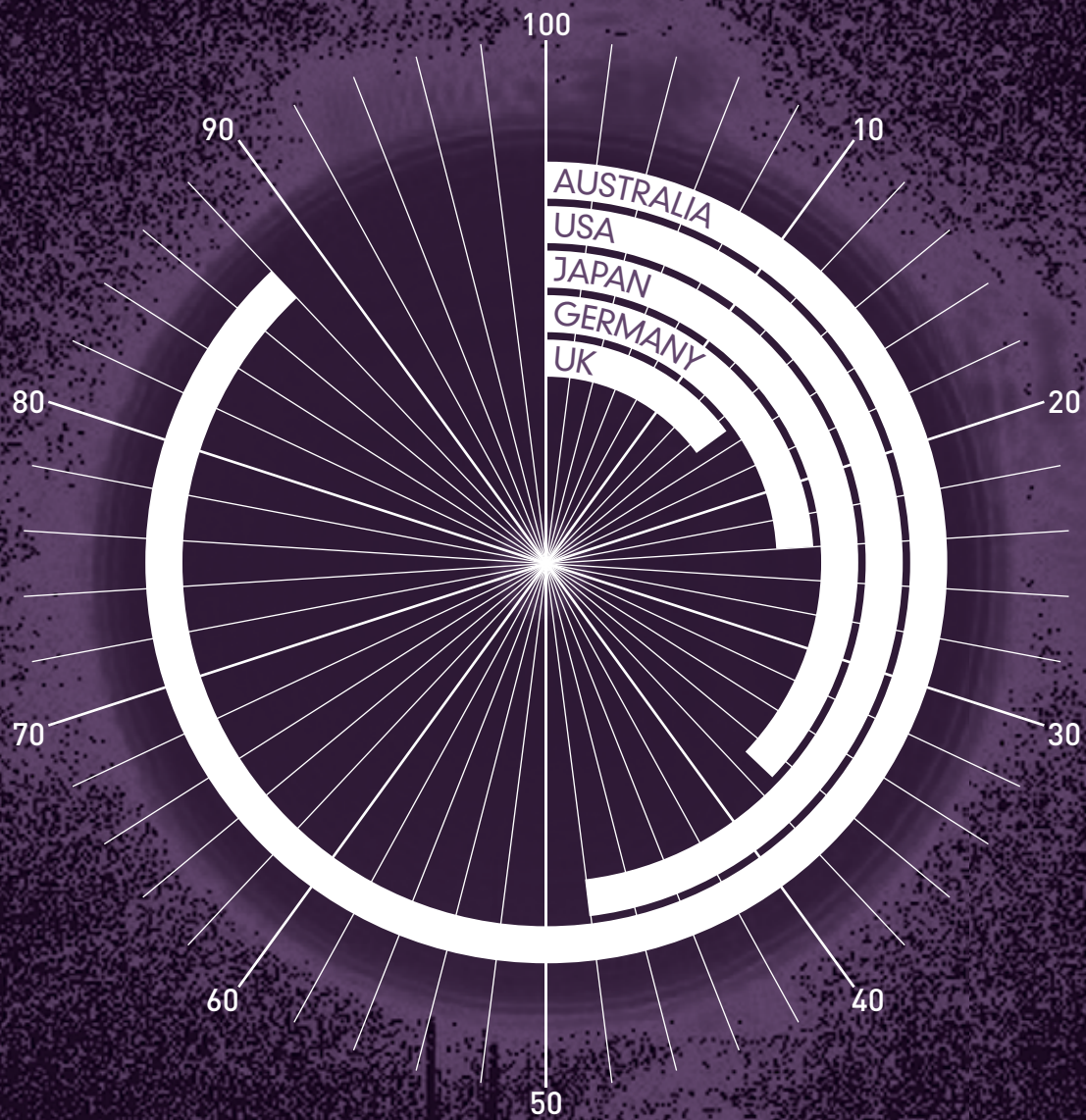
DR DAVID SHELUDKO

Research Fellow, University of Melbourne

JOSHUA TORRANCE

MSc Student, University of Melbourne





VISITORS TO CXS 2005 – 2011

During the period, CXS invited 272 eminent professors, researchers and professionals from around the world to carry out joint research work; give seminars and lectures; take part in collaborative discussions and workshops; and conduct short courses.





PRESENTATIONS, CONFERENCES & LABORATORY VISITS

DR BRIAN ABBEY

- Speaker – *Coherent diffractive imaging of biological and materials specimens*, CXS Scanning Transmission and Coherent Diffraction Microscopy Workshop, Melbourne, Australia, June 2011
- Speaker – *Opportunities and challenges for CDI at XFEL sources*, CXS Biophotonics Workshop, Melbourne, Australia, October 2011
- Speaker – CXS End of Year Meeting, Melbourne, Australia, November 2011

DR BENEADICTA ARHATARI

- Attended – Melbourne HPC GPU Computing workshop, Melbourne, Australia, June 2011
- Speaker – *PacRim 9, The 9th International Meeting of Pacific Rim Ceramic Societies*, Cairns, Australia, July 2011
- Poster Presentation – *4th International Workshop on FEL Science*, Cairns, Australia, August 2011
- Speaker – *X-ray micro-tomography for biological structures*, CXS 6th International Workshop – Facilitating Imaging and Biophotonics, Melbourne, Australia, October 2011
- Speaker – CXS End of Year Meeting, Melbourne, Australia, November 2011

DR EUGENE BALAUR

- Poster Presentation – *4th International Workshop on FEL Science*, Cairns, Australia, August 2011
- Speaker – CXS End of Year Meeting, Melbourne, Australia, November 2011

GUIDO CADENAZZI

- Speaker – CXS End of Year Meeting, Melbourne, Australia, November 2011

AIDAN CARROLL

- Attended – Melbourne HPC GPU Computing workshop, Melbourne, Australia, June 2011
- Attended – Synchrotron and Neutron New Users Symposium, Sydney, Australia, July 2011
- Poster Presentation – *4th International Workshop on FEL Science*, Cairns, Australia, August 2011

DR BO CHEN

- Poster Presentation – *4th International Workshop on FEL Science*, Cairns, Australia, August 2011
- Speaker – *Coherent diffraction imaging with partially coherent source*, CXS Biophotonics, Melbourne, Australia, October 2011
- Speaker – CXS End of Year Meeting, Melbourne, Australia, November 2011

EVAN CURWOOD

- Attended – *4th International Workshop on FEL Science*, Cairns, Australia, August 2011

NADIA DAVIDSON

- Attended – High Performance Computation Workshop, University of Melbourne, Australia, February 2011
- Speaker – CXS End of Year Meeting, Melbourne, Australia, November 2011

RUBEN DILANIAN

- Poster Presentation – *36th Lorne Protein Conference*, Victoria, Australia, February 2011
- Attended – CXS Scanning Transmission and Coherent Diffraction Microscopy Workshop, Melbourne, Australia, June 2011
- Invited talk – *4th Asia-Meeting*, Cairns, Queensland, Australia August 2011
- Speaker – *Challenges of protein nanocrystallography*, *4th International Workshop on FEL Science*, Cairns, Australia, August 2011
- Speaker – *Simulation study of the validity of the powder diffraction structure analysis using the XFEL sources*, *6th CXS International Workshop*, Melbourne, Australia, October 2011

CHANDNI DOSHI

- Attended – Melbourne HPC GPU Computing workshop, Melbourne, Australia, June 2011
- Poster Presentation – *4th International Workshop on FEL Science*, Cairns, Australia, August 2011

DR ERIC HANSEN

- Poster Presentation – *36th Lorne Protein Conference*, Victoria, Australia, February 2011

DR XIAOTAO HAO

- Speaker – *Time resolved fluorescence imaging of conjugated polymer thin films*, BioPhysChem 2011, Wollongong, New South Wales, Australia, December 2011



LIISA HIRVONEN

- Speaker – *Structured Illumination microscopy of living cells*, BioPhysChem 2011, Wollongong, New South Wales, Australia, December 2011

DR MICHAEL JONES

- Attended – Melbourne HPC GPU Computing workshop, Melbourne, Australia, June 2011
- Poster Presentation – 4th International Workshop on FEL Science, Cairns, Australia, August 2011
- Speaker – *Phase-diverse coherent diffractive imaging of P.falciparum infected red blood cells*, CXS 6th International Workshop – Facilitating Imaging and Biophotonics, Melbourne, Australia, October 2011
- Speaker – CXS End of Year Meeting, Melbourne, Australia, November 2011

DR MARK JUNKER

- Poster Presentation – 4th International Workshop on FEL Science, Cairns, Australia, August 2011

PROFESSOR DAVID KIELPINSKI

- Invited Speaker – *Attosecond Science in Australia*, the inaugural workshop of the Max Planck Centre for Attosecond Science in Asia, POSTECH, Pohang, Korea, July 2011
- Attended – International Conference on Quantum Electronics/Conference on Lasers and Electro-optics- Pacific Rim, Sydney, Australia, August 2011

- Panel Member – Kioloa workshop on Ultracold Atoms, New South Wales, Australia, November 2011

DANE LABAN

- Speaker – *Zeptosecond timing resolution from a high-order harmonic Gouy phase interferometer*, International Conference on Quantum Electronics/Conference on Lasers and Electro-optics- Pacific Rim, Sydney, Australia, August 2011

ALEX MAIER

- Presented – *Using an optical dipole trap in an ultracold plasma electron source*, KOALA, Melbourne, Australia, November 2011

ANDREW MCCULLOCH

- Poster – *Emission measurements of shaped electron bunches from a cold atom source*, International Conference on Quantum Electronics/Conference on Lasers and Electro-optics- Pacific Rim, Sydney, Australia, August 2011
- Presented – *Using an optical dipole trap in an ultracold plasma electron source*, KOALA, Melbourne, Australia, November 2011

LACHLAN MCKIMMIE

- Speaker – *Quantum measurement in living cells: fluorescent diamond nanocrystals for biology*, International Conference on Quantum Electronics/Conference on Lasers and Electro-optics- Pacific Rim, Sydney, Australia, August 2011

ASSOCIATE PROFESSOR ANDREI NIKULIN

- Poster Presentation – *Looking at nanoscale properties in macro-systems*

with X-ray diffraction imaging, XXII Congress and General Assembly, International Union of Crystallography, Madrid, Spain, August 2011

PROFESSOR KEITH NUGENT

- Invited Speaker – Centre for Free Electron Laser Source, University of Hamburg, Germany, 2011
- Attended – The official opening of the ARC Centre of Excellence for Particle Physics at the Terascale, University of Melbourne, Australia, 2011
- Attended – Centre of Excellence bid in Materials Conservation, University of Melbourne, Australia, 2011
- Attended – Workshop on Major Research Infrastructure, Sydney, Australia, February 2011
- Attended – National Imaging Facility Governing Board Meeting, Brisbane, Australian February 2011
- Keynote Speaker – Crystal 27 Conference, Rotorua, New Zealand, April 2011
- Attended – CXS Scanning Transmission and Coherent Diffraction Microscopy Workshop, Melbourne, Australia, June 2011
- Invited Speaker – 4th International Workshop on FEL Science, Cairns, Australia, August 2011
- Attended – Centre Directors Meeting, Canberra, Australia, September 2011
- Attended – MOU signing ceremony between ANSTO and Monash University, Melbourne, Australia, September 2011





- Panel Member – Victoria Prize and Fellowships Final Selection Meeting, Melbourne, Australia, September 2011
- Attended – Australian International Collaborative Research Workshop, Prato, Italy, November 2011
- Seminar Presentation – Cornell University, Ithaca, USA, November 2011
- Speaker – Australian Nanotechnology Network Early Career Symposium, Macquarie University, New South Wales, Australia, November 2011
- Attended – User and FI Engagement Meeting, Perth, Western Australia, November 2011
- Plenary Talk – KOALA Conference, Melbourne, Australia, November 2011

CATHERINE PALMER

- Speaker – Melbourne Protein Group Meeting, Australian, 2011

ASSOCIATE PROFESSOR ANDREW PEELE

- Speaker – *La Trobe University science at the Australian Synchrotron*, La Trobe-NUS Workshop on synchrotron and Nanoscale Science, National University of Singapore, Singapore, June 2011
- Attended – CXS Scanning Transmission and Coherent Diffraction Microscopy Workshop, Melbourne, Australia, June 2011
- Speaker – *Quantitative phase imaging with polychromatic sources*, XXII Congress and General Assembly, International Union of Crystallography, Madrid, Spain, August 2011

- Invited Speaker – 4th International Workshop on FEL Science, Cairns, Australia, August 2011

DR DANIELE PELLICCIA

- Poster Presentation – 4th International Workshop on FEL Science, Cairns, Australia, August 2011
- Poster Presentation – Looking at nanoscale properties in macro-systems with X-ray diffraction imaging, XXII Congress and General Assembly, International Union of Crystallography, Madrid, Spain, August 2011
- Speaker – *Coherence characterisation for hard X-ray diffraction imaging of embedded nanoparticles*, CXS 6th International Workshop – Facilitating Imaging and Biophotonics, Melbourne, Australia, October 2011
- Speaker – CXS End of Year Meeting, Melbourne, Australia, November 2011

ISAAC PETERSON

- Poster Presentation – 4th International Workshop on FEL Science, Cairns, Australia, August 2011

THANH BAO PHAM

- Attended – Melbourne HPC GPU Computing workshop, Melbourne, Australia, June 2011
- Poster Presentation – 4th International Workshop on FEL Science, Cairns, Australia, August 2011

MICHAEL PULLEN

- Speaker – *Carrier-envelope phase effects in few-cycle ionisation of atomic hydrogen*,

International Conference on Quantum Electronics/Conference on Lasers and Electro-optics- Pacific Rim, Sydney, Australia, August 2011

COREY PUTKUNZ

- Presented – *Using an optical dipole trap in an ultracold plasma electron source*, KOALA, Melbourne, Australia, November 2011
- Speaker – CXS End of Year Meeting, Melbourne, Australia, November 2011

ASSOCIATE PROFESSOR HARRY QUINEY

- Attended – BioFELS Workshop, Lawrence Berkeley National Laboratory, California USA, January 2011
- Invited Speaker at Colloquium, *Biomolecular imaging using XFEL sources: towards the molecular microscope*, School of Physics, University of Melbourne, Australia, February 2011
- Speaker – *Biomolecular imaging using Free-Electron lasers*, Seminar at European XFEL GmbH, Hamburg, Germany, February 2011
- Attended, Blasted Biological Molecules, Victorian Chapter of the Australian Academy of Science, Melbourne, Australia, June 2011
- Attended – CXS Scanning Transmission and Coherent Diffraction Microscopy Workshop, Melbourne, Australia, June 2011
- Attended – Establishing Research Networks Early Career Network Meeting, Melbourne, Australia, July 2011



- Speaker – *Electronic damage in biomolecular imaging using XFEL sources*, 4th International Workshop on FEL Science, Cairns, Australia, August 2011
- Presentation – SACLA XFEL Seminar, Partial coherence in diffractive imaging applications, Japan, September 2011
- Presentation – Japan Atomic Energy Commission, *Electronic damage in biomolecular imaging using XFEL sources*, Japan, September 2011
- Attended – Biophysical Imaging using XFEL Sources Seminar, 37th Annual Meeting, Himeji, Japan, September 2011

PROFESSOR MIKE RYAN

- Chair – Membrane Proteins Session, Lorne Protein Conference, Australia, February 2011
- Invited Speaker – 3rd Asia Pacific Protein Association Conference, Shanghai, China, May 2011
- Invited Speaker – 36th Federation of European Biochemical Society Congress, Biochemistry for tomorrow's medicine, Torino, Italy, June 2011
- Invited Speaker – Mitochondrial Dynamics: from mechanisms to disease Conference, Sardinia, September 2011
- Invited Speaker – Kolling Institute, Royal North Shore Institute, Sew South Wales, Australia, November 2011

REBECCA RYAN

- Poster Presentation – 4th International Workshop on FEL Science, Cairns, Australia, August 2011

- Poster Presentation – *Electronic damage in nanocrystals due to irradiation by an XFEL pulse*, CXS Biophotonics, Melbourne, Australia, October 2011

PROFESSOR ROBERT SANG

- Poster Presentation – *A zeptosecond phase interferometer*, XXVII International Conference on Photonic, electronic and Atomic Collisions, Belfast, Ireland, July 2011
- Poster Presentation – *Experimental intense few cycle light field physics research at Griffith University*, Short Wavelength Atomic and Molecular Processes, Dublin, Ireland, July 2011
- Attended – International Conference on Quantum Electronics/Conference on Lasers and Electro-optics- Pacific Rim, Sydney, Australia, August 2011

ASSOCIATE PROFESSOR ROB SCHOLTEN

- Invited Speaker – *super-resolution optical microscopy of cellular structures and thin films*, International Conference on Materials for Advanced Technology, Singapore, June 2011
- Speaker – *Arbitrarily-shaped high-coherence electron bunches from cold atoms*, American Physical Society Division of Atomic Molecular and Optical Physics, Atlanta, USA, June 2011
- Presented – *Using an optical dipole trap in an ultracold plasma electron source*, KOALA, Melbourne, Australia November 2011

DAVID SHELUDKO

- Presented – *Using an optical dipole trap in an ultracold plasma electron source*, KOALA, Melbourne, Australia, November 2011

ASSOCIATE PROFESSOR TREVOR SMITH

- Attended – 6th Asian Photochemistry Conference, Wellington, New Zealand, February 2011
- Speaker – *Organic photovoltaic materials at high spatial and temporal resolution*, BioPhysChem 2011, Wollongong, New South Wales, Australia December 2011

DR VICTOR STRELTSOV

- Attended – 36th Lorne Protein Conference, Victoria, Australia, February 2011
- Poster Presentation – 36th Lorne Protein Conference, Victoria, Australia, February 2011
- Speaker – *Structural studies of Amyloid- β oligomerisation and metal binding in Alzheimer's disease*, IUCrXXII Congress, Madrid, Spain, August 2011
- Speaker – *Structural characterization of Amyloid- β oligomerisation, metal binding and Pt-based inhibitors for Alzheimer's disease*, 4th Protein Misfolding and Neurological Disorders meeting, Heron Island, Australia, September 2011

DANIEL THOMPSON

- Attended – Victorian summer School in Ultracold Atomic Physics, Australia, Jan 2011





- Poster Presentation – *Narrow linewidth tunable external cavity diode laser using wider bandwidth filter*, International Conference on Quantum Electronics/ Conference on Lasers and Electro-optics- Pacific Rim, Sydney, Australia, August 2011

PROFESSOR LEANN TILLEY

- Speaker – *Biology with X-ray Lasers: Toward the molecular movie*. Lawrence Berkeley National Laboratory, CA, USA, January 2011
- Speaker – Menzies Research Institute Tasmania, University of Tasmania, Australia, February 2011
- Speaker – EMBL Hamburg, DESY, Germany, May 2011
- Speaker – Bernhard Nocht Institute for Tropical Medicine, Hamburg, Germany, May 2011
- Chair – Malaria Cell Biology Colloquium, Australian Society for Parasitology Annual Meeting, Cairns, Australia, July 2011
- Attended – CLEO Pacific Rim Conference, Super Resolution Symposium, Sydney, Australia, August 2011
- Keynote Speaker – Victorian AgriBiosciences Centre, Department of Primary Industries, Melbourne, Australia, August 2011
- Speaker – *High resolution imaging of malaria parasite-infected erythrocytes*, Organelles Symposium, ComBio2011, Cairns, Australia, September 2011

- Keynote Speaker – James Cook University, Cairns, Australia, September 2011
- Attended – Imaging in Cell Biology Workshop, Sansom Institute for Health Research, Adelaide, Australia, September 2011
- Attended – Victorian Infection and Immunity Network Symposium, Bio21 Institute, Australia, September 2011
- Attended – Queensland Institute for Medical Research, Brisbane, Australia, September 2011
- Attended – Research Domain Technology Forum, Melbourne Brain Centre, Melbourne Australia, November 2011
- Attended – School of Chemistry, University of Melbourne, Australia, November 2011
- Attended – Victorian Platform Technologies network Workshop, Melbourne Centre for nanofabrication, Melbourne, Australia, December 2011

ANGELA TORRANCE

- Invited Speaker – 4th International Workshop on FEL Science, Cairns, Australia, August 2011
- Speaker – CXS End of Year Meeting, Melbourne, Australia, November 2011

PROFESSOR LAP VAN DAO

- Invited Speaker – Institute of Mechanic and Information Technology, Ho Chi Minh City, Vietnam, September 2011

DR GRANT VAN RIESSEN

- Speaker – *Coherent X-ray Diffraction*, La Trobe-NUS Workshop on synchrotron and Nanoscale Science, National University of Singapore, Singapore, June 2011
- Speaker – *the Soft X-ray branchline for X-ray microscopy at the Australian Synchrotron*, CXS Scanning Transmission and Coherent Diffraction Microscopy Workshop, Melbourne, Australia, June 2011
- Invited Speaker – 4th International Workshop on FEL Science, Cairns, Australia, August 2011

WILLIAM WALLACE

- Poster Presentation – *Above-threshold ionization in atomic hydrogen using intense, few-cycle laser pulses*, XXVII International Conference on Photonic, electronic and Atomic Collisions, Belfast, Ireland, July 2011
- Poster Presentation – *Carrier-envelope phase effects in ionisation of atomic hydrogen using few-cycle laser pulses*, Intense field, Short Wavelength Atomic and Molecular Processes, Dublin, Ireland, July 2011
- Poster Presentation – *Above-threshold ionization in atomic hydrogen using intense few-cycle laser pulses*, International Conference on Quantum Electronics/ Conference on Lasers and Electro-optics- Pacific Rim, Sydney, Australia, August 2011

AWARDS & HONOURS

A HIGHLY COMMENDED CERTIFICATE FOR TEACHING EXCELLENCE IN AUSTRALIA

In 2011 Dr Eroia Barone-Nugent was awarded a certificate of high commendation from the Minister for Science and Innovation, the Honourable Kim Carr. This recognition was issued by the Prime Minister's Office for contributions to science in Australia. Eroia was recognised for her contribution to science education through the *Growing Tall Poppies* program at Santa Maria College and the wider education community. The program focuses on how the physical sciences are a means of making important contributions to humanity, and increasing the numbers of girls studying Physics to Year 12 at Santa Maria College. Eroia has delivered the authentic science program to hundreds of students across schools from all three education sectors.

CXS recognised a number of its members for their work in 2011. We extend our congratulations to each of them for their efforts and awards in the following honours:

- Eroia Barone-Nugent was awarded a Highly Commended Certificate for contributions to science education in Australia from the Prime Minister's Office for Science, Industry and Innovation.
- Leann Tilley received the 2011 Beckman Coulter Discovery Science Award from the Australian Society for Biochemistry and Molecular Biology, for distinguished contributions to the field

of biochemistry and molecular biology, having demonstrated involvement in research innovation technology transfer and communication.

- Harry Quiney was awarded the 2010 David Syme Research Prize.
- Megan Dearnley was awarded the CXS top-up scholarship, Caswell Grave Scholarship, Network researcher Exchange Training and Travel Scholarship, Anders Travel Award and the Bruce Stone Travel Award.
- Alex Maier was nominated as a finalist for the 2011 Eureka People's Choice Award. He also won the LaTrobe University DVC Excellence in Research Award for Mid-Career Researchers and the Khwarizmi Award.
- Diana Stojanovski received the LaTrobe University Deans Award 2011.
- Catherine Palmer was awarded the Student Poster Prize at the Lorne Protein Conference 2011 and the LIMS Miller Travel Scholarship 2011.
- Aidan Carroll was awarded an APA PhD Scholarship at La Trobe University 2011.
- Ved Mooga received the LIMS Miller travel grant to attend the Mitochondrial Dynamics and function conference in Canada in 2011.



Ceremony at Parliament House Canberra: Eroia Barone-Nugent awarded with Highly Commended Certificate for contributions to science education in Australia. Left Prof Jeremy Mould, Mrs Mould, Dr Eroia Barone-Nugent.

MAJOR AWARDS & HONOURS 2005 – 2011

The following major awards & honours have been received by CXS members

- Roche Molecular Biochemicals Medal 2006 **Michael Ryan**
- Australia Research Council Federation Fellowship 2007 **Keith Nugent**
- DAAD Fellowship 2007 **Claudia Leidhold**
- Deutscher Akademischer Dienst German Academic Exchange Fellowship 2007 **Michael Baker**
- Rio Tinto OTX Prize 2007 **Corey Putkunz**
- Inaugural Graeme Clarke Research Outcomes Forum Address 2008 **Keith Nugent**
- Knowledge Transfer Award 2009 **Keith Nugent**
- National Australia Bank School's First State Award 2009 **CXS & Santa Maria College**
- Under the Coverslip Scientific Photography Competition 2009 **Clare Henderson**
- Alan Walsh Medal 2010 **Robert Scholten**
- Alex von Humboldt Research Fellowship 2010 **Michael Baker**
- Bancroft-Mackerras Medal 2010 **Leann Tilley**
- CSIRO Payne Scott Award 2010 **Connie Darmanin**
- David Syme Research Prize 2010 **Harry Quiney**
- Eureka Prize – Sleek Geeks 2010 **CXS & St Helena College**
- Tall Poppies Award 2010 **Marc Kvangsakaul**
- Anders Travel Award 2011 **Megan Dearnley**
- Beckman Coulter Discovery Science Award 2011 **Leann Tilley**
- Bruce Stone Travel Award 2011 **Megan Dearnley**
- Caswell Grave Scholarship 2011 **Megan Dearnley**
- CXS Top-Up Scholarship 2011 **Megan Dearnley**
- CXS Travel Scholarship 2011 **Andrew McCulloch**
- David Syme Research Prize 2011 (announced Jan 2012) **Robert Scholten**
- Khwarizmi Award 2011 **Alex Maier**
- La Trobe University Dean's Award 2011 **Diana Stojanovski**
- LTU DVCR Excellence in Research Award for Mid Career Researcher 2011 **Alex Maier**
- Network Researcher Exchange Training and Travel Scholarship 2011 **Megan Dearnley**
- Prime Minister's Office for Science, Industry & innovation Highly Commended Certificate 2011 **Eroia Barone-Nugent**

SCHOLARSHIPS & STUDENTSHIPS

CXS would like to congratulate the following students for their successful applications in 2011:

- Ryan Williams, a third year biochemistry student, received a CXS Vacation Scholarship in the AGM Lab with the Biological Sciences Program at La Trobe University.
- Naylan Gaffney was awarded a PhD scholarship with the Short Wavelength Laser Source Program at Swinburne University of Technology.
- Hoang Vu Le, was awarded a CXS Vacation Scholarship with the Short Wavelength Laser Source Program at Swinburne University of Technology.
- Victor Streltsov received a Japanese Society for Promotion of Science (JSPS) Fellowship under the JSPS Invitation Fellowships Program for Research in Japan.
- Luke Formosa received a CXS Vacation Scholarship with the Biological Science Program at La Trobe University.
- Abeer Singh received a studentship with the Ryan Lab for the Biological Science Program at La Trobe University.



RESEARCH TRAINING & PROFESSIONAL EDUCATION

The Centre met all of its recruitment and professional education targets for 2011, and has exceeded expectations in the areas of *Postgraduate Recruitment* and *Presentations to Schools and/or Teaching Communities*.

CXS SPONSORED EVENTS

CXS sponsored the following events in 2011:

- Lorne Conference on Protein Structure and Function, Lorne Australian, February 2011
- The 4th Annual Conference on Optics, Atoms and Laser Applications – ION – KOALA 2010, Melbourne, Australia 2011
- The 4th International Conference on FEL Science, Cairns, Australia 2011
- Visit of Nobel Prize winner Professor Martin Chalfie, Melbourne, Australia 2011



WORKSHOPS

CXS conducted the following interdisciplinary workshops in 2011:

- Talking Backwards 2011, Melbourne, Australia, May 2011
- Scanning Transmission and Coherent Diffraction Microscopy Workshop, Melbourne, Australia, June 2011
- Organisers and Co-sponsor of the 4th International Conference on FEL Science, Cairns, Australia, August 2011
- CXS Annual Workshop 2011, Melbourne, Australia, October 2011
- CXS Roundtable Discussion Day, Melbourne, Australia, October 2011
- Biophotonics Workshop, Bio21, Melbourne, Australia, October 2011
- Fortnightly Workshop of the Experimental Methods and Theory and Modelling Programs, Melbourne, Australia, throughout 2011



CXS' PEER REVIEWED PAPER
 IMPACT FACTORS PER ANNUM
 2005 – 2011

VISITORS TO CXS

1. PETER CARLTON, Japan
2. MARTIN CHALFIE, United States of America
3. JIANHUI CHEN, China
4. JOE CHEN, United Kingdom
5. ROD CLAPP, Australia
6. PAUL CURMI, Australia
7. CYRIL CURTAIN, Australia
8. CANDIDA DA FONSECA PEREIRA, Australia
9. MARTIN DE JONGE, Australia
10. ASHWANTHA KUMAR ENJAPOOR, Australia
11. PETER FRANKLIN, United States of America
12. YOSHIRO FUJIWARA, Japan
13. RICHARD GARRETT, Australia
14. KATHARINA GAUS, Australia
15. RAFAEL GOLDSHMIT, Australia
16. SHUNJI GOTO, Japan
17. ROSEMARY HARTY, Australia
18. ROBERT HATCH, Australia
19. TAKAI HATSUI, Japan
20. IRENE HATZINISIRIOU, Australia
21. STEPHEN HLADKY, United Kingdom
22. YEN-CHIEH HUANG, Taiwan
23. TETSUYA ISHIKAWA, Japan
24. JUNG HO JE, Korea
25. YASUMASA JOTI, Japan
26. MING KALANON, Australia
27. HIDEO KITAMURA, Japan
28. PETER KNER, United States of America
29. YOSHIKI KOHMURA, Japan
30. GEOFFREY KONG, Australia
31. LUKASZ KOWALCZYK, Australia
32. NAOKI KUNISHIMA, Japan
33. STEVEN LANE, United States of America
34. CAROLYN LARABELL, United States of America
35. WAI-KEUNG LAEU, Taiwan
36. TATIANA LATYCHEVSKAIA, Switzerland
37. GREG LA BLANC, Australia
38. YIN-YU LEE, Taiwan
39. MARK LE GROS, United States of America
40. JOSH LILLY, Australia
41. CHRISTIAN LOEBBE, Australia
42. CONNY LUDWIG, Australia
43. JOM LUITEN, Netherlands
44. YASUKO MATSUMOTO, Japan
45. JABEZ MCCLELLAND, United States of America
46. SIMONE MEUTER, Australia
47. RICK MILLANE, New Zealand
48. VENGAMANAI DU MODEPALLI, Australia
49. DAMIEN MYERS, Australia
50. YOSHINORI NISHINO, Japan
51. DO YOUNG NOH, Korea
52. SATOMI OTSUKA, Japan
53. ABBAS OURMADZ, United States of America
54. SERGUEI PATCHKOVSKII, Canada
55. ADI PATERSON, Australia
56. SARAH RUSSELL, Australia
57. TAKAHIRO SATO, Japan
58. MARKUS SAUER, Germany
59. KEI SAWADA, Japan
60. CATHER SIMPSON, New Zealand
61. GERALD SMITH, New Zealand
62. CHRISTIAN SOELLER, New Zealand
63. CHANGYONG SONG, Japan
64. JOHN SPENCE, United States of America
65. ERIK STREED, Australia
66. YUKO SUGANO, Japan
67. GAVIN SYMONDS, Australia
68. YUKIO TADAHASHI, Japan
69. RENZHONG TAI, China
70. YUKIO TAKAHASHI, Japan
71. HIROMITSU TOMIZAWA, Japan
72. KENSUKE TONO, Japan
73. LYNNE TURNBULL, Australia
74. HIDEKO UTAKA, Japan
75. EDGAR VREDENBREGT, Netherlands
76. BONNIE WALLACE, United Kingdom
77. PAUL WARDILL, Australia
78. GEOFF WATERHOUSE, New Zealand
79. GARTH WILLIAMS, United States of America
80. MAKINA YABASHI, Japan
81. KAZUTO YAMAUCHI, Japan
82. JUN YE, United States of America
83. KOJI YONEKURA, Japan
84. HANIS YUSOFF, Malaysia
85. DAVID ZHU, Australia

COLLABORATIONS

A number of ongoing collaborations continue to develop with the following groups:

- **Victorian Leaders in Electron Microscopy, Australia**
Leann Tilley organised a series of meetings of Victorian leaders in electron microscopy to discuss strategies for the NRIC round. A series of documents describing the capabilities of Victoria's major light and EM imaging facilities and visions for the future of imaging in Australia was produced.
- **Carola Hunte, Germany**
Mike Ryan met with Carola Hunte in Freiburg Germany and discussed the possibility of performing some membrane protein structure determination in his OPS visit in 2012.
- **Cochlear Ltd, Australia**
Benedicta Arhatari collaborated on the tomography imaging of three sample of ceramic and defects evaluation.
- **DSTO, Germany**
Benedicta Arhatari collaborated on tomography imaging of two samples of carbon composites, CSiC, for high temperature material, with and without ZrB2 coating.
- **Oxford Engineering Science, England**
The Experimental Methods Program worked with Professor Korsunsky, Diamond Light Source, and Dr Kawal Sawheny, head of the Optics and Metrology group.
- **London Centre for Nanotechnology, England**
The Experimental Methods Program worked with Professor Ian Robinson's group at the London Centre for Nanotechnology in preparation for their upcoming LCLS experiments.
- **University of Arizona, USA**
The Attosecond Science Program initiated a modelling of filamentation results collaboration with Professor Miroslav Kolesik.
- **Queensland University of Technology, Australia**
The Attosecond Sciences Program worked with Maksym Rybachuk on experimental micro-structuring of surfaces with few-cycle laser pulses.
- **Voronezh State University, Russia**
The Attosecond Sciences Program is working with Mikhail Frolov on modelling of strong-field ionisation by analytic theories.
- **Tsukuba University, Japan**
The Attosecond Science Program is working with Xiao-Min Tong on new simulations of the atomic hydrogen experiments.
- **University of Bordeaux, France**
The Attosecond Science Program is working with Fabrice Catoire to simulate the HHG experiment.
- **National Research Council, Canada**
Dave Kielpinski worked with Dr Serguei Patchkovskii of the National Research Council of Canada.
- **ELETTRA, Italy**
The Experimental Methods Program is continuing with coherence characterisation measurements with Alessandra Gianoncelli, and further beamtime provided in 2012.
- **SLS, Germany**
Mark Junker visited SLS to discuss prospect of further industrial collaborations.
- **European XFEL Hamburg, Germany**
Harry Quiney visited the Centre for Free-Electron Laser Science to discuss damage mechanisms in XFEL imaging of biomolecules





CELLULAR NANO-IMAGING CONSORTIUM

The Cellular Nano-Imaging Consortium (CNIC) is an affiliation of scientists with interests in Super-Resolution Optical Microscopy managed under the auspice of CXS. Its inception is the direct result of a joint initiative undertaken by CXS Direct Professor Keith Nugent, Deputy Director Leann Tilley and CXS member Associate Professor Trevor Smith, School of Chemistry, University of Melbourne, to bring together institutions and research leaders with cross-disciplinary expertise and an interest in using and/or developing nano-imaging optical methods.

CNIC provides online access to information about conventional and super-resolution optical imaging techniques, as well as what resources are currently (and potentially) available to interested parties. Through CNIC, workshops and conference sessions will be organised to inform Australian scientists about new high-resolution imaging modalities. CNIC aims to co-ordinate efforts to generate a super-resolution imaging capability in Victoria, providing information and access to the new techniques.

CNIC is working to ensure that all Victorian scientists have access to the Super-Resolution Microscopy format they need to be competitive as international research leaders.

The CNIC website can be visited at www.coecxs.org/cnic



SCIENTIFIC LINKAGES

CXS is pleased to announce the signing of a Memorandum of Understanding with:



Australian Synchrotron



National Synchrotron Radiation Research Center of Taiwan



ELETTRA



CRC for Biomedical Imaging Development



The Centre for Biophotonics Science and Technology



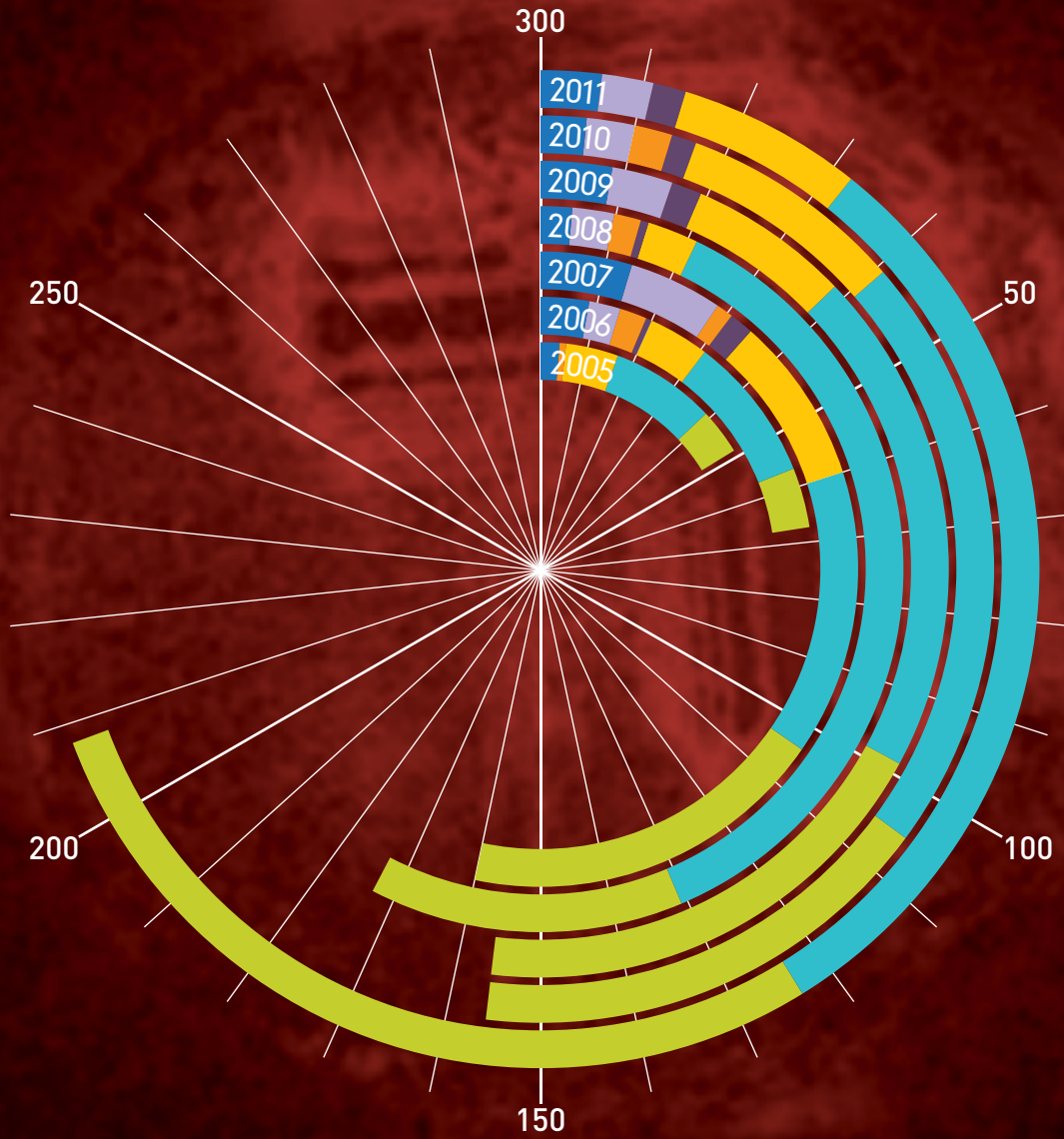
COMMERCIALISATION

The Ultra-Cold Plasma Source Program developed the MOGLab's range of external cavity diode laser (ECDL) controllers.



Each MOG unit provides everything needed to run an ECDL and lock it to an atomic transition. Marketing material has been produced and a targeting marketing strategy was developed in 2008. All revenue derived from this activity will be the property of The University of Melbourne and one student inventor. There were been 50 sales in 2008 and there is no license agreements to date.

CXS and Melbourne Ventures have produced a DVD on the commercialisation of IP.



- Community Presentations
- CXS Workshops
- Public Lectures
- CXS Newsletters
- Overseas Visits by CXS Members
- Conference Presentations
- Visitors to CXS

OUTREACH 2005 – 2011

CXS has exceeded all of its performance indicators in the area of outreach. The centre's focus on liaising with related research institutions to formulate collaborative arrangements and information sharing has been highly successful, and our community outreach and secondary school interactions via the Growing Tall Poppies program has achieved a quantifiable impact with Santa Maria College student numbers into physics increasing by 75% over the last 3 years.



OUTREACH

As part of the CXS Outreach Program, a number of key initiatives took place in 2011:

- Theory and Modelling Program hosted the Growing Tall Poppies program on X-ray Sudoku, June 2011.
- CXS took part in the Growing Tall Poppies Alumnae Meeting at Santa Maria College, Northcote in September 2011 .
- Leann Tilley and Robin Anders interviewed for Millions Against Malaria Foundation documentary about Ken Evers's and Tim Pryse's journey around the world in a GA8-TC Airvan to raise money for the fight against malaria.
- Synergy, Bulletin of the La Trobe University Faculty of Science Technology and Engineering, Women in Science, *Women are leading the way in research at La Trobe University*, Summer 2011 edition.
- Leann Tilley attended the Women in Science and Engineering Summit held on Monday 11 April at Parliament House in Canberra. The Summit brought together leaders, advocates, and high-achieving young women in science and engineering. Real commitments were made by the leaders of funding bodies, research institution and universities. The ARC and the NHMRC agreed to change how they assess research publications in the grant applications of those with interrupted careers. CSIRO and WEHI committed to increasing the number of awards designed to bring women back to the workforce after maternity leave. ATN Universities have set a performance target for the number of female staff who teach science, engineering and technology subjects. Other institutions committed to fully covering the costs of maternity leave for staff paid on research grants to avoid disincentives to employing women on grant funds.
- Mike Ryan made presentations on research in the Department of Biochemistry including CXS activities, as part of an Austrade Expo in India.
- Alex Maier visited Coburg primary school to talk about different scales and they compared fruit flies to house flies.
- The Melbourne Protein Group Committee established the annual Tilley Prize for a promising young Protein Scientist.
- Brian Abbey gave the highlight lecture, *Neutron Strain Tomography using Bragg-edge Transmission* in France, September 2011.
- The Experimental Methods Program held an outreach program for year 10 students from Parade College, "Sowing the seeds of science", in which students performed tomography imaging of rat middle ear images and analysed results.
- David Kielpinski attended AIP Physics Lectures at the Anglican Church Grammar School and met with the high school students, May 2011.
- The Attosecond Science Program staff and students assisted in showing visitors the laboratories at Griffith University during Griffith University Open Day, August 2011.
- Trevor Smith held a colloquium at the University of Queensland entitled, *Microscopy with high spatial and temporal resolution*, November 2011.
- Leann Tilley took part in the Research mentor Program at the University of Melbourne, November 2011.
- Leann Tilley took part in the Bio21 Careers Forum at the University of Melbourne, November 2011



THE GROWING TALL POPPIES IN SCIENCE PROGRAM WITH SANTA MARIA COLLEGE NORTHCOTE

Growing Tall Poppies has the aim of encouraging girls to continue with the study of physics. It does this by allowing the students to work with scientists and allow them to get to know the scientists and understand the relevance of their work to society.

In order to simplify the logistics of the program, in 2011 we chose to concentrate the program into the schools' work experience week. This decision has afforded us the opportunity to organise the GTP student groups well in advance. By building the program into the week set aside for students to be out of school and experiencing career directions, it also provides the mechanism to increase the scale the program as many students can be out of school without the complications of missing other subject classes.

In 2011, the Growing Tall Poppies Program expanded to host eight student groups throughout the year. A total of fifty-five Year 10 and 11 students worked with scientists in the CXS teams. As the program has now been running for three full years, a gathering of all the students who have participated was organised to celebrate the progress that has been made. The inaugural GTP Celebration Luncheon was held at Santa Maria College and was an opportunity for students, teachers and scientists to meet and celebrate the advances that have been made to date.

OUTCOMES

GTP has been in place now for three complete years, which is sufficient time to accurately assess its effectiveness as an outreach program. CXS is delighted to report that GTP appears to have had a remarkable impact on the retention rate of students from Year 11 into Year 12 Physics. Figure 2 shows the retention rates from 2003-2012. Rigorous statistical analysis has confirmed that the trend indicated by the lines in figure XX is highly significant.

The encouraging statistics recorded at Santa Maria College showing a greater uptake and retention to Year 12 Physics demonstrates the importance of having a strong relationship with a focus school to allow outcomes to be monitored and measured. This provides a clear metric of success and feedback to allow further development of the program for even greater effectiveness at increasing numbers in the physical sciences.





Year 10 Growing Tall Poppies Program at the Australian Synchrotron Mary Le.

GROWING TALL POPPIES IN PHYSICS @ YEAR 11

During 2011 we have further advanced the *Growing Tall Poppies* program to become fully integrated into the V.C.E. syllabus in Year 11 Physics. The students' learning has been rich and they have received a wonderful background to the uses of, and careers in physics through working with CXS scientists and with the Australian Synchrotron. The Santa Maria physics students spent a day at the Structural Determination Methods Program at CSIRO to work with mentor scientist Connie Darmanin, who guided the students in relation to the techniques for crystallising protein. The students were able to experiment with various techniques, use cutting edge equipment to make their own protein crystals, which they later analysed at the Australian Synchrotron in Clayton.

Students worked with Dr Tom Caradoc-Davies at the synchrotron to take X-ray diffraction data of the crystals and partially analysed the patterns to learn how the protein structure is derived. They performed experiments using the MX1 beamline, and learned about the physics of the synchrotron which relates directly to their VCE outcomes. Students reported a heightened engagement with their studies and found the aspect of how the synchrotron is relevant to curing disease very interesting.

Under the mentorship of Harry Quinley, Year 10 science students in the Theory and Modelling Program explored the computer analysis of diffraction data. The project

elaborated the similarities of diffraction data analysis with solving Sudoku puzzles and created a colourful and stimulating environment for students. Students constructed Sudoku board games and glimpsed the nature of the mathematical work at CXS. The students not only developed the board game but connected a mathematical 'iterative process' to calculating the shape of biologically significant molecules.



Year 10 Growing Tall Poppies Program class of 2011.



Year 10 Students undertaking Climate Change research with Dr Ian Smith (CSIRO Climate Scientist) with Nadine Khalil, Lidia Cavalieri.

GROWING TALL POPPIES IN SCIENCE @ YEAR 10

2011 saw the completion of three full years of the *Growing Tall Poppies* program. Nineteen Year 10 students participated in four programs during work experience week with a further three groups (a total of twenty additional students) throughout the year.

The Climate Change group in the School of Earth Sciences at the University of Melbourne also became involved and hosted a year 10 group. Here the students collected data about Australian climate during the period of settlement since the 1800s. The students used real data from the web-based Climate Change Research Program called SEARCH. The GTP students organised and analysed the data, and in so doing contributed to the understanding of how weather and climate has changed since colonisation. The unusual part of this scientific work is that scientists work with historians to extract the data from documents and then analyse it to make sense of how climate has changed over the period of settlement in Australia. One group of students found the data analysis so interesting that they voluntarily went on to explore how the SEARCH program could be incorporated into a classroom setting to more students the opportunity to work with real data and gain greater understanding of climate change. The resulting curriculum material will be used at Santa Maria College in 2012.

A further group of students worked with filmmakers and Tania Smith to create a film that communicates how science is

being investigated through the *Growing Tall Poppies* program students. The project enabled the inclusion of media students in GTP, broadening its impact. Promoting science communication and literacy is an important goal for the GTP program; communication is a central part of what scientists do.

The *Growing Tall Poppies* program Alumni Luncheon was a wonderful celebration for all students who have participated in the *Growing Tall Poppies* program over the past three years. Over sixty students attended from years 10-12, as well as scientists from CXS and science teachers from Santa Maria College. Celebrations such as these allow strong connections and collegial networks to be maintained for our students after they have left the school.

The principal, Ms Deborah Barker and CXS Director, Prof. Keith Nugent welcomed the sixty-strong group of Santa Maria College students and encouraged them to visualise their potential and to retain the support structure formed through the *Growing Tall Poppies* program. CXS are thrilled to have the GTP alumni join its unique community.





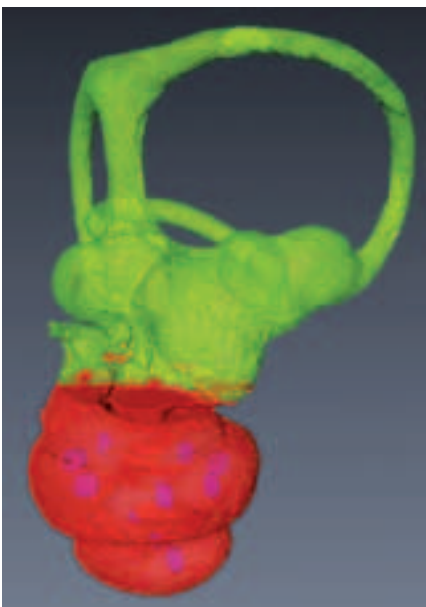
The Growing Tall Poppies program Alumni Luncheon.

GROWING TALL POPPIES CASE STUDY

A Growing Tall Poppies project, including seven students from Santa Maria College was carried out with the Experimental Methods Program at La Trobe University. “Deaf-initely” a challenge – the project was an experimental study of 3D tomographic imaging of the cochlea. This project allowed participating students to work with scientists to contribute to solutions to some of the issues facing our world.

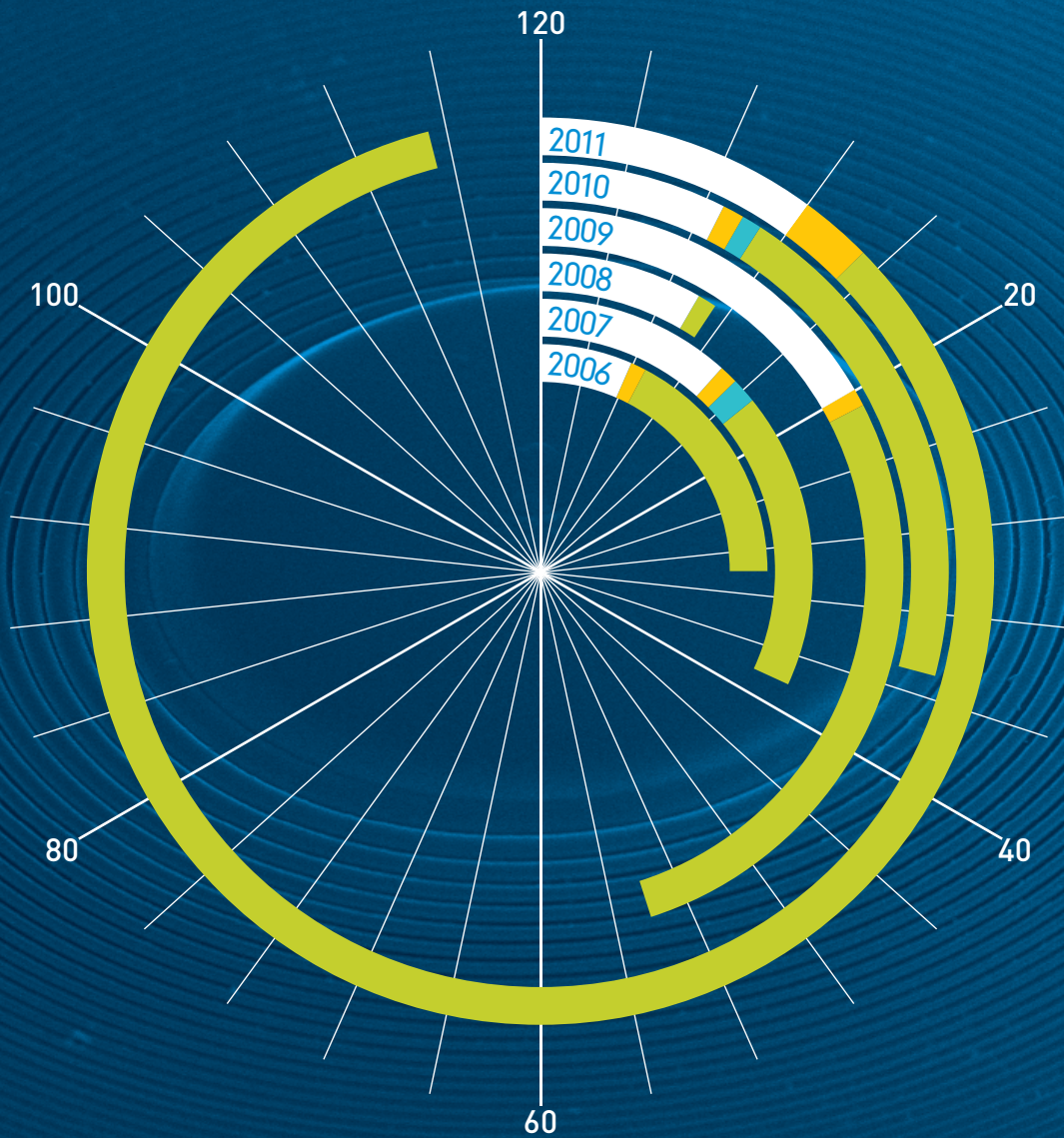
Firstly, students took tomography data of a rat inner ear sample, and then segmented part of the inner ear by choosing colour for different parts. Finally, they virtually implanted the electrode inside the cochlea.

You will see the electrode as array of purple rings inside the cochlea in figure x.



Left: Fig x.

Right: Santa Maria College Students and their CXS Scientific Mentors.



- Print Media
- Radio
- Podcasts
- Internet

MEDIA 2005 – 2011

There have been a minimum of 291 recorded media commentaries on CXS from 2005 to September 2011, with online media dominating, as per the worldwide trend. The documented spike in this statistic during 2011 is the combined result of various CXS members performing dual and linked roles with organisations outside of CXS and the more comprehensive use of our media monitoring facility.

The top 10 countries in which CXS related media have been published between 2005-2011 are:

1. Australia
2. United States of America
3. United Kingdom
4. India
5. Canada
6. Germany
7. Singapore
8. South Africa
9. Bulgaria
10. Japan



MEDIA COMMENTARIES

NEWSPAPER ARTICLES, MAGAZINE ARTICLES AND ELECTRONIC MEDIA

- **Drug Discovery and Development Magazine**, *Cold electrons aid design of drugs*, 8 Feb 2011 <http://www.dddmag.com/news/2011/08/cold-electrons-aid-design-drugs>
- **The Australian**, *Australian Synchrotron appoints new Director*, 28 Feb 2011 <http://www.theaustralian.com.au/higher-education/australias-synchrotron-appoints-new-director/story-e6frqjx-1226013719836>
- **BioTechnology News**, *Synchrotron keeps on syncing*, 1 Mar 2011 <http://www.industry-news.net/>
- **Melodika.net**, *Xradia strengthens global sales and support for 3D X-ray microscopy solutions*, 22 May 2011 http://www.melodika.net/index.php?option=com_content&task=view&id=165485&Itemid=50
- **The Age**, *Baillieu urged to save hub of science*, 22 May 2011 <http://www.theage.com.au/victoria/baillieu-urged-to-save-hub-of-science-20110521-1exzm.html>
- **Yahoo!7 News**, *Synchrotron future in doubt over lack of funds*, 23 May 2011
- **Innovation Reports**, *New malaria protein structure upends theory of how cells grow and move*, 31 May 2011 http://www.innovations-report.de/html/berichte/biowissenschaften_chemie/malaria_protein_structure_upends_theory_cells_grow_176139.html
- **Science in Public**, *Fukushima, supermassive black holes and our chance to guide the future of physics – physics in June*, 31 May 2011
- **Medical News Today**, *Potential drug target for future malaria and anti-cancer treatments*, 31 May 2011 <http://www.medicalnewstoday.com/releases/226930.php>
- **The Medical News**, *Scientists study key malaria protein structure to demonstrate how cells grow and move*, 31 May 2011 <http://www.news-medical.net/news/20110531/Scientists-study-key-malaria-protein-structure-to-demonstrate-how-cells-grow-and-move.aspx>
- **The Australian**, *Victoria must fund synchrotron*, 31 May 2011 <http://www.theaustralian.com.au/national-affairs/victoria-must-fund-synchrotron-canberra/story-fn59niix-1226065980876>
- **HPC Wire**, *Australia's MASSIVE supercomputer is open for general use*, 31 May 2011 <http://www.hpcwire.com/hpcwire/2011-05-30/australias-massive-supercomputer-is-open-for-general-use.html>
- **Science AAAS News**, *Australian government silent on synchrotron budget while scientists plan expansion*, 11 May 2011
- **Renewable Energy World.com**, *New tools let chemistry solve the energy crisis*, 16 May 2011 <http://www.renewableenergyworld.com/rea/blog/post/2011/05/new-tools-let-chemistry-solve-the-energy-crisis>
- **UniSA News**, *Substance over style: what hair can tell us*, 17 May 2011 <http://www.unisa.edu.au/unisanews/2011/May/story4.asp>
- **Presse Box**, *Femtopower™ x PRO CEP*, 18 May 2011 <http://www.pressebox.de/inaktiv/femtolasers-produktions-gmbh/boxid/424314>
- **Marie's Two Cents**, *Hydrogen Energy*, 18 May 2011 <http://symbolic-mirage.blogspot.com.au/2011/05/hydrogen-energy.html>
- **Free Republic**, *Splitting water to create renewable energy simpler than first thought?*, 19 May 2011 <http://www.freerepublic.com/focus/f-news/2721656/posts>
- **PhysicsOrg.com**, *Osmosis in colloidal suspensions*, 19 May 2011 <http://www.physorg.com/news/2011-05-osmosis-colloidal-suspensions.html>
- **India Vision**, *H2O: Splitting water breakthrough*, 19 May 2011 <http://www.indiavision.com/news/article/scitech/188747/>
- **Fuelcellworks**, *Splitting water to create renewable energy simpler than first thought?*, 21 May 2011 <http://fuelcellworks.com/news/2011/05/20/splitting-water-to-create-renewable-energy-simpler-than-first-thought/>
- **RedOrbit**, *New malaria protein structure upends theory of how cells grow and move*, 31 May 2011 http://www.redorbit.com/news/health/2056225/new_malaria_protein_structure_upends_theory_of_how_cells_grow/
- **LabSpaces.net**, *New malaria protein structure upends theory of how cells grow and move*, 31 May 2011 http://www.labspaces.net/111065/New_malaria_protein_structure_upends_theory_of_how_cells_grow_and_move
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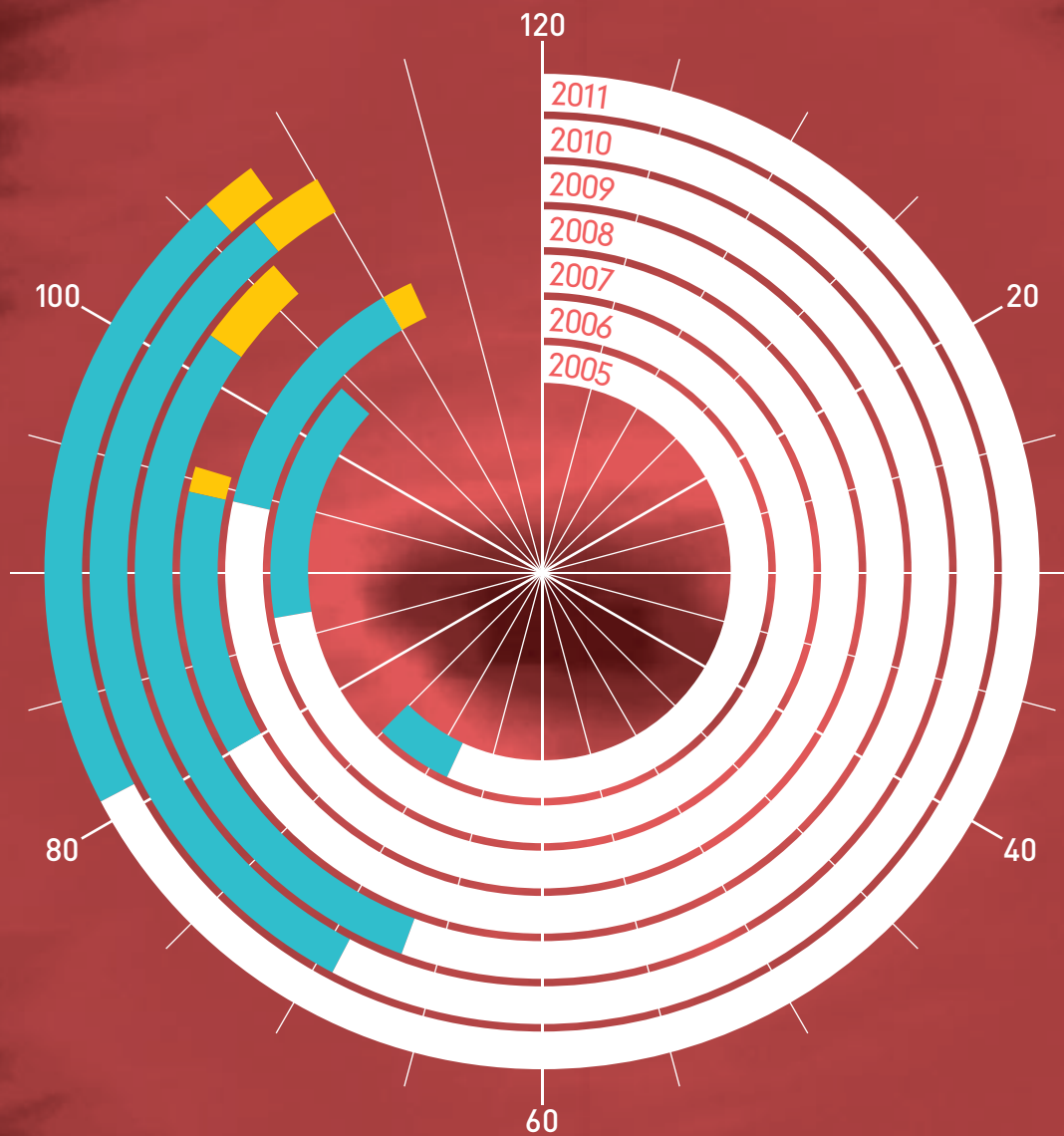
- **Bioscience Technology Online**, *New malaria protein structure upends theory of how cells grow and move*, 31 May 2011 <http://www.biosciencetechnology.com/News/2011/05/New-Malaria-Protein-Structure-Upends-Theory-of-How-Cells-Grow-and-Move/>
- **The Age**, *Out of sync with the state of Victoria*, 1 Jun 2011 <http://www.theage.com.au/national/out-of-sync-with-the-state-of-victoria-20110531-1feid.html>
- **HPC Wire**, *The Weekly Top Five*, 3 Jun 2011 http://www.hpcwire.com/hpcwire/2011-06-02/the_weekly_top_five.html
- **PhysOrg.com**, *First Australian team wins beam time on world's most powerful X-ray laser*, 7 Jun 2011 <http://www.physorg.com/wire-news/68808826/first-australian-team-wins-beam-time-on-worlds-most-powerful-x-r.html>
- **Medilexicon**, *Scientists have discovered a new type of cell in the immune system*, 14 Jun 2011 <http://www.medilexicon.com/medicalnews.php?newsid=228470>
- **Science Alert**, *Study pins new defence cell*, 15 Jun 2011 <http://www.sciencealert.com.au/news/20111406-22268.html>
- **Health News**, *New cell type offers new hope*, 16 Jun 2011 <http://www.healthcanal.com/medical-breakthroughs/18099-New-cell-type-offers-new-hope.html>
- **PhysOrg.com**, *Brookhaven lab wins two R&D 100 awards for imaging devices used in scientific research*, 22 Jun 2011 <http://www.physorg.com/wire-news/70213333/brookhaven-lab-wins-2-rampd-100-awards-for-imaging-devices-used.html>
- **CSIRO**, *CSIRO collaboration on 'world's top 100' list*, 23 Jun 2011 <http://www.csiro.au/news/CSIRO-collaboration-on-worlds-top-100-list>
- **Nanotechnology Now**, *Brookhaven lab wins two R&D 100 awards for imaging devices used in scientific research*, 24 Jun 2011 http://www.nanotech-now.com/news.cgi?story_id=42815
- **News RX**, *New cell type offers immunology hope*, 25 Jun 2011 <http://www.newsrx.com/health-articles/2544614.html>
- **Australasian Science**, *Saving the Australian Synchrotron*, 28 Jun 2011 <http://www.australasianscience.com.au/article/issue-julyaugust-2011/saving-australian-synchrotron.html>
- **CampusDaily.com.au**, *Insight for new malaria treatment*, 28 Jun 2011 http://www.campusdaily.com.au/read-university-news.php?title=insight_for_new_malaria_treatment_30733
- **The Conversation**, *Malaria breakthrough shines light on drug resistance*, 28 Jun 2011 <http://theconversation.edu.au/malaria-breakthrough-shines-light-on-drug-resistance-2047>
- **MSN News**, *Revealed: How drugs "beat malaria"*, 29 Jun 2011 <http://news.in.msn.com/international/article.aspx?cp-documentid=5248431>
- **India Report**, *How drugs beat malaria*, 29 Jun 2011
- **Indian Express**, *Drug action to beat malaria revealed*, 29 Jun 2011 <http://www.indianexpress.com/news/drug-action-to-beat-malaria-revealed/810295/>
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- **ABC AM with Tony Eastley**, *Research gives vital insight into how anti-malarial drugs work*, 29 Jun 2011
- Professor Leann Tilley was Robin Anders were interviewed for the Millions Against Malaria Foundation Documentary about Ken Evers and Tim Pryse’s journey around the world in a GA8-TC Airvan to raise money for the fight against malaria.
- Professor Keith Nugent appeared on 774 ACE afternoon radio to discuss mirages, 28th June 2011.



- Journals
- Conference Proceedings
- Book Chapters

PUBLICATIONS 2005 – 2011

Collectively, researchers from CXS have authored 13 book sections; 152 papers at 63 separate conferences in 17 countries; and 546 peer reviewed papers in journals from June 2005 to December 2011.

CXS has published 554 peer-reviewed papers in journals from June 2005 to December 2011. The average impact factor for CXS over this period is 4.259. CXS has maintained a steady output with an increasingly high impact in top quality journals.



PUBLICATIONS

CXS published 82 papers in peer-reviewed journals in 2011 with an average impact factor of 5.510.

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CONFERENCE PROCEEDINGS

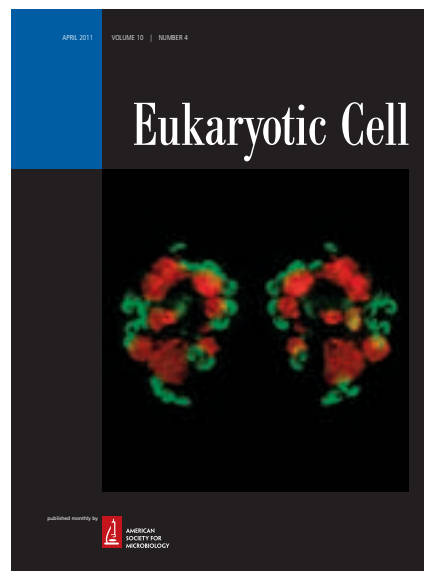
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9. Peele, A. G. (2011). The Australian Synchrotron. SCANZ Crystal27, Rotarua, NZ.
10. Peele, A. G. (2011). Advances at The Australian Synchrotron. CAM2011, Melbourne.
11. Peele, A. G. (2011). The Australian Synchrotron and Sustainable Innovation. PACIA2011, Melbourne.
12. Peele, A. G. (2011). Welcome and an Introduction to Synchrotron Light and The Australian Synchrotron. New Synchrotron and Neutron Users Symposium, UNSW.
13. Peele, A. G. (2011). CXS Experimental Methods Program. CXS workshop on X-ray Free Electron Laser Science, Cairns, Qld
14. Pelliccia, D., A. Y. Nikulin, et al. (2011). Coherence characterization for hard x-ray diffraction imaging of embedded nanoparticles. ICMAT2011 Singapore.





GRANT INCOME 2005 – 2011

CXS has brought in \$27,818,370 of additional funding since it began in June 2005. The figures below do not include the original ARC Centre of Excellence Funding or its nodes matching funding.



GRANTS

CXS members attracted \$3,577,105 in additional support in 2011:

ARC	
LIEF - Melbourne and La Trobe rapid integrated X-ray diffraction facility	\$360,000
LIEF - Advanced surface imaging and spectroscopy facility	\$600,000
DECRA - Nano-resolution hard X-ray diffraction imaging with conventional laboratory sources	\$375,000
LIEF - A cellular nano-imaging facility: Probing cellular complexity	\$350,000
Nano-scale phase diverse coherent diffractive imaging using partially coherent electron sources	\$375,000
Australian Synchrotron	
Gratings interferometer for phase contrast mammography	\$4,100
US Air Force	
Precision attosecond physics with atomic hydrogen	\$380,012
Ian Potter Foundation	
CXS Annual Workshop 2011	\$20,000
University of Melbourne	
Victorian Microscopy Network Participation in NRIC	\$15,000
Fast super-resolution fluorescence microscopy	\$19,500
Bid for an Australian Research Council Centre of Excellence	\$30,000
AMMRF	
Correlative fluorescence and EM Imaging of the Malaria Parasite Plasmodium falciparum	\$3,900
La Trobe University	
standard method for mounting non-reproducible biological specimens for correlative imaging	\$4,800
Probing electronic interactions in dimensionally reduced systems	\$7,000
NHMRC	
Project Grant - Transforming the diagnosis of mitochondrial disorders using high throughput sequencing, functional prediction and experimental validation	\$648,675
Project Grant - Mechanisms regulating mitochondrial outer membrane permeabilisation during programmed cell death	\$296,175
Equipment Grant - Protein interactions facility	\$24,323
ISAP	
Coherence Measurements and related diffractive imaging experiments	\$11,300
Funding for CXS experiments, Travel Grant	\$11,000
AINSE	
Travel Support	\$220
MRGSS	
Quantum rotation sensing: geometric phase, turbulence and nanobiological systems	\$45,000

CXS LOCATIONS



PARKVILLE CAMPUS

Corner Swanston Street and Tin Alley,
Parkville

PHYSICS BUILDING

CXS Head Office

The Experimental Methods Program
(also at La Trobe University)

The Theory and Modelling Program

The Ultra-Cold Plasma Source Program

PARKING

'Scratch & Display' car parking permits are available for the use of official visitors to the campus and nearby University parking areas. Upon notification, CXS staff can arrange permits in advance.



BUNDOORA CAMPUS

Kingsbury Drive, Bundoora

PHYSICAL SCIENCES BUILDINGS 1 AND 4

The Biological Sciences Program

The Experimental Methods Program
(also at University of Melbourne)

PARKING

Parking for visitors at there is on a fee-paying basis. Tickets can be purchased at car parks from the ticket machines. Upon notification, CXS staff and visitors can arrange daily temporary permits in advance.



CLAYTON CAMPUS

Wellington Road, Clayton

PHYSICS BUILDING

The Detector and Beamline
Development Program

PARKING

Parking permits are required during weekdays and short-term parking zones are also available.

Parking without a permit is available in the blue, red and yellow zones after 5pm on weekdays and all weekend.





HAWTHORN CAMPUS

John Street, Hawthorn

CENTRE FOR ATOMIC OPTICS AND ULTRAFAST SPECTROSCOPY

The Short Wavelength Source Program

PARKING

Parking in university car parks is on a fee-paying basis only. Tickets can be purchased in car parks from the ticket machines or from multi deck car park.

This campus is also situated a couple of minutes' walk from the Glenferrie train station & tram stops.

NATHAN CAMPUS

170 Kessels Road, Nathan QLD 4111

SCHOOL OF BIOMOLECULAR AND PHYSICAL SCIENCES

PARKING

Griffith University offers a variety of parking options on the Nathan campus. Casual visitors can choose from \$5/day parking permits, metered parking or pay and display parking.

CLAYTON

Gate 5, Normanby Road, Clayton

MANUFACTURING AND INFRASTRUCTURE TECHNOLOGIES

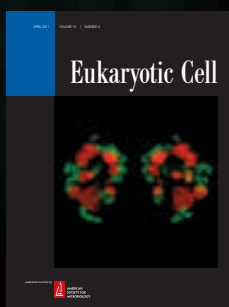
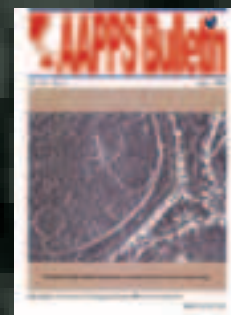
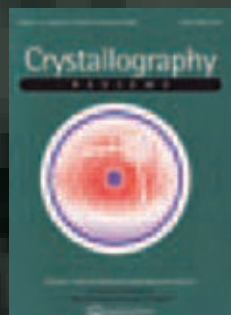
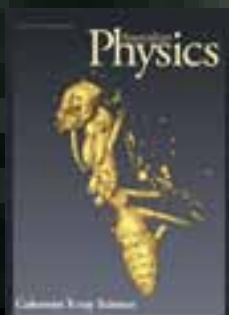
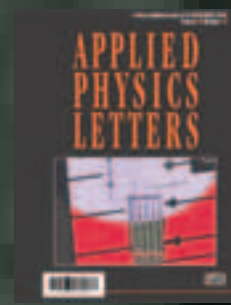
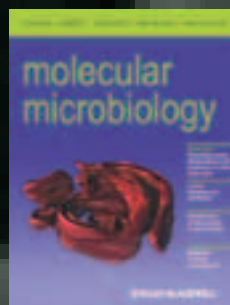
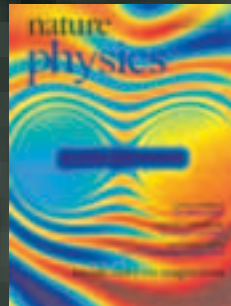
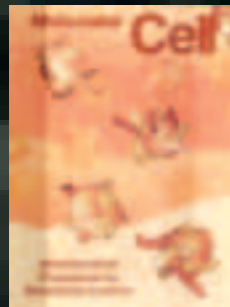
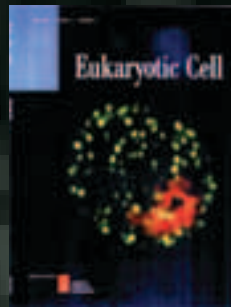
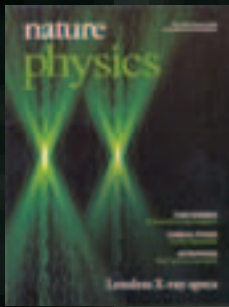
The Structure Determination
Methods Program

PARKVILLE

343 Royal Parade, Parkville

MOLECULAR AND HEALTH TECHNOLOGIES

The Structure Determination
Methods Program



JOURNAL COVERS
2005 – 2011

FINANCIAL STATEMENT

CXS FINANCIAL REPORT JANUARY - DECEMBER 2011

	2011 REPORTING PERIOD (\$)		2012 REPORTING PERIOD (ESTIMATED) (\$)	
Carry Forward	\$2,603,014		\$2,765,546	
Other Funds	\$2,200,000	ARC Income	\$2,200,000	ARC Income
	\$127,212	ARC Indexation	\$216,751	ARC Indexation
	\$864,120	Node Contribution	\$825,000	Node Contribution
	\$181,567	ARC Federation Fellow Support	\$0	ARC Federation Fellow Support
Total Income	\$5,975,913		\$6,007,297	
Expenditure	\$1,978,093	Salaries	\$1,585,042	Salaries
	\$443,876	Equipment	\$1,135,000	Equipment
	\$300,256	Travel, Accommodation and Conference	\$422,300	Travel, Accommodation and Conference
	\$183,855	Materials, Provisions and Services	\$270,800	Materials, Provisions and Services
	\$132,935	Scholarships	\$159,500	Scholarships
	\$122,098	Marketing, Outreach and Sponsorship	\$131,000	Marketing, Outreach and Sponsorship
	\$40,254	General	\$14,500	General
	\$3,210,367		\$3,718,142	
Balance	\$2,765,546		\$2,237,084	

IN-KIND REPORT JANUARY - DECEMBER 2011

University of Melbourne	\$3,574,118
La Trobe University	\$513,252
Monash University	\$387,158
Swinburne University of Technology	\$335,000
Griffith University	\$80,172
CSIRO	\$260,794
Total	\$5,150,494



ARC Centre of Excellence for
COHERENT X-RAY SCIENCE

ARC CENTRE OF EXCELLENCE FOR COHERENT X-RAY SCIENCE
SCHOOL OF PHYSICS

THE UNIVERSITY OF MELBOURNE
SCHOOL OF PHYSICS
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Australian Government
Australian Research Council

