Diamond Light Source Ltd Review 2018/19

Foreword

The past 12 months have seen an increase in the complementary capabilities and facilities that Diamond is able to offer its over 10,000 users. With the operations of the electron Bio-Imaging Centre (eBIC) now fully integrated into the user programme, researchers can access a one-stop shop for structural biology right here at Diamond. The unique offer enabled by further integrated facilities such as the electron Physical Science Imaging Centre (ePSIC), the MPL (Membrane Protein Lab), the XChem Fragment Screening service and the XFEL Hub, put Diamond at the leading edge of transformative science on the world stage.

An increase in Diamond's scientific output naturally leads to a demand to further develop our data analysis capabilities. Progress in this area is extensive, with efficient data analysis pipelines delivering results in close-to-real time. One particular project is focusing on citizen science as a means to help train Artificial Intelligence systems, which is a key focus of the UK's industrial strategy.

Located on a world-leading site for scientific discovery, Diamond aims to be a cornerstone of the Harwell Campus. We are pleased to have seen key investments in our new neighbours, the Rosalind Franklin Institute (RFI) and Faraday Institution (FI), further increasing the impact of the Harwell Campus on UK science and innovation. We will continue to strengthen our relationships with these institutes and act as a catalyst for the activities they are undertaking.

Professor Sir Adrian Smith
Chairman of the Board of Directors

"An increase in Diamond's scientific output naturally leads to a demand to further develop our data analysis capabilities. Progress in this area is extensive, with efficient data analysis pipelines delivering results in close-to-real time."

> **To remain at the cutting edge of science, we need to ensure we continue to attract people from all over the world because they bring their different perspectives and skills.**

CEO Welcome

As we close the financial year 2018-19, it is good to reflect upon the achievements of this period. 2018 was the Year of Engineering and this saw an increase in news and features from the engineering team resulting in some striking headlines. For example, the Daily Express showcased the work done with Martian Meridianiites within the facility. These minerals were named after the place they were discovered on Mars and provide direct evidence that there used to be surface water on this planet. This wonderful and engaging science was made possible by the design of a special cold cell built by our talented engineers.

The Year of Engineering has left a legacy of enhanced engagement, which we can now build on ensuring that career opportunities are more widely promoted, and staff continue to be good role models helping to attract the best talents into our organisation.

With the investment made in Diamond over the past 18 years, funded by the taxpayers through the Science and Technology Facilities Council (STFC) - UK Research & Innovation (86%) and the Wellcome Trust (14%), our institute now offers access to 32 beamlines and five complementary facilities (eBIC, ePSIC, MPL, XFEL Hub and XChem). The final beamline of the current phase of construction – DIAD – saw first light in the past year and will take first users in the next twelve months. All are pushing the boundaries of visualisation of molecules and materials at the atomic level, and enabling high quality science for both industry and academia. An indication of the role Diamond plays in establishing the UK at the forefront of science worldwide is the high impact of its work embodied in almost 8,000 peer review scientific articles published since the organisation was created, with citation rates significantly higher than the national average across the spectrum of science it serves.

A great illustration of the impact we are having is the work by an international team led by the University of Portsmouth and the US National Energy Research Laboratory that will enable a natural plastic digesting enzyme to be exploited more effectively in waste treatment. The unique visualisation tools used to elucidate the way the enzyme works were provided by several of our beamlines. The research made the headlines all over the world, generating the equivalent of over £23M of advertising spend in press and broadcast coverage.

This review contains many more examples of high impact science drawn from across the broad range of areas of fundamental science that Diamond serves, and the societal challenges it helps address. These include health and wellbeing, the environment, transport and energy challenges of the future, as well as new functional materials, including electronic devices and high-performance engineering alloys, and new processing technology for innovative manufacturing.

All of these achievements reflect the skills, hard work and commitment of the dedicated staff that we have within our walls. They also reflect the strong engagement of a vibrant and growing user community in academia and industry. In the last financial year, we received 1,788 proposals for experiments on our instruments via peer reviewed access routes, requesting a total of 22,117 shifts. After peer review, 1,191 proposals were awarded beamtime. This resulted in 12,497 experimental shifts being awarded across 30 beamlines and eight electron microscopes. We welcomed 6,332 onsite user visits from academia across all instruments, with an additional 4,459 remote user visits. The machine continues to perform to the highest standard with 98.4% uptime and 90.3 hours mean time between failures (MTBF).

However, we cannot afford to rest on our laurels. The pace of technical development is rapid and relentless so if we are to continue to offer the scientific community the best opportunities for world-leading research, we need to plan to take advantage of such advances. We have already started a very substantial rolling programme of upgrades to beamlines supported by a considerable uplift in capital from our shareholders. We aim to complement this programme with the Diamond-II upgrade of the machine and instruments, which with a factor of 20 times reduction in emittance coupled with an increase in electron beam energy from 3.0 to 3.5 GeV will provide up to a factor of 70 increase in brightness and coherence of Diamond's photon beams at the higher energies. A new lattice geometry will allow us to not only keep and enhance all current beamlines, but offers the opportunity for up to five new additional beamlines to be created. The science case has been well received and approved by our Science Advisory Committee (SAC) and Diamond Industrial Science Committee (DISCo). The Conceptual Design Report (CDR) has also been approved by an international expert panel, clearing the way to work on the Technical Design Report (TDR) for which we will need an increase in staff and resources for much more detailed planning.

To remain at the cutting-edge of science, we need to ensure we continue to attract people from all over the world because they bring their different perspectives and skills. We also need to engage more closely with other facilities that provide complementary technical expertise. These are global endeavours, but the highest density of world-class light source facilities and suitably trained scientists and engineers are in Europe, so it is more critical than ever that we maintain close and effective ties with our closest and strongest allies. To this end, in 2017 we became Members of LEAPS – the League of European Accelerator-based Photon Sources – an organisation that brings together every synchrotron and Free Electron Laser (FEL) facility in Europe. Over the past year, the collaboration has developed a collection of projects for enabling technology, from new sources and optics to detectors and data analysis tools, that we will work on together to ensure that we are all able to support the most brilliant science and innovation well into the future.

Prof Andrew Harrison
CEO Diamond Light Source

Governance

Diamond Light Source Ltd was established in 2002 as a joint venture limited company funded by the UK Government via the Science and Technology Facilities Council (STFC), now under UK Research & Innovation (UKRI), and by the Wellcome Trust, owning 86% and 14% of the shares respectively. Diamond now employs almost 700 scientists, engineers, technicians and support staff from 39 countries worldwide. The Chief Executive and Directors are advised by committees representing key stakeholder groups, including the Science Advisory Committee (SAC), Diamond User Committee (DUC), and Diamond Industrial Science Committee (DISCo).

Diamond is free at the point of access for researchers accessing Diamond via peer review, and provided the results are published in the public domain for everyone's benefit. Allocation of beamtime is via a peer review process to select proposals on the basis of scientific merit and technical feasibility. Eight peer review panels meet twice a year to assess the proposals submitted for each six-month allocation period. Diamond also welcomes industrial researchers through a range of access modes including proprietary research.

SAC: Advises Diamond Management on scientific and technical issues, including facilities and operation.

DUC: Represents the views of users to Diamond Management on matters relating to the operation and strategy of the facility.

DISCo: Advises Diamond Management on all matters relating to industry and industrial users of the facility, including opportunities to engage industry, best practice for industrial engagement and industrial research priorities.

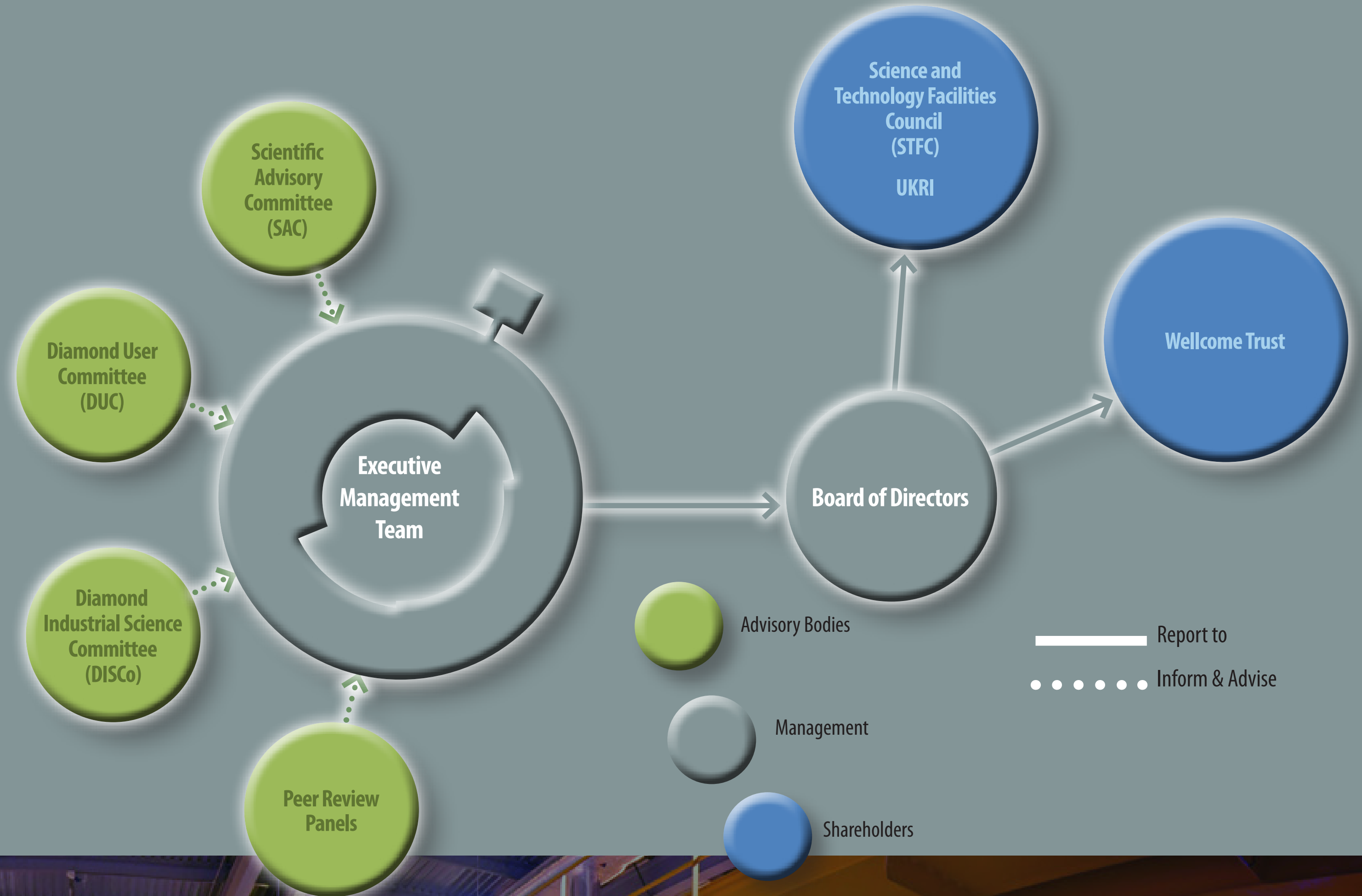
Peer Review Panels: Assess scientific merit of proposals to use the synchrotron and provide recommendations to Diamond Management on the allocation of beamtime to each project.

Executive Management Team: Hears from representatives from around Diamond and provides recommendations on strategy and operation to the Board of Directors.

Board of Directors: Decides on matters relating to Diamond's strategy and operation, and reports to Shareholders.

STFC: Holds 86% of shares as a joint venture partner. Hears from the board and makes wider strategic decisions.

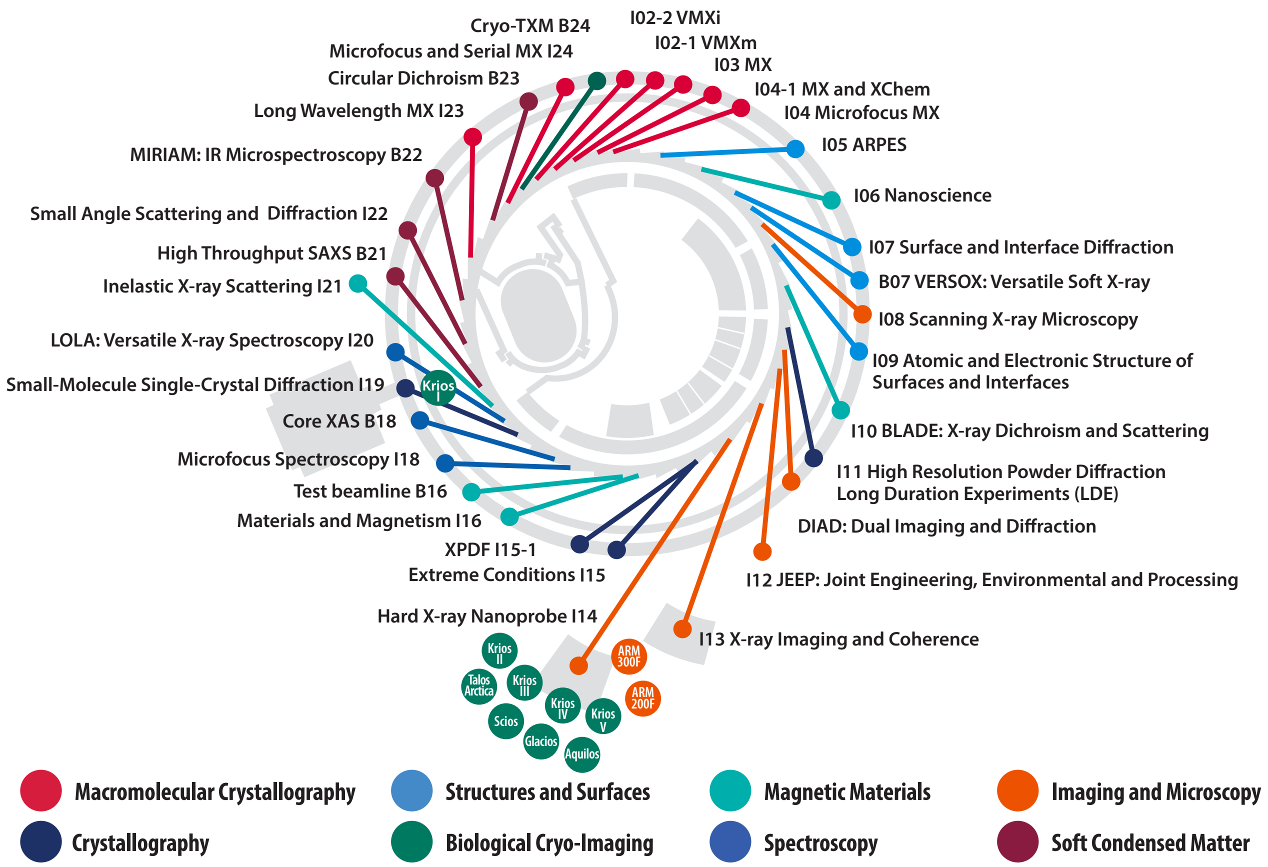
The Wellcome Trust: Holds 14% of shares as a joint venture partner. Hears from the board and makes wider strategic decisions.



Beamline Development and Technical Summary

In its twelfth year of experiments, Diamond is now operating with 32 beamlines and 11 electron microscopes. The next year will see the completion of the latest phase of construction when the DIAD beamline welcomes first users. Of the electron microscopes, nine are cryo-electron microscopes specialising in life sciences, with two provided for industry use in partnership with Thermo Fisher Scientific, and make up eBIC (electron Bio-Imaging Centre). The two remaining microscopes dedicated to advanced materials research are supplied by Johnson Matthey and the University of Oxford. These microscopes form ePSIC (electron Physical Science Imaging Centre) and are operated under strategic collaboration agreements to provide for substantial dedicated peer reviewed user access. Both the eBIC and ePSIC centres are next to the Hard X-ray Nanoprobe beamline (I14). For academic research, Diamond instruments (beamlines and microscopes) are free at the point of access through peer review. For proprietary research, access can be secured through Diamond's industry team.

Following a restructure in 2018, the instruments are organised into eight science groups as described below.



Electron Microscopes

Microscope	Main Capabilities	Accelerating Voltages	Operational Status
Titan Krios I	Cryo-EM, Cryo-ET	80, 120, 200, 300 kV	Operational since 2015
Titan Krios II	Cryo-EM, Cryo-ET	80, 120, 200, 300 kV	Operational since 2016
Titan Krios III	Cryo-EM, Cryo-ET	80, 120, 200, 300 kV	Operational since 2017
Titan Krios IV	Cryo-EM, Cryo-ET	80, 120, 200, 300 kV	Operational since 2017
Titan Krios V	Cryo-EM, Cryo-ET	80, 120, 200, 300 kV	Operational since 2018
Talos Arctica	Cryo-EM, Cryo-ET	200 kV	Operational since 2016
Glacios	Cryo-EM, Cryo-ET	200 kV	Installed, March 2019
Scios	Cryo-SEM, Cryo-FIB	3 to 30 kV	Operational since 2017
Aquilos	Cryo-SEM, Cryo-FIB	3 to 30 kV	Operational since 2019
JEOL ARM200F	Atomic scale STEM imaging, EELS, EDX, electron diffraction	80, 200 kV	Operational since 2017
JEOL ARM300F	Atomic scale TEM and STEM imaging, electron diffraction, 4D-STEM, EDX	30, 60, 80, 160, 200, 300 kV	Operational since 2017

Diamond's beamlines: current operational status April 2019

Beamline Name and Number	Main Techniques	Energy / Wavelength Range	Status
I02-1 - Versatile MX micro (VMXm)	Micro- and nano-focus in vacuum cryo-macromolecular crystallography (VMXm)	7 - 28 keV	Commissioning
I02-2 - Versatile MX *in situ* (VMXi)	*In situ* microfocus macromolecular crystallography, Serial Synchrotron Crystallography	10 - 25 keV	Commissioning
I03 - MX	Macromolecular crystallography (MX), Multiwavelength Anomalous Diffraction (MAD)	5 - 25 keV	Operational
I04 - Microfocus MX	MX, MAD	6 - 18 keV	Operational
I04-1 - Monochromatic MX	MX, XChem fragment screening	13.53 keV (fixed wavelength)	Operational
I05 - ARPES	Angle-Resolved PhotoEmission Spectroscopy (ARPES) and nano-ARPES	18 - 240 eV; 500 eV	Operational
I06 - Nanoscience	X-ray Absorption Spectroscopy (XAS), X-ray photoemission microscopy and X-ray magnetic circular and linear dichroism	80eV - 2200eV	Operational
I07 - Surface and Interface Diffraction	Surface X-ray diffraction, Grazing Incidence X-ray Diffraction (GIXD), Grazing Incidence Small Angle X-ray Scattering (GISAXS), X-ray Reflectivity (XRR)	6 - 30 keV	Operational
B07 - VERSOX: Versatile Soft X-ray	Ambient Pressure XPS and NEXAFS	250 - 2800 eV	Operational
	NEXAFS and High-Throughput XPS	50 - 2200 eV	Commissioning
I08 - Scanning X-ray Microscopy	Scanning X-ray microscopy, NEXAFS/ XANES, X-ray fluorescence	I08 branch: 250 eV - 4.4 keV	Operational
		J08 - Soft and Tender X-ray Ptychography branch: 250 - 2000 eV	Construction
I09 - Atomic and Electronic Structure of Surfaces and Interfaces	XPS (including HAXPES), X-ray Standing Waves (XSW), Near Edge X-ray Absorption Fine Structure (NEXAFS), energy-scanned photoelectron diffraction	Hard X-rays: 2.1 - 18+ keV Soft X-rays: 0.1 - 2.1 keV (currently 0.1 - 1.9 keV)	Operational
I10 - BLADE: Beamline for Advanced Dichroism Experiments	Soft X-ray resonant scattering, XAS and X-ray magnetic circular and linear dichroism	Circular: 400-1600eV; Linear Horizontal: 250-1600eV; Linear Vertical: 480-1600eV	Operational
I11 - High Resolution Powder Diffraction	X-ray powder diffraction	6 - 25(30) keV (0.5 - 2.1 Å)	Operational
DIAD: Dual Imaging and Diffraction	Simultaneous imaging and diffraction	8 - 38 keV	Construction
I12 - JEEP: Joint Engineering, Environmental and Processing	Time-resolved imaging and tomography (phase- and attenuation-contrast), time-resolved powder diffraction, single crystal diffraction, diffuse scattering, energy dispersive X-ray diffraction (EDXD), high-energy small angle X-ray scattering (under development)	53 keV - 150 keV monochromatic or continuous white beam	Operational
I13 - X-ray Imaging and Coherence	Phase contrast imaging, tomography, full-field microscopy (under commissioning), coherent diffraction and imaging (CXRD,CDI), ptychography and photocorrelation spectroscopy (XPCS) (under commissioning), innovative microscopy and imaging	Imaging branch: 8 - 30keV Coherence branch: 7 - 20keV	Operational
I14 - Hard X-ray Nanoprobe	Scanning X-ray fluorescence, X-ray spectroscopy, ptychography and transmission diffraction	5 - 23 keV	Optimisation
I15 - Extreme Conditions	Powder diffraction, single crystal diffraction	Monochromatic and focused 20 - 80 keV White beam	Operational
I15-1 - XPDF	X-ray Pair Distribution Function (XPDF)	40, 65, and 76 keV	Operational
I16 - Materials and Magnetism	Resonant and magnetic single crystal diffraction, fundamental X-ray physics	2.5 - 15 keV	Operational
B16 - Test beamline	Diffraction, imaging and tomography, topography, reflectometry	4 - 20 keV monochromatic focused 4 - 45 keV monochromatic unfocused White beam	Operational
I18 - Microfocus Spectroscopy	Micro XAS, micro Extended X-ray Absorption Fine Structure (EXAFS), micro fluorescence tomography, micro XRD	2.05 - 20.5 keV	Operational
B18 - Core XAS	X-ray Absorption Spectroscopy (XAS)	2.05 - 35 keV	Operational
I19 - Small-Molecule Single-Crystal Diffraction	Small-molecule single-crystal diffraction	5 to 25 keV / 0.5 to 2.5 Å	Operational
I20 - LOLA: Versatile X-ray Spectroscopy	X-ray Absorption Spectroscopy (XAS), X-ray Emission Spectroscopy (XES) and Energy Dispersive EXAFS (EDE)	Dispersive branch: 6 - 26 keV	Optimisation
		Scanning branch: 4 - 20 keV	Operational
I21 - Inelastic X-ray Scattering	Resonant Inelastic X-ray Scattering (RIXS), X-ray Absorption Spectroscopy (XAS)	Currently 250 - 1500 eV (to be upgraded to 250 - 3000 eV)	Optimisation
B21 - High Throughput SAXS	BioSAXS, solution state small angle X-ray scattering	8 - 15 keV (set to 13.1 keV by default)	Operational
I22 - Small Angle Scattering and Diffraction	Small angle X-ray scattering and diffraction: SAXS, WAXS, USAXS, GISAXS. Micro-focus.	7 - 20 keV	Operational
B22 - MIRIAM: Multimode InfraRed Imaging And Mircrospectroscopy	IR micro- & nano-spectroscopy, IR imaging, THz spectroscopy	nanoFTIR : 4000-900 cm-1 (2.5-11 µm) microFTIR: 10,000-100 cm-1 (1-100 µm) Spectroscopy (FTIR): 10,000-10 cm-1 (1-1000 µm) Imaging (FPA): 10,000-900 cm-1 (1-11 µm)	Operational
I23 - Long Wavelength MX	Long wavelength macromolecular crystallography	3 - 8 keV (1.5 - 4.1 Å)	Optimisation
B23 - Circular Dichroism	Circular Dichroism (CD)	125-500 nm & 165-650 nm for CD Imaging at 50 µm resolution, 96-cell High-Throughput CD (HTCD) and High-Pressure CD up to 200 MPa	Operational
I24 - Microfocus and Serial MX	Macromolecular crystallography, MAD, Serial Crystallography	6.5 - 25.0 keV	Operational
B24 - Cryo Transmission X-ray Microscopy (TXM)	Full field X-ray imaging	200eV - 2600eV	Optimisation

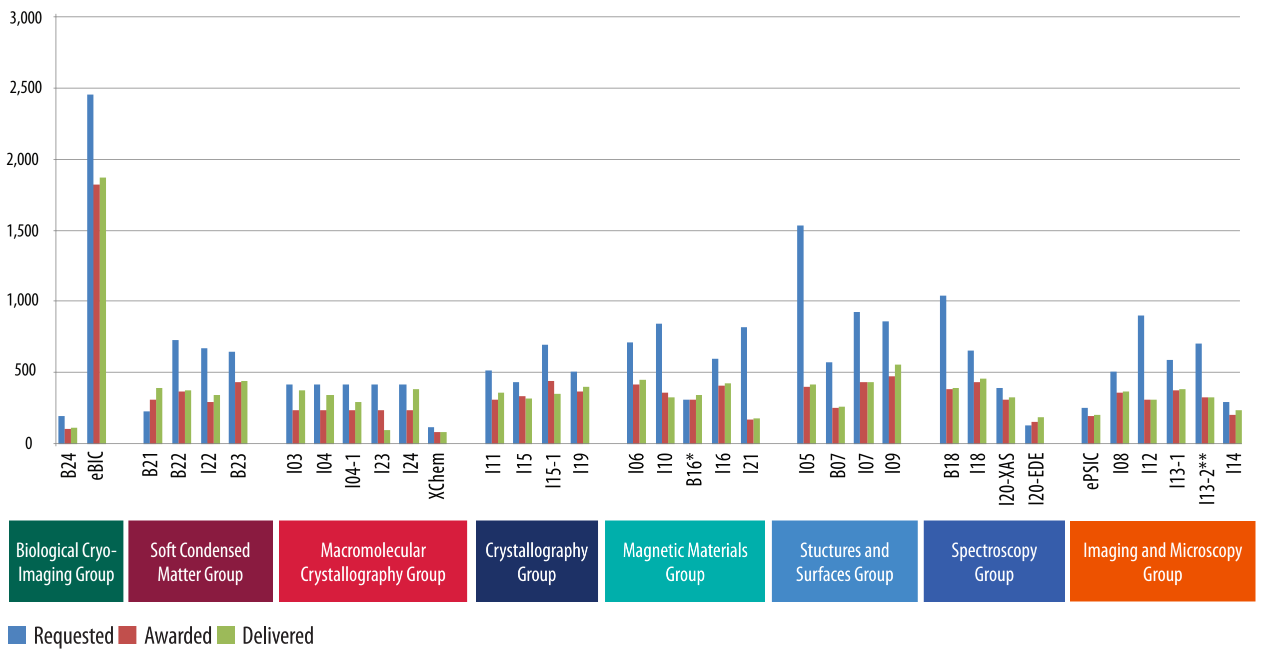
Key Facts and Figures

Facility usage

In our twelfth year of operations (1st April 2018 to 31st March 2019), we received 1,788 proposals for experiments on our instruments via peer reviewed access routes, requesting a total of 22,117 shifts. After peer review, 1,191 proposals were awarded beamtime. This resulted in 12,497 experimental shifts being awarded across 30 beamlines and eight electron microscopes. We welcomed 6,332 onsite user visits from academia across all instruments, with an additional 4,459 remote user visits.

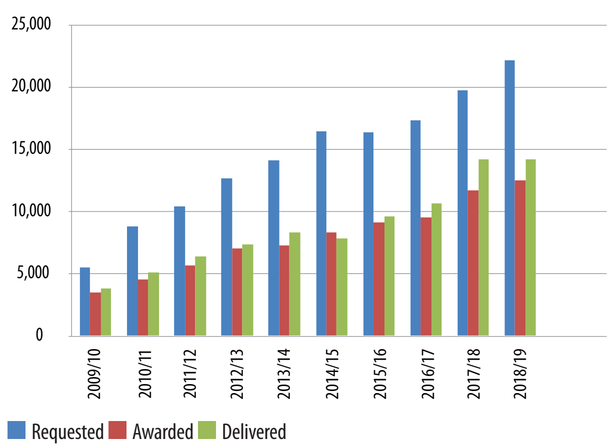
In the past 12 months, Diamond has continued to review its reporting method on facility usage. Our new reporting tool is continuously being developed and improved and allows us to report more precisely and more consistently. As a result, some of the reporting criteria and results in this review have evolved compared to previous years.

User shifts requested, awarded and delivered by group, beamline and electron microscope 2018/19



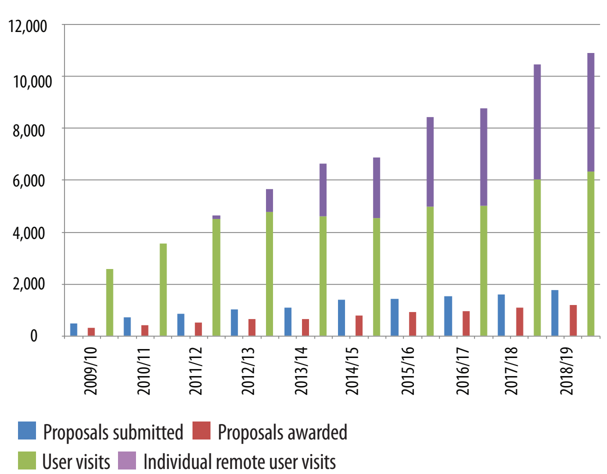
* B16 is an optical testing beamline with only 50% of beamtime for users.
** I13-2 Provides 35% of the available shifts to the Diamond Manchester Collaboration: these shifts are not included in this section.

Total user shifts requested, awarded and delivered



Various improvements have been made regarding the count of requested shifts for rapid access as well as regarding the count of requested shifts for proposals requesting more than one instruments.

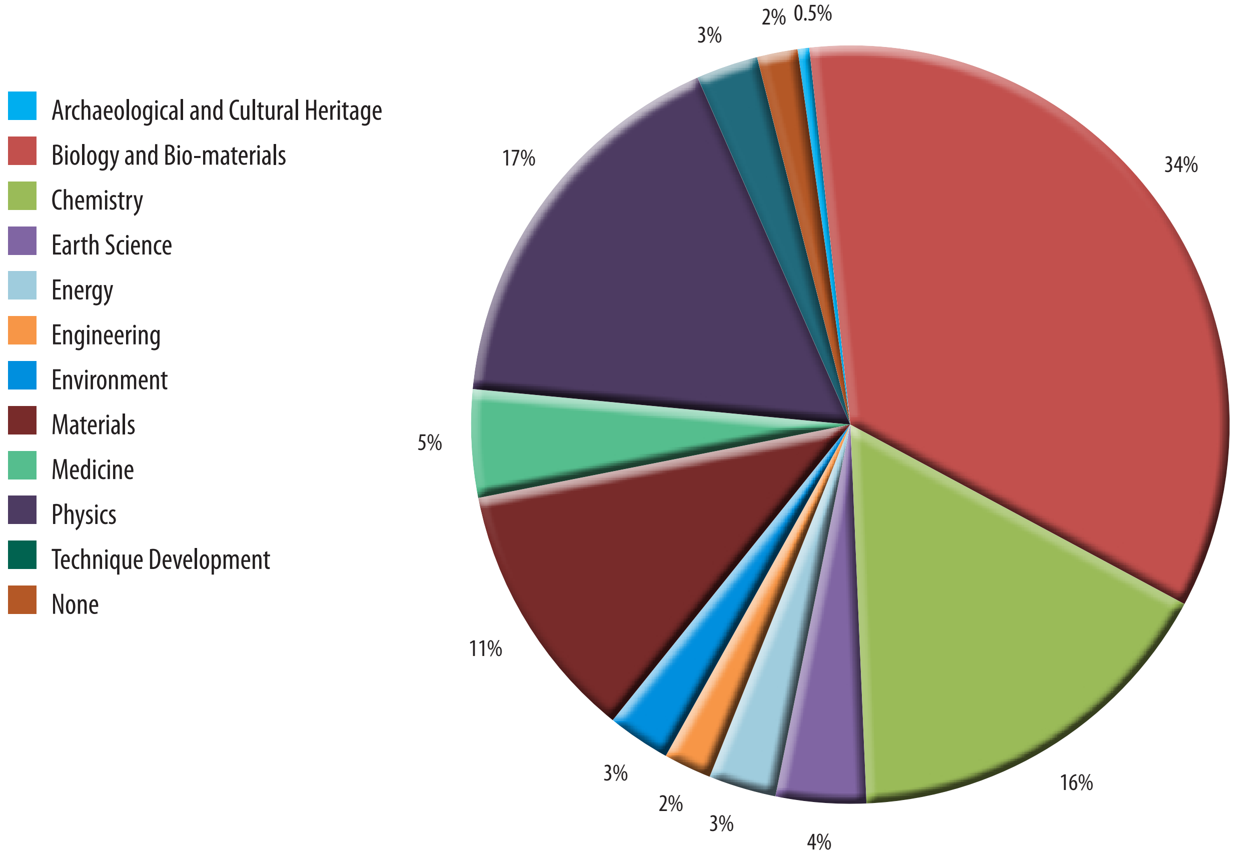
Total numbers of proposals and users per year



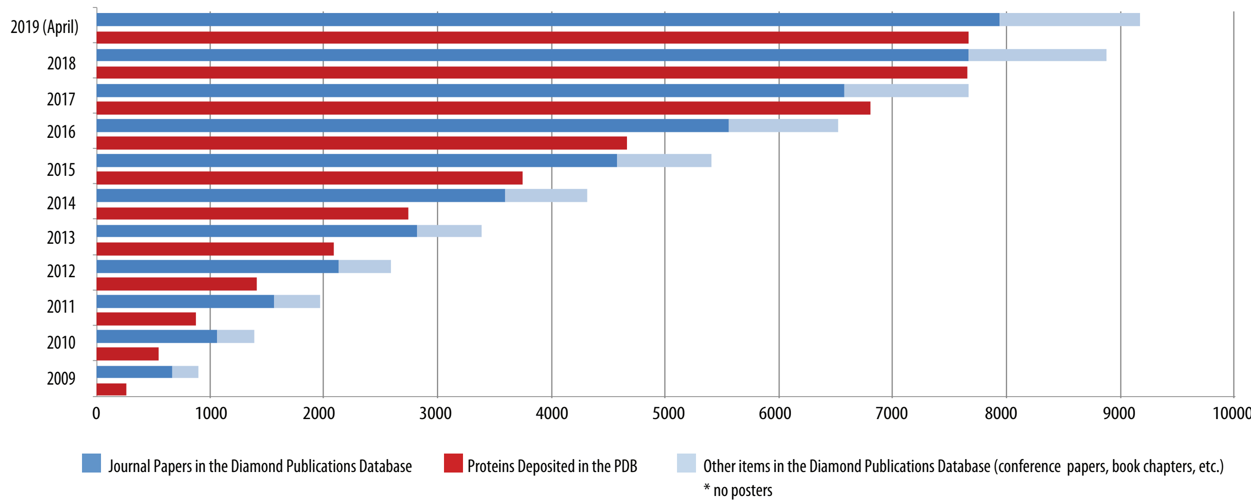
Members of staff visiting as part of peer reviewed access routes are now included in the count for user visits. In-house research is still excluded from this report.

Proposals by discipline and research theme

Experimental shifts scheduled by Diamond by main subject area for 2018/19



Cumulative number of items in Diamond Publications Database by our scientists and users and cumulative number of protein structures solved



Machine performance

	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19
Total no. operational beamlines by end FY	17	19	20	22	24	25	26	28	31	32*
Scheduled hours of machine operation	5712	5808	6000	5832	5976	5808	5928	5688	6072	5904
Scheduled hours of user operation	4728	4728	5064	4872	5088	4944	5040	4584	5160	4992
Machine uptime %	97.0	97.5	97.7	98.3	98.2	97.6	97.6	98.7	98.2	98.4
Mean time between failures (hours)	26.2	28.5	55.4	52.4	60.3	38.6	119.4	103.1	79.9	90.3

** Across all access routes.*

Macromolecular Crystallography Group

Macromolecular crystallography (MX) is a key technique in the structural biologist's toolkit for understanding the function of biologically relevant molecules by revealing their shape and interactions at atomic resolution. The information derived from MX experiments can be complemented by many other techniques at Diamond for life science research (see the Soft Condensed Matter and Imaging and Microscopy sections of this review), coupled with experiments in the researcher's lab, to giver deeper insight adopting an integrated structural biology approach.

At Diamond, seven beamlines (I03, I04, I04-1, I23, I24, VMXi, and VMXm), alongside the XChem fragment screening facility, the UK XFEL Hub, and the Membrane Protein Facility, are dedicated to exploiting the technique of MX for the benefit of the UK structural biology community, alongside researchers from Europe and further afield.

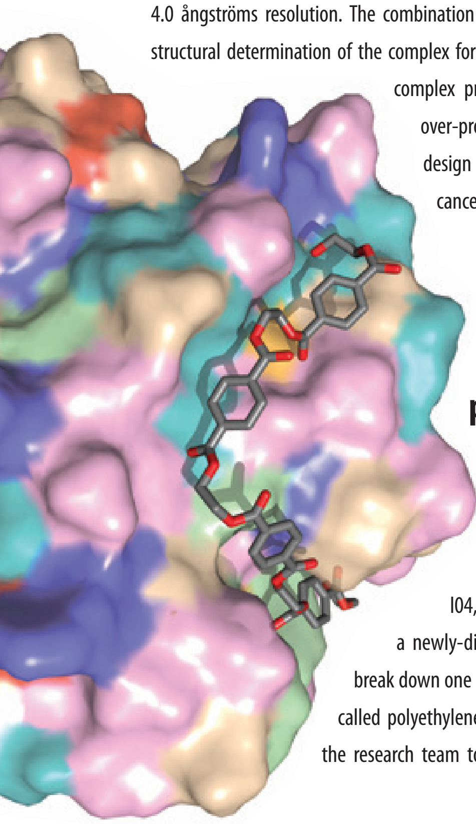
Studies from MX this year included work to further understand breast cancer processes, developing enzymes to tackle plastic pollution, and further insights into Parkinson's disease.

New discoveries in breast cancer

An Italian research team used the MX beamlines I04 and I04-1 to determine the 3D structure of a key cellular complex (the LGN:Insc polypeptide complex) associated with asymmetric cell division. The research provided a valuable advance in the understanding of the molecular principles of cell division and stem cell replication, and gives the potential for development of new therapeutic options for breast cancer.

Till now, the process of stem cell division has been largely unclear but it has been known that defects in the delicate and co-ordinated process of asymmetric cell division can cause cell over-proliferation and cancer. The study involved testing of many crystals on the beamlines to obtain two diffracted to 3.4 and 4.0 ångströms resolution. The combination of these two datasets allowed full structural determination of the complex for the first time and showed that the complex promotes cell division and stabilises over-proliferation. This is a vital step in the design of new treatment approaches for cancer.

Culurgioni S *et al.* doi: 10.1038/s41467-018-03343-4



Breakthrough in plastic recycling

An international team of researchers used the state-of-the-art Long-Wavelength MX beamline, I23, along with I03 and I04, to determine the 3D structure of a newly-discovered enzyme (PETase) that can break down one of the most polluting types of plastic called polyethylene terephthalate or PET. This allowed the research team to design an improved enzyme that can digest PET faster and which shows great potential for future engineering for industrial recycling applications. The work offers the exciting possibility of turning polyester plastics back to useful improved plastic products rather than sending them to landfill or manufacturing from new plastic materials.

The research builds on the remarkable discovery in 2016 of a strain of bacteria called *Ideonella sakaiensis* in Japan which was found to be surviving on a diet of PET. The data collected at Diamond showed that the structure of PETase secreted by the bacteria is similar to that of naturally occurring enzymes called cutinases, which break down the protective natural coatings on some plant leaves. By changing the DNA sequence of the PETase structure to mimic a cutinase the team were able to increase the PET-degrading activity, offering potential for further improvements to be made in the future.

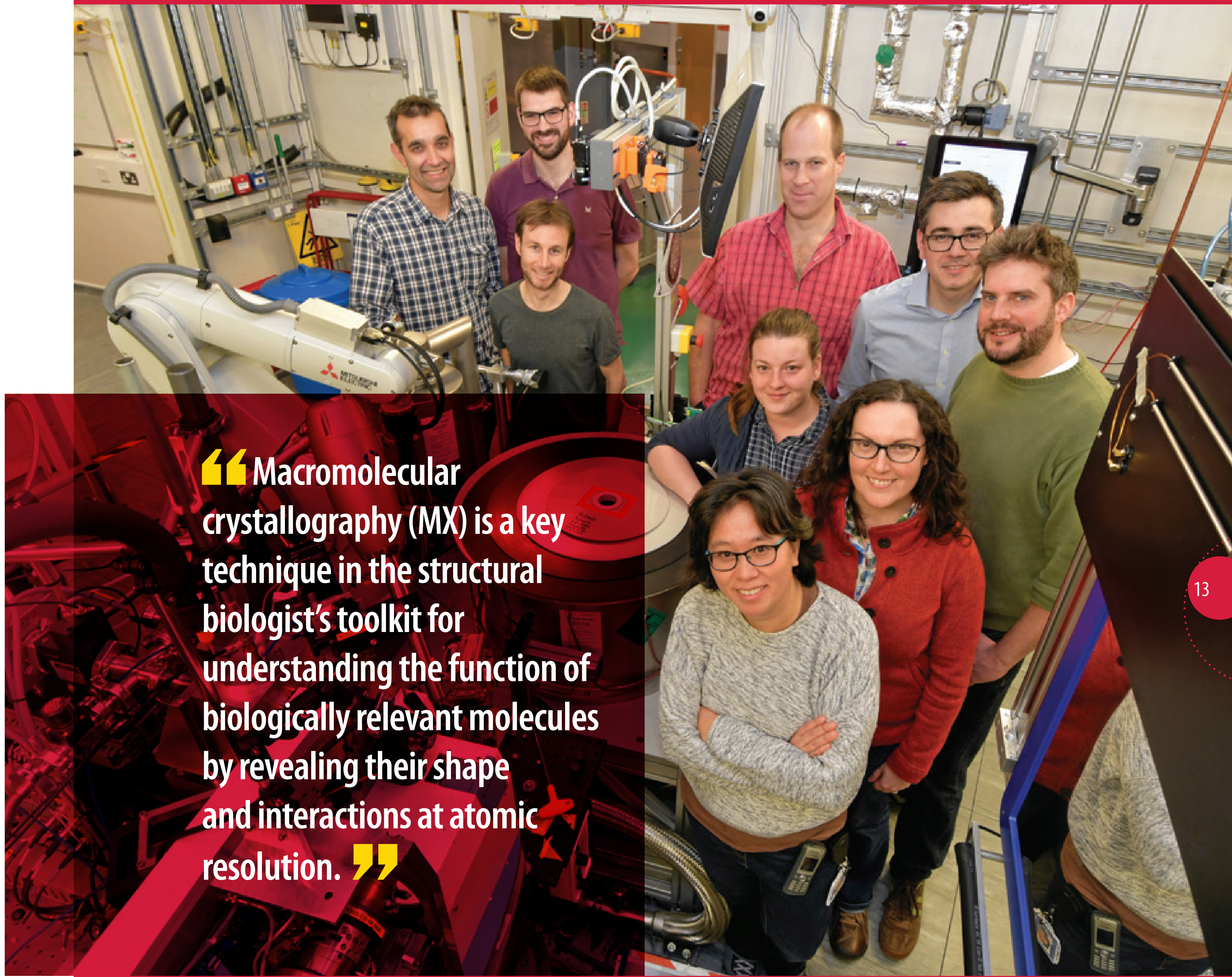
Austin HP *et al.* doi: 10.1073/pnas.1718804115

Potential new therapies for inherited Parkinson's disease

Researchers have uncovered the structure of an enzyme that is commonly defective in inherited forms of Parkinson's disease which affects about 10% of patients. They used the Microfocus MX beamline, I24, to determine the structure of active Parkin following earlier research on beamlines I04 and I02 that resolved inactive Parkin states. This research provides a key step in designing new therapies for Parkinson's disease.

The study found that dramatic structural rearrangements take place when Parkin is activated on damaged mitochondria, and identified a novel element essential for full Parkin activation. Being able to compare the active Parkin structure with previously resolved inactive forms is an important milestone in designing new therapies for an inherited disease that affects younger patients. Diamond research has been instrumental in understanding the whole mechanism of this debilitating disease.

Gladkova C *et al.* doi: 10.1038/s41586-018-0224-x



"Macromolecular crystallography (MX) is a key technique in the structural biologist's toolkit for understanding the function of biologically relevant molecules by revealing their shape and interactions at atomic resolution."

The I04-1 beamline team, clockwise from left: Jose Brandao-Neto, Richard Gillams, Frank von Delft (PBS), Alex Dias, Romain Talon, Ailsa Powell, Alice Douangamath, Anthony Aimon, Rachel Skyner.

Biological Cryo-Imaging Group

Established a little over a year ago, this Science Group brings together all the dedicated facilities for X-ray, light and electron microscopy at Diamond. Beamline B24 is the source of X-rays for the full field cryo-transmission microscope for imaging of biological specimens, and has established a cryo-super resolution fluorescence microscopy facility with the University of Oxford. The group includes the electron Bio-Imaging Centre (eBIC) which is the national centre for cryo-electron microscopy.

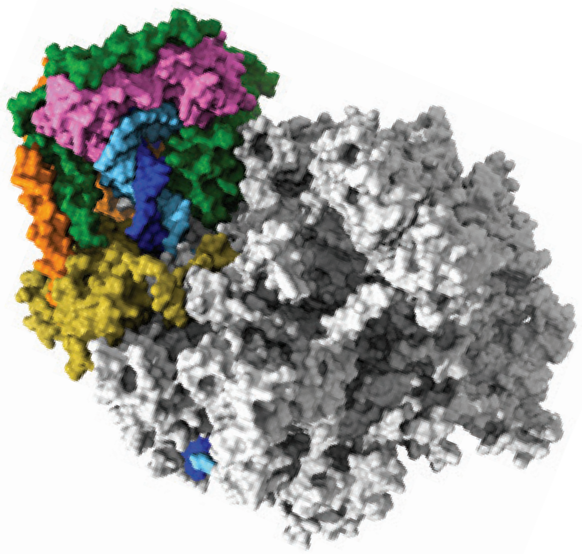
Studies conducted this year include research at eBIC to understand the complex cellular mechanisms that influence cancer, and the development of neurodegenerative diseases such as Alzheimer's and Parkinson's disease.

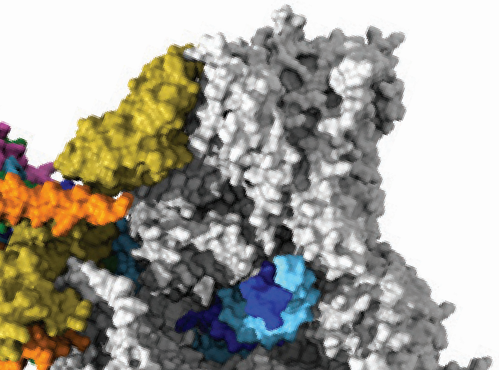
Researching critical disease mechanisms

The enzyme called RNA polymerase (Pol) III plays an important role in copying genes involved in important body functions such as cell growth, RNA processing and protein transport. The enzyme has a significant impact on lifespan as deregulation of these genes is associated with the development of cancer and neurodegenerative diseases including Alzheimer's and Parkinson's disease. A team of researchers from the Institute of Cancer Research in London aimed to improve understanding of the structure of Pol III in order to design new therapies to tackle these diseases.

The team used cryogenic electron microscopy at eBIC to produce high-resolution maps of the complex process which results in 'DNA melting' where double stranded DNA is split into single coils. This process appears to be highly efficient and this work to unravel these important molecular mechanisms provides vital information for the design of future treatments for these devastating illnesses.

Abascal-Palacios G *et al.* doi: 1038/nature25441





Understanding the mechanisms behind gene stability

A team of scientists from Imperial College London used the cryogenic electron microscope (cryo-EM) at eBIC to provide new insights into some of the complex molecular mechanisms involved in maintaining gene stability. These mechanisms are known to have a significant impact on cell chemistry, tissue degeneration and the development of cancer.

Certain proteins called histones are able to pack DNA very tightly into the nucleus of cells in a DNA/histone complex called chromatin. This system allows each cell in the body to contain about two metres of DNA and plays a vital role in the regulation of gene expression. The basic repeating structural unit of chromatin is called the nucleosome and contains DNA wrapped around a set of eight histones.

Nucleosomes can move along DNA, be chemically modified and can be replaced with a different variant by specialised enzymes. The research team focused on the so-called SWR1 chromatin remodelling complex, which is able to exchange histone variants in nucleosomes and plays an important role in preventing genome expression instability. They revealed for the first time the molecular interactions between SWR1, the nucleosome, and DNA that are required for the initiation of the histone exchange. This pioneering work will lead to further exploration of the structural mechanism and dynamics of chromatin remodelling, and will help in the understanding of cancer development and growth.

Ayala R *et al.* doi: 10.1126/science.aat7716

B24 beamline team, from left to right: (Front) Matt Spink, Ilias Kounatidis, Maria Harkiolaki (PBS). (Behind) Adam Prescott, Adam Taylor, Thomas Fish.

"Studies conducted this year include research at eBIC to understand the complex cellular mechanisms that influence cancer, and the development of neurodegenerative diseases such as Alzheimer's and Parkinson's disease."

Structures and Surfaces Group

The new Structures and Surfaces Group consists of four beamlines: I05 (Angle Resolved Photoelectron Spectroscopy – ARPES), I07 (Surface and Interface X-ray Diffraction), B07 (Versatile Soft X-ray Scattering – VERSOX) and I09 (Atomic and Electronic Structure of Surfaces and Interfaces). The group is designed to provide more extensive internal collaborative research and improved offline facilities to serve the user community. The alignment also allows closer working with engineering colleagues and software developers that are aligned with the new groups, leading to common solutions across the beamlines.

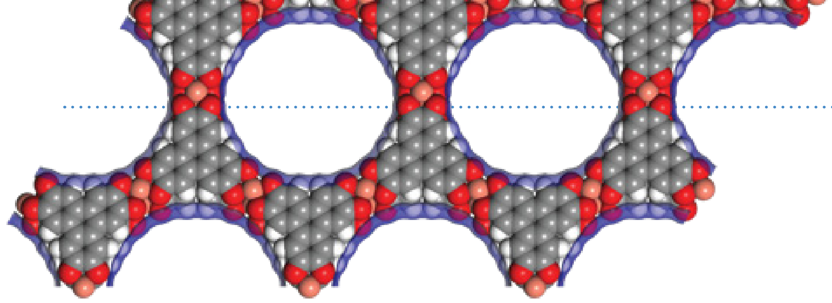
The diversity of the science programme is a strength of this group and recent research has included pioneering work on 2D semiconductors, the structure and orientation of semiconductive porous ultrathin films and the development of new electronic devices.

Developing a new class of electronic devices

New research from Diamond and the University of Würzburg in Germany has identified suitable channel material for a new class of electronic devices called Mottronics. These devices are based on charge correlations between electrons. Transition metal oxides exhibit a number of phenomena such as electronic phase transitions that are of potential interest for future device applications. However, further progress in material development is required to make high quality thin films of prototypical Mott materials available, and to establish methods to control their electronic phase (insulating or metallic). The research team investigated the electronic properties of $LaTiO_3$ thin films using the I09 beamline, and a combination of soft and hard X-ray photoelectron spectroscopy and valence band photoemission. Their findings are not only important steps in material research on the prototypical correlated compound $LaTiO_3$, they also demonstrate that it is a promising channel material for future Mott transistor devices.

Scheiderer P *et al.* doi: 10.1002/adma.201706708

"The group is designed to provide more extensive internal collaborative research and improved offline facilities to serve the user community."



First discovery of the Holstein polaron

A team of Korean researchers used beamline I05 to make the first experimental discovery of the spectroscopic signature of so-called Holstein polarons, following the first presentation of their theoretical existence in the 1930s. Holstein polarons are small composite particles composed of an electron dragging a cloud of lattice distortions, and were predicted to play a key role in high-temperature superconductivity and solar cells.

The team observed a surface-doped 2D semiconductor, where an anomalous superconductivity with the transition temperature as high as 12 Kelvin was recently reported. They found that the coupling strength between electrons and lattice distortions gradually increases with the charge carrier density, which suggests their importance. This work provides an important stepping stone to the resolution of major issues in condensed matter physics.

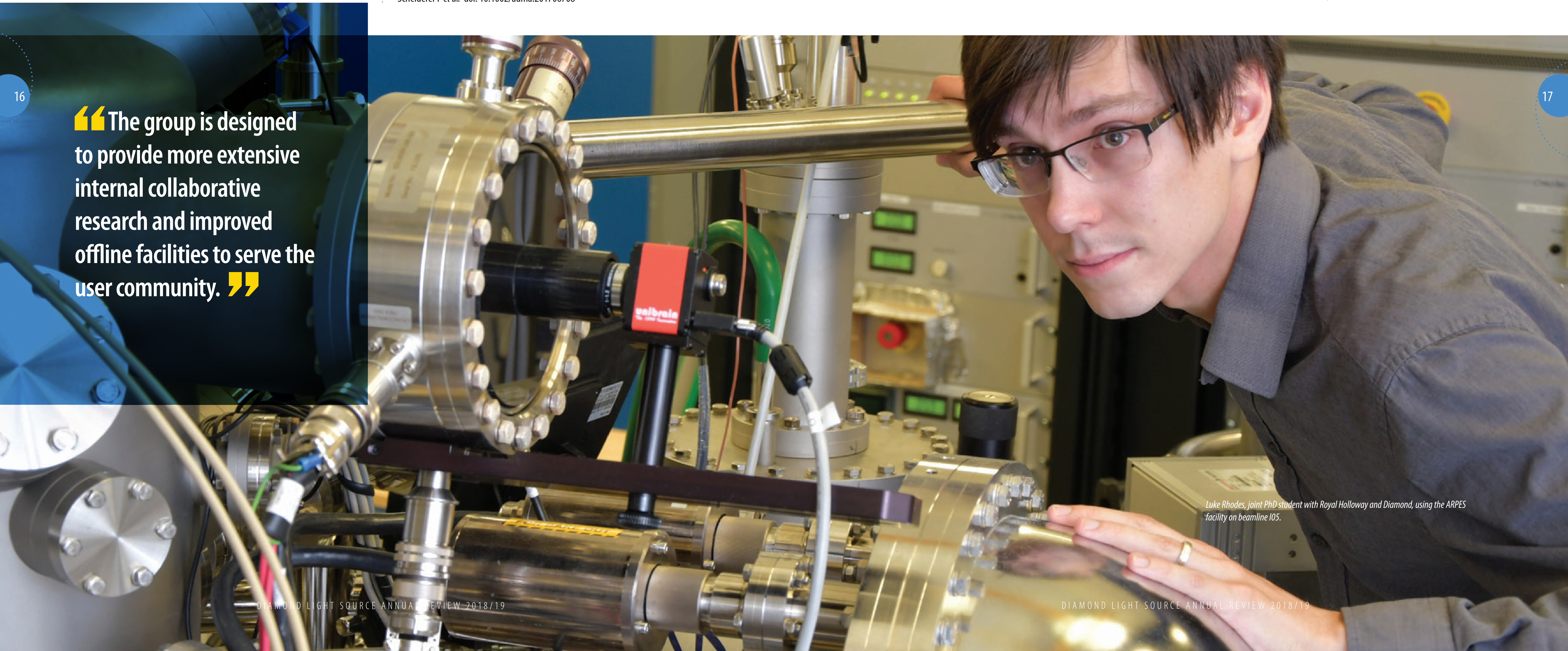
Kang M *et al.* doi: 10.1038/s41563-018-0092-7

Investigating ultra-thin films for new electronic devices

Recent studies of metal-organic frameworks (MOF) in ultrathin films in studies at Diamond will aid the production of new electronic devices. Electrically conductive MOFs are promising materials for electronic devices, owing to their unique capability to adsorb guest molecules. Processing them as ultrathin films is one of the key requirements for the development of electronic devices in areas of key environmental value such as photovoltaics, photocatalysis, or sensing.

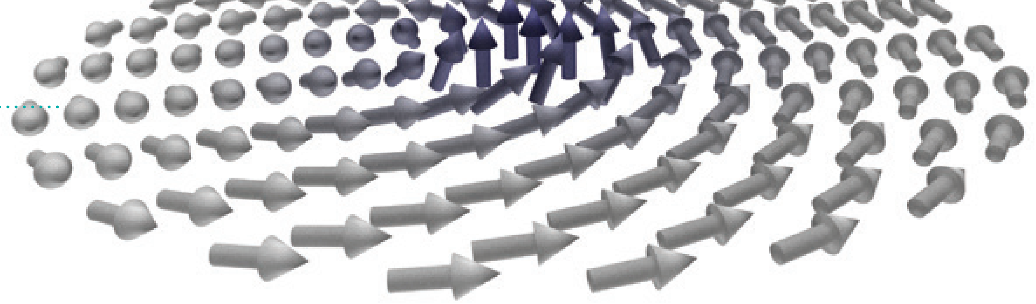
A team of researchers from Valencia University studied ultrathin films of a conductive MOF composed of 2D layers (Cu-CAT-1) and characterised their thickness and chemical purity. They used the Surface and Interface Diffraction beamline (I07) to get detailed information about the crystallinity and preferential orientation with respect to the surface of the substrate, and to combine this information with electrical conductivity measurements. The results will aid the production of high-quality MOF films on a wide variety of substrates and to control their orientation, crystallinity, homogeneity and thickness.

Rubio-Gimenez V *et al.* doi: 10.1002/adma.201704291



Luke Rhodes, joint PhD student with Royal Holloway and Diamond, using the ARPES facility on beamline I05.

Magnetic Materials Group



The Magnetic Materials Group concentrates on work at the frontiers of condensed matter physics, materials science and engineering ranging from topological states of matter, superconductivity, spintronics (the study of electron spinning and associated magnetism in solid state devices), two-dimensional systems, skyrmions (particles that may provide new forms of data storage) and multiferroics.

The group comprises scientists and engineers working across five beamlines (I06, I10, I16, B16 and I21) covering the soft to hard X-ray range, and a variety of techniques, from resonant X-ray scattering, coherent diffraction imaging, photoemission electron microscopy to absorption spectroscopy.

Recent studies at Diamond have included early research in new forms of data storage, the design of energy-efficient IT components and new techniques to measure interactions of electrons.

Developing energy efficient data storage

A research team from Diamond Light Source, the University of Oxford, and the University of Wisconsin-Madison have recently published work that could lead to a major breakthrough in data storage and eventually replace silicon technology. The team produced and studied a new iron oxide/cobalt material that contained magnetic vortices which would protect stored information from thermal fluctuations. They used X-ray Photoemission Electron Microscopy (X-PEEM) on the Nanoscience beamline (I06) to visualise the vortices. They also managed to manipulate the vortices with a magnetic field, and observed the presence of what could be interpreted as 'bits' of magnetic information in the cobalt layer, in the form of a different type of magnetic knot known as a 'meron'.

In spite of its extraordinary success till now, the use of silicon for data storage is energy inefficient and much research is underway to develop environmentally friendly and cost-efficient alternatives. If the results from this study are confirmed by higher-resolution data, the existence of 'merons' would be extremely exciting. Further beamtime at Diamond has been allocated for a new experimental campaign to control the density of magnetic vortices, and to investigate their presence in other materials and architectures.

Chmiel FP *et al.* doi: 10.1038/s41563-018-0101-x

"Recent studies at Diamond have included early research in new forms of data storage, the design of energy-efficient IT components and new techniques to measure interactions of electrons."

The Magnetic Materials Group Mechanical & Electrical Technicians that underpin the research across the facilities of the group, from left to right, back: Tom Rice, Chris Callaway, Andy Malandain, Ryan Russell. Front: Matthew Hilliard, Lee White, Mark Sussmuth, Richard Mott, Mike Matthews, Sam Embling.

Improving understanding in condensed matter physics

An international team of researchers has demonstrated a new method for studying the microscopic structure of chemical bonds, the valence electron density of crystals, and light-matter interactions at the atomic-scale resolution, using synchrotron radiation. The goal of the work was to develop a technique that provides spectroscopic and structural information on valence electrons in a single measurement, and this new approach now allows the measurements of atomic scale interactions of valence electrons.

The research group used beamline I16 due to its high photon flux, the high collimation of the X-ray source, and the combined energy resolution of the monochromator-analyser setup. They combined spectroscopic information with structural information to enhance understanding of microscopic inter-molecular processes. Their results provide the first observation of parametrically down-converted X-ray signal photons at optical wavelengths. They demonstrated that the conversion of X-rays into optical photons can be used as a new tool to probe microscopic valence charge densities and optical properties of materials on the atomic scale.

Schori A *et al.* doi: 10.1103/PhysRevLett.119.253902

Designing the next generation of memory devices

A joint UK/China study has allowed new insights into the structure of magnetic skyrmions. These are particles within magnetic materials that allow increased storage density and require less energy, and are therefore promising candidates for the next generation of memory devices.

The established methods for studying skyrmions such as neutron diffraction and electron microscopy are not sensitive to the near-surface region of a sample, which is the area most relevant for applications. Therefore, the research team used the soft X-ray diffractometer RASOR on the Beamline for Advanced Dichroism (I10) to obtain the detailed 3D structural information of the skyrmion lattice state. They designed a new X-ray technique for the direct measurement of the helicity angle – a quantity that is characteristic for the different types of skyrmions. They were able to fully reconstruct the detailed structure of the skyrmion lattice as a function of depth, which is crucial information for enabling future skyrmion-based devices.

Zhang SL *et al.* doi: 10.1073/pnas.1803367115

Imaging and Microscopy Group

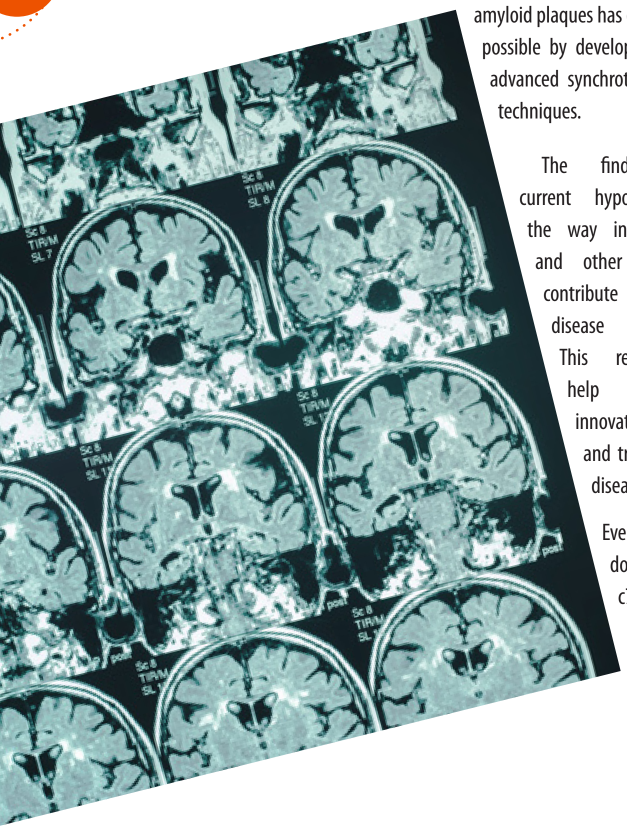
Imaging and Microscopy brings together eight experimental facilities (Beamlines I08, I12, I13-1, I13-2, I14, the new J08 branchline, Dual Imaging and Diffraction (DIAD) and the electron Physical Science Imaging Centre (EPSIC)) into one imaging group. These facilities use electrons and X-rays to image samples under different experimental conditions across a diverse range of length scales and time scales. Different contrast mechanisms allow for imaging of sample properties such as elemental composition, density and structure in minute detail. The facilities are therefore valuable for a wide range of scientific areas, from chemistry and catalysis to environmental science, materials science, biology, medicine and cultural heritage.

Studies performed this year included developing greater understanding of Alzheimer's disease, improving new 3D printing techniques and optimising data from soft tissue samples.

Characterising amyloid plaques in Alzheimer's disease

A combined US/UK research team has used X-ray spectromicroscopy on the Scanning X-ray Microscopy beamline (I08) at Diamond to characterise the precise distribution and chemical state of iron and calcium compounds within the amyloid plaques found in the brains of people with Alzheimer's disease. Both compounds are suspected of playing a role in the development of the disease.

The team were able to examine the plaques at nanometre resolution, while simultaneously allowing high chemical sensitivity to identify differences in metal chemistry within very localised regions of interest. They also used X-ray Magnetic Circular Dichroism to probe the magnetic state of the iron within the amyloid plaques. This level of characterisation of inorganic compounds in amyloid plaques has only been made possible by development of these advanced synchrotron microscopy techniques.



The findings extend current hypotheses about the way in which these and other metals may contribute to Alzheimer's disease development. This research could help direct future innovative diagnosis and treatment of the disease.

Everett J *et al.* doi: 10.1039/c7nr06794a

Improving 3D printing processes

A team from Diamond Light Source and the University of Manchester used high-energy X-ray imaging on beamline I12 to optimise 3D printing techniques and develop the next generation of 3D printers and materials.

Laser additive manufacturing (LAM) is a type of 3D printing that is becoming widely adopted across a wide range of industries. The technique uses a laser beam to melt powder particles in layers to produce solid objects including jewellery, sports equipment and dental implants. However, the process has been difficult to optimise and results in some defects which has meant that LAM cannot be used to construct safety-critical objects such as biomedical devices.

The team was able to record the entire LAM process up to 10,000 frames per second to give detailed information on the melting process. This work clarifies aspects of the physics behind LAM, which had previously only been known in theory and will be critical for the future development of the technique.

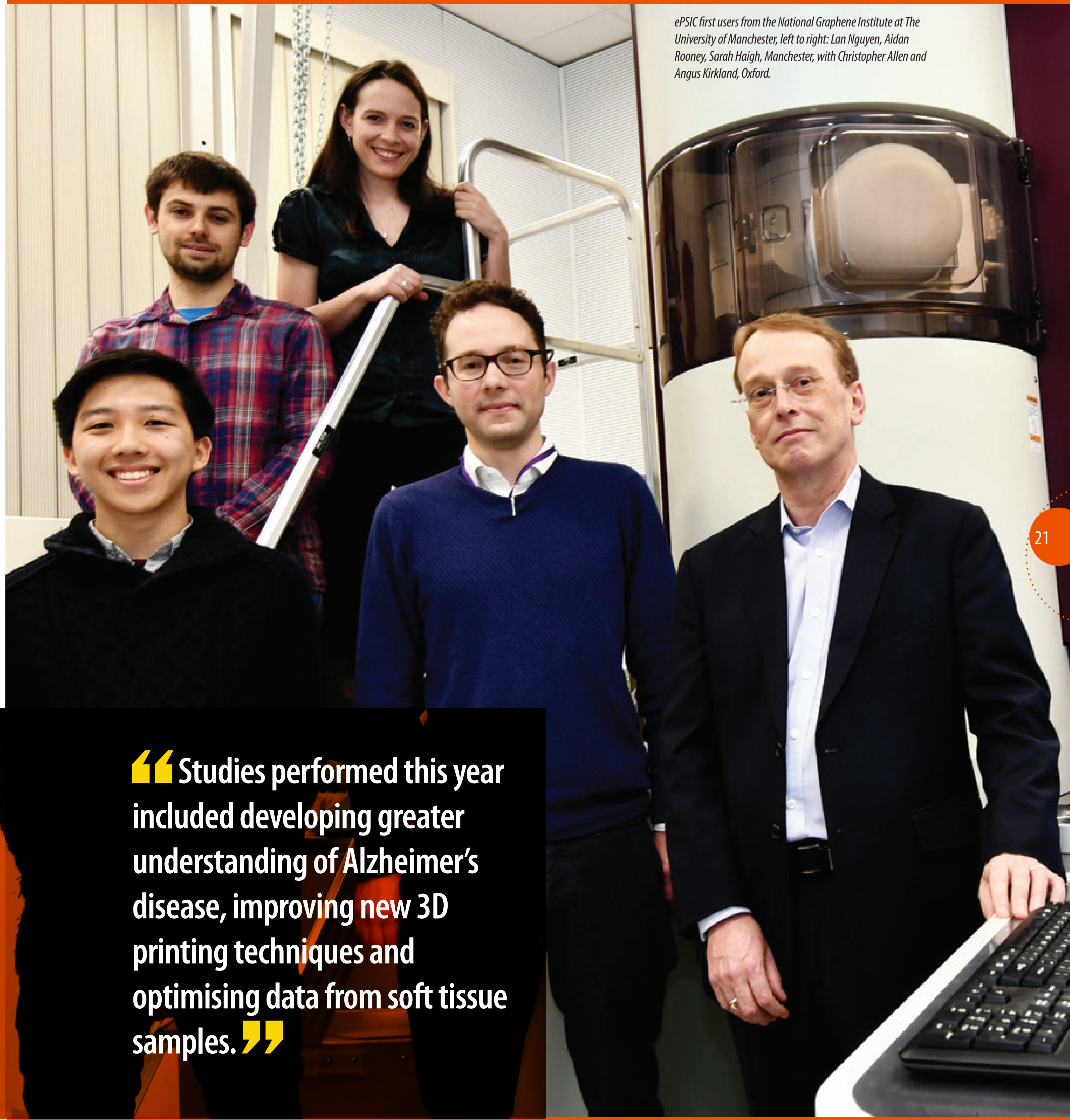
Leung C *et al.* doi: 10.1038/s41467-018-03734-7

Optimising data from soft tissue samples

A team from the Wolfson Centre for Age Related Diseases at King's College London have identified synchrotron micro-computed tomography (SR-μCT) on the Diamond-Manchester Imaging Branchline (I13-2) as an optimal technique to maximise information derived from precious soft tissue samples. The team were able to use this 3D imaging followed by reversible wax embedding with contrast enhancing iodine staining and subsequent histology to show spinal cord features and unprecedented cellular-level detail to track how disease spreads through spinal tissue. 2D histological stains and antibody markers used on these tissues could be aligned to 3D datasets, demonstrating the compatibility of the techniques.

Previous techniques used on soft tissue samples either damaged the samples or were too slow to image samples at a useful spatial resolution. This study opens the door to future studies that could accurately characterise pathology in soft tissues across extended tissue regions, or compare large numbers of samples comprising multiple time points and treatments.

Strotton MC *et al.* doi: 10.1038/s41598-018-30520-8



ePSIC first users from the National Graphene Institute at The University of Manchester, left to right: Lan Nguyen, Aidan Rooney, Sarah Haigh, Manchester, with Christopher Allen and Angus Kirkland, Oxford.

> "Studies performed this year included developing greater understanding of Alzheimer's disease, improving new 3D printing techniques and optimising data from soft tissue samples."

Crystallography Group

The Crystallography Science Group comprises beamlines I11, I15, I15-1 and I19, and gathers Diamond's technical and scientific expertise in crystallography together to provide a platform for future development and pioneering experiments. The group's beamlines use various X-ray scattering and diffraction techniques to study structural properties of crystalline, amorphous and liquid materials in different conditions. These powerful facilities are used in a wide range of science disciplines, from Condensed Matter Physics, Chemistry, Engineering, Earth and Materials to Life Sciences.

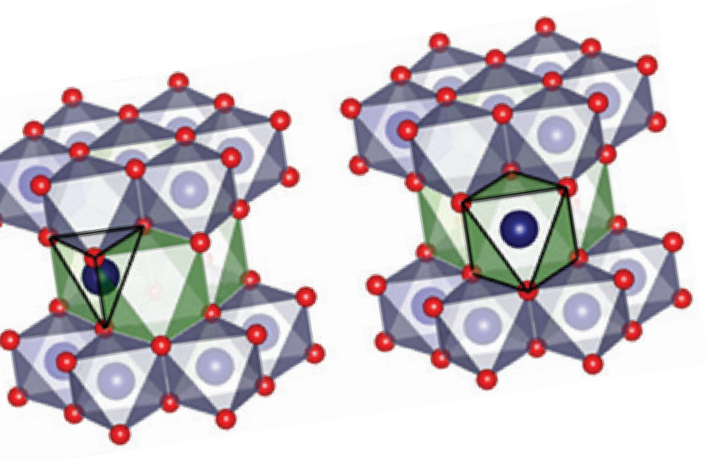
Studies in 2018 have included improving the design of lithium-ion batteries and the development of new materials with the potential for a vast range of industrial applications including the purification and storage of gases, and data recording and storage.

Improving lithium-ion car batteries

A new German/UK study provides clear evidence of the microscopic changes that take place in lithium-ion batteries which currently limit their effectiveness. This work could lead to significant advances in the design of lithium-rich cathode materials to reduce the cost of batteries and increase the range of electric vehicles, which are both urgently required to support the development of eco-friendly transport.

Current lithium oxide cathode materials have poor capacity retention and voltage fade. Understanding the fading mechanism at a microscopic level is the first step to improving their cycling stability. Using the High-Resolution Powder Diffraction beamline (I11) allowed researchers to collect high-resolution, time-resolved measurements over the critical first cycle, followed by regular long-term data collections over the subsequent 100+ charge-discharge cycles. The research showed, for the first time, that irreversible migration of transition-metal atoms occurs upon battery cycling. Future investigations will need to focus on how transition-metal motion can become completely reversible to ensure high capacity retention during cycling.

Kleiner K *et al.* doi: 10.1021/acs.chemmater.8b00163



Designing new industrial materials

An international team of researchers has been investigating combinations of new materials that have great potential in many industrial applications. Metal-organic frameworks (MOFs) are promising materials for gas and liquid storage, purification and separation. They are known as 'molecular sponges' as they are the most porous materials yet discovered.

The research team has been investigating combinations of several different types of glass that were created by melting MOF crystalline structures. They used Pair Distribution Function (PDF) measurements on the X-ray Pair Distribution Function (XPDF) beamline (I15-1), combined with electron microscopy, and differential scanning calorimetry, to examine the structure of the MOF glassy mixtures to see how they mix. Their results showed that the basic metal-organic ligand connectivity of the crystalline MOF state remains unaffected in each of the individual glass domains present in the material, which is an important step in designing new materials.

Blanc F *et al.* doi: 10.1038/s41467-018-04553-6

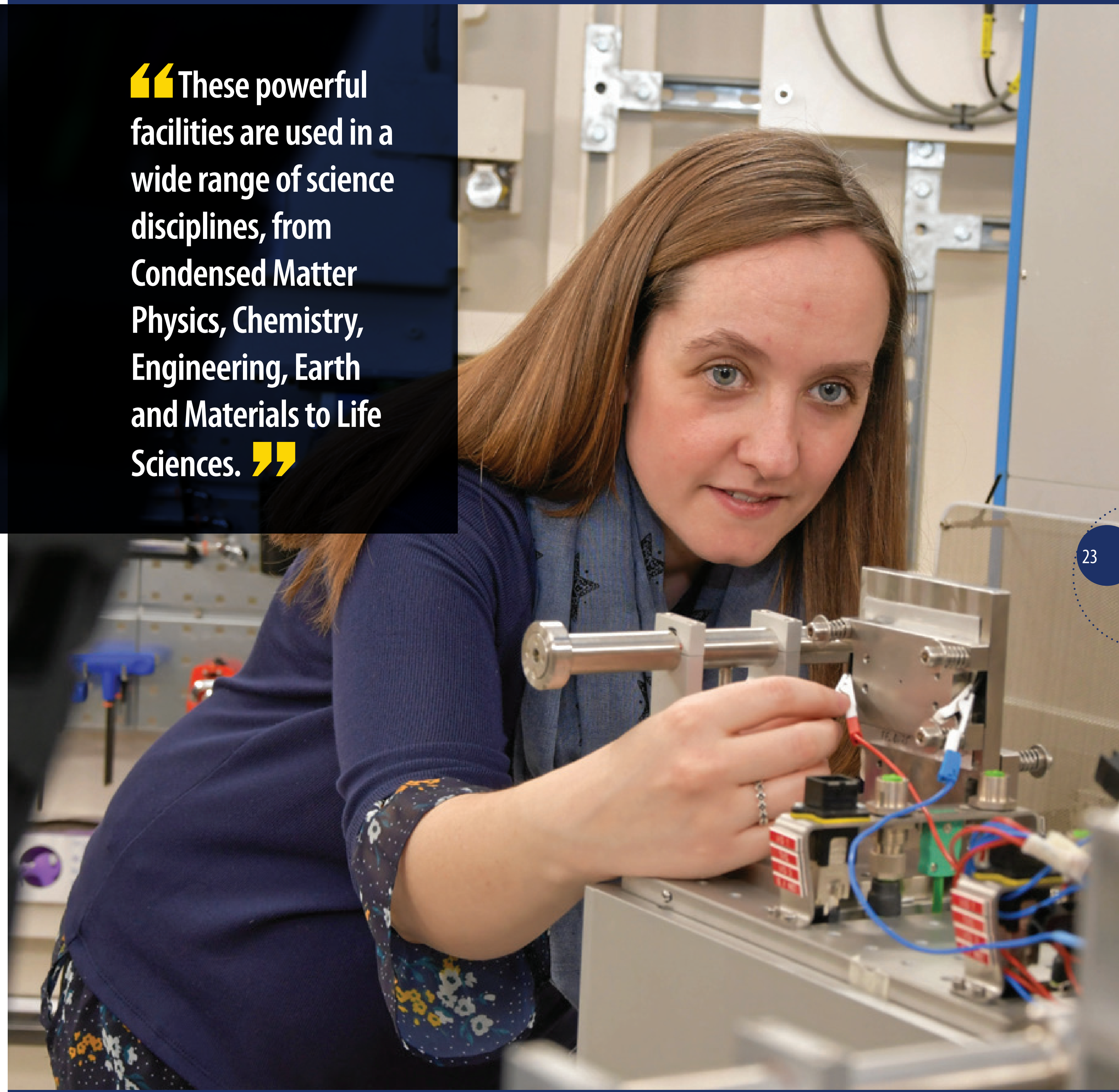
Breakthroughs in new data storage

A study on the Small-Molecule Single-Crystal Diffraction beamline (I19) has provided researchers with new insights into the complex crystal structures of hexaferrites. These are an important class of magnetic oxides with applications in data storage and electronics that have been the subject of numerous studies since their discovery in the 1950s.

However, the availability of modern characterisation methods opens the possibility of accessing new complex stacking sequences and associated properties that lie beyond those that could be studied and understood with previously available tools. The team were able to grow a series of complex hexaferrite crystals, and solve their atomic-level crystal structure using high-resolution synchrotron X-ray diffraction, electron diffraction and imaging methods, and their physical characterisation by magnetometry. They determined the single-crystal structures of nine hexaferrite materials, including a new hexaferrite stacking sequence with the longest lattice parameter of any hexaferrite to have its structure fully determined. This work will be vital in exploring new applications in recording and data storage devices and electrical components such as antennae.

Delacotte C *et al.* doi: 10.1107/S2052252518011351

"These powerful facilities are used in a wide range of science disciplines, from Condensed Matter Physics, Chemistry, Engineering, Earth and Materials to Life Sciences."



Senior Support Scientist Sarah Day working on the LDE battery pouch cell experiment on I11.

Spectroscopy Group

The Spectroscopy Group consists of four beamlines: the Microfocus Spectroscopy beamline (I18) the Core Extended X-ray Absorption Fine Structure (EXAFS) beamline (B18), and the two independently operating branches of the Versatile X-ray Absorption Spectroscopy (XAS) beamline, I20-Scanning and I20-EDE (Energy Dispersive EXAFS).

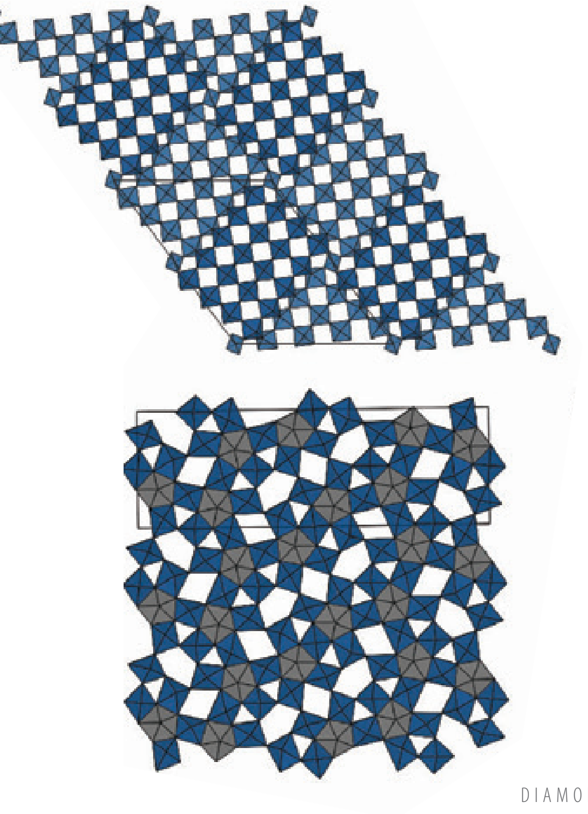
Each beamline has its unique characteristics and is optimised for performing different types of experimental studies covering a wide range of scientific disciplines, from chemistry and catalysis to environmental and life sciences, materials science, hard condensed matter and cultural heritage. In the past year studies have been performed on lithium-ion battery materials, on new drug candidates to penetrate tumours, and on developing highly efficient catalytic converters for diesel engines.

New fast charging and high-power battery materials

A team from the University of Cambridge studied a new material that could improve the charging speed and storage capacity of rechargeable batteries for use in electric vehicles and mobile devices. Niobium tungsten oxide is able to store an unexpectedly large quantity of energy and the team used the Core X-ray Absorption Spectroscopy (XAS) beamline (B18) to investigate the chemical changes that occur in these materials.

Their results showed that both niobium and tungsten ions are able to store 'extra' charge in the battery, beyond what is usually expected, and that they work together. This is different from many battery materials containing multiple types of ion, where they are usually not active at the same time and some are not active at all. The new battery material is designed to be used as the negative electrode (anode), and to work with any of the many positive electrodes (cathodes) that are used in commercial lithium-ion batteries. Further studies on this material are eagerly expected.

Griffith KJ *et al.* doi: 10.1038/s41586-018-0347-0



Studying new anticancer therapies

A new osmium-based anticancer drug candidate called FY26 has been shown to penetrate a tumour model effectively. A research team from the University of Warwick used the Microfocus Spectroscopy beamline (I18) which can resolve individual cells within a model tumour and has high sensitivity to detect the drug at low concentrations to see how the drug would behave in tumours before it was tested in clinical trials.

The X-ray fluorescence maps clearly showed effective drug penetration and also demonstrated that FY26 can alter the distribution of zinc and calcium, which plays a role in cancer cell death. These findings are encouraging in the light of increasing resistance to some of the most effective current anticancer therapies that use platinum, and provide a strong platform on which to conduct further trials of the drug.

Sanchez-Cano C *et al.* doi: 10.1016/j.jinorgbio.2018.04.014

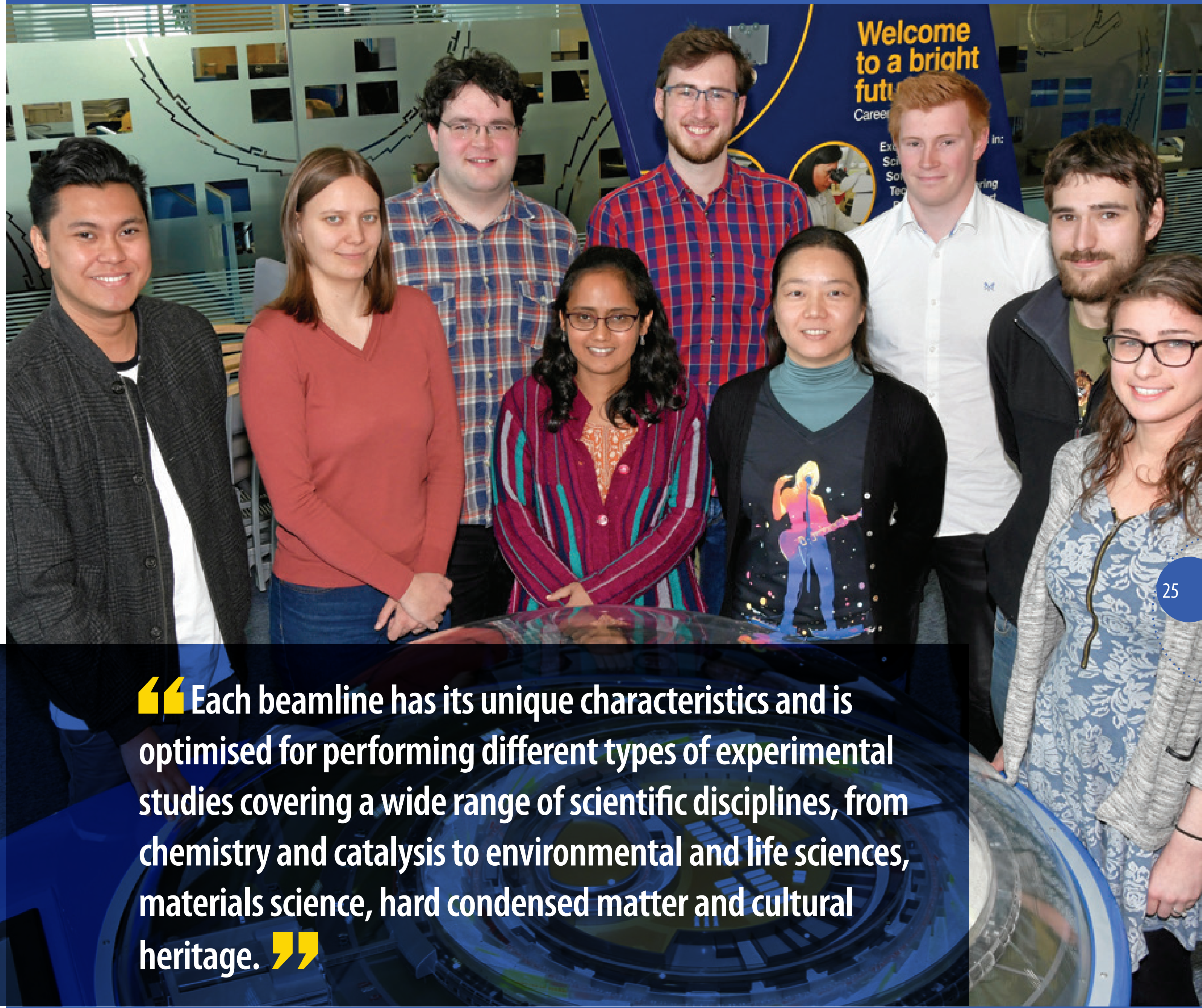
Improving the effectiveness of catalytic converters

Studies on the scanning branch of the versatile X-ray absorption spectroscopy beamline (I20-Scanning) have identified iron species that are highly efficient at catalysing toxic nitrogen oxides (NO_x) in diesel fumes into harmless nitrogen and water. Although iron-based microporous materials are known to be active catalysts for NO_x removal, it is still not clear which combination of iron species and porous structure give the best performance.

The research team from University College London, the Research Complex at Harwell and Diamond collected X-ray Absorption Near Edge Structure (XANES) and X-ray Emission (XES) spectra, which allowed them to extract detailed chemical information of the iron species.

Their study suggests that the best performing material contains isolated octahedral Fe^{3+} species. This knowledge can now be used to develop more efficient catalysts to minimise the polluting impact of diesel engines.

Beale AM *et al.* doi: 10.1016/j.apcata.2018.11.026



"Each beamline has its unique characteristics and is optimised for performing different types of experimental studies covering a wide range of scientific disciplines, from chemistry and catalysis to environmental and life sciences, materials science, hard condensed matter and cultural heritage."

Spectroscopy PhD students and PDRAs, from left to right: James Bucag, Iuliia Mikulska, Evan Lynch, Sylvia Britto, Pip Hellier, Tathiana Kokumai, Alex Mayer, Steve Richards, Hayley Simon.

Soft Condensed Matter Group

This group of beamlines (B21, B22, I22 and B23) can analyse a range of samples that include two-dimensional thin films (photovoltaics), living mammalian cells, three-dimensional matrices (metal-organic frameworks) and nano-particles in non-crystalline states. The group provides the infrared (IR) and Circular Dichroism (CD) spectroscopy and both Small and Wide-Angle X-ray Scattering (SAXS and WAXS) capabilities of Diamond.

There is a dedicated laboratory space for visiting users which houses vital equipment for sample preparation and analysis such as centrifuges, a small tissue-culture facility, spectroscopy equipment and the ability to work with different gases.

Studies from this group over the past year have included new insights into the development of acute myeloid leukaemia, the early detection of multiple sclerosis and the infrared analysis of living cells.

Understanding how leukaemia develops

A recent study at Diamond has shown how acute myeloid leukaemia (AML) cells are able to alter the body's natural defence system in order for the disease to progress. A team of UK researchers used Synchrotron Radiation Circular Dichroism (SRCD) spectroscopy on beamline B23 to study the interactions of the AML cell-specific receptor with its natural ligand, commonly present in the blood and surface of the endothelium. This receptor is responsible for the activity of one of the crucial immune evasion pathways operated by AML cells.

The team were able to discover that AML cells used the so-called 'stress hormone' cortisol to increase the surface presence of latrophilin 1, a receptor protein that is normally found in neurons and stem cells. Increased production of this protein was shown to increase the secretion of chemicals called immune suppression factors which damage the immune system and allow the AML to spread. This work will help in the search for effective therapies against this rapid and often fatal disease.

Sakhnevych S *et al.* doi: 10.1038/s41423-018-0053-8

Towards the earlier detection of multiple sclerosis

A team of Israeli researchers have been able to identify, for the first time, the critical conditions that alter the myelin sheath that surrounds nerves and which lead to the development of the auto-immune disease multiple sclerosis, which affects more than 2.3 million people worldwide and has no cure.

It is well known that fatty, membranous materials (such as myelin) can organise into a variety of shapes, including stacked sheets (lamellae), tubes, or cubes. Controlling these phases is essential to proper function. The researchers used the Small Angle Scattering & Diffraction beamline (I22) to map the delicate and complicated force balance between the myelin sheath constituents and their effect on the myelin structure. They were able to compare the structures of healthy and diseased myelin and showed the structural phase transition in myelin composition between the different states.

The study showed that myelin lipid composition, and the physiological environmental conditions, are critical for myelin to function properly. These observations could provide valuable early warnings for the development of multiple sclerosis.

Shaharabani R *et al.* doi: 10.1073/pnas.1804275115

Analysing living cells in their natural environment

Researchers from Diamond and the Universities of Salford and Manchester have designed a new dynamic cell system that allows scientists to analyse living cells with visible and infrared (IR) microscopy in their natural environment for the first time. The team used the Multimode Infrared Imaging And Microspectroscopy (MIRIAM) beamline (B22) and modified a commercially-available liquid sample holder with a narrow gap for the cells to sit in, and just enough water to stay alive, without inducing mechanical stress.

Previously, study of living cells in their aqueous environment has been a challenge for researchers as the presence of water obscures key biological information and prevents high quality data from being gained. This system allows cell viability for up to 24 hours and is potentially suitable for a range of live cell applications of IR microspectroscopy. It is now available to other infrared users of Diamond and paves the way for further dynamic flow studies of cells which could be useful in providing insights into diseases and drug-cell interactions.

Doherty J *et al.* doi: 10.1039/c8an01566j

Principal Beamline Scientist, Nathan Cowieson, on beamline B21.

"Studies from this group over the past year have included new insights into the development of acute myeloid leukaemia, the early detection of multiple sclerosis and the infrared analysis of living cells."

Integrated Facilities

Diamond Light Source is uniquely placed; with a large number of integrated facilities and scientific collaborations on site, Diamond is a powerful resource for advancing research and allowing for growth. These complementary assets continue to allow us to be a leading facility enabling inter- and multi-disciplinary research.

Diamond's integrated facilities have continued to expand and improve, allowing more in-depth and longer-term research to take place, taking full advantage of the expertise here on campus.

eBIC

The electron Bio-Imaging Centre (eBIC) is the first high-end cryo-electron microscopy (cryo-EM) facility worldwide to be embedded in a synchrotron following the award of a £15.6 million grant from the Wellcome Trust, the Medical Research Council (MRC), and the Biotechnology and Biological Sciences Research Council (BBSRC). It is a 'one-stop shop' for structural biology, and one of the largest cryo-EM sites in the world.

eBIC provides scientists with state-of-the-art equipment and expertise for single particle analysis and cryo-electron tomography. Users can combine these techniques with many of the other cutting-edge approaches at the synchrotron. For the academic user programme the facility houses four Titan Krios microscopes, a Talos Arctica, and a Scios cryo-FIB/SEM. A partnership with the University of Oxford also allows users to access the Krios microscope in Oxford.

At the 2018 opening ceremony, Nobel Prize winner Dr Richard Henderson said that, "Coupling [cryo-EM] techniques with the capabilities at Diamond creates a unique environment that will help keep the UK at the forefront of world-leading science." Collaboration with Thermo Fisher Scientific further expands Diamond's cryo-EM capability by providing two new dedicated microscopes and professional cryo-EM services designed exclusively for the pharmaceutical industry. The new instruments have been installed, and the industrial programme is now underway.

To date, eBIC has produced 65 user publications, and held its first user meeting in April 2019 in Nottingham in collaboration with CCP-EM and their Spring Symposium.

ePSIC

The electron Physical Science Imaging Centre (ePSIC) at Diamond is a national centre for aberration-corrected transmission electron microscopy. Since its opening in 2017, researchers from around the world have brought their samples to ePSIC to image their atomic structure with sub-ångström resolution.

The two transmission electron microscopes in the centre, a JEOL ARM 200 and a JEOL GRAND ARM 300, were brought to Diamond through collaboration with Johnson Matthey and Oxford University respectively. The combined capabilities of these two instruments have enabled ePSIC to become an international leader in cutting-edge material science electron microscopy and a unique resource within the UK.

The facility attracts established electron microscopists looking to develop new techniques and scientists with limited previous electron microscopy experience. The collaboration of the expert staff at ePSIC with this wide range of users is helping to bring cutting-edge microscopy techniques to the wider material science community.

MPL

The Membrane Protein Laboratory (MPL) is a well-established, state-of-the-art facility that enables membrane protein research, and assists researchers investigating proteins that are embedded in cell membranes. It provides the resources that allow scientists from around the world to visualise their protein of interest on the atomic scale. Many of these proteins are important drug targets and this research is vital in the development of new therapies.

In 2018 the facility moved into the Research Complex at Harwell (RCaH) to be part of the Harwell Cell and Structural Biology Partnership. Andrew Quigley, MPL Facilities Coordinator, said: "We will continue to maintain our close proximity to the beamlines allowing MPL staff and users to collaborate closely with beamline staff to create a highly productive working environment. In addition, the close proximity of the MPL and eBIC will greatly enhance our ability to understand the structures of membrane proteins by cryo-electron microscopy."

XChem

Diamond's XChem facility specialises in X-ray structure-accelerated, synthesis-aligned fragment medicinal chemistry. Integrated into the I04-1 beamline and nearby Lab XChem, it offers a highly streamlined process for full X-ray screening experiments. XChem allows up to 1,000 compounds to be screened individually in less than a week, and the process covers soaking, harvesting automatic data collection and data analysis.

Exciting recent developments have included:

- Release of the alpha version of Fragalysis software.
- Expanded lab capacity and increased XChem beamtimes, to meet increased demand.
- A dedicated XChem support team to assist with research and an XChem Block Access Group (BAG).
- Faster gridscans and X-ray scans to further integrate XChem in the MX workflows.
- Dataset delivery times increasing to around 30 datasets per hour in spring 2019.

XFEL Hub

The XFEL (X-ray Free Electron Laser) Hub at Diamond was initially funded by the Wellcome Trust and the BBSRC to provide expertise and support to the UK community engaged in XFEL-related research; from experimental conception to beamtime proposals, through sample preparations and testing, to XFEL data collection, analysis, and publication.

Recent reviews of the Hub by the Diamond Scientific Advisory Committee and international experts have established it as a centre of excellence within Diamond, and will allow the Hub to continue to provide travel assistance to the UK life scientists who are awarded XFEL beamtime around the world. Ongoing grants from valued funders including the Wellcome Trust and Royal Society continue to build the Hub's reputation around the world.

Exciting research successes from XFEL include a world record for productivity on the LCLS/MFX Instrument (54 data sets of correlated time-resolved serial femtosecond crystallography and time-resolved X-ray emission spectroscopy from about 12 types of metalloenzymes in four 12-hour shifts).

> "Diamond's integrated facilities have continued to expand and improve, allowing more in-depth and longer-term research to take place, taking full advantage of the expertise here on campus."

Nadisha Gamage, Research Technician, working in the MPL.

Industrial Liaison

The industrial user programme continues to flourish and over the past year we have seen record growth that has led to expansion of both the team and the services available for our clients. Over 150 clients worldwide are making regular use of Diamond's facilities and the Industrial Liaison Office (ILO) has supported over 600 different experimental sessions over the past year.

Our industrial users have diversified their use of the facilities available at Diamond. The majority of our clients continue to represent the life science sector, in particular structural biology, and as research and development in this area is driven by increasingly complex and challenging targets, a multi-technique approach is proving vital. Our clients can now access both world leading technology and talent across macromolecular crystallography, fragment-based drug discovery, small-angle X-ray scattering and cryo-electron microscopy (cryo-EM) techniques.

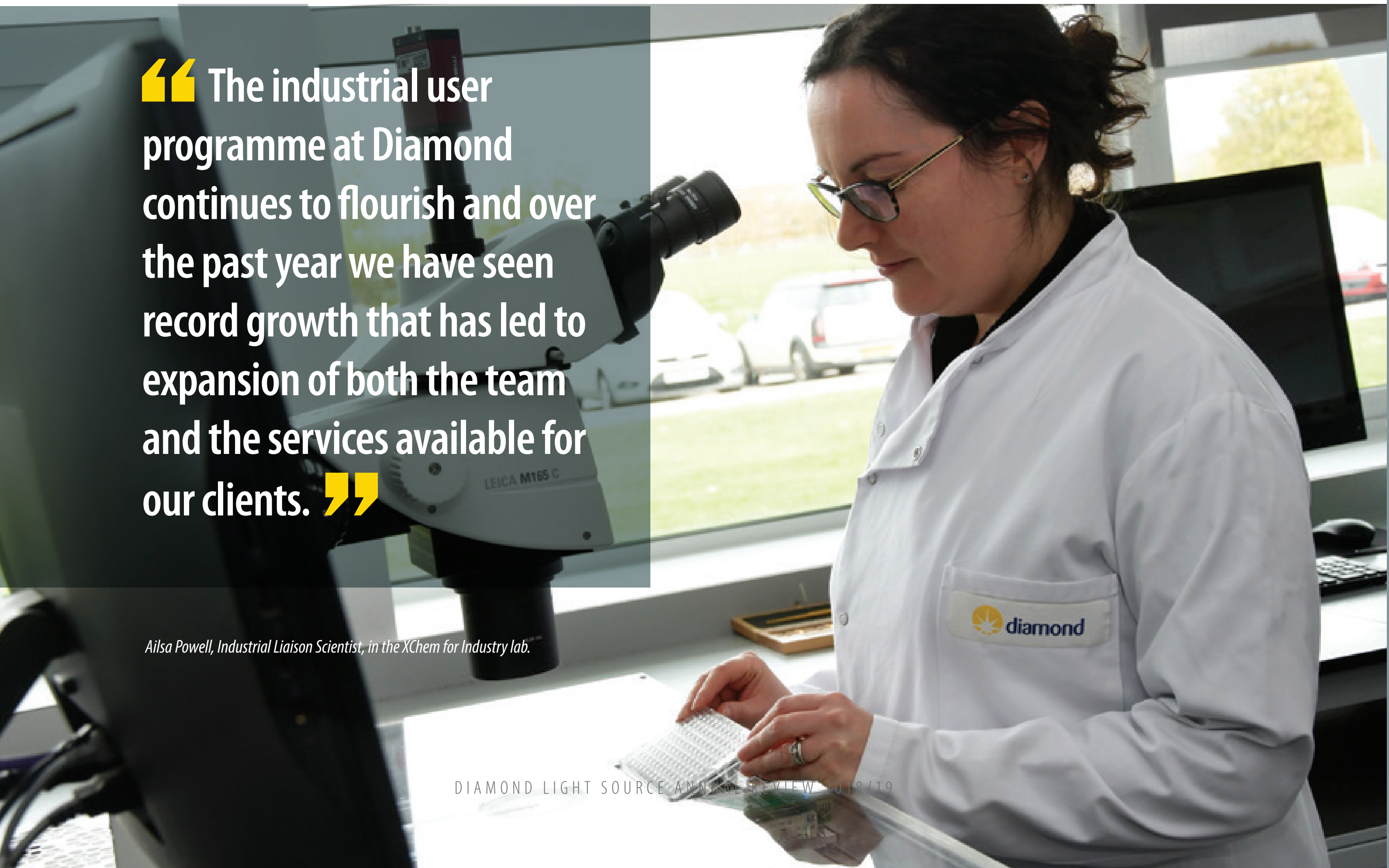
Perhaps our most significant collaboration of 2018 was entering into partnership with Thermo Fisher Scientific to provide two new dedicated microscopes at Diamond for industrial use. This partnership has confirmed the position of the electron Bio-Imaging Centre (eBIC) as one of the largest and most advanced cryo-EM facilities in the world, as part of a hub of complementary advanced synchrotron-based methods to advance our understanding and treatment of viruses and diseases. A key aspect of the partnership is the joint provision of the key expertise needed to exploit these resources fully and offer professional cryo-EM services in sample preparation, cryo-EM screening and high-end data collection, designed exclusively for the pharmaceutical industry.

Fragment-based lead discovery is a drug discovery process that has revolutionised the pharmaceutical industry, providing valuable and cost-effective insights for rational drug design in the early stages. The XChem facility for X-ray structure-accelerated, synthesis-aligned fragment medicinal chemistry, established at Diamond in partnership with the Structural Genomics Consortium, provides a streamlined, secure and effective route to fragment screening. Over the past few years, both academic and industrial user demand has soared, driving the need for expansion and growth. We are delighted to report that over the last year the dedicated XChem for Industry facility has been commissioned and is fully operational.

The ILO has been collaborating with colleagues across the Science and Technology Facilities Council (STFC) in a major funding programme supporting UK companies overcoming product, manufacturing or process performance issues to accelerate productivity. Two companies have recently been awarded funding to work with Diamond under the Bridging for Innovators (B4I) scheme to characterise battery materials and novel vaccines, respectively.

Continuing the theme of collaboration, we have also supported Newton Fund partnerships with Indonesia and Thailand. The Newton Fund's aim is to develop science and innovation partnerships that promote the economic development and welfare of collaborating countries. This work has included delivery of an intensive industrial engagement workshop at the Synchrotron Light Research Institute, Thailand and hosting an Indonesian visiting scientist within the team for a year.

For further information about any of our work with industry, please contact industry@diamond.ac.uk


"The industrial user programme at Diamond continues to flourish and over the past year we have seen record growth that has led to expansion of both the team and the services available for our clients."

Ailsa Powell, Industrial Liaison Scientist, in the XChem for Industry lab.

"Our collaborations have gone from strength to strength over the last few years, with 2018 being no exception. New funding and the evolution of research partnerships have powered world-changing projects this year across many disciplines."

Celebrating the Thermo Fisher Scientific agreement during the official launch of eBIC. Left to right: Dave Stuart, Diamond Light Source, Rishi Matadeen, Dan Shine and Raymond Schrijver, Thermo Fisher Scientific, Jason van Rooyen and Elizabeth Shotton, Diamond Light Source.

Collaborations Update

Our collaborations have gone from strength to strength over the last few years, with 2018 being no exception. New funding and the evolution of research partnerships have powered world-changing projects this year across many disciplines.

University of Manchester at Harwell

The University of Manchester has had a formal partnership with Diamond since 2010, now known as The University of Manchester at Harwell (UoMaH). The UoMaH collaboration is an ongoing relationship of key national players in X-ray imaging, tomography, and providing access to new technology.

The collaboration has initiated activities around research themes in energy storage, extreme environments, fusion, resilience, magnetism, fission, catalysis and data. UoMaH aims to build partnerships with government, facility, industrial and academic researchers at Diamond and Harwell, to discover and develop innovative scientific techniques and technologies, and to act as a portal to facilitate the connections between the university and world-leading capabilities of national facilities like Diamond to deliver social, economic and cultural impact.

UK Catalysis Hub

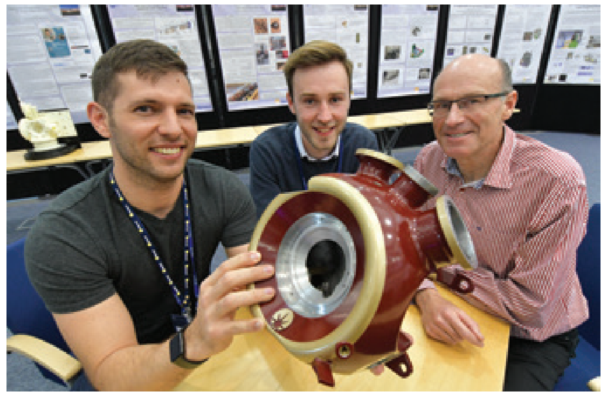
Catalysis is of great significance to the UK's Industrial Strategy, making it a strong area of focus for Diamond. The physical home of the UK Catalysis Hub – a national network with over 35 collaborating universities – is located next to Diamond at the Research Complex at Harwell (RCaH). Established in 2013 with funding from the Engineering and Physical Sciences Research Council (EPSRC), with an additional £14 million in funding from the council committed in October 2018, the Hub seeks to coordinate, promote and advance the UK catalysis research portfolio.

The Hub has a Block Allocation Group on the X-ray Absorption Spectroscopy (XAS) beamline B18. This increases the efficiency of data acquisition and allocates small amounts of time for proof of concept investigations and rapid access for *in situ* and *ex situ* applications before a full study starts. This opportunity is open to every academic working in catalysis in the UK.

Education, Training and Engagement

Over the past year we have continued to communicate the breadth of research and technology undertaken at Diamond, support and learn from our users, and inspire the next generation of scientists. We welcomed just over 6,000 visitors to the facility, which included nearly 1,500 for scientific and technical events and over 3,000 school students and members of the public. Many of the public visitors come to our highly successful Inside Diamond open days. We also hosted a range of large and small, tailored events for schools which included work experience, workshops and open days.

We have continued our valuable collaboration with the engagement teams at the Science and Technology Facilities Council (STFC) and across the rest of the campus to offer visitors access to a wider range of events and experiences and continue to travel further afield to reach a geographically and culturally diverse range of audiences. We are also starting a new exciting project to develop Diamond's first visible light beamline (ViSR), which will offer wonderful opportunities to highlight experimental techniques and experiments to visitors.



Pablo Sanchez Navarro, Frankie Bailey and Stewart Scott look at a 3D printed prototype vacuum vessel, to be used on beamline VMXm, during the Early Career Engineering School.

Higher Education engagement

Our links and support for higher education continue to offer students a range of opportunities to engage with our world-leading staff and resources. The demand for student visits remains high and we supported 22 visits from undergraduate and postgraduate groups, offering a range of access, talks and training.

We currently support 81 students on PhD studentships co-funded with a range of universities and other research facilities, giving students access to a wide breadth of resources and expertise. This is a programme that continues to grow in popularity and we look forward to an additional 19 students joining later in 2019.

Our undergraduate placements continue to be in high demand. In June 2018 we welcomed 14 undergraduates for the summer and another 10 to complete 12-month Year in Industry projects. 2019 has seen no let-up in demand for these placements and from the 843 applicants we look forward to welcoming 25 new undergraduate students in June.

Scientific workshops and conferences

Diamond runs a broad portfolio of workshops, meetings and conferences tailored towards the needs of our staff and user community. These included:

- Two biennial student workshops: the BCA-CCP4 (British Crystallographic Association-CCP4) Summer School and the SR (Synchrotron Radiation) School, which saw a combined intake of over 120 postgraduate students and gave broad-based introductions to key synchrotron techniques.
- A five-day Early Career Engineering School that aimed to provide 60 engineers from around the world with a basic grounding in a range of areas specific to working at a light source.
- A series of scientific workshops in September 2018 to engage with our academic and industrial user communities to explore how the Diamond-II upgrade could best support research and innovation. The useful findings were fed into the Diamond-II Science Case.

Visitor numbers by event type FY 2018/19

Visitors	Event type
1,456	Scientific & Technical
635	PhD & Undergraduate Student
3,176	Public & Schools
779	VIPs & Stakeholders

Students Miya Manzur and Eloise Thompson working in the Health Physics lab during Diamond's work experience week.

> "A wonderful opportunity to see public engagement done really well."
>
> **visitor to recent Inside Diamond open days**

DIAMOND LIGHT SOURCE ANNUAL REVIEW 2018/19

Diamond Light Source Ltd
Harwell Science & Innovation Campus
Didcot, Oxfordshire OX11 0DE
Tel: +44 (0)1235 778 639
Fax: +44 (0)1235 778 499
www.diamond.ac.uk

Acknowledgement:
We would like to thank the authors and all colleagues who contributed to this publication.

MIX
Paper from responsible sources
FSC® C007881
FSC www.fsc.org

Printed on Forest Stewardship Council (FSC) accredited paper stock.

Published May 2019