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CLF Annual Report

2017-2018

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Contents

Foreword

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This annual report for the Central Laser Facility (CLF) at the STFC Rutherford Appleton Laboratory provides highlights of scientific and technical research that has been carried out by users of the Facility and its staff over the financial year 2017-18.

The CLF and its community have continued to deliver scientific output and technical development of the highest order.

Vulcan – has started on the design of a new short-pulse beamline for the Vulcan TAP area. This will be based on the OPCPA technique that the CLF has pioneered and will deliver a PW level pulse (30J in 30fs) in addition to the existing PW (500J, 500fs) and long pulse (250J) capabilities. This will enable new areas of imaging and combined proton/ electron interactions to take place.

Gemini – has maintained its pre-eminent stature as a driver for secondary sources for applications as well as fundamental science, yielding several high-impact papers this year. Highlights include demonstration of radiation reaction — where the radiation emitted by a near-light speed electron beam in presence of an intense field exerts a back action on the electron itself, slowing it down — which was published in Physical Review X.

Artemis – will be moving across campus to the Research Complex at Harwell as part of a major upgrade. The upgraded Artemis will include a new laser system – a mid-IR system running at 100 kHz – which is a joint purchase with Ultra. The laboratories will hold three dedicated XUV beamlines for imaging, photoemission from condensed matter, and gas-phase photoelectron spectroscopy. This year saw detailed planning for the upgraded labs, which will re-open in 2019.

Target Fabrication – has continued to deliver high specification targets to the internal user programme, including development of novel microcone targets for electron guiding. In addition, investment in x-ray CT for characterisation and single point diamond turning for precision machining has expanded the capabilities of the group with world leading technologies. Scitech Precision Limited (the spin out from CLF Target Fabrication) provided microtargets to many national and university laboratories across the world, in addition to supplying precision laser machining services to support the high tech businesses on the wider campus.

Plasma Physics Group – has continued to improve its provision of codes, cluster resources, and direct user support. The group has recently installed a new 1500 core cluster resource, with commissioning taking place in the 2017/18 period.

The CLF's facilities in the Research Complex at Harwell, *Ultra* and *Octopus*, continue to serve a multidisciplinary community, with user programmes in areas ranging from fundamental chemistry and materials science to biomedical and environmental research.

Ultra – delivered 60 weeks of access to the academic community and four weeks to industrial users. The facility continues to develop capability and scientific applications of its non-linear vibrational spectroscopic techniques, for example the use of the surface sensitive technique on studies of earth abundant metal catalyst surface and hybrid Raman-IR 2DIR techniques applied to drug discovery. A new programme was awarded, titled "Time and length scale correlations in biomolecular dynamics", that will provide insights into protein dynamics and advance the facility through the introduction of time resolved 2DIR capability.

Octopus – continues to deliver 100 user weeks per year to the user community. This includes 10 weeks of proof of concept access where prospective users can make short visits for feasibility studies. In addition there has been an increase in access to the facility by industrial users, particularly through the Bridging for Innovators (B4I) programme. A new microscope offering super-resolution microscopy at cryogenic temperatures is now available for users and has already been accessed by a number of groups. Correlative microscopy has continued to be a focus for development, in collaboration with Diamond, eBIC, and the Rosalind Franklin Institute.

The CLF's Centre for Advanced Laser Technology and Applications (CALTA) was established in 2012 to develop a new class of lasers capable of delivering high energy, high peak power pulses at high repetition rate and high efficiency to drive new applications in advanced imaging, materials processing, non-destructive testing and fundamental science. Based on laser diode pumped Ytterbium-YAG in the form of a transparent ceramic, CALTA's DiPOLE Diode Pumped Solid State Laser (DPSSL) architecture has demonstrated stable 1 kW operation for extended periods in 100 J, 10 ns pulses delivered at 10 Hz. With an overall optical efficiency of >20%, DiPOLE systems have the potential to transform single shot demonstrations of effects into real world applications.

Following delivery of the first 1 kW DiPOLE system to the HiLASE Centre in Dolní Břežany, Czech Republic, work is well advanced on the construction of a second system destined for the European XFEL in Hamburg. Funded through a joint STFC / EPSRC research grant, the "DiPOLE 100" will be used to drive materials to high energy density states to be diagnosed using the XFEL x-ray beam. A unique temporal pulse shaping capability, developed specifically for the XFEL application, will enable precise control of the energetic states produced while the high repetition rate will enable rapid accumulation of data for improved measurement accuracy. The system build is nearing completion and commissioning of the first stage of amplification is underway.

Further development of the DiPOLE technology is an essential element of a Widespread Teaming collaboration between STFC and the HiLASE Centre. The €50M project to establish HiLASE as a Centre of Excellence is jointly funded by the EC and the Czech Ministry of Science. STFC is assisting in the establishment of the Centre and is playing a leading role in the development of advanced DPSSL technology. This includes the design and construction of a 100 Hz version of the DiPOLE 10J laser, increasing the pulse energy of the DiPOLE architecture and developing efficient second and third harmonic generation at 10Hz. This will extend STFC's lead at the forefront of DPSSL technology.

Economic Impact – continues to increase, with the CLF building strong relationships with industry. Six new commercial contracts were established with companies this year to gain access to our facilities (Ultra, Octopus and Gemini). Additionally the CLF is building industry partnerships to help solve industrial challenges, and a pilot innovation project between the CLF and India's Tata Institute of Fundamental Research is underway.

In summer 2017, the CLF/STFC spinout company Cobalt Light Systems Ltd was acquired by Agilent Technologies for £40M. The company is based around CLF's patented technology developed at its Ultra facility.
Company products include airport security scanners used at over 75 airports worldwide. Agilent will now develop their global centre for Raman spectroscopy at the Harwell Campus.

Despite an uplift in funding and consequently an uplift in the volume of user access we are able to offer, demand for access to the CLF both from UK and international scientists continues greatly to exceed the time available for the scheduling of experiments. It is not surprising then that the standard of the research presented in this report is excellent, demonstrating once again the internationally leading position of the CLF and our user community. The close partnership we have with our user community remains central to our success, together with the ability and dedication of our staff.

I hope that you enjoy reading this selection of abstracts. Please visit the CLF website to access the full papers and find out more about the exciting times ahead at the CLF!

Professor John Collier FLSW
Director, Central Laser Facility

Overview of the Central Laser Facility (CLF)

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The CLF is a world leading centre for research using lasers in a wide range of scientific disciplines. This section provides an overview of the capabilities offered to our international academic and industrial community.

Vulcan

Vulcan is a highly versatile eight beam Nd: glass laser facility that operates to two independent target areas. The eight beams can be configured in a number of combinations of long (>500 ps) and short (<30 ps) pulse arrangements.

Target Area Petawatt is Vulcan's highest intensity area, capable of 500 J / 500 fs pulses focused to 10^{21} W/cm^2. The ps OPCPA front end ensures that the ASE contrast of the PW system is better than 10^{10} at 1 ns. To complement the short pulse beamline, an additional 250 J long pulse beam line, as well as a variety of possible probe beams, can be configured in the area. A compressor has been installed in the Vulcan front-end to help with characterising the contrast and for the development of new short-pulse diagnostics.

Target Area West is Vulcan's most flexible target area, offering up to eight long pulse beams or two short and six long pulse beams. The two short pulse beams operate independently and can be configured so that one operates at 80-100 J / 1 ps (10^{20} W/cm^2) and the other one at either at 80-100 J / 1 ps or at 300 J / 10 ps in flexible geometries. TAW can be also be configured with all eight beams in long pulse mode by using a compressor by-pass arrangement delivering a maximum of 2.5 kJ with all beams. Temporal pulse shaping is available for long pulse operation and there are a number of focusing, beam smoothing, probe beam and harmonic conversion options.

We have started on the design of a new short-pulse beamline for the Vulcan TAP area. It will be based on the technique of OPCPA which the CLF has pioneered and will deliver a PW level pulse (30 J in 30 fs) in addition to the existing PW (500 J, 500 fs) and long pulse (250 J) capabilities. This will enable new areas of imaging and combined proton/ electron interactions to take place.

Gemini

Gemini is a Titanium-Sapphire based dual-beam high power laser system with two synchronised Petawatt-class beams, enabling pump-probe studies at extreme light intensities (~10^{22} W/cm^2). In recent years, Gemini has emerged as one of the preeminent centres in the world for laser-driven acceleration. Gemini offers a unique capability of generating high quality electron beams with GeV energies, and using them for interactions at extreme conditions generated by its second laser beam. This year, Gemini performed several experiments that utilised this capability, ranging from staged electron acceleration to QED experiments looking to generate electron-positron pairs from intense photon-photon interactions. Gemini also specialises in the application of laser-driven secondary sources. An experiment in Gemini used the betatron emission from a laser wakefield accelerator to image complex microstructures in alloys, and found that the image quality was better than those taken with synchrotrons in some cases. In collaboration with industrial and academic partners, Gemini also performed some proof-of-principle experiments to demonstrate the capability of laser-driven x-ray sources for non-destructive testing in industrial environments.

Artemis

Artemis is the CLF's facility for ultrafast laser and XUV science. It offers ultrashort pulses at high repetition-rate, spanning the spectral range from the XUV to the far-infrared. The facility is configured flexibly for pump-probe experiments. Tuneable or few-cycle pulses can be used as pump and probe pulses, or to generate ultrafast, coherent XUV pulses through high harmonic generation. Two XUV beamlines lead to end-stations for time-resolved photoelectron spectroscopy (for both gas-phase and condensed matter experiments) and coherent lensless XUV imaging. This year, an additional amplifier has been added to the laser system to boost the energy available for high harmonic generation.

Artemis has received funding for a major upgrade, and is re-locating across campus to the Research Complex at Harwell (RCaH), adding a new laser system and a third

XUV beamline. The new 100 kHz laser system operates at 1700 nm and 3000 nm, and is a joint purchase with *Ultra*. Over 2017-18, detailed planning of the project has taken place, for a re-opening of the upgraded facility in 2019.

Octopus and Ultra

The CLF operates two facilities in the RCaH: *Ultra*, for ultrafast molecular dynamics measurements in chemistry and biology, and *Octopus*, a cluster of advanced laser microscopes for life science research.

In the molecular and materials dynamics area *Ultra* offers a state-of-the-art high power high repetition rate fs / ps system to generate pulses for a range of highly sensitive pump and probe vibrational spectroscopy techniques.These techniques capture "movies" of the atomic and molecular dynamics, which can be used to study processes ranging from reactions in nature, energy capture and storage, catalysis and fundamental quantum level research on molecular and bio-molecular electronics, probes, therapeutics, enzymes and DNA. Kerr gated time resolved resonance Raman (TR^3) is unique in enabling highly fluorescent samples to be studied. Time-Resolved Multiple-Probe Spectroscopy (TR^MPS) captures reactions from their earliest beginning on femtosecond timescales to completion on milliseconds timescales. Fast scanning ultrafast 2DIR spectroscopies capture intra- and inter-molecular vibrational coupling and energy transport applied in fundamental molecular dynamics research and in pharmaceutical analytical research. Broad spectral band surface sum frequency generation provides insights into the chemical changes that occur at interfaces and surfaces where many reaction in nature and industry occur.

In the imaging area, the *Octopus* cluster offers a range of microscopy stations linked to a central core of pulsed and CW lasers offering "tailor-made" illumination for imaging. Microscopy techniques offered include total internal reflection (TIRF) and multi-wavelength single-molecule imaging, confocal microscopy (including multiphoton), fluorescence energy transfer (FRET) and fluorescence lifetime imaging (FLIM). Super-resolution techniques available are Stochastic Optical Reconstruction Microscopy (STORM) with adaptive optics, Photoactivated Localization Microscopy (PALM), Structured Illumination Microscopy (SIM) and Stimulated Emission Depletion Microscopy (STED), Light Sheet Microscopy, and super-resolution cryo-microscopy. Laser tweezers are available for combined manipulation/ trapping and imaging with other *Octopus* stations, and can also be used to study Raman spectra and pico-Newton forces between particles in solution for bioscience and environmental research.

Chemistry, biology, and spectroscopy laboratories support the laser facilities, and the CLF offers access to a multidisciplinary team providing advice to users on all aspects of imaging and spectroscopy, including specialised biological sample preparation, data acquisition, and advanced data analysis techniques. Access is also available to shared facilities in the Research Complex, including cell culture, scanning and transmission electron microscopy, NMR, and x-ray diffraction.

Engineering Services

Engineering is fundamental to all the operations and developments in the CLF. Mechanical, electrical and computing support is provided for the operation of the laser facilities, for the experimental programmes on these facilities and for the CLF's research and development activities. The engineering team operates across all of the CLF's facilities, and endeavours to continually improve and expand the capabilities and reliability of the CLF. Mechanical and electrical CAD tools and workshop facilities enable a rapid response.

Theory and Modelling

The Plasma Physics Group supports scheduled experiments throughout the design, analysis and interpretation phases, as well as users who need theoretical support in matters relating to CLF science. We support principal investigators using radiation hydrodynamics, particle-in-cell, hybrid and Vlasov-Fokker-Planck codes, as well as by providing access to large-scale computing. Access to the PRISM suite has been renewed for a further year, as endorsed by the CLF User Forum. Support for student training in plasma physics, computational methods and opportunities for networking with colleagues will continue to be provided. Extended collaborative placements within the group are particularly encouraged.

In 2017 the group successfully bid for £300k of capital funding. This will be used to acquire a new 1500 core cluster resource that will be hosted by SCD as part of the SCARF infrastructure.

Target Fabrication

The Target Fabrication Group makes almost all of the solid targets shot on the CLF's high power lasers. A wide variety of microtarget types are produced in collaboration with the user community to enable the exploration of many experimental regimes. The integrated range of fabrication techniques includes thin film coating, precision micro assembly, laser micromachining, and chemistry processes, all verified by sophisticated characterisation. Additionally the advanced capabilities within STFC in both high precision micro machining and MEMS microfabrication are utilised. The Target Fabrication Group is ISO9001 accredited and consequently provides a high level of traceability for all supplied microtargets. The Group is also responsible for the production of targets for academic access shots on the Orion Facility at AWE. Commercial access to target fabrication capabilities is available to external laboratories and experimentalists via the spin-out company Scitech Precision Ltd.

In the reporting year, the Diamond Point Turning machine was commissioned by the Precision Development Facility in RAL Space and began producing surfaces of a few nm roughness. The x-ray CT system was also commissioned, giving high precision of the internal structure of microtargets. The programme for high repetition rate solid targetry was extended by fielding the high accuracy tape target system on a Gemini experiment.

Centre for Advanced Laser Technology and Applications (CALTA)

The CLF's **C**entre for **A**dvanced **L**aser **T**echnology and **A**pplications **(CALTA)** was established in 2012 to develop a new class of lasers capable of delivering high energy, high peak power pulses at high repetition rate and high efficiency, to drive new applications in advanced imaging, materials processing, non-destructive testing and fundamental science. Based on laser diode pumped Ytterbium-YAG in the form of a transparent ceramic, CALTA's DiPOLE Diode Pumped Solid State Laser (DPSSL) architecture has demonstrated stable 1 kW operation for extended periods in 100 J, 10 ns pulses delivered at 10 Hz. With an overall optical efficiency of >20%, DiPOLE systems have the potential to transform single shot demonstrations of effects into real world applications.

Hosting CALTA at the STFC's Central Laser Facility enables DiPOLE technology and associated applications to be developed in the shortest possible time. CALTA draws on CLF infrastructure and expertise (cleanrooms, optical metrology and advanced diagnostics, etc.), STFC's capability in cryogenics and high performance computing, and commercial connections within the Business and Innovation Department. Rapid access to these resources is fundamental to CALTA's Business Model and central to its present and future success.

The first 1 kW DiPOLE system was developed under a commercial contract for the HiLASE Centre in the Czech Republic. Following delivery and installation, a joint CLF / HiLASE team commissioned the laser to its full design specification in December 2016, producing 100 J in 10 ns pulses at 10 Hz. This performance gives DiPOLE an enduring world lead in this area of laser technology. Construction of a second 1 kW laser, destined for the European XFEL in Hamburg, is well underway. Funded through a joint STFC/EPSRC research grant, the "DiPOLE 100" will be used to drive materials to high energy density states to be diagnosed using the XFEL x-ray beam. A unique temporal pulse shaping capability, developed specifically for the XFEL application, will enable precise control of the material energetic states produced, while the high repetition rate will enable rapid accumulation of data for improved measurement accuracy.

The system build is nearing completion and commissioning of the first stage of amplification is progressing. Final commissioning of the system will take place at RAL prior to packaging and delivery to Hamburg in 2019.

Further development of the DiPOLE technology is an essential element of a **Widespread Teaming** collaboration between STFC and the HiLASE Centre. The €50M project to establish HiLASE as a Centre of Excellence is jointly funded by the EC and the Czech Ministry of Science. STFC is assisting in the establishment of the Centre and is playing a leading role in the development of advanced DPSSL technology. This includes the design and construction of a 100 Hz version of the DiPOLE 10 J laser, increasing the output power of the DiPOLE architecture and developing efficient second and third harmonic generation at 10 Hz. This work will extend STFC's lead at the forefront of DPSSL technology.

Economic impact

In summer 2017, the CLF/STFC spinout company Cobalt Light Systems Ltd, which develops and markets disruptive technology using Spatially Offset Raman Spectroscopy (SORS), was acquired by Agilent Technologies, a US company, for £40M. SORS is an exclusive CLF technique which differs from traditional Raman spectroscopy in that it can identify materials through opaque containers deeper beneath the surface than was achievable by previous methods. The SORS technique was originally developed using the CLF's cutting edge ultra-fast laser, Ultra. Cobalt was formed in 2008 and attracted numerous awards, including RAEng's prestigious MacRobert Award in 2014 and the Queen's Award for Enterprise in 2015. The company developed a number of SORS products including table-top devices to identify liquid explosives concealed within bottles, which are currently in operation at over 75 airports worldwide. Using the same technique, hand-held instruments were also developed by Cobalt to test the contents of bottles and jars for explosives, narcotics and hazardous substances quickly and efficiently. After the purchase by Agilent Technologies, the company will be moving from its previous base near Didcot, Oxfordshire, back to the Harwell Campus next to RAL. This will become Agilent's global centre for Raman spectroscopy.

Access to Facilities

Calls for access are made twice annually, with applications peer reviewed by external Facility Access Panels.

The CLF operates "free at the point of access", available to any UK academic or industrial group engaged in open scientific research, subject to external peer review. European collaboration is fully open for the high power lasers, whilst European and International collaborations are also encouraged across the CLF suite for significant fractions of the time. Dedicated access to CLF facilities is awarded to European researchers via the LaserLab-Europe initiative (www.laserlab-europe.net) funded by the European Commission.

Hiring of the facilities and access to CLF expertise is also available on a commercial basis for proprietary or urgent industrial research and development.

Please visit www.clf.stfc.ac.uk for more details on all aspects of the CLF.

Industrial Impact and Innovation

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This article highlights the economic impact, industrial user engagement, and innovation activities of the CLF for the reporting period April 2017 to March 2018.

Economic impact

The CLF spinout company Cobalt Light Systems Ltd, which develops and markets disruptive technology using Spatially Offset Raman Spectroscopy (SORS), has been acquired by Agilent Technologies, a US company, for £40M. SORS is an exclusive CLF technique, which differs from traditional Raman spectroscopy in that it can identify materials through opaque containers deeper beneath the surface than with previous methods. The SORS technique was originally developed using the CLF's cutting edge ultra-fast laser, Ultra. Cobalt was formed in 2008 and attracted numerous awards including RAEng's prestigious 2014 MacRobert Award and the 2015 Queen's Award for Enterprise. The company developed a number of SORS products, including table-top devices to identify liquid explosives concealed within bottles that are currently in operation at over 75 airports worldwide. Using the same technique, hand-held instruments have also been developed by Cobalt to quickly and efficiently test the contents of bottles and jars for explosives, narcotics and hazardous substances. The company will be located at the Harwell Campus next to STFC RAL and will become Agilent's global centre for Raman spectroscopy.

Industrial users and engagement

Six paid-for access projects with industrial users were completed this year, delivering experimental access to Gemini, Ultra, and Octopus. The CLF's expertise, in combination with its world-class capabilities and laser-based techniques, continues to make an impact on a wide variety of industrial science themes and R&D areas, including fluorescence microscopy for studying catalytic materials, laser-driven accelerators for defence sector technologies development, and 2DIR spectroscopy supporting pharmaceutical research.

The Coconut Collaborative Ltd (CCL) and UK National Measurement Laboratory LGC Ltd collaborated with the CLF under the new Analysis for Innovators (A4I) scheme, to access CLF's Raman spectroscopy and multispectral imaging capability and assess whether this is a basis for an enhanced level of quality control and screening in CCL's manufacturing plants. This screening approach could avoid annual costs in excess of £500k through reduced production and material charges. James Averdieck, Managing Director of CCL, said, "*It has enabled us, at a time when our core staff are stretched in supporting our strong organic growth, to work in a time efficient way with world class institutions and scientists to develop and prove a principle for solving a very unique but real rancidity measurement problem. We are impressed with the encouraging results.*"

The A4I scheme is funded by Innovate UK to help companies to gain access to world-leading expertise, cutting-edge facilities, techniques and technologies to solve existing analysis or measurement problems facing businesses. UK businesses can apply for a share of up to £4 million to work with scientists and research facilities to resolve productivity and competitiveness issues.

The CLF has received funding from another scheme recently introduced to boost industrial collaboration with national facilities. Bridging for Innovators (B4I) is an Industrial Strategy Challenge Fund (ISCF) programme run by STFC to help UK industry overcome product, manufacturing or process performance issues and boost productivity.

The CLF hosted an industry engagement workshop that focused on laser-driven sources of x-rays and particles, and their application to many high value sectors, including advanced imaging and inspection for aerospace, nuclear and new materials. Over 30 people attended, including university users, companies and organisations such as Rolls Royce, National Composites Centre, TWI Ltd, and Stirling Dynamics. By connecting world-leading research with business, this event has helped set an example for the future, namely that strong relations between academia and industry increase the feasibility of tackling some of the greatest challenges of the twenty-first century.

The CLF developed an industrial capability portfolio for laser-driven x-rays by engaging a number of companies and organisations who use x-ray imaging for product quality control. A range of samples were loaned by High Value Manufacturing Catapult centres (Manufacturing Technology Centre, National Composites Centre, Warwick Manufacturing Centre), Rolls Royce, and Southampton μ-vis X-ray Imaging Centre. Phase contrast x-ray radiographs and MeV energy absorption radiographs generated at CLF demonstrated high resolution imaging capability through a range of materials and a range of thicknesses, indicating the strong potential impact of laser-driven x-rays for industrial non-destructive testing and advanced imaging.

Industry Partnership

The CLF's partnership with Johnson Matthey (JM) continues, with a JM research fellow joint appointment at the CLF to solve industrial challenges and add insight into fundamental R&D through the application of advanced laser spectroscopy and laser microscopy techniques on Ultra and Octopus. Regions of scientific interest for JM include next-generation battery technology, fuel cell characterisation, and catalytic science of zeolites for clean air applications.

The CLF continues to collaborate with the Defence Science and Technology Laboratory (Dstl) novel detectors group to deliver a programme of R&D focusing on advanced inspection and disruption technologies for defence applications based on laser-driven secondary sources. Dstl fund an applications development scientist appointment at CLF and at least one experimental access time on either Gemini or Vulcan each year.

The collaboration between the CLF, the University of Bristol, and Queen's University Belfast under an industrial partnership with Sellafield Ltd continues the development of laser-driven x-rays and neutron sources for inspection and waste assay applications. The Pulsed Laser Accelerators for The Inspection of NUclear Materials (PLATINUM) project is of three-year duration, funded by the STFC Innovation Partnership Scheme. This year the team completed an experiment using the Vulcan laser to demonstrate that laser-driven x-rays have the source qualities to resolve corrosion-induced cracking in grout surrounding uranium, and imaged through at least 400 mm of grout in a single pulse exposure. The CLF-led experiment was delivered in collaboration with the University of Strathclyde, Queen's University Belfast and the University of Bristol.

International Impact

A pilot innovation project between the CLF and India's Tata Institute of Fundamental Research was announced which will focus on skills enhancement, with engineers from India receiving training in next-generation laser technology during their time at the CLF. The CLF's Dr Rajeev Pattathil stated, "*There is now a strong demand from academic communities on both sides for establishing a joint innovation centre in order to translate the research we do into societal applications that will benefit the people in both countries.*"

Build and delivery of the DiPOLE D100X system, 100 J at 10 Hz, to the high-energy density end station of the European XFEL Facility continues to be on track. This is the second build contract for the CLF's world leading 100 J level high peak power and high average power laser system and paves the way for more interest from international facilities for this innovative technology.

Innovation

We constantly scan for innovation and technology transfer opportunities across the whole of the CLF, with a view to capturing and driving forward the most high impact ideas and inventions.

During this year, two proof-of-concept projects remained active – one based on the development of an advanced Raman spectroscopy readout system, and one based on the application of laser microscopy for targeted therapeutics. One project came to a close, based on the development of the DiPOLE10 laser for laser peening applications. The laser peening laboratory is now equipped with robotic handling capability for sample materials to be peened and a water flow system for surface cooling. A series of experiments and demonstrations have taken place. A university group is scheduled to access this capability for materials science experiments.

A new project for the development of an advanced capability for the CLF's DiPOLE laser has commenced, aiming to increase the repetition rate by a factor of ten.

In this year two new patents were filed, five new patents were granted related to the patent families, and thirteen invention disclosure forms were submitted for consideration that may lead to future patents.

Communication and outreach activities within the CLF

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Introduction

The Central Laser Facility (CLF) recognises the importance of communication with our current and potential users, STFC, UKRI and other funders, new industry partners, the wider scientific community, and the general public. Over the past year, a CLF communications team has been established and a social media account has been added to the range of channels we use to reach our stakeholders.

The communications team now includes an Impact and Engagement Officer, and a communications sandwich student, who shares their time with ISIS. Twenty-two staff from across the CLF have now been trained to edit the CLF website and help keep it up to date. The team has published over 40 news articles to the website this year. The CLF website has attracted over 11,000 users over the past six months, with almost 53,000 unique page views. Excluding 1250 users based at Harwell, this corresponds to 55 external users per day. A CLF Twitter account @CLF_STFC was started on the 1st February 2018, and had gained nearly 300 followers by the end of March 2018.

Public engagement encompasses outreach activities that will inspire the next generation and raise the profile of our world-class research, as well as communication activities that offer a platform on which to demonstrate the high-impact and inspiring science that the CLF delivers. Opportunities for communication and engagement in the reporting period 2017-2018 have been diverse, reaching across the UK and around the world. Here we highlight a selection of those activities.

The CLF 40th Anniversary

STFC celebrated the CLF's 40th anniversary by hosting a one-day conference on the 'Impact and Importance of UK Laser Science on the Global Stage'. Leading speakers from the world of laser science spoke at the event, including renowned physicist Professor Sir Peter Knight from Imperial College London.

The CLF produced a booklet and held a photographic exhibition, "40 Years in Pictures", to commemorate the anniversary. The CLF website featured an interactive timeline of CLF history, and the communications team also produced anniversary content for the STFC and CLF websites.

The Incredible Power of Light Roadshow

The *Incredible Power of Light* roadshow visited Norwich as part of the Norwich Science Festival in October 2017.

The roadshow was set up in 2015 by STFC in partnership with the Biotechnology and Biological Sciences Research Council (BBSRC) and the Engineering and Physical Sciences Research Council (EPSRC). It was designed to support the UK laser science community, showcasing the unparalleled range of state-of-the-art laser technology provided by the CLF.

The portable interactive roadshow was designed for people of all ages to enjoy and learn from, featuring interactive exhibits, including a walk-through of the laser area of the Vulcan laser, informative artwork, digital media and a 'live' laser show highlighting the CLF's world-class science.

We have particularly focused on exhibiting the roadshow in harder to reach areas of the UK, with the knowledge that people from these areas will find it more difficult to visit RAL site for our events and open days. We have also aimed to reach a more diverse audience through these efforts, giving more people an equal chance to learn about and be fascinated by science.

Speakers at the CLF 40th Anniversary included Dr Andrew Taylor, Executive Director of STFC National Laboratories, Professor Sir Peter Knight from Imperial College London and STFC Chief Executive Dr Brian Bowsher

(Credit: STFC)

The *Incredible Power of Light Roadshow* has proved popular and has been very well received. Families in particular have tended to visit multiple times during the duration of the show, because the children have asked to return.

After much success, the *Incredible Power of Light Roadshow* was decommissioned in 2018 after 16 events at 15 venues across the UK, having captured the attention of thousands of people over its 6,228 mile journey.

Artist Helen Towrie becomes CLF Impact and Engagement Officer

Helen Towrie, an artist who was originally recruited for three months to help with the CLF's 40th Anniversary, has been kept on for a year with the expanded role of Impact and Engagement Officer.

One major change made by Helen is the establishment of the CLF Twitter feed, the first and, so far, only social media channel for the CLF. Through this account, which is aimed at the science community and CLF users, she has shared stories and photos depicting day-to-day life in the CLF, as well as science highlights, workshops, events, STFC tweets, and other laser-related news. In its first two months, the Twitter account has garnered around 200 followers, and it is becoming a hub for users to interact with the CLF in an informal way.

As well as writing articles for the CLF website, STFC website, and the STFC internal newsletter (in.brief), Helen has also delivered articles to external newsletters such as LaserLab Europe. She also aids CLF engagement by photographing the laboratories and people at work, keeping the CLF's visual identity up-to-date.

Despite these changes to her remit, illustration has remained a large part of Helen's job. She has continued to use informative and representative illustrations to help break down complicated scientific subjects into easy to follow concepts for use on various media platforms. She has also used her artistic and creative thinking skills to help scientists to help explain their work more effectively to non-scientific audiences.

Helen has been commissioned by STFC and ISIS to carry out various art and design projects throughout the year; for example, she created artwork for STFC to illustrate dressmakers in the lab, and developed several pieces depicting the RAL landscape and ISIS applications.

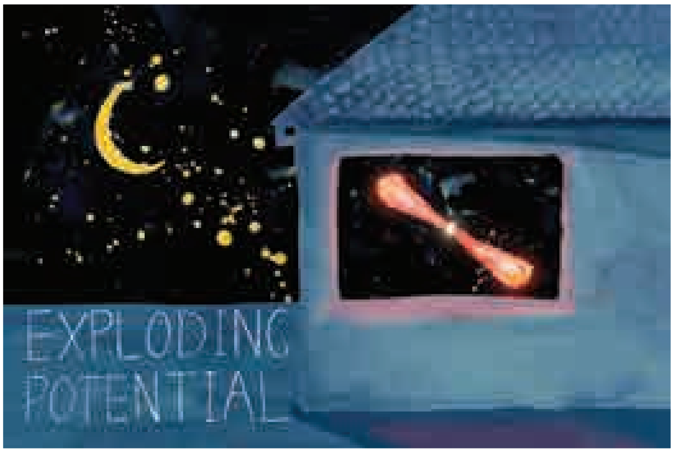
Sandwich Student in the Communications Team

In 2017, Emily Cooke, a sandwich student was recruited to spend 50% of her time with ISIS, and 50% of her time with CLF – a first joint appointment for both facilities. Emily's role was intended to help the CLF and ISIS with communications in general and science writing in particular, and to establish a stronger bond between ISIS and CLF. The appointment has proved invaluable to our outreach and engagement efforts.

Emily has worked with Helen in her role as Impact and Engagement Officer, and together they formed a new CLF communications team. As a team, they have written articles for the CLF website, and helped to generate content for STFC social media channels. On top of this, they have worked to support tour visits and education access days, and have helped the STFC central communications team to get CLF news stories and features out to the general public, the user community and industry.

The communications team also produced a special issue of in.brief (the STFC weekly internal newsletter) in March 2018, carrying 15 stories about CLF work and staff. An internal email newsletter specifically for CLF staff was successfully piloted in early 2018, and will now be issued every two months, featuring a mixture of CLF highlights, staff news and events.

Training Weeks in 2017 continued to provide an excellent opportunity for participants to network with other members of the EU high power laser community, as well as benefit from hands-on and classroom learning provided by the CLF.



A series of illustrations depicting high power laser scientific highlights for the special CLF edition of in.brief

Cosmic rays and the RAL landscape

High Energy Density & High Intensity Physics

Plasma density optimisation of laser-wakefield acceleration for high-brightness bremsstrahlung emission applied to advanced manufacturing imaging

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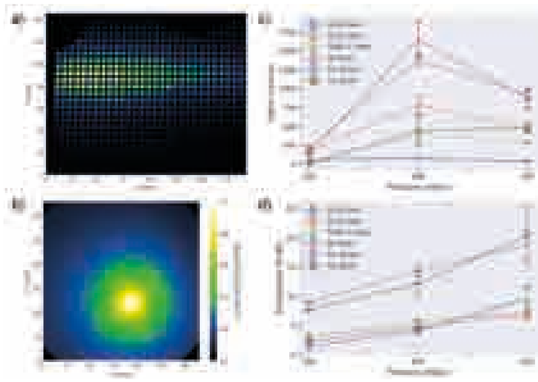
O.J. Finlay *(The Cockcroft Institute, Sci-Tech Daresbury, Keckwick Lane, Daresbury, UK)*
M.J.V. Sreeter, J.-N. Gruse, Z. Najmudin *(The John Adams Institute for Accelerator Science, Imperial College London, UK)*

Laser-wakefield acceleration of electrons generates high-energy (GeV-scale) beams that, when propagated through solid materials, will stimulate bremsstrahlung x- ray emission that has both small (<50 μm) source size and high energy (>1MeV) for achieving high resolution penetrative radiography.
Laser-driven x-ray imaging requires bright beams for high signal-to-noise acquisition and therefore high-quality imaging.
X-ray emission is dependent on the electron beam charge and spectral distribution; therefore, mechanisms for optimising and tuning the electron beam properties are advantageous for development of this source for applications. Here we report on x-ray emission optimised for different material properties by varying the gas pressure of the wakefield accelerator.
Experimental results are presented of LWFA electron beam charge and x-ray emission after the beam is incident on a range of converter materials to produce bremsstrahlung. The x-rays were then used to image a number of high-density, industrially-relevant samples with sub-millimetre internal features, to demonstrate the capability of this new x-ray technology.



Bremsstrahlung x-ray beam generated from laser-accelerated electrons detected by (a) CsI scintillator array to measure divergence and energy and (b) LYSO scintillator screen for imaging. Effect of gas pressure and convertor material on (c) x-ray flux and (d) x-ray divergence.

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Experimental Evidence of Radiation Reaction in the Collision of a High-Intensity Laser Pulse with a Laser-Wakefield Accelerated Electron Beam

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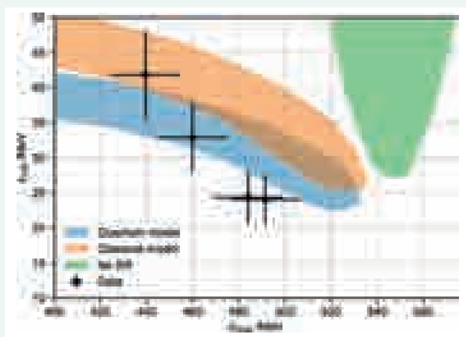
The dynamics of energetic particles in strong electromagnetic fields can be heavily influenced by the energy loss arising from the emission of radiation during acceleration, known as radiation reaction. When interacting with a high-energy electron beam, today's lasers are sufficiently intense to explore the transition between the classical and quantum radiation reaction regimes. We present evidence of radiation reaction in the collision of an ultrarelativistic electron beam generated by laser-wakefield acceleration ($\varepsilon > 500$ MeV) with an intense laser pulse ($a_0 > 10$). We measure an energy loss in the postcollision electron spectrum that is correlated with the detected signal of hard photons (γ rays), consistent with a quantum description of radiation reaction. The generated γ rays have the highest energies yet reported from an all-optical inverse Compton scattering scheme, with critical energy $\varepsilon_{crit} > 30$ MeV.



Experimentally measured ε_{crit} as a function of ε_{final} measured at the electron spectral feature (points). The shaded areas correspond to the results a hypothetical ensemble of identical experiments would measure 68% of the time under different assumed radiation reaction models for a uniform distribution of a_0 between 4 and 20.

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Excitation and Control of Plasma Wakefields by Multiple Laser Pulses

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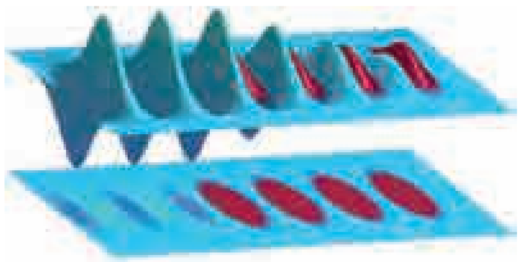
An experimental demonstration of a new method to drive a laser wakefield accelerator is presented. A train of laser pulses were generated to resonantly excite a plasma wave. This was achieved in Gemini Target Area 2 by spectrally filtering a stretched laser pulse using a Michelson interferometer, to generate a train of short pulses as shown in red in the figure. An important first step was experimentally shown in achieving an energy recovery plasma accelerator by proving that a plasma wave can be damped by an out-of-resonance trailing laser pulse.
The wakefields were measured using the Frequency Domain Holography (FDH) technique and are found to be in excellent agreement with analytical and numerical models of wakefield excitation in the linear regime. A further, simpler measurement method was also applied called Temporally Encoded Spectral Shifting (TESS) and was found to be an excellent analysis tool, that agreed well with the FDH analysis that was performed on the data.

These results indicate a promising direction towards achieving highly controlled, GeV-scale laser-plasma accelerators operating at multikilohertz repetition rates. A route towards achieving energy recovery, by dampening of the plasma wave, is shown experimentally for the first time.



Model of a train of pulses (in red) used to drive a plasma wave (in blue).

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Characterisation of a Laser Plasma Betatron Source for High Resolution X-ray Imaging

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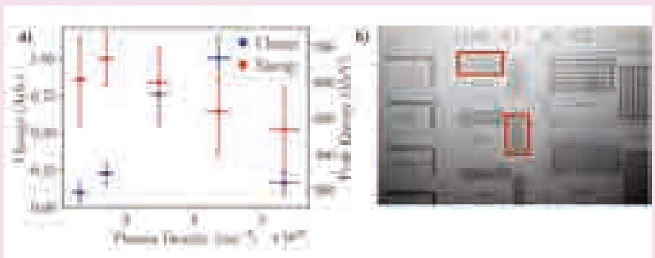
We report on the optimisation of an x-ray source, generated by a laser-driven plasma wakefield accelerator for an imaging experiment in Gemini Target Area 3. The highest x-ray signal was observed at a plasma electron density of $(4.4 \pm 0.2) \times 10^{18}$ cm^{-3}. This coincided with the highest observed electron beam charge measured by the electron spectrometer. The peak electron energy at this density was limited by dephasing to 0.52 ± 0.12 GeV.
The spectra of the optimised source was consistent with an on-axis synchrotron spectra with a critical energy of 10.9 ± 0.4 keV and the number of photons incident on the detector was calculated to be $(3.7 \pm 0.1) \times 10^9$. The x-ray beam was used to image a resolution grid placed 37 cm from the source, which gave an estimated spatial resolution of 4 μm x 5 μm. A number of samples were also imaged radiographically as part of ongoing work to develop laser plasma generated betatron radiation as a viable industrial imaging tool.



a) Plot showing the dependence of the electron bunch charge and maximum electron energy on the plasma density. The highest x-ray flux corresponds to the density of 4.4×10^{18} cm^{-3} that produces the highest charge beam. b) Radiographic image of a JIMA resolution grid. The red boxes highlight the smallest resolved features.

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Radiation pressure-driven plasma surface dynamics in ultra-intense laser pulse interactions with ultra-thin foils

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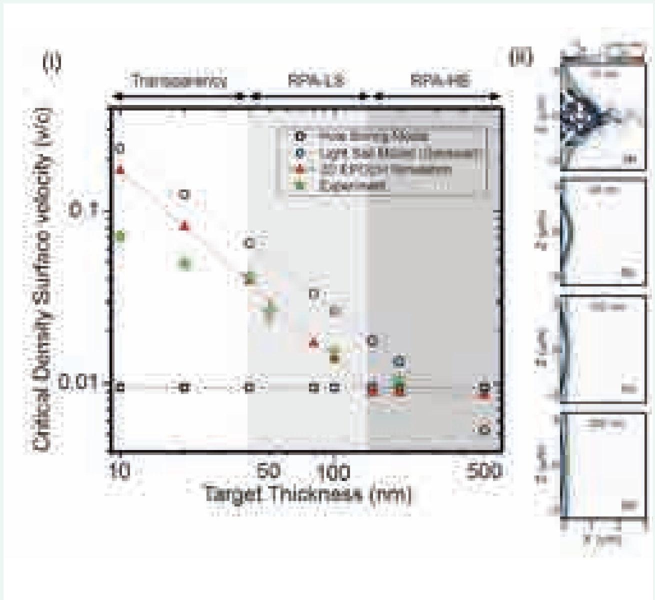
The dynamics of the plasma critical density surface in an ultra-thin foil target, irradiated by an ultra-intense pulse from the Gemini laser, are investigated both experimentally and numerically. Through variation of target thickness, from tens-to-hundreds of nanometres, the conditions for which hole-boring and light-sail models of radiation pressure acceleration dominate are investigated. It is shown that the onset of relativistic transparency limits the velocity of the critical surface, and the effectiveness of radiation pressure acceleration.



(i) Comparison of experiment and simulation results, and hole-boring and light-sail model calculations for the maximum plasma critical density surface velocity as a function of target thickness.
(ii) (a) Combined 2D plot of electron density and laser intensity, from a 2D particle-in-cell simulation with l = 10 nm, at the timestep corresponding to relativistic transparency. (b)-(d) Same, but for (b) l = 40 nm, (c) l = 100 nm and (d) l = 200 nm. The degree of target expansion increases with decreasing target thickness.

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Laser-wakefield accelerators for high-resolution X-ray imaging of complex microstructures

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Laser-wakefield accelerators (LWFAs) are high acceleration-gradient plasma-based particle accelerators, capable of producing ultra-relativistic electron beams. Within the strong focusing fields of the wakefield, accelerated electrons undergo betatron oscillations, emitting a bright pulse of x-rays with a micrometre-scale source size that may be used for imaging applications. Non-destructive x-ray phase contrast imaging and tomography of heterogeneous materials can provide insight into their processing, structure, and performance. To demonstrate the imaging capability of x-rays from an LWFA, we have examined an irregular eutectic in the aluminum-silicon (Al-Si) system. The lamellar spacing of the Al-Si eutectic microstructure is on the order of a few micrometres, thus requiring high spatial resolution. An upper bound on the resolving power of 2.7 µm of the LWFA source in this experiment was measured. These results indicate that betatron x-rays from LWFAs can perform high resolution imaging of eutectics and, more broadly, complex microstructures.

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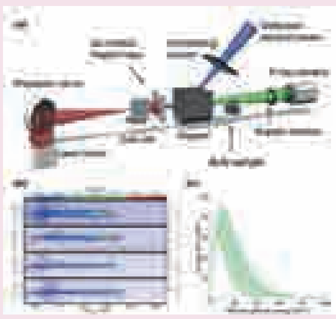

Fig 1. Experimental details for X-ray imaging using a laser wakefield accelerator. (a) Schematic of layout (b) Typical electron beams with a quasi-monoenergetic peak energy and broad low-energy tails (c) Best-fit to the betatron X-ray spectrum.

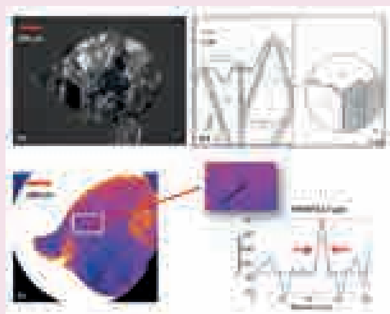

Fig 2. Al-Si sample investigated using a LWFA X-ray source. (a) Optical microscope image. (b) X-ray phase contrast (c) Schematic showing growth of irregular eutectics where ß represents the faceted phase (e.g., Si), α is the non-faceted, higher volume fraction phase (e.g., Al), and l is the melt ahead of the interface. The inset shows the α phase and the defect growth mechanism for the ß phase. *Retrieved with permission from D. J. Fisher and W. Kurz, Acta Metallurgica 28, 777 (1980).*

Measurements of self-guiding of ultrashort laser pulses over long distances

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We report on the evaluation of the performance of self-guiding over extended distances with f/20 and f/40 focussing geometries. Guiding over 39 mm or more than 100 Rayleigh ranges was observed with the f/20 optic at n_e 1.5 x 10^{18} cm^{-3}. Analysis of guiding performance found that the extent of the exiting laser spatial mode closely followed the matched spot size predicted by 3D nonlinear theory. Self-guiding with an f/40 optic was also characterised, with guided modes observed for a plasma length of 90 mm and a plasma density of n_e 9.5 x 10^{17} cm^{-3}. This corresponds to self-guided propagation over 53 Rayleigh ranges and is similar to distances obtained with discharge plasma channel guiding.

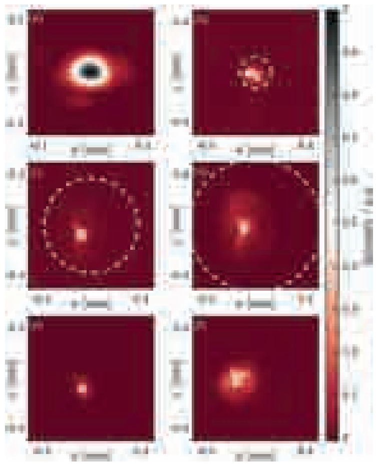

Figure 1: Measured laser focus from f/40 geometry before entering the plasma (a) and the plane of exit from the plasma (b)–(f) for different gas cell lengths and plasma densities. The white dashed line depicts the size of the laser nearfield for vacuum propagation over the same distance.

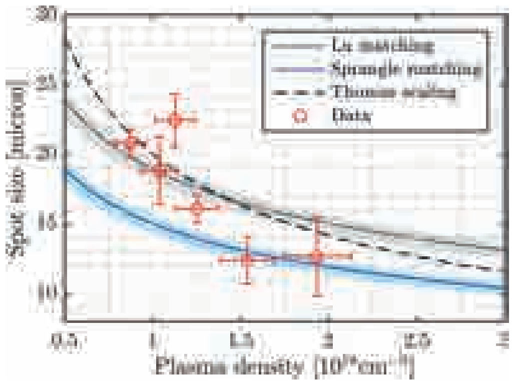

Figure 2: Variation of the measured exit mode size with plasma density for f/40 focussing optic with a 60 mm long gas cell.

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Comparative study of betatron radiation from different injection mechanisms in a gas jet

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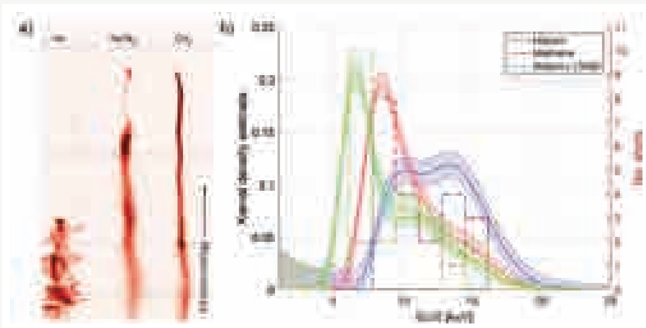
High power laser systems have enabled the development of compact particle accelerators, using plasma as the accelerating structure. Electron beams with energies in the GeV range are routinely produced using Gemini. A useful by-product of these accelerators is the generation of hard x-ray radiation, called betatron radiation, that is emitted as electrons oscillate in the focusing field present in the accelerator.

We investigate the generation of betatron radiation in three types of medium (helium, helium + 1% nitrogen, and methane clusters), and explore the various merits of each medium. The mechanism for electron injection into the wakefield is different in all these cases and influences the properties of the electron beams and radiation.

While self-injection produces betatron radiation with higher critical energies, ionisation and cluster injection achieves a higher x-ray flux. The critical energies for ionisation and cluster injected electron beams also exhibit a lower spread than self-injection.



a) Electron spectra generated by interaction with helium (self-injection), 1% nitrogen doped helium (ionisation injection) and methane (cluster injection).
b) Critical energy of emitted betatron radiation from the three targets.

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Polarization Dependence of Bulk Ion Acceleration from Ultrathin Foils Irradiated by High-Intensity Ultrashort Laser Pulses

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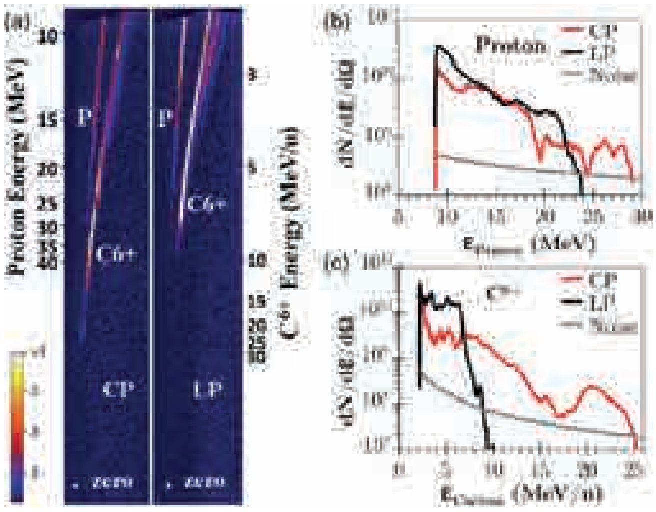
The acceleration of ions from ultrathin (10–100 nm) carbon foils has been investigated using intense (~6 × 10^{20} Wcm^{-2}) ultrashort (45 fs) laser pulses, highlighting a strong dependence of the ion beam parameters on the laser polarization, with circularly polarized (CP) pulses producing the highest energies for both protons and carbons (25 – 30 MeV/nucleon); in particular, carbon ion energies obtained employing CP pulses were significantly higher (~2.5 times) than for irradiations employing linearly polarized pulses. Particle-in-cell simulations indicate that radiation pressure acceleration becomes the dominant mechanism for the thinnest targets and CP pulses.



(a) Raw data from BAS-TR image plates for CP and LP laser pulses irradiating 10 nm amorphous carbon targets. The corresponding CP (red) and LP (black) background-subtracted proton (b) and C^{6+}spectra (c) with vertical axis units of particles/MeV/sr are also shown. The noise level of +2σ is also plotted.

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Low-Density Hydrodynamic Optical-Field-Ionized Plasma Channels Generated With An Axicon Lens

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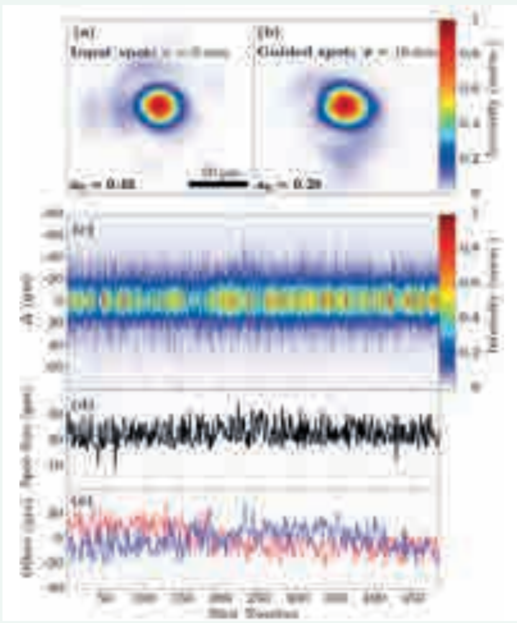
We demonstrate optical guiding of high-intensity laser pulses in long, low density hydrodynamic optical-field-ionized (HOFI) plasma channels. An axicon lens is used to generate HOFI plasma channels with on-axis electron densities as low as $n_e(0) = 1.5 \times 10^{17}$ cm^{-3} and matched spot sizes of a few tens of micrometres. Control of these channel parameters via adjustment of the initial cell pressure and the delay after the arrival of the channel-forming pulse is demonstrated.

For laser pulses with a peak axial intensity of 4 × 10^{17} W cm^{-2}, highly reproducible, high-quality guiding over more than 14 Rayleigh ranges is achieved at a pulse repetition rate of 5Hz, limited by the available channel-forming laser and vacuum pumping system. Plasma channels of this type would seem to be well suited to multi-GeV laser wakefield accelerators operating in the quasi-linear regime.



Transverse fluence profiles of the guided laser pulse at: (a) the entrance, and (b) the exit of a 16mm long HOFI channel. Panels (c)-(e) demonstrate the stability of the waveguides over 485 consecutive shots, showing (c) the transverse profile, (d) the D4σ spot size and (e) the vertical (blue) and horizontal (red) position of the spot centre.

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Experimental Observation of a Current-Driven Instability in a Neutral Electron-Positron Beam

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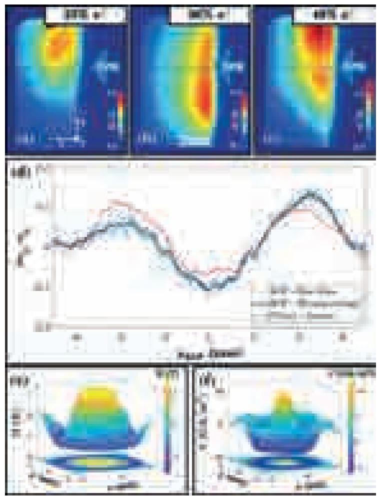
We report on the first experimental observation of a current-driven instability developing in a quasineutral matter-antimatter beam. Strong magnetic fields (≥ 1 T) are measured, via means of a proton radiography technique, after the propagation of a neutral electron-positron beam through a background electron-ion plasma. The experimentally determined equipartition parameter of $\epsilon_B \approx 10^{-3}$ is typical of values inferred from models of astrophysical gamma-ray bursts, in which the relativistic flows are also expected to be pair dominated. The data, supported by particle-in-cell simulations and simple analytical estimates, indicate that these magnetic fields persist in the background plasma for thousands of inverse plasma frequencies. The existence of such long-lived magnetic fields can be related to analogue astrophysical systems, such as those prevalent in lepton-dominated jets.



(a)–(c) Typical optical density of the proton radiographies of the background gas after the passage of the electron-positron beam for different percentages of positrons in the beam: 23% (a), 38% (b), and 48% (c). The beam propagates from right to left, as indicated by the arrow, with the main propagation axis represented by the dashed blue line. The spatial scale is common for all frames and refers to the interaction plane. Each radiograph is taken (280±30) ps after the transit of the EPB [corresponding proton energy of (1.1±0.5) MeV]. (d) Comparison between the experimental proton distribution and the output of the particle-tracing simulation for frame (c). The lineout position is highlighted by the white dashed rectangle in frame (c). and it is taken at the detection plane, with the spatial scale thus magnified by a factor M≃8. (e) Distribution of the azimuthal magnetic field used as an input for the particle-tracing simulation and (f) related current density.

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General features of experiments on the dynamics of laser-driven electron–positron beams

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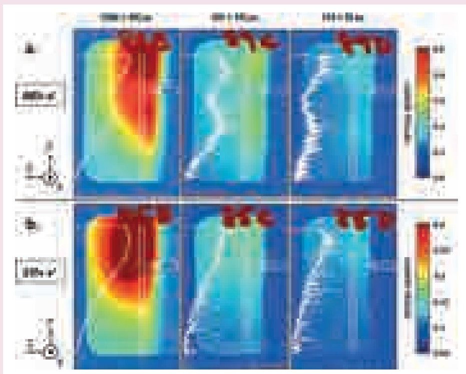
The experimental study of the dynamics of neutral electron–positron beams is an emerging area of research, enabled by the recent results on the generation of this exotic state of matter in the laboratory. Electron–positron beams and plasmas are believed to play a major role in the dynamics of extreme astrophysical objects such as supermassive black holes and pulsars. For instance, they are believed to be the main constituents of a large number of astrophysical jets, and they have been proposed to significantly contribute to the emission of gamma-ray bursts and their afterglow.
However, despite extensive numerical modelling and indirect astrophysical observations, a detailed experimental characterisation of the dynamics of these objects is still at its infancy. Here, we will report on some of the general features of experiments studying the dynamics of electron–positron beams in a fully laser-driven setup.



Proton radiographs of the background plasma after the propagation of a quasi-neutral EPB with 48% e+ population in row (a.), and a non-neutral EPB with 23% e+population in row (b.). Different columns correspond to different proton energies, and therefore, different probe times after the passage of the EPB (as labelled). Each row corresponds to a single shot, highlighting the multi-frame capability of this radiographic technique. The colour-bars represent the optical density on the RCFs for the respective rows, with a higher number corresponding to higher proton density). Lineouts (white solid line) are taken from the regions between the white-dashed lines. For an EPB with 23% e+ population (row b.), no clear modulation is seen on the proton radiographs (smooth monotonically decreasing profile, corresponding to the initial proton beam distribution). A pronounced modulation is observed for an EPB with 48% e+ population (row a.). The modulation can be seen on all three layers of RCF indicating that the magnetic fields responsible for modulation are long-lived within the background plasma.

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Simulated Optimisation of a 10 mJ Class, mid-IR Driven Laser Wakefield Accelerator Demonstrating a High Charge, MeV Electron Source Created via Extreme Laser Redshifting

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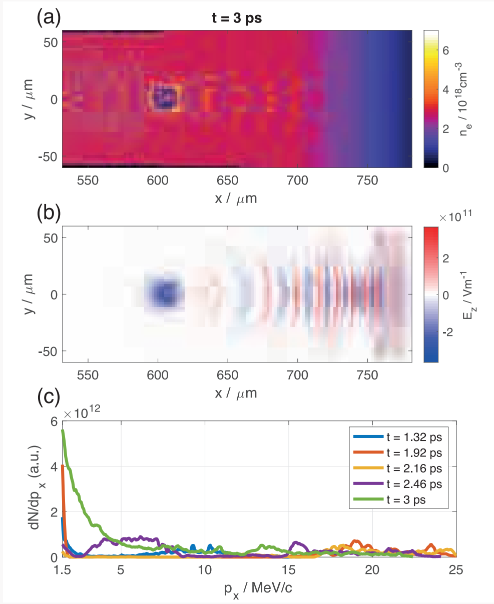
LWFA scalings were reviewed for mid-IR laser pulses, which must be more energetic for the same electron energy, but this is compensated for by a higher charge. A larger wakefield can be driven, which would be beneficial for diagnostics. 2D PIC simulations of LWFAs driven by a 25 mJ, 30 fs, 4 µm laser pulse (based on the Chimera system at Imperial College London) showed potential for a table-top source of 20-40 MeV electron beams, accelerated in easy to produce, millimetre-scale targets. For high ratios of electron to critical density there was a large redshift of the laser. Some of the light became so redshifted that the plasma was opaque to it and it became trapped, resembling the formation of a postsoliton. A large population of electrons was injected in to the approximately stationary postsoliton bubble and was accelerated up to 5 MeV. This effect was confirmed in 3D simulations.



A 2D PIC simulation of a Laser Wakefield Accelerator showing extreme laser red-shifting, causing some light to be trapped in the plasma. (a) shows the plasma density and (b) the laser electric field. (c) shows the electron momentum spectra at various times in the simulation. The stationary bubble driven by very long wavelength light, at t = 3 ps, is a bright source of few MeV electrons.

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Near-100 MeV protons via a laser-driven transparency-enhanced hybrid acceleration scheme

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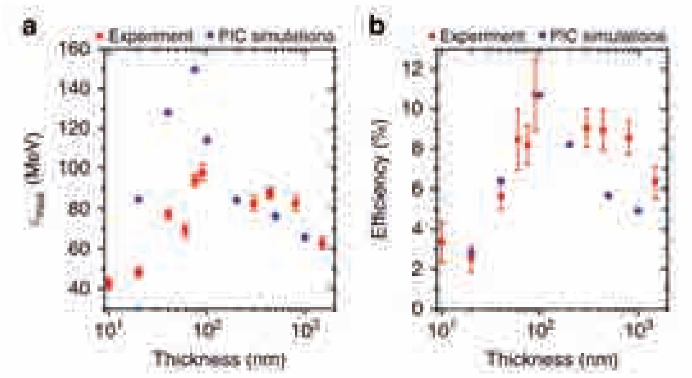
Laser-plasma ion acceleration offers several applications based on the compact and efficient nature of the interactions. This motivates research into novel acceleration schemes to improve the achievable ion energies.

In the ultrathin target regime, several acceleration mechanisms occur over the course of one laser pulse. Operating in this hybrid-acceleration regime allows for greater control of the ions accelerated through optimisation of the experimental conditions. Here we present experimental results of high-energy proton acceleration, exceeding 94 MeV, utilising radiation pressure and sheath acceleration processes. Via 2D particle in cell simulations, we find that target transparency leads to a double-peaked electrostatic field structure at the target rear. A jet of super-thermal electrons is then accelerated, which enhances the maximum energy that protons contained within that target can reach.



(a) Proton maximum energy scaling and (b) conversion efficiency scaling with target thickness.

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Reflection of intense laser light from microstructured targets as a potential diagnostic of laser focus and plasma temperature

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The spatial-intensity profile of light reflected during the interaction of an intense laser pulse with a microstructured target is investigated experimentally, and the potential to apply this as a diagnostic of the interaction physics is explored numerically.

Diffraction and speckle patterns are measured in the specularly reflected light in the cases of targets with regular groove and needle-like structures, respectively, highlighting the potential to use this as a diagnostic of the evolving plasma surface.

Ray-tracing and numerical modelling shows that, for a laser focal spot diameter smaller than the periodicity of the target structure, the reflected light patterns can potentially be used to diagnose the degree of plasma expansion and, by extension, the local plasma temperature at the focus of the intense laser light. The reflected patterns could also be used to diagnose the size of the laser focal spot during a high intensity interaction, when using a regular structure with known spacing.

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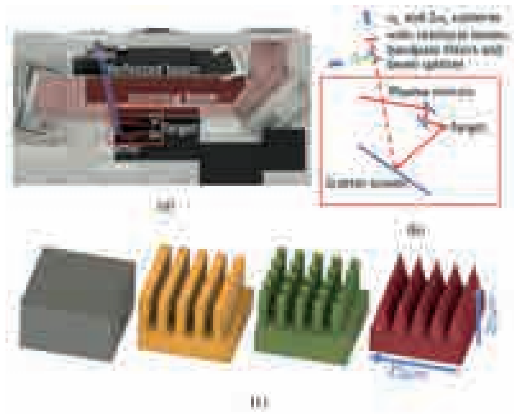

Figure1: (a) Plan view of the experiment arrangement. The incoming laser beam is shown in red and light reflecting out of chamber to the CCDs is shown in blue. (b) Schematic showing the path of the incoming laser beam (solid red line), from the double plasma mirror onto target and finally onto the scatter screen. The imaging line is shown by the dashed red line. (c) Schematic illustrating the four types of targets employed; From left to right: flat foil, grooves, pillars and needles.

Observation of extremely strong shock waves in solids launched by petawatt laser heating

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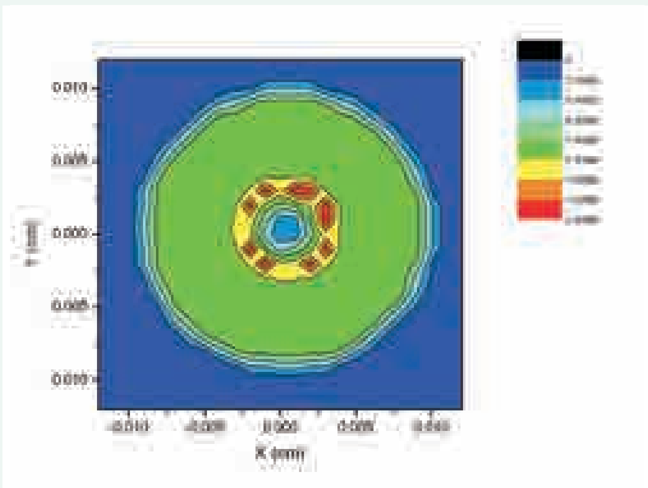
Understanding hydrodynamic phenomena driven by fast electron heating is important for a range of applications, including fast electron collimation schemes for fast ignition and the production and study of hot, dense matter. In this work, detailed numerical simulations modelling the heating, hydrodynamic evolution and XUV emission in combination with experimental XUV images indicate shock waves of exceptional strength (200 Mbar) launched due to rapid heating of material via a petawatt laser. In our recent publication in Physics of Plasmas (PoP 24, 083115, 2017), we discuss in detail the production of synthetic XUV images and how they assist us in interpreting experimental XUV images captured at 256 eV using a multi-layer spherical mirror. Experimental work was conducted at the VULCAN PW facility.



A synthetic time-integrated XUV image obtained by post processing the baseline radiation-hydrodynamic simulation output using the SPECT3D code (colour scale is in arbitrary units). The imager is assumed to look at the target's rear surface along the target normal.

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Experimental demonstration of a compact epithermal neutron source based on a high power laser

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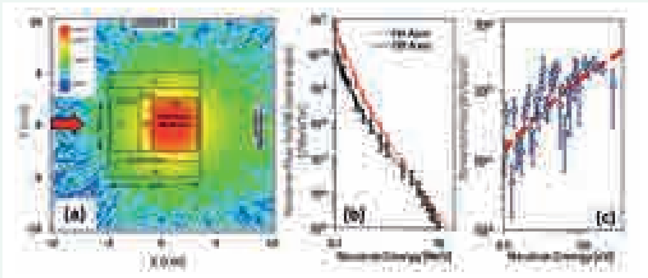
The current trend in the development of laser-driven fast neutron sources warrants investigation of producing sources with lower neutron energies. While fast neutrons are useful in applications such as radiography, most of the applications can be realised at wavelengths closer to materials scattering/diffraction lengths. In particular, sources of epithermal neutrons (eV-100keV) are of high interest for a wide range of applications, from material science to nuclear waste transmutations and healthcare.

An experiment was performed employing the Beam 7 arm of Vulcan laser to moderate the fast neutrons (~MeV), produced via pitcher-catcher technique, into the epithermal region (0.5 eV-0.1 keV) employing a compact moderator. Using ^{3}He proportional counters, the epithermal flux of ~ 10^5 n/Sr/pulse in the energy range 0.5-300 eV was measured in the experiment. While these proof-of-principle results are encouraging, there is significant scope for further optimisation of the epithermal neutrons flux by optimising the moderator design as well as the fast neutron source.



(a) The design of the moderator superimposed on the neutron (in the range 1eV-1keV) flux distribution across the mid-plane of the moderator, obtained from MCNPX simulation for 1 MeV neutrons entering the moderator from the left side (shown by red arrow). (b) A typical spectrum of fast neutrons produced in the experiment, measured by two scintillator detectors, one along the axis and the other 35° off axis. (c) Epithermal neutron spectrum generated by the moderator, averaged over 16 measurements, where the red line is an eye-guide to the data points.

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An ultra-high gain and efficient amplifier based on Raman amplification in plasma

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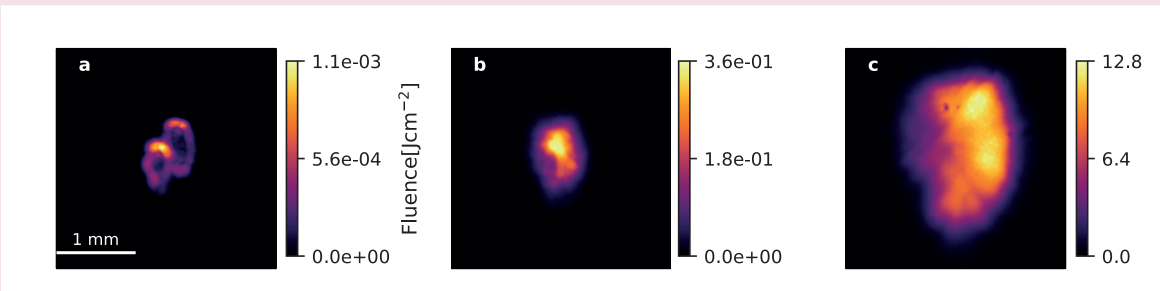
Raman amplification arising from the excitation of a density echelon in plasma could lead to amplifiers that significantly exceed current power limits of conventional laser media. Here we show that 1 – 100 J pump pulses can amplify picojoule seed pulses to nearly joule level. The extremely high gain also leads to significant amplification of backscattered radiation from "noise", arising from stochastic plasma fluctuations that competes with externally injected seed pulses, which are amplified to similar levels at the highest pump energies. The pump energy is scattered into the seed at an oblique angle with 14 J sr^{-1}, and net gains of more than eight orders of magnitude. The maximum gain coefficient, of 180 cm^{-1}, exceeds high-power solid-state amplifying media by orders of magnitude. The observation of a minimum of 640 J sr^{-1} directly backscattered from noise, corresponding to ≈10% of the pump energy in the observation solid angle, implies potential overall efficiencies greater than 10%.



Transverse profile of the Raman signal. Recorded beam profiles for three different nominal pump energies: (a) 3 J, (b) 20 J, (c) 70 J.

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Development of focusing plasma mirrors for ultraintense laser-driven particle and radiation sources

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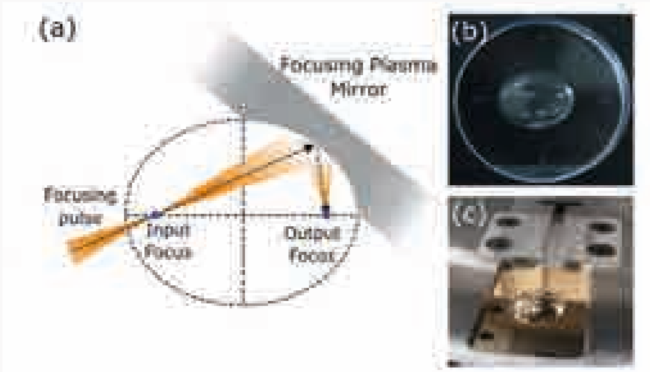
Increasing the achievable peak intensity of high power laser pulses opens up new regimes of laser-plasma interactions, resulting in enhanced ion energies and more efficient photon generation. Here we report on a programme of work to design, manufacture and optimise a small F-number focusing plasma mirror concept, capable of increasing the peak intensity of the Vulcan-PW laser system. This optic form, which re-images and demagnifies the laser focus, is small, enhances pulse intensity contrast and eliminates the requirement to expose conventional optics directly to target debris. It is thus an attractive approach for achieving higher intensities, without requiring significant alteration to the laser. Two approaches for manufacturing this innovative optic are described, namely diamond machining and injection moulding, and the results of characterisation tests are presented. The method developed to align these optics on the Vulcan-PW laser is outlined, together with initial results from their deployment.



(a) Illustration of ellipsoidal focusing plasma mirror concept. Images of (b) the manufactured diamond machined optic and (c) the injection moulding tool.

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Laser Science & Development

Artemis Upgrade, Relocation and the New 100 kHz OPCPA Laser for Ultra / Artemis

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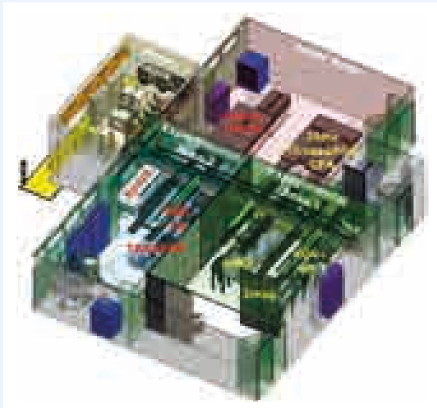
The Ultra and Artemis laboratories provide ultrafast dynamics and spectroscopy facilities for UK and international scientists, addressing problems across physics, chemistry and biology. Synergies in the technology and experimental approaches of these two CLF facilities will be exploited in the coming years by the relocation of Artemis to the Research Complex at Harwell, the home of Ultra.

The acquisition of a new 100 kHz optical parametric chirped pulse amplifier (OPCPA) laser system will upgrade the facilities and underpin future laser technology for both facilities, and the existing Artemis Ti:sapphire chirped pulse amplifier (CPA) will be upgraded with the addition of a third amplification stage. The separation of the laser and plant room from the experimental areas, and the introduction of additional beamlines with more specific end stations, will provide a more efficient user experience, whilst the laser upgrades will significantly enhance the experimental capabilities of both the Ultra and Artemis facilities.

We are actively engaging with the user community through our user meetings, conferences and scientific collaborations, and welcome suggestions from existing and potential new users to aid in shaping the future direction.



Schematic of new Artemis laser facility. Top left: plant room containing vacuum pumps and laser chillers. Top: laser room containing upgraded 1 kHz Ti:sapphire CPA and new 100 kHz OPCPA. Bottom right: Experimental area 1 containing existing Artemis beamlines: atomic and molecular optics (AMO), XUV flat-field (FF) and imaging (Imag.). Bottom left: Experimental area 2 containing new Artemis beamlines: soft x-ray transient absorption (SXR TA) and time and angularly resolved photoelectron spectroscopy (TR-ARPES) and Ultra spectroscopy (Spect.) area.

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Characterisation of the Carrier Envelope Phase of Few-Cycle Short-Wave Infrared Pulses

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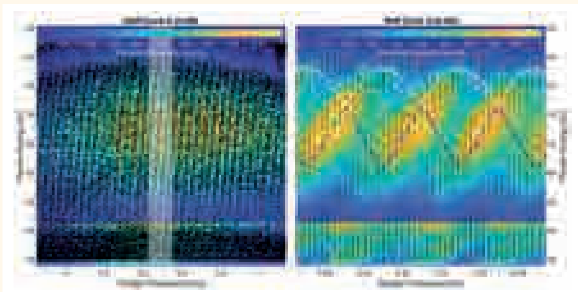
Carrier envelope phase (CEP) stabilized few-cycle optical pulses in the short-wave infrared (SWIR) spectral region have many applications in strong-field physics, such as the generation of coherent femtosecond soft x-ray (SXR) pulses in the water window (~280—530eV) for transient absorption x-ray spectroscopy.

In attosecond pump-probe spectroscopy applications, a single probe pulse with a well-defined time-delay with respect to the pump pulse is desired. Since any measurement is averaged over an ensemble of pulses, it is therefore necessary to ensure that the CEP is controllable and held constant over the course of a single measurement. One method of generating CEP stable pulses is to use the idler wave from an optical parametric amplifier (OPA), followed by spectral broadening and temporal compression in a gas-filled hollow-core fibre succeeded by a pair of fused silica wedges.

We used high harmonic generation (HHG) in argon to generate extreme ultraviolet radiation up to 100eV, and demonstrated the passive CEP stabilisation via the measurement of half-cycle cut-off spectra. Thus, we have shown that it is possible to obtain CEP sensitive measurements from a passive stabilisation alone.



Averaged half-cycle cut-off spectra. Left: False colourmap of the harmonic spectra as a function of wedge thickness averaged over 25 repeat scans. The HCOs for each individual scan are marked by the black circles. The intensity of the lower energy harmonics has been scaled by a factor of x7. Right: Zoom in of the shaded white region marked on the left-hand plot. The individual HCOs are marked by the black dots. The white and blue dots/lines mark the theoretical primary (i.e. highest energy) and secondary HCOs calculated from the driving electric field.

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Measurements of the sample vibration in the material science station of Artemis

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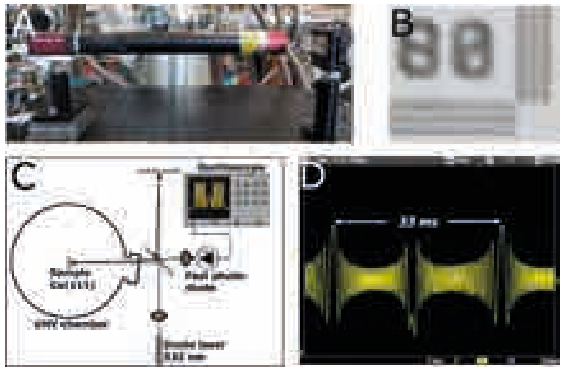
The vibration of the sample stage on the manipulator of the material science station at Artemis is measured by two methods: a microscope, and a Michelson interferometer. The amplitude of sample vibration is found to be smaller than 3 μm with all four turbo pumps on, but two scroll pumps off. The running of scroll pumps introduces a sample vibration as large as 10 μm.

This work ensures the current manipulator is suitable for angle-resolved photoemission spectroscopy (ARPES) with small spot sizes ("micro-ARPES") down to 10 μm, and helps us to understand — so as to minimize — vibration transfer in the design of the new Artemis laboratory.



A. The microscope to monitor the vibration of samples.
B. An 80 line pairs/mm resolution test pattern is shown in the image. It is blurred due to the 10 μm vibration induced by the scroll pumps.
C. The schematic of Michelson interferometer setup.
D. The interference signal of the vibration induced by the scroll pump.

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Benchmarking the performance of the spin-resolved time-of-flight electron analyzer in Artemis

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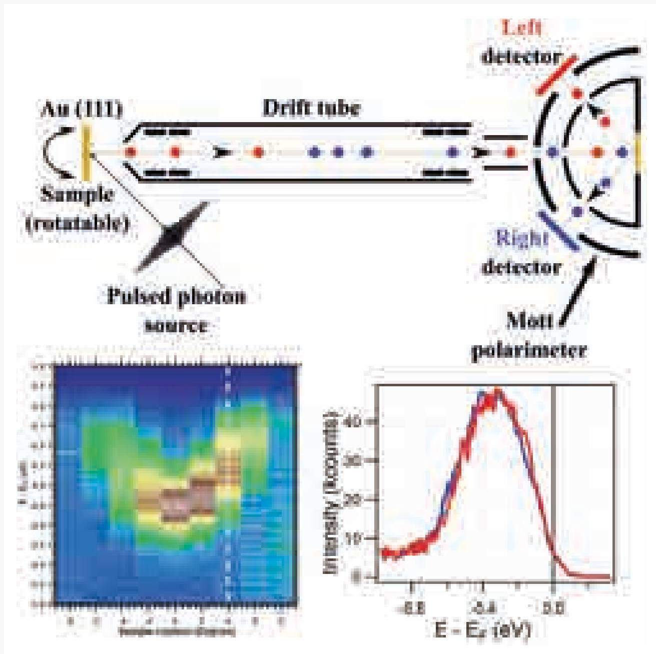
We have benchmarked the performance of the spin-resolved time-of-flight (Spin-TOF) electron energy analyzer at Artemis by measuring the spin-polarized surface state on an Au(111) crystal. To avoid space charge effect, an XUV flux of around 10^6 photons/pulse (10^9 photons/s) at around 15.5 eV was employed.
The parabolic dispersion of the Au(111) surface state was observed, with an energy resolution of around 130 meV. By using a Mott polarimeter, the spin-polarized states were successfully resolved at about 0.11 A^{-1}. The measurement took about 48 hours to reach a satisfactory signal-to-noise ratio, however, which indicates that a higher repetition rate source will be necessary for the study of electron dynamics using the spin-TOF analyzer.



(Top) Schematic of the Spin-TOF measurement. Spin-polarized electrons created from the surface of Au(111) fly into the analyzer and get distinguished at the Mott polarimeter.
(Bottom left) The parabolic surface state measured with spin-integration.
(Bottom right) The spin-resolved spectra (red for spin-up, blue for spin-down) measured at about 0.11 A^{-1}, which is indicated by the white dashed line on the left graph. The binding energy offset of the red peak relative to the blue peak is due to the Rashba splitting of the Au(111) surface state.

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CARAVAGGIO: a new experimental station for characterising materials and optics over a wide range of temperatures

A.M. Wojtusiak, M. De Vido, K. Ertel, I. Cheshire, T.J. Butcher, P. Mason *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

CARAVAGGIO, a new experimental station to characterise optical components and materials and to perform proof-of-concept demonstrations, has been commissioned. CARAVAGGIO is an important tool to enable the scaling of DiPOLE technology, as it allows the optimisation of concepts and optics before they enter the system. The layout of CARAVAGGIO is highly flexible, which allows a variety of measurements to be taken.
It consists of two main beamlines: one operating at room temperature, which can be used for measuring reflectivity and transmission of optics over a wide range of angles, while the other allows to measure the optical properties of materials over a temperature range between 77K and 500K.

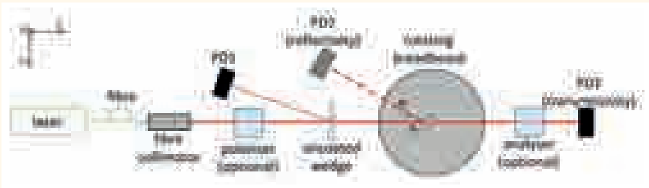

Figure 1: Experimental setup for the room temperature beamline of CARAVAGGIO.

Figure 2: Experimental setup for the optical cryostat beamline of CARAVAGGIO.

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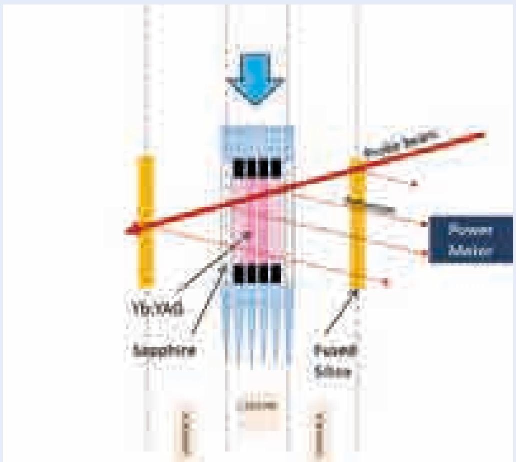
Suppression of reflected power in the DiPOLE cryogenically cooled amplifier head

J. Fullalove, J.M. Smith, K. Ertel, T. Butcher, J. Phillips, P. Mason, S. Banerjee, M. De Vido *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell campus, Didcot, UK)*

The DiPOLE prototype laser has been developed within CALTA at the CLF as a next generation, high energy, high average power, cryogenically cooled, diode pumped solid state laser (DPSSL). The amplifier head at the heart of DiPOLE houses a number of optics including multiple gain media disks, sapphire pressure windows and fused silica vacuum windows. In this report we detail a successful investigation and rectification of a phenomenon that resulted in a gradual decrease in the output energy of the amplifier during operation. The phenomenon was traced to an increase in the reflectivity of anti-reflection coated optics within the amplifier head, likely due to a condensation layer forming under cooling.



A cross-section of the CW beam which is propagated through and reflected by the DiPOLE amplifier head.

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Increasing the productivity of the DiPOLE prototype laser

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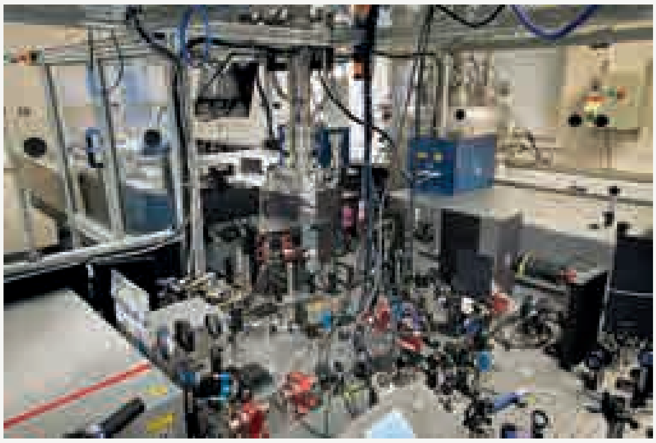
The DiPOLE laser system was constructed as a proof of concept system, to establish a new architecture of scalable laser systems. The system has since become a test bed, enabling development of technologies and testing of optics.

The system started as a development space and therefore did not require, or indeed have, a long-term schedule for experiments and maintenance. Despite this approach, work carried out with the DiPOLE system had continued to deliver useful scientific output. While making changes to the DiPOLE system to accommodate laser shock peening experiments, however, the need for scheduling became more apparent.

Recently a new system that schedules experimental campaigns has been trialled, to allow more effective resource management and provide the necessary preparation time for a successful experiment. In 2017/18, a total of 27 experimental sessions of varying duration were scheduled and all successfully completed, including planned developments to the DiPOLE system itself.



The DiPOLE laser system.

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Femtosecond Timing Monitor for Gemini Laser area

N. Bourgeois *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)* **M.J.V. Streeter** *(The John Adams Institute for Accelerator Science, Imperial College London, UK)*

We present a diagnostic for monitoring the temporal overlap of the North and South beams of the Gemini laser.
The Femtosecond Timing Monitor (FTM) is installed in the Gemini laser area, and measures the pulse separation accurately over a 10 ps time window. This diagnostic also gives a direct indication of which pulse is ahead in time.

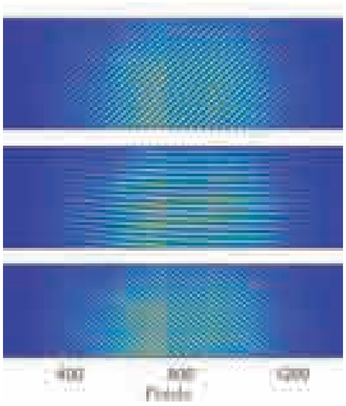

Figure 1: Timing fringes from the interference of the North and South beams. a) Δt = 1.26 ps South beam late, b) Δt = 74 fs, c) Δt = 1.40 ps South beam early.

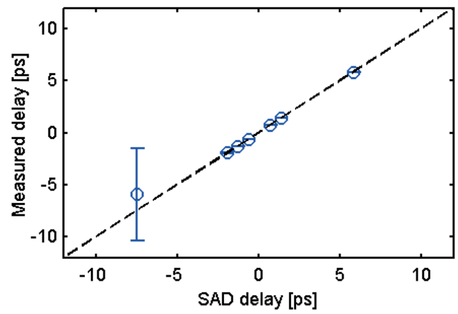

Figure 2: Measured pulse separation against delay introduced on the Split And Delay (SAD) table

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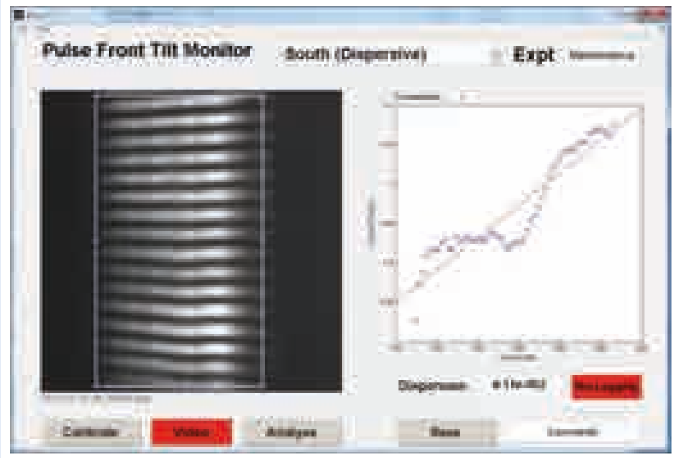
Implementation of a spectrally-resolved inverted-field autocorrelator for angular dispersion measurements in Gemini

C.D. Gregory, Y. Tang, O. Chekhlov, S. Hawkes, C.J. Hooker, V.A. Marshall, B.T. Parry, D.R. Symes *(Central Laser Facility, Gemini Laser Group, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

Misalignment of the Gemini compressors can result in uncompensated angular dispersion of a laser beam, which increases the pulse duration, reduces the temporal contrast, and distorts the focal spot. After compressor alignment in the laser area, any residual minor misalignment is currently corrected for by making small changes to the compressor gratings while monitoring experimental observables in the target area (for example, focal spot shape or electron beam pointing).

A new diagnostic is being implemented to improve the accuracy of the laser area diagnostics, with the goal of eventually allowing a precise value of the angular dispersion to be measured on-shot. The system uses a spectrometer to analyse the output of an interferometer in a technique known as SRIFA (spectrally-resolved inverted-field autocorrelation). When commissioned, this diagnostic will provide a real-time measurement of the angular dispersion of the Gemini beam.



User interface for the new diagnostic, showing an example of raw data on the left, and the calculated dispersion on the right.

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Software developments in Gemini

V.A. Marshall *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

The Gemini laser system software consists of a network of distributed applications, which are used to control elements of the laser and monitor a large number of parameters, both on-shot and continuously. There have been a number of changes and upgrades to the software this year.

At the request of the users, the interface with the Newport ESP300 slide has been upgraded to provide finer and easier-to-use control over the relative timing of the two beams. Other changes offer:

- improved temperature monitoring at multiple locations throughout Laser Area 3 to determine the effect (or otherwise) of temperature variations;
- better management of the 15 attenuating filter wheels used in front of cameras and diagnostics, so that failed wheels can be identified more easily;
- more detailed daily beam characterisation reports that can be emailed to laser operators and users.

ESP300 control application user window.

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Manufacture and assembly of shell-and-cone targets for plasma collision experiments

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C. Spindloe *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*
M. Harris *(RAL Space, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

This article gives a brief introduction to complex shell-and-cone targets Scitech Precision Ltd assembled for an experimental campaign involving the collision of plasmas. The main purpose of the experiment was to drive the target from two sides using two nanosecond lasers. The plasma that is ejected from the cones collides in the middle, which is observed. Diagnostics used were proton radiography and hard x-ray measurements.

The target consists of two gold micro cones, which had a wall thickness of ~20 µm and a height of ~380 µm. A 60 µm thick plastic hemisphere was glued inside the gold micro cone.

Subsequently two such cones were attached to an aluminum bridge with a 100 µm ±5 µm gap to complete the target.
The small size and delicacy of the micro components made handling the target very difficult. Many different processes were used in the fabrication of the targets, including diamond point turning, PVD, CVD and laser micro machining, as well as complex manual assembly.

The article describes the target, its components and the different assembly processes in more detail.

Figure 1: Image showing a completed target. The aluminum bridge holds the whole assembly together and facilitates the mounting process.

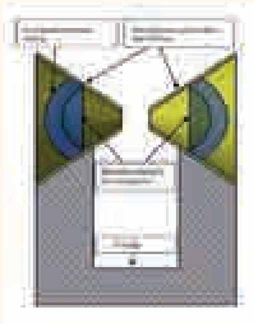

Figure 2: Drawing showing the full target.

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Development of patterned tape-drive targets for high rep-rate HPL experiments

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L. Harman, P. Sykes *(Scitech Precision Ltd, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*
W. Robins *(Precision Development Facility, RAL Space, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*
B. Kettle, S. Mangles *(Faculty of Natural Sciences, Department of Physics, Imperial College London, UK)*

As high power lasers offer increasingly high repetition rates, delivery of solid targets for experiments is becoming a pressing issue. A tape substrate mounted on a driving mechanism aligned to the focal position of the beam can provide a constant 'stream' of targets for laser interaction. While this is a practical method for target delivery and thin CH tapes can be readily procured, the target material and coating thickness is very limited, and any coatings/patterns must be post-processed which is extremely time consuming and difficult.

A method for manufacturing custom-coated targets on a substrate material to specific thicknesses is presented. The fabrication process employs various technologies, including thin-film coating, chemical etching and laser-machining. The process theoretically allows the delivery of several thousands of targets in a single cycle. The benefits and challenges in producing such target tapes are discussed, as well as the methods for improving the technology for the future.

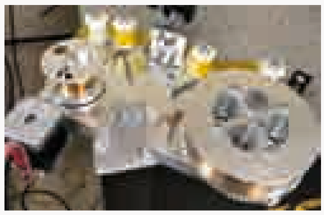

Figure 1: Completed sections of 100 nm Ge target tape. The black vertical markings indicate the joint location of each strip.
Figure 2: Prototype of high-stability tape drive system.

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Study of the prompt aberrations of the Vulcan TAP Beamline

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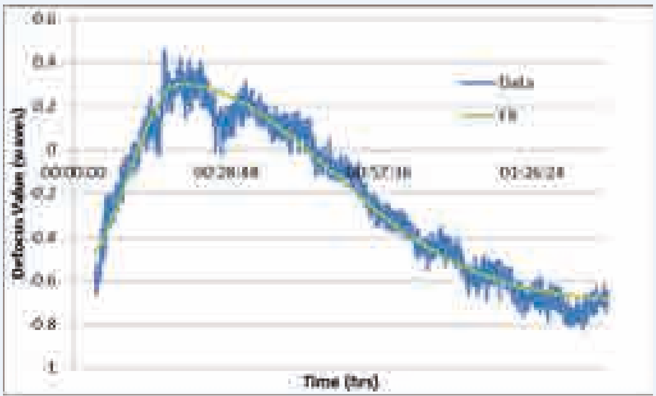
In this paper we discuss the progress that we have made in addressing the on-shot aberrations that occur when the Vulcan laser is fired, primarily addressing the amount of defocus. We see that there is evidence that the time since the last laser shot plays a significant role in the variability of this parameter and we report our investigation into its temporal evolution. Results shows that it is crucial for there to be a minimal amount of time between running the adaptive optic and then firing the laser.



Typical decay of the defocus term after a full disk shot showing exponential fits to determine some temporal constants of the system.

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Control of the temporal shape of nanosecond long lasers using feedback loops

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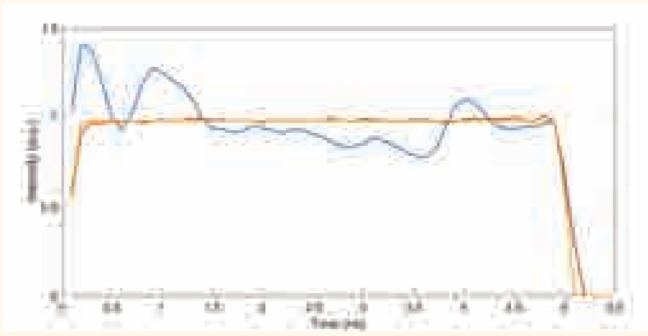
We present developments in the control of the temporal pulse shape of nanosecond long pulsed lasers. An active feedback loop between the output of a regenerative amplifier and its input to obtain the desired pulse shape is demonstrated. We compare several algorithms to achieve this, and the differences due to the targeted pulse shape and duration, in this paper. It is found that the algorithm that is based on the ratio of the target and measured pulse profiles provides the most robust solution. The method proposed here can be used to obtain any pulse shape with minimal knowledge of the laser amplification system.

Deformation of the pulse temporal profile due to our regenerative amplifier system. We input a 5 ns top hat temporal profile in into our system (yellow) and get the blue waveform at the output. After the described corrections we obtain the waveform in red.



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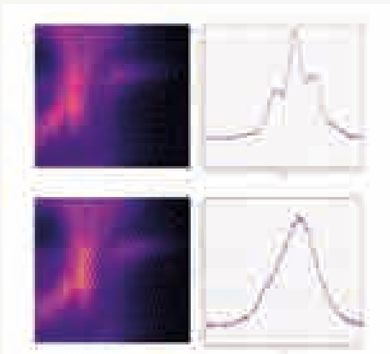
Progress Towards Coherent Combination of Free-Space Femtosecond Laser Pulses

W.H. Fraser, V.C. Lindsay, B. Parry, M. Galimberti *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

We have successfully achieved spatial and temporal locking of two ~100 fs duration laser pulses in the far field. The work is another step towards realising full coherent combination of multiple large aperture beams as part of the HAPPIE project.

Mirrors mounted on piezo tip/tilt and tip/tilt/piston platforms act to stabilise two 10 mm square beams to an external spatial set-point, and maintain them in phase at frequencies up to ~200 Hz.

This report focuses on developments required to accomplish reliable temporal stabilisation. A piezo phase-shifter and additional PID loop were introduced to permit robust correction in the presence of fast phase noise.



The top images show the focal spots and spectra of the short pulses with a path difference of ~100 μm between the two arms. The bottom images are with the path difference minimised, and spatial and temporal stabilisation enabled. Static interference fringes are observed in the far-field, with no interference in the spectral domain.

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Theory & Computation

Enhancing the propagation of fast electron beam through the use of graded-resistivity guides.

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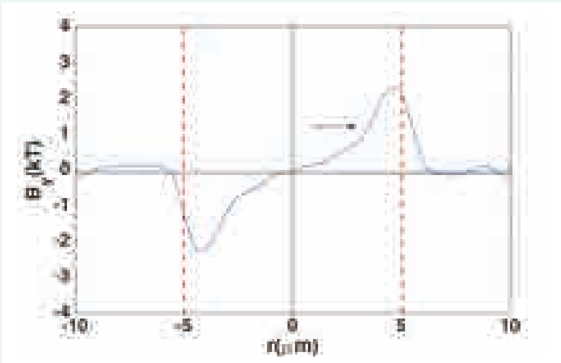
A.P.L. Robinson *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*
J. Pasley and N.C. Woolsey *(York Plasma Institute, Department of Physics, University of York, UK)*

We observe an increase in the width of a collimating magnetic field, and higher resistive guide heating, where a graded-resistivity guide element was employed in order to collimate a relativistic electron beam. The electron beam is generated from the interaction of a Vulcan PetaWatt-like laser pulse with a solid target. Simulations performed using the three-dimensional hybrid-particle-in-cell code ZEPHYROS show that the resistive magnetic field extends over much of the guide element. This field deflects relativistic electrons into the guide which acts to smooth current density gradients. These smooth gradients limit the growth of magnetic fields within the guiding element, preventing electron beam filamentation, which is a problem with guides using a step change in resistivity. As a result, relativistic electron confinement improves, and simulations show increased heating at-depth, coupled with a reduction in temperature inhomogeneities.

Contact: R.A.B. Alraddadi (ralraddadi@ksu.edu.sa)



Cross-section of the magnetic field, B, as a function of radial position r at x=10 μm, taken at 2.2 ps and limited to -10 < r < 10 μm in y-midplane. The vertical dashed lines show the boundaries of the guide element. The arrow shows the gradient in the magnetic field inside the guide-element.

Modelling the effects of the radiation reaction force on the interaction of thin foils with ultra-intense laser fields

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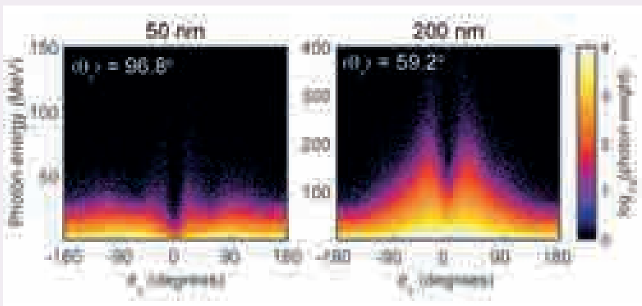
The effects of the radiation reaction (RR) force on thin foils undergoing radiation pressure acceleration (RPA) are investigated. Using QED-particle-in-cell simulations, the influence of the RR force on the collective electron dynamics within the target can be examined. The magnitude of the RR force is found to be strongly dependent on the target thickness, leading to effects that can be observed on a macroscopic scale, such as changes to the distribution of the emitted radiation and the target dynamics. This suggests that such parameters may be controlled in experiments at multi-PW laser facilities.



A plot of the photon angular distributions from a 50 nm (left) and a 200 nm (right) aluminium foil target. These distributions are compared at the time of maximum synchrotron emission, corresponding to 13 and 31 laser periods respectively.

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Plasma Diagnostics

Assessment of cameras for low intensity acquisitions

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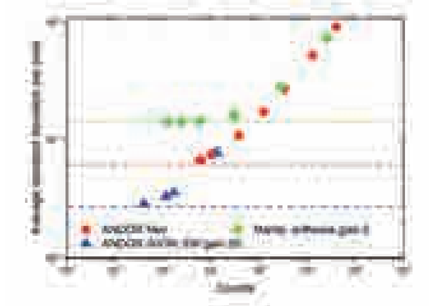
Three high bit depth cameras were tested to benchmark their performance in low intensity acquisitions: the iXon and the Neo by Andor, and the Manta by Allied Vision. These cameras are regularly used in the Central Laser Facility to probe laser plasma interactions where very low intensity signals are common.

The cameras were subjected to progressively lower intensities of light, to assess their read noise floors and dynamic ranges. It was concluded that the Neo and iXon were the least noisy cameras. For single photon situations, the iXon performed best, with a dynamic range of near 15 bits, and a read noise of only 2 counts. For low but above 10 photons per pixel acquisitions, the Neo performed well, with a dynamic range of 13 bits and a read noise of 6 counts. The Manta was found to perform very well, given its size and lack of cooling. If used for small (sub 1s) exposure times and as a single shot device, it had a dynamic range of 12 bits and a read noise floor of 14 counts (at 16 bit scaling).



Plot of counts to the average standard deviation per pixel. The noise falls linearly until the noise floor (indicated by the dashed lines) is hit, where it begins to flatten out. The data for the Manta camera is the raw counts produced from saved files (12 bit scaled up to 16 bit).

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Specular Transmittance of 3D printed plastic at different thickness

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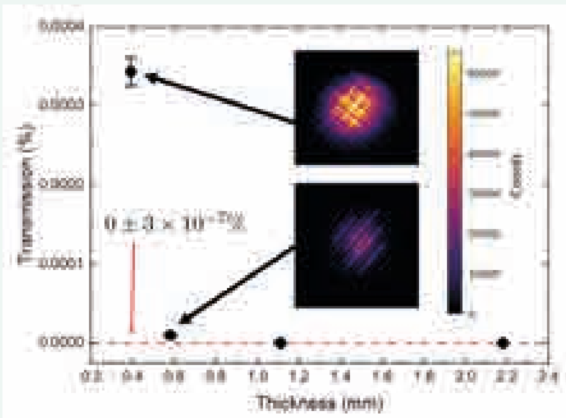
D.R. Rusby, S. Allum, D. Neely *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*
D. Wilsher *(Applied Science, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

The optical transmittance of 3D-printed acrylonitrile styrene acrylate (ASA) sheets was tested, to determine the light tightness of enclosures made from this material. At greater than 1.1 mm thickness, it was found that the material is opaque to the limit of 3 x10^{-7}% transmission.



Graph showing transmission of laser light through the printed plastic sheets of different thicknesses. An image captured for the two non-zero transmissions is also shown. At greater than 1.1 mm, the transmittance is below the detectable background (measured with an Andor Neo which, with the lens used, had a noise floor of 3 x 10^{-7}%). The top colour map was taken with a 0.3 s exposure, the lower one with 6 s.

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Simulating short pulse scintillation light with a pulsed LED

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S. Hopkins, K. Rodgers, R. Sarasola, D. Neely *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell campus, Didcot, UK)*

Light emitting diodes (LEDs) were tested as a short pulsed light source, simulating the output for fast scintillators. These Scintillators usually have a pulse duration between the nanosecond and microsecond range. Commercial LEDs of wavelengths of 400-800nm are readily available, and offer a cheap solution for matching the wavelength and pulse duration of these scintillators. It was found that a pulse as short as 4ns could be obtained at 405nm.

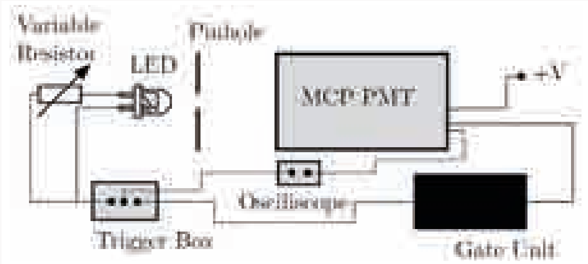

Fig 1: Setup for the LED characterisation test. The LED was pulsed with a driving pulse from a trigger box. This also triggered the PMT, and sent a driving pulse to the oscilloscope to be recorded. The LED light was funnelled through a pinhole to avoid scattered light from falling onto the PMT.

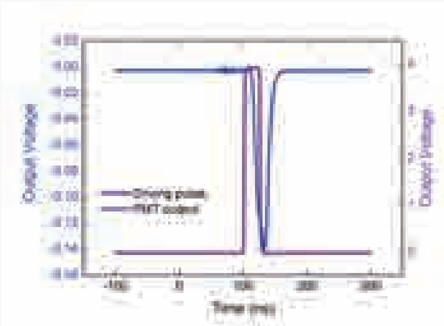

Fig 2: Trace of a 25ns pulse detection from a 405nm LED. Pulse matches typical LYSO emission in wavelength and pulse duration.

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Application of silicon photomultipliers in scintillation based radiation detectors

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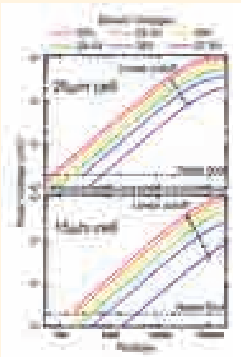
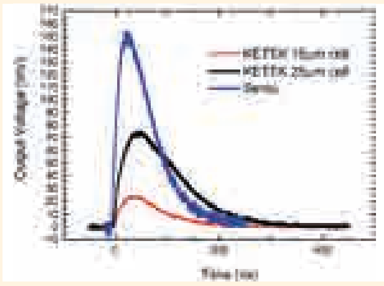
J. Matheson *(Department of Particle Physics, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*
C.D. Armstrong, R. Heathcote, R. Clarke, G. McBride, D. Neely *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

An application for silicon photomultipliers as sensitive time resolved radiation detectors was investigated. Absolute light response, with and without amplification, was investigated for different models of SiPM. Radiation spectra with LYSO were also obtained. It was found that, in terms of sensitivity, the SiPMs with the set-up used were able to produce readouts in the order of 10s of photons, but require amplification to approach this level.





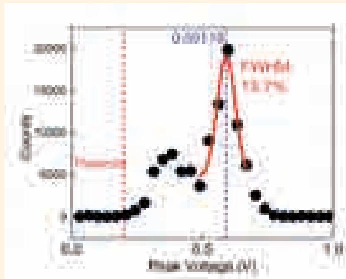


Fig 1: (left) Fitting of the response curves of different biased voltages as indicated and plot of the number of photons below which the response is linear. Linearity is defined as where the non-linear component of the fit contributes less than 10%. These 'cut-off' values are also indicated by vertical dashed lines on the left of the plot.
Fig 2: (middle) Typical trace from the KETEK SiPMs, cell sizes indicated. Peak heights of traces illustrated are representative of a 511 keV LYSO detection. A similar output from the SensL chip is also shown. As can be seen, the SensL chip is much faster both in rise time and recovery than the KETEK ones. Biased voltage of 30V used, scope coupling at 50Ω
Fig 3: (right) Spectra of activated Tc decay (emitting 141 keV x-ray) at 9.75 MBq, detected by a KETEK SiPM with a Cremat amplifier. The count rate is much higher, as seen by the peak height compared to the background.

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A novel in-situ dual channel alignment system for precision alignment of complex targetry

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K.L. Lancaster, D. Farley, C.D. Murphy, J. Pasley, W. Trickey, C. Baird, C. Underwood *(York Plasma Institute, Department of Physics, University of York, UK)*
P. Koester *(Intense Laser Irradiation Laboratory, INO-CNR, Pisa, Italy)*
A. Horne, Z. Davidson, R. Gray *(Department of Physics, University of Strathclyde, Glasgow, UK)*

As targetry for High Energy Density Physics (HEDP) experiments has become more complex, methods to position the laser focal spot more accurately on the desired region of the target prior to the shot are needed. When the target feature sizes are similar in scale to the spatial jitter of the laser, a second requirement for on-shot laser positional information becomes important.

We have successfully designed and deployed a novel in-situ front surface imaging diagnostic for both pre-shot target alignment and on-shot focal spot position determination. The dual channel system is designed to align targets with feature sizes of 20-50 μm. An IR channel (1053 nm) was used to align the target prior to the shot, and then a second-harmonic channel (527nm) was used to image the self-emission indicating on-shot position of the focal spot. This alignment system was deployed during a recent experiment using the VULCAN Petawatt system and proved invaluable for categorising successful shots.

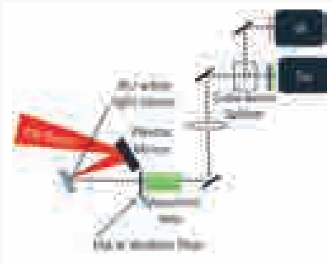

Fig 1: In-situ layout of the alignment system

Fig 2: a) image of self-emission directly on cone tip, b) clipping the cone tip, and c) completely displaced from the cone tip.

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3D ray tracing of a high intensity laser beam through plasma guiding structures

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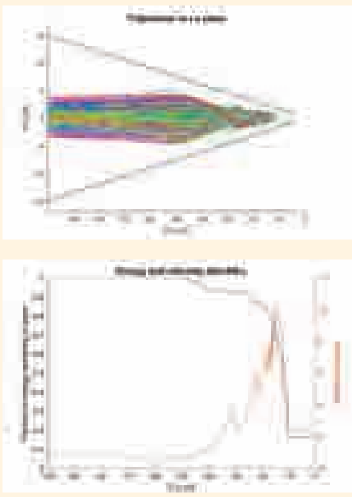
C.D. Armstrong *(Department of Plasma Physics, University of Strathclyde, Glasgow, UK; Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

High power lasers are challenging to focus down to useful intensities using normal optical components. This project seeks to use the optical properties of plasma to do this.

A 3D ray tracing program has been developed using MATLAB to study how a high power, short pulse laser beam may travel through a plasma guiding structure. The guiding structures predominantly used in this study were hollow tapered cones on the micron scale. The motivation for this was the prospect of confining the beam sufficiently to increase the intensity, potentially by a factor of up to 10.

Significant increases in intensity were observed in the simulations, despite modelling the effects of the beam losing energy to the plasma. The effect of varying a number of parameters of the beam-cone configuration have been investigated. Wave optics effects were not treated here, but it is hoped that this geometrical study will provide some insight into laser confinement by short-lived plasmas.



Trajectories (top) and intensity (bottom) for f3 beam entering double edge plasma modelled cone with scale length 0.5μm. Note the light stops at boundary with over-dense region.

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Ultrafast & XUV Science

Ponderomotive acceleration of photoelectrons in pump-probe experiments

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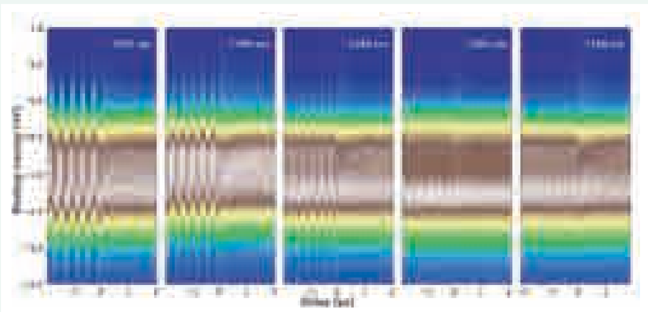
Photoemission is one of the most direct probes of the electronic band structure of a material. The application of femtosecond lasers in photoemission allows the technique to explore the dynamics of quasiparticles on their native timescales of femtoseconds to picoseconds. In some materials however, a complication can arise in photoemission spectra due to acceleration of the outgoing photoelectrons by the pump laser pulse as it reflects off the sample. This leads to an oscillation of the electron kinetic energy when the probe pulse precedes the pump. The effect is strongly wavelength dependent, increasing in amplitude as the wavelength increases into the infrared. These are the spectral regions increasingly of interest in condensed matter research, so it is important to understand the effect properly. In this work we demonstrate the influence the pump laser wavelength in pump-probe photoemission experiments on the W(110) surface and on the magnetization dynamics of Gd(0001). The effect has been observed previously on Gd and explained by Bovensiepen et al. [1] by ponderomotive acceleration of the outgoing photoelectrons by a transient optical grating formed by interference between the incoming and reflected laser pulse. We observe two significant differences from the published results. Firstly, the amplitude of the oscillations before time zero in our experiment is up to 50 times larger than observed previously, and secondly electrons excited from different initial states can show different oscillation amplitudes. The latter is surprising, as electrons should be screened within a fs and not react differently to a transient potential. We have extended the validity of the model of ponderomotive acceleration to correctly include the time when the pump and probe pulses overlap. This has allowed us to identify unequivocally a transient increase of the magnetizaton of gadolinium on the timescale of 100fs after excitation by a femtosecond laser pulse.



Oscillatory ponderomotive acceleration by the pump pulse of photoelectrons ejected from W(110) by XUV photons at 36eV. The pump wavelength decreases from left to right: 1610nm, 1450nm, 1384nm, 1300nm, 1148nm.

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Soft x-ray interferometry for pump-probe spectroscopy and hyperspectral imaging

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During high harmonic generation, laser-driven electrons may return to their parent ion and recombine along two predominant paths, known as the "long" and "short" quantum trajectories. The relative amplitude and phase of these trajectories plays a key role in the microscopic and macroscopic response of the generating medium to the driving laser field. Developing interferometric techniques capable of accessing the individual trajectory contributions to each harmonic is crucial for accessing the quantum dynamics inherent in high harmonic generation.

We report on an interferometer operating at extreme ultraviolet wavelengths in which trajectory-dependent interference can be identified. This interferometer is based on two longitudinally separated sources driven by the same laser pulse, such that it is inherently synchronized. The high stability of this technique, combined with sensitivity to quantum trajectories, offers a new route for the measurement and timing of ultrafast processes.

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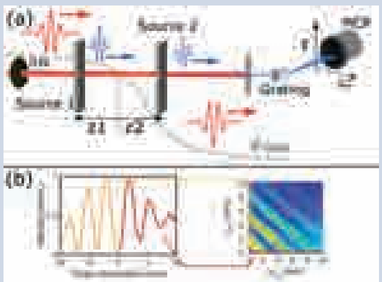
(a) Experimental setup. The spatially-resolved harmonic spectrum generated from two longitudinally separated gas targets is recorded as a function of the positions (z1,z2) of each gas cell. The Gouy phase shift across the focus and variation in the atomic dipole phase results in interference between the harmonics generated in each target.
(b) Left: The on-axis harmonic interference resulting from moving a single cell about the focus while keeping the other static.
Right: On-axis interferogram for q=15 resulting from moving both cells about the focus.



Ultrafast Multiphoton Photoelectron Circular Dichroism in alpha-Pinene

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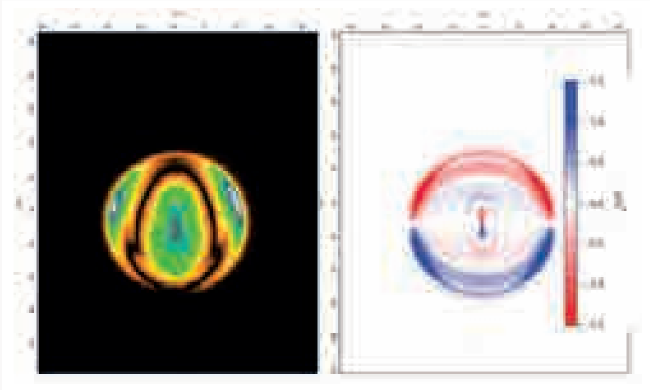
Photoelectron Circular Dichroism (PECD) was recorded by using velocity map imaging (VMI) to record the angular distributions of photoelectrons emitted upon ionization of a cooled supersonic beam of α-pinene enantiomers. As a chiral molecule, the distribution of photoelectrons has a forward-backward asymmetry (relative to the laser beam direction) allowing probing of the chirality. Measurements were made with a (2+1) resonant multiphoton ionization scheme at 400 nm, 370 nm, and with (1+1) ionization scheme at 200 nm. As can be seen in the 400 nm false colour-mapped images, very substantial chiral asymmetries (~10%) are recorded.



VMI dichroism images of R-α-pinene in a supersonic molecular beam, recorded with alternating left- and right- circularly polarised laser pulses at 396.52 nm. The laser beam propagates vertically in these figures. The left panel shows a raw 2D projection image, the right shows the antisymmetric Abel inverted 3D-slice. The red-blue colour coding of the latter indicates a strong (~10%) chiral asymmetry between electrons emitted up- and down- in the figure.

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Observation of Layer Pseudospin Interference in Bilayer MoS_2

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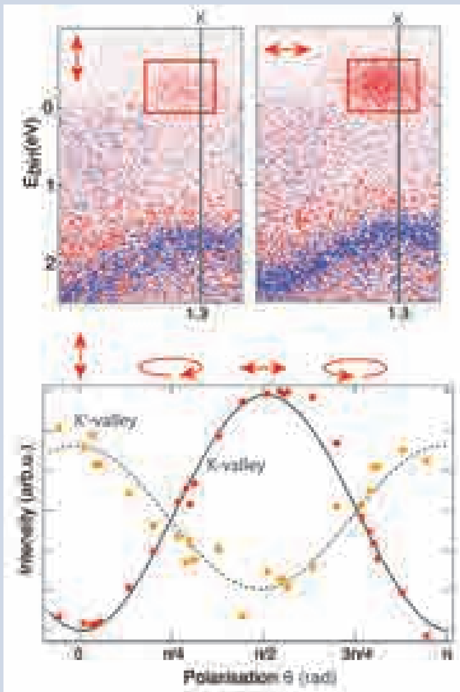
L. Bignardi, D. Lizzit, P. Lacovig, S. Lizzit *(Elettra-Sincrotrone Trieste, Italy)*
D. Biswas, I. Markovic, P.D.C. King *(SUPA, School of Physics and Astronomy, University of St. Andrews, UK)*
P. Majchrzak, C. Cacho, A. Jones, R. T. Chapman, A. Wyatt, E. Springate *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

The semiconducting transition metal dichalcogenides, such MoS_2, comprise a class of materials where optical selection rules can be used to selectively excite electrons with opposite spin- and valley-quantum numbers. This dichroism effect, which is also referred to as the valley pseudospin, requires single-layer MoS_2, where the lattice inversion symmetry is inherently broken by the Mo and S atoms in the unit cell. This is not true for bilayer MoS_2 where the inversion symmetry leads to an absence of valley pseudospin polarisation. Here, we use elliptically polarized pump pulses followed by extreme ultraviolet (XUV) probe pulses to perform polarization-, time- and angle-resolved photoemission spectroscopy (TR-ARPES) to investigate the pseudospin associated with the two MoS_2 layers in a single-domain bilayer film. While the polarization of this layer pseudospin is minimal, we find an unexpected linear dichroism effect for the excited electrons in the conduction band states of the sample. A calculation of the optical transition probabilities reveals that this effect stems from an interference effect between the valleys of two MoS_2 layers. This constitutes the first observation of a layer pseudospin interference effect.



Observation of linear dichroism in bilayer MoS_2. The top panels display the response to an optical excitation with linear vertical and horizontal polarized pump pulses. In this case a larger response is seen in the case of linear horizontal polarization. The bottom graph displays the intensity of excited electrons for a range of polarization angles, exhibiting a clear polarization dependence that switches between the K and K' valleys of the material.

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Imaging & Dynamics for Physical & Life Sciences

DNA double-strand breaks probed with super-resolution imaging nanoscopy

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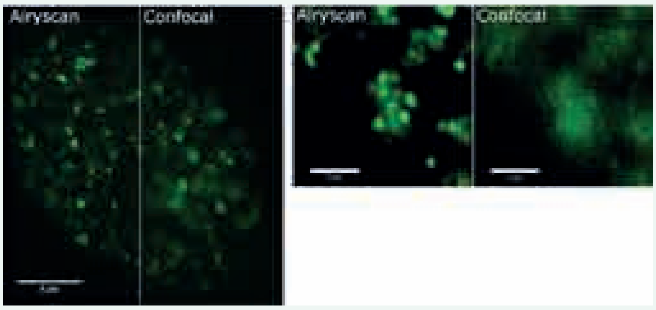
S. Barnard *(Public Health England, Centre for Radiation, Chemical and Environmental Hazards, Chilton, Didcot, UK)*

Genomic DNA is continuously damaged by metabolic processes and by external sources, such as ionising radiation. The phosphorylation of histone H2AX on serine residue 139 (described as γ-H2AX) is an excellent indicator or marker of DNA double-strand breaks (DSBs). The yield of γ-H2AX (foci) is shown to have some correlation with the dose of radiation or other DSB-causing agents. There is, however, some discrepancy in the DNA DSB foci yield among imaging and other methods, such as gel electrophoresis.

We have compared the performance of several super-resolution techniques for determining the amount and spatial distribution of γ-H2AX foci formation in the nucleus of cells after x-ray irradiation. The super-resolution imaging methods used include stimulated emission depletion (STED), ground-state depletion microscopy followed by individual molecule return (GSDIM), and structured illumination microscopy (SIM), as well as an improved confocal, Airyscan and HyVolution 2. By using these imaging techniques to achieve resolutions as low as 30 nm, each focus may be further resolved. This increases the number of foci observed per radiation dose compared to standard microscopy, and provides a more reliable quantification of DSBs.



Clear comparison between the foci resolved with Airyscan versus confocal. Fluorescence images of x-ray irradiated Hela cells labelled with γ -H2AX-A488.

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Solid immersion microscopy images cells under cryogenic conditions with 12 nm resolution

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M. Darrow *(Diamond Light Source, Harwell Science & Innovation Campus, Didcot, UK)*
M. Romano, K. Beis *(Department of Life Sciences, Imperial College London, UK)*

The resolution in conventional cryogenic fluorescence microscopy (~400 nm) is hindered by the use of dry objective lenses. Here we applied a super-hemispherical solid immersion lens (*super*SIL) in conventional cryogenic microscopy to achieve at least 12 nm resolution, in combination with single molecule localisation microscopy. The new technique enables optical imaging at macromolecular level, bridging the resolution gap between optical and electron microscopy.

SuperSIL multi-colour imaging of E.coli cells under cryogenic conditions.
(A) Secondary ABC transporter protein SbmA labelled with EGFP;
(B) Anti-bacterial peptide Bac7 labelled with BODIPY;
(C) The overlay image of the SbmA and Bac 7. Scale bars: 1μm.

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Investigating the processes of cell receptor signal regulation

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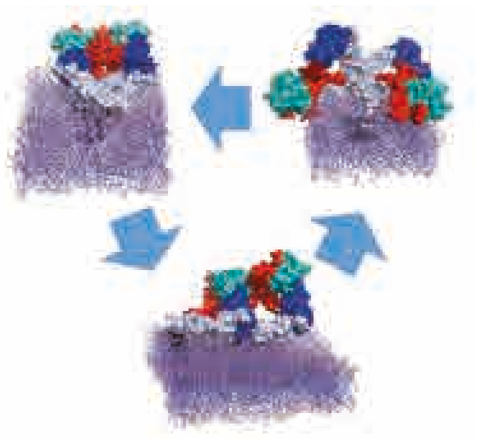
A. Lajevardipour, A.H.A. Clayton *(Centre for Micro-Photonics, Faculty of Science, Engineering and Technology, Swinburne University of Technology, Hawthorn, Australia)*
S. Sagawa, Y. Shan, D.E. Shaw *(D.E. Shaw Research, New York, USA)*
P.J. Parker *(Protein Phosphorylation Laboratory, The Francis Crick Institute, London, UK)*

The epidermal growth factor receptor (EGFR) is a protein tasked with transducing external signals across the cell surface, and EGFR activation in the absence of a signal is implicated in breast and lung cancer. Current models of EGFR autoinhibition are based on structural data from receptor fragments and do not explain how mutations achieve signal-independent phosphorylation.

We have used a repertoire of OCTOPUS imaging technologies to study the structure of whole receptors in the cell membrane and this data has been informed with simulations. This has revealed an extracellular head-to-head interaction through which ligand-free receptor polymer chains of various lengths assemble. This head-to-head interaction prevents kinase-mediated dimerization leading to autoinhibition. Mutations of the receptor or certain intracellular treatments split the head-to-head polymers into two different forms of dimers that are either intracellularly active or inactive.

Contrary to the previously proposed models, our results suggest that only dysregulated EGFRs have populations of symmetric and asymmetric kinase dimers that coexist in equilibrium at the plasma membrane under the modulation of the C-terminal domain.



Collage of simulations showing the relations between the inactive 'back-to-back' EGFR dimer (top left) , autoinhibited 'head-to-head' dimer (bottom) and the always active 'stalk-to-stalk' dime.

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Probing Charge-transfer Dynamics of Porphyrin-C_{60} Dyes and Bodipy Polymers for Solid State Tandem Solar Cells

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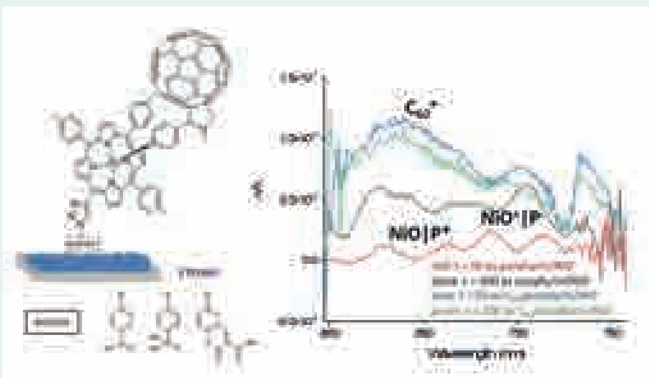
I.P. Clark, I. Sazanovich *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

A series of zinc tetraphenyl porphyrin photosensitizers furnished with three different anchoring groups, benzoic acid, phenylphosphonate and coumarin-3-carboxylic acid were prepared using 'click' methodology. Their adsorption behaviour on the electrode surface, kinetics of charge-separation at the dye-electrode and dye-redox mediator interfaces and performance in solar cells is described. The photocurrent of the p-DSCs increased with increasing dye loading and corresponding light harvesting efficiency of the electrodes. Coordinating the zinc to a pyridyl-functionalised fullerene (C_{60}PPy) extended the charge-separated state lifetime from ca. 200 ps to 4 ns and a positive improvement in the absorbed photon to current conversion efficiency (APCE) was observed. Finally, we confirmed the viability of electron transfer from the appended C_{60}PPy to PCBM, a typical electron transporting layer in organic photovoltaics. This has implications for assembling efficient solid-state tandem solar cells in the future.



Left: Porphyrin-Fullerene conjugates for investigation in this project. The porphyrins on the left are functionalised with different anchoring groups to compare the effect of anchoring on electron transfer from NiO to the Porphyrin. The C_{60} derivative is coordinated through the Zn.
Right: Representative spectra at selected time delays of porphyrin 3 (coumarin anchor) anchored to NiO in the presence and absence of C_{60} to show the relevant intermediates in the cascade.

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Photocatalytic Methanol Degradation on a TiO_2 Surface Monitored by IR-Vis Sum Frequency Generation through a Transparent Electrode Material

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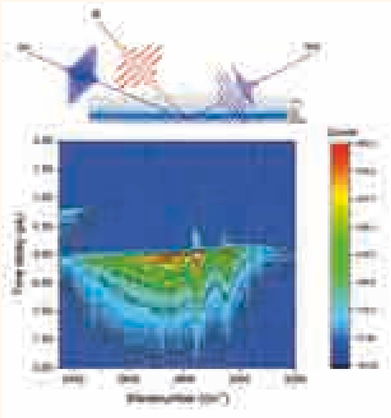
P.M. Donaldson *(Central Laser Facility, Research Complex at Harwell, STFC Rutherford Appleton Laboratory, Harwell Oxford, Didcot, UK)*

The surface specificity of IR-Vis vibrational sum frequency generation (VSFG) spectroscopy is used to probe a photocatalytically active TiO_2 surface through a transparent conductive oxide (TCO) layer. We demonstrate the feasibility of monitoring a dynamic process in this novel experimental geometry by using methanol as a probe molecule. 355 nm LED illumination is used to carry out in situ photolysis of surface adsorbed methanol species, resulting in a loss in intensity of the corresponding C-H stretching modes in the VSFG spectra.

The presence of a TCO layer also enables electrochemical control of the system, opening the door to exciting applications of *in situ* VSFG spectroscopy to the field of photoelectrochemistry.



SFG spectra of MeOH adsorbed on TiO_2 surface through a multi-layer structure at varying time delays between IR and Vis pulses.

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Mapping Catalysis with Time-resolved Infra-red Spectroscopy

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I.P. Clark, I.V. Sazanovich, M. Towrie *(Central Laser Facility, Research Complex at Harwell, STFC Rutherford Appleton Laboratory, Harwell Oxford, Didcot, UK)*

The use of time-resolved infra-red spectroscopy to map the key carbon-carbon bond formation steps underpinning manganese-catalysed C-H functionalisation reactions is described. UV light is used to dissociate a carbonyl ligand from an organometallic manganese catalyst to initiate subsequent interactions with substrates such as alkynes and alkenes. Analysis of the resulting spectra allows for the important interactions between the metal and the substrates to be deconvoluted, as well as the direct observation of the subsequent carbon-carbon bond formation events that underpin the catalytic cycle. The observation of a range of processes was enabled through the temporal flexibility of the Time-resolved multiple probe spectroscopy ($TR^{M}PS$) method.

Scheme 1

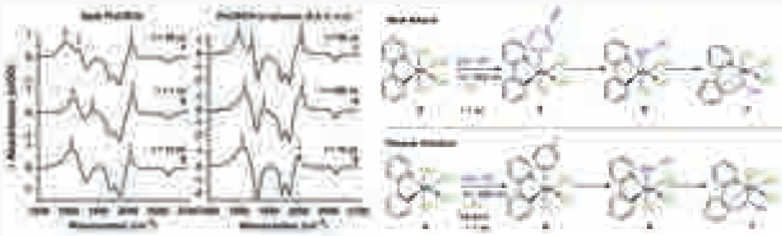

Figure 1

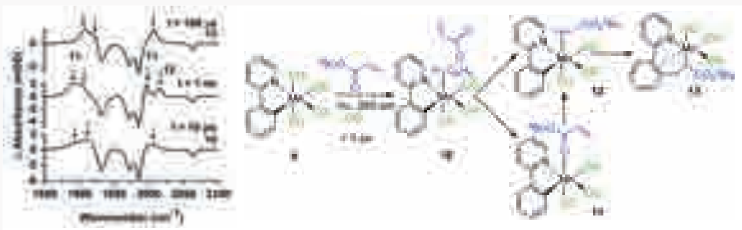

Figure 2

Scheme 1. Mn-catalysed C-H functionalisation reaction and structure of key intermediate.
Figure 1: Left TRIR spectra obtained from the photolysis of 4 in neat PhC≡CH and in toluene solution. Right Reaction scheme showing the structures of the complexes formed.
Figure 2: Left TRIR spectra obtained from the photolysis of 4 in neat $^{n}BuCO_2CH{=}CH_2$. Right Reaction scheme showing the structures of the complexes formed.

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Artemis Operational Statistics

R. T. Chapman *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

The Artemis team delivered a total of nine user experiments from April 2017 to March 2018, as well as three weeks of development projects in partnership with facility users and three weeks of internal development. In total, we delivered 21 weeks of user access and eight weeks of dedicated experiment setup. Table 1 shows the schedule for the year.

Experiments

Three of the nine experiments conducted used the angle resolved photoemission chamber for studying condensed matter samples. Two further experiments were carried out using the spin time of flight chamber in conjunction with condensed matter samples. Three further experiments utilised the AMO chamber, two using velocity map imaging for coulomb explosion imaging and photoelectron circular dichroism, the third using the time of flight detector for photoelectron spectroscopy. The one remaining experiment used the polychromatic beamline with a flat-field spectrometer and multiple gas targets. The Artemis team dedicates approximately one week of set-up to each experiment before users arrive. Similar experiments are grouped together, to minimize set-up time.

Facility performance and reliability

Figure 1 shows the availability and reliability calculations for the 2017-18 year. We run the laser continuously from Mondays through to Fridays during experiments, and regularly carry on data-taking over weekends. In this calculation, the availability for unsupported data-taking overnight and at weekends is weighted equally with supported hours. The experiments for Crepaldi and Vallance were rerun in the 2018-2019 year due to the laser failures in this year.

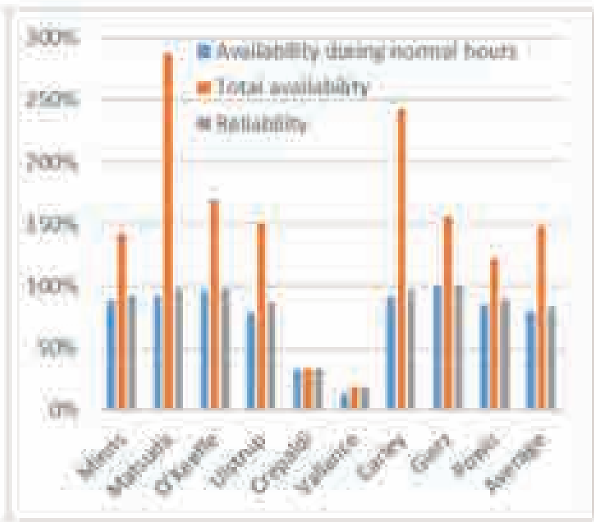

Figure 1: Artemis availability and reliability for user experiments in 2017-18.

Week Beginning	Experiment
03/04/2017	Mims 16120015
10/04/2017	Setup for Mims
17/04/2017	Few Cycle Idler Development
24/04/2017	Toroidal Mirror Upgrade
01/05/2017	TOPAS Service
08/05/2017	Mims 16120015
15/05/2017	
22/05/2017	Setup for Matsuda
29/05/2017	Matsuda 17120002
05/06/2017	
12/06/2017	HHG tests at 1700 nm
19/06/2017	Ptychography Development
26/06/2017	Laser Service
03/07/2017	Few Cycle Idler Development
10/07/2017	Laser repair
17/07/2017	Laser Amplifier Upgrade
24/07/2017	
31/07/2017	Setup for O'Keeffe
07/08/2017	O'Keeffe 17120006
14/08/2017	
21/08/2017	
28/08/2017	
04/09/2017	Artemis User meeting
11/09/2017	Setup for Ulstrup
18/09/2017	Ulstrup 17120000
25/09/2017	
02/10/2017	Crepaldi 17120003
09/10/2017	Laser repair
16/10/2017	Ulstrup 17120000
23/10/2017	HHG tests at 1700 nm
30/10/2017	AMO Installation
06/11/2017	Setup for Vallance
13/11/2017	Vallance 17120001
20/11/2017	Laser repair
27/11/2017	
04/12/2017	Laser service
11/12/2017	HHG tests at 1700 nm
18/12/2017	Maintenance
25/12/2017	
01/01/2018	Setup for Carley
08/01/2018	TOPAS Service
15/01/2018	Carley 16120022
22/01/2018	
29/01/2018	Setup for Gierz
05/02/2018	Gierz 17220003
12/02/2018	
19/02/2018	
26/02/2018	Spin TOF Removal
05/03/2018	AMO Installation
12/03/2018	Setup for Powis
19/03/2018	Powis 17220004
26/03/2018	

Figure 2: Artemis Schedule for 2017-2018

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Gemini Operational Statistics

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During the reporting year, April 17 – April 18, a total of eight complete experiments were delivered in the Gemini Target Area and two experiments in TA2. In total 34 high power laser experimental weeks were delivered the Gemini Target Area and 18 weeks to TA2. The delivered schedule is presented in Figure 2.

The availability of the Gemini laser system (delivery to the Gemini Target Area) was 86% during normal working hours, rising to 140% with time made up from running out of normal working hours. The reliability of the Gemini laser was 91%. An individual breakdown of the availability and reliability for the experiments conducted is presented in Figure 1.

The high levels of total availability were made possible by the continued unique operational model employed on Gemini, which involves running the laser late into the evening. In addition, frequent weekend operational days were made available.

One system access slot was fielded during the year to demonstrate the HAMS target positioning system in the Gemini Target Area.

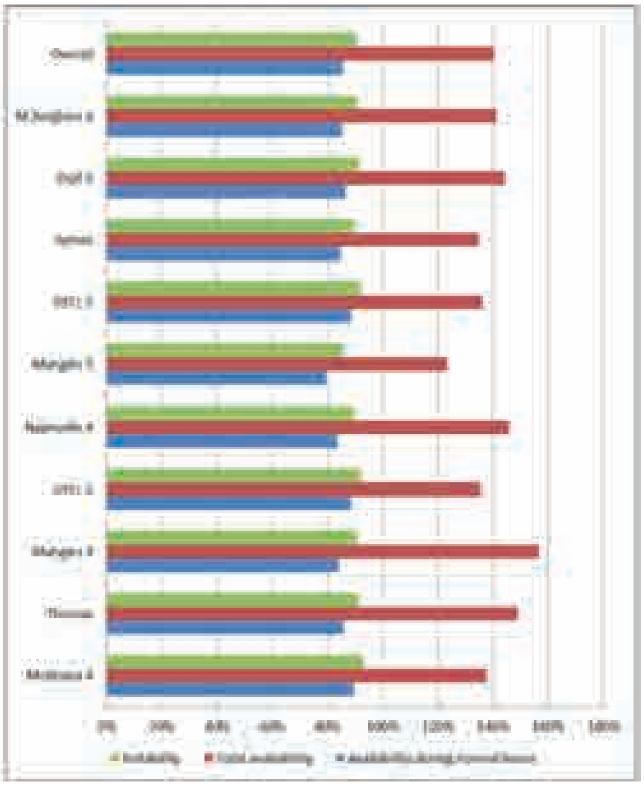

Figure 1: 2017/18 Operational statistics.

Week beginning	Gemini	TA2
03/04/2017		
10/04/2017	System Access	
17/04/2017	HAMS	
24/04/2017		
01/05/2017	Changeover	
08/05/2017		
15/05/2017	McKenna	
22/05/2017	[illegible]	
29/05/2017		
05/06/2017		
12/06/2017		
19/06/2017	Maintenance	
26/06/2017		
03/07/2017		
10/07/2017		
17/07/2017	Thomas	Brenner part 1
24/07/2017	[illegible]	17110022
31/07/2017		
07/08/2017		
14/08/2017	Mangles	
21/08/2017	[illegible]	
28/08/2017	Changeover	
04/09/2017		
11/09/2017	Commercial Access	
18/09/2017	[illegible]	Brenner part 2
25/09/2017		17110022
02/10/2017		
09/10/2017	Maintenance	
16/10/2017		
23/10/2017		
30/10/2017	Najmudin	Brenner Part 3
06/11/2017	[illegible]	17110022
13/11/2017		
20/11/2017		
27/11/2017	Changeover	
04/12/2017		
11/12/2017	Commercial Access	
18/12/2017	[illegible]	
25/12/2017	Christmas	Christmas
01/01/2018		
08/01/2018	Commercial Access	
15/01/2018	[illegible]	
22/01/2018	Joint magnet	
29/01/2018	Set up	
05/02/2018		
12/02/2018	Mangles	Hooker part 1
19/02/2018	[illegible]	17210008
26/02/2018		
05/03/2018		
12/03/2018	Changeover	
19/03/2018	Zepf	Hooker part 2
26/03/2018	[illegible]	17210008

Figure 2: 2017/18 Gemini operational schedule

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Octopus and Ultra Operational Statistics

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Octopus facility

In the reporting period (April 2017 to March 2018), 58 unique User groups submitted a total of 69 proposals bidding for time at the Octopus facility. 36 experiments comprising 89 weeks access time were awarded and delivered to the UK User community throughout the year. A full breakdown of number of weeks applied for versus number of weeks scheduled is shown in Figure 1, indicating an oversubscription ratio of 2.16:1. Figure 3 shows that Biology and Bio-materials formed the majority of applications.

There were a total of 17 formal reviewed publications recorded throughout the year.

Ultra facility

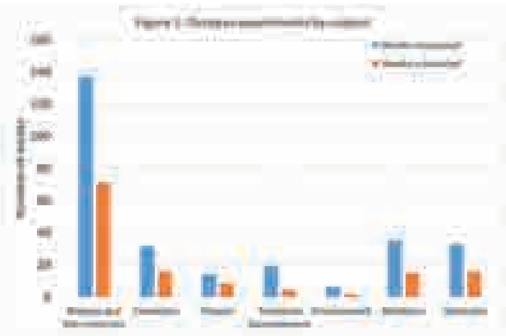
In the reporting period (April 2017 to March 2018), 21 unique User groups submitted a total of 29 proposals bidding for time at the Ultra facility. 21 experiments comprising 58 weeks access time were awarded and delivered to the UK User community. A full breakdown of number of weeks applied for versus number of weeks scheduled is shown in Figure 2 indicating an oversubscription ratio of 1.21:1. Figure 4 shows that Chemistry formed the majority of applications.

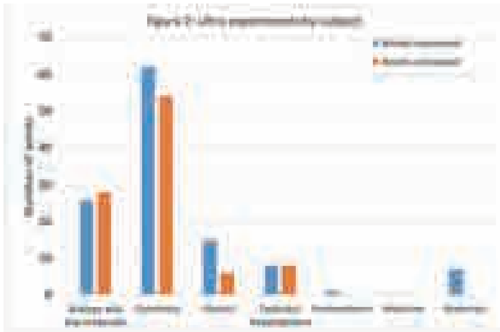
There were a total of 21 formal reviewed publications recorded throughout the year.

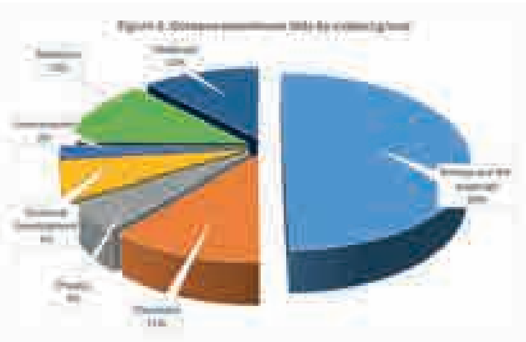
In addition, there were 12 publications recorded by individual merit scientists working in the Lasers for Science Facility.

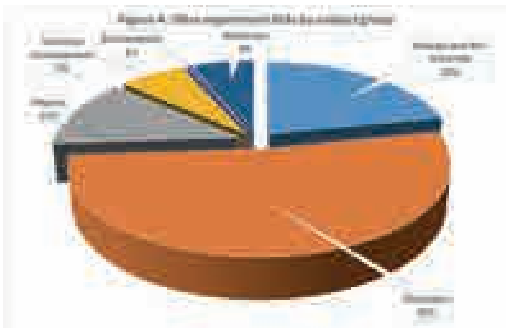
User satisfaction

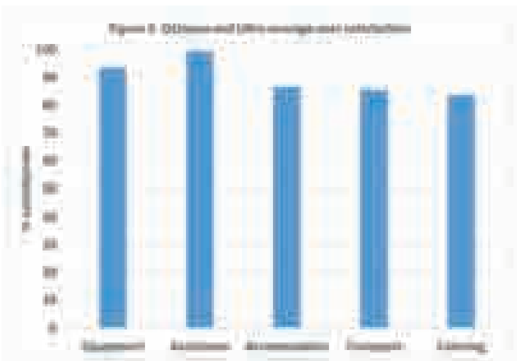
The average User satisfaction marks obtained from the scheduled Octopus and Ultra Users are shown in Figure 5, with an average satisfaction of 89.7% across the categories. In total, 80 hours downtime were reported over the combined 147 weeks of access.











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Target Fabrication Operational Statistics

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Experimental Support

This paper details Target Fabrication support given to experimental groups in the Vulcan target areas TAW and TAP, as well as the Gemini Target Area, between April 2017 and April 2018. Target Fabrication supported 11 solid target Vulcan experiments and four solid target Gemini experiments, totalling 55 weeks of Vulcan access (plus training weeks) and 16 weeks of Gemini access. Gemini experiments were also supported for filters and other diagnostic elements, which are non-trivial but not reported on in these statistics. The total number of weeks supported is greater than that for the last two years: 71 compared to 56 (2016-2017) and 57 (2015-2016).

The Target Fabrication group also supported academic access experiments at AWE and internal experiments, such as the April 2017 HAMS campaign.

This report does not include support for other areas of the CLF, including Artemis and the LSF.

1) Target Numbers

For the reporting year, the total number of targets produced for each experiment is shown in Table 1. High specification targets are defined as targets that have taken significant staff research and development time, or approximately more than ten times the effort of a typical target.

The total number of targets supplied to target areas at RAL by the group this reporting year is 2551 compared to 1546 last reporting year, 2371 in 2015-2016 and 1937 in 2014-2015.
This reporting year saw a large number of requests for high-quantity low-complexity foil targets, which explains the large increase on last year. The number of high specification targets increased to 119 from 98 last reporting year and 87 in 2014-2015.

Experiment	Targets Produced	No. of High-spec Targets	Modified Targets (% of total)
0517 TAW	391	26	91%
0617 TAW	303		
0717 GTA	51	3	27%
0717 TAP	121	17	7%
0817 GTA	209		56%
0817 TAP	68	30	
0817 TAW	175		48%
1017 GTA	12		
1017 TAP	34		
1017 TAW	174		77%
0118 TAP	352		
0118 TAW	156	43	78%
0218 GTA	27		41%
0318 TAP	125		
0318 TAW	353		74%
TOTAL	2551	119	50.5%

Table 1: Target production summary for 2017-2018. High-specification targets include 3D micro-structures, low density targets and mass limited targets. Modified targets are not in the pre-approved target list and the number incorporates modifications to approved designs and additional requests.

2) Experimental Response

It is seen as a significant strength of Target Fabrication to be rapidly responsive to experimental results and conditions by working collaboratively with user groups. The Target Fabrication group responds to experimental changes during a campaign, and often implements a number of modifications or redesigns to the original requests. The number of modifications and variations on each experiment is variable, dependent on the type of experiment and also on experimental conditions, such as diagnostic and laser performance.

Target Fabrication's Quality Management System enables tracking of the targets delivered and whether they are modified from the initial design during the run. This is a useful metric as it gives an idea of the extra resources needed to support an experiment. For the reporting year, data is shown in Table 1. These are targets that were delivered but were not initially defined on the approved target list; this includes modifications to designs or completely new requests during the campaign. It is important to note this capability to change designs can often ensure experimental success.

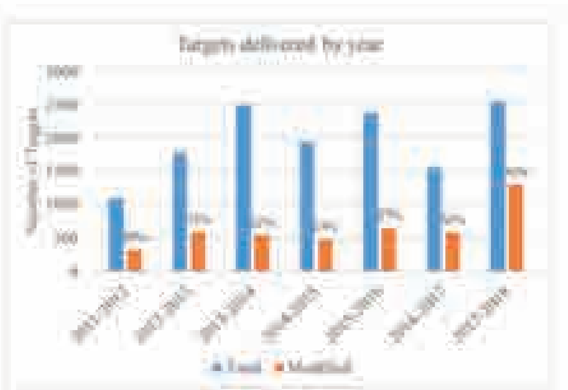

Chart 1: Totals targets delivered by year. Also included is the number of targets modified in some way from original requests.

Chart 1 shows that this reporting year, for the first time, modified targets account for the majority of targets delivered. As shown in Table 1, five of the 15 supported experiments had over 50% of targets modified; these five experiments had significant changes made during the campaigns due to unforeseen circumstances and were largely responsible for the high target total. In the last reporting period, there were four experiments where over 50% of targets were modified. Although the total number of modified targets significantly increased this period, the number of experiments supported with significant changes was similar to last period. It should be noted that the vast majority of experiments ran more or less to the agreed target list and required few modifications, as shown in Table 1.

3) Target Categories

Targets can be separated into seven main categories, as shown in Table 2 and Chart 2.

Ultra-thin foil targets are specified as having a thickness <500 nm, require a coating capability and a skilled fabricator to process; thick foils make up the rest of single component foils. Multilayer foils are stacks or layers of foils that require thin film coating capability to deposit multiple layers onto an existing foil; there are often different composition layers with different thicknesses. Alignment targets are specified as wires or pinholes that are used for set-up purposes. 3D micro-structures are complex 3D geometries that require skilled assembly or micro-machining to produce them.

Target Category	2017-2018	2016-2017	2015-2016	2014-2015
Ultra-thin Foil	485	449	197	530
Thick Foils	1208	743	1349	708
Multi-Layered Foils	577	237	605	500
Alignment	159	78	110	85
3D Micro-structures	73	38	99	82
Mass-limited	47	0	11	0
TOTAL	**2551**	**1546**	**2371**	**1937**

Table 2: Target type by year. Ultra-thin foils and multi-layered foils require thin-film coating capability. 3D Microstructures require skilled manual fabrication. Mass-limited requires MEMS capability.

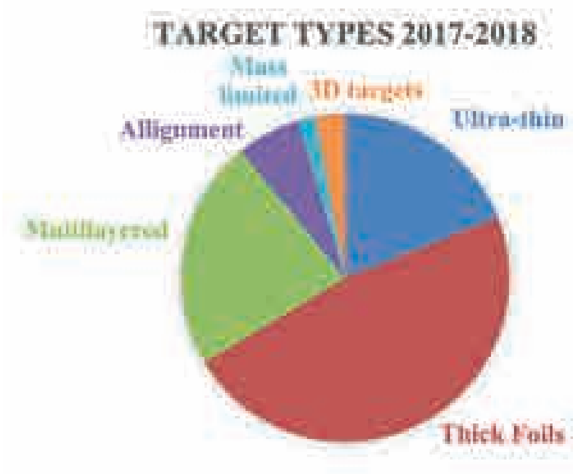

Chart 2: Target types for 2017-2018. This year included a number of high-quantity low complexity thick-foil experiments.

It should be noted that Chart 2 is not a reflection of staff effort, because assembly time for a single thick foil target is relatively short, whereas for a batch of 3D targets, trials, manufacture and characterisation activities can amount to weeks of effort.

4) Adapting to Demand

Experiments usually require similar targets with varying thickness, composition or geometry; for example, a thin foil experiment typically requests a thickness scan of a particular material. In such experiments each thickness or composition change requires a separate thin-film coating run. Experiments using 3D targets are such that each geometry change requires a new assembly set up.

This reporting period, within the total of 2551 targets, there were 371 unique target variations which averages seven targets per variation. Last reporting year the average number of targets per variation was six (277 total), the same average as the two previous years.

'Number of target variations' is a good measure of how complex an experiment is: for example, 0617 TAW experiment had one target variation accounting for over 200 targets and was therefore a relatively low complexity experiment; the 0817 TAP experiment averaged two targets per variation and was an example of a low total number of targets but high effort experiment. The flexibility provided by the group to provide such variability is a key capability of the CLF and enables the user community to fully utilize the limited time that is available during each experiment.

5) Waste Reduction

Unexpected delays or changes during an experiment often result in a number of targets that have been fabricated but that are not used by the end of experimental campaign. Un-shot targets in this reporting period totalled 284, accounting for 11% of the total targets made. The comparison with previous years is shown in Chart 3 below. 2013-2014 shows the highest return rate, largely due to increased effectiveness of recording from that year forward.

Any un-issued or returned targets are carefully sorted, and

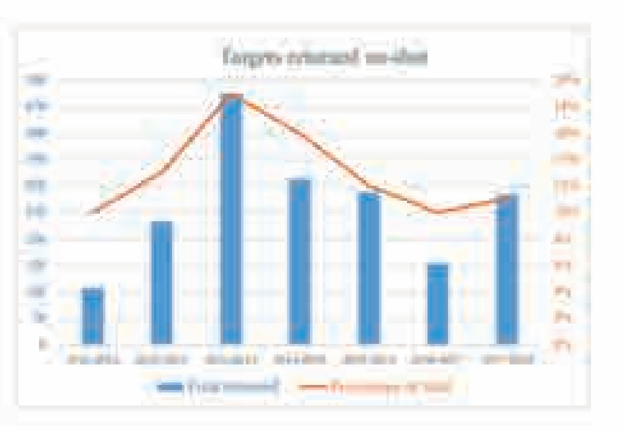

Chart 3: Total number of targets returned un-shot in blue. In orange is the returned targets as a percentage of total target delivered in that reporting year.

high specification targets are stored under closely controlled conditions for potential use on future experiments. Where possible, all spare target components and mounts are also stored for future use. The variety of mounts and components held in stock by the Target Fabrication group contributes to its ability to adapt target designs quickly in response to experimental changes. Target Fabrication also began using its new 3D printing capability to manufacture the majority of target posts, both reducing cost and improving adaptability and responsiveness.

There has been a noticeable reduction in waste since the implementation of the ISO9001 Quality Management System (QMS), which has allowed the Target Fabrication group to plan experimental delivery of targets in a more structured way. The improved planning processes enable long-term delivery projects to be managed effectively. It should be noted that this has not led to less flexibility, as the percentage of modified and re-designed targets is in line with the figures for before QMS implementation (2009-2010, 2010-2011).

Fewer than 1% of targets were returned as non-conforming under the QMS, compared to 3% last reporting period. It should be noted that accurate reporting is difficult because these are often just captured as "returned un-shot". Work is ongoing to ensure that user groups record targets that do not meet their requirements as "non-conforming", rather than simply requesting additional targets.

Orion Academic Access

The Target Fabrication group has continued to support and supply targets to the Orion Academic Access campaign. In the reporting year, targets were delivered to a continuation of the Strathclyde-led consortium investigating proton focusing. As in the previous year, target delivery was a collaboration that included target component supply from the Technische Universität Darmstadt (TUD) and General Atomics (GA), with design, assembly and manufacture also from the CLF. A total of 11 complex targets were delivered to add to the complement of un-shot targets from the previous campaign for a single week experiment. The targets required the integration of a range of complex assembly and characterisation capabilities across the collaboration.

External Contracts

Scitech Precision Ltd (a spinout company from the Central Laser Facility) provides high power laser targets and micro engineering solutions to the high power laser community, and supplied targets, specialist coatings, laser machining services and consultancy across the world. In the year 2017-2018, a total of 42 unique customers were supplied with 141 contracts. Of these contracts, 57% were for high power laser targets, 29% for laser micromachining, 10% for phase plates, and 4% for MEMS based contracts (not target related). The spread of contracts is similar to the previous year, with approximately one-third of the business comprising laser machining support for the Harwell Campus, including Diamond Light Source, and a number of spin out and spin in companies. Target contracts were delivered to large scales facilities for experiments, including experiments carried out on the Orion laser at AWE, LMJ in France, SG-II in China, and LLE in the US.

Summary

Target Fabrication has supported 15 experiments in the CLF and eleven other international facilities in the last year, as well as providing an increasing amount of characterisation services and acting as a knowledge base for Target Fabrication activities throughout Europe.

Total targets delivered were higher than the previous three reporting years, largely due to four low-complexity, high-quantity thick foil experiments. The number of modified targets was also very high at 50.5% of the total targets delivered, due to five of the 15 experiments requiring a large quantity of changes; it is, however, worth noting that the number of experiments with significant modifications was largely in line with previous years.

The type of targets has largely followed the same pattern over the past three years, with a large proportion (41.6%) requiring coating plant capability (multi-layered and ultra-thin foils). The complexity of experiments this reporting period has remained largely the same; individual target variations averaged seven, compared to six in the previous three years.

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Vulcan Operational Statistics

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Vulcan has completed an active experimental year, with 55 full experimental weeks allocated to target areas TAW and TAP between April 2017 and March 2018.

Table 1 shows the operational schedule for the year, and reports the shot rate statistics for each experiment.

Numbers in parentheses indicate the total number of full energy laser shots delivered to target, followed by the number of these that failed and the percentage of successful shots. The second set of numbers are the availability of the laser to target areas during normal operating hours and including outside hours operations.

PERIOD	TAW	TAP
2017		
08 May - 11 Jun	D Neely *Intense terahertz radiation from picosecond laser-produced plasmas* (177, 8, 95.5%) (92.4%, 117.6%) (5 weeks + one day overrun (Saturday ops))	
26 Jun - 30 Jul	S White *K-edge shifts for shock compressed matter* (101, 12, 88.1%) (77.5%, 132.1%) (5 weeks + 1 week overrun)	N Booth *Anisotropy measurements of resistive plasmas for investigating the microphysics of warm dense matter* (83, 7, 91.6%) (63.6%, 115.4%) (5 weeks + 1 week overrun)
21 Aug - 24 Sep	L Willingale *Relativistic magnetic reconnection field dynamics* (56, 16, 71.4%) (79.7%, 107.9%) (5 weeks)	K Lancaster *Production of hot dense plasmas via resistive guiding of fast electrons* (46, 1, 97.8%) (79.1%, 121.7%) (5 weeks + 3 day overrun)
09 Oct - 19/12 Nov	K Glize *Characterization of the density modulation driven by crossing beams* (59, 19, 67.8%) (77.2%, 103.7%) (6 weeks + 2 day overrun)	G Hicks *Ion acceleration from low-Z over-critical gas jets* (46, 3, 93.5%) (76.5%, 123.5%) (5 weeks + 1 week overrun)
2018		
15/08 Jan - 11 Feb	C Brenner (136, 29, 78.7%) (74.5%, 109.5%) (4 weeks + 1 week overrun)	S Kar *Advanced schemes for light-sail acceleration by employing PW pulses at moderate intensities* (86, 9, 89.5%) (70.8%, 102.7%) (5 weeks + 1 week overrun)
25 Feb/04 Mar - 01/08 Apr	M Borghesi *Thin shell instabilities in collisionless plasmas* (98, 22, 77.6%) (78.4%, 113.3%) (5 weeks + 3 day overrun)	P McKenna *Highly-efficient direct laser acceleration of electrons in self-generated magnetic channels* (47, 6, 87.0%) (78.7%, 111.6%) (5 weeks + 2 day overrun)

Table 1: Experimental schedule for the period April 2017 – March 2018.

(Total shots fired, failed shots, reliability)
(Availability normal, additional hours)

The total number of full disc amplifier shots that have been fired to target this year is 935. Table 2 shows that this figure is less than in the three previous years. 132 shots failed to meet user requirements. The overall shot success rate to target for the year is 86%, compared to 88%, 88%, 91% and 90% in the previous four years. Figure 1 shows the reliability of the Vulcan laser to all target areas over the past five years.

	No of shots	Failed shots	Reliability
13 - 14	1015	121	88%
14 - 15	1087	133	88%
15 - 16	1143	108	91%
16 - 17	948	93	90%
17 - 18	934	132	86%

Table 2: Shot totals and proportion of failed shots for the past five years.

The shot reliability to TAW is 83%, down 6% from the previous year. The shot reliability to TAP is 92% - down slightly from 93% in 2016-17.

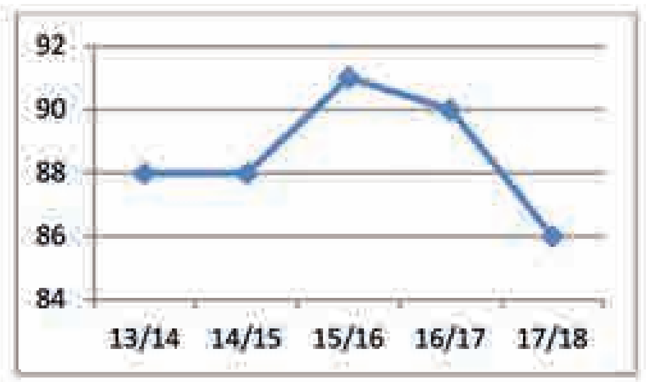

Figure 1: All areas shot reliability for each year 2013-14 to 2017-18.

Analysis of the failure modes reveals that, as in recent years, the two overriding causes of failed shots are beam alignment and front end related issues. These two causes are manifested in low or high energy output of the rod amplifier chain (outside of ±20% of the requested energy). Approximately three-quarters of failed shots are due to this cause. Investigation into the reasons for this instability have revealed:

1. Instability in the pulse energy is introduced during propagation from the front end room to the laser area

2. There is a discrepancy in the pulse energy measured at the end of the rod chain during a test (rod chain) shot and a full energy (disc amplifier) shot.

Additional diagnostics are being installed in the laser system to monitor stability and improve performance.

There is a requirement, which was originally instigated for the EPSRC FAA, that the laser system be available from 09:00 to 17:00 hours Mondays to Thursdays, and from 09:00 to 16:00 hours on Fridays, during the five-week periods of experimental data collection (a total of 195 hours over the five-week experimental period). The laser has not always met the startup target of 9:00 am, but it has been common practice to operate the laser well beyond the standard contracted finish time on several days during the week. In addition, the introduction of early start times on some experiments continues to lead to improvements in availability.

On average, Vulcan has been available for each experiment to target areas for 77.2% of the time during contracted hours, compared with 85.8% for the previous year. Although this figure is considerably down, the overall availability to all target areas has only dropped slightly from 112.4% in 2016-17 to 111.5%. The time that the laser is unavailable to users is primarily the time taken for beam alignment at the start of the day.

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B Gardner, N Stone, P Matousek
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CONFERENCE PROCEEDINGS

ARTEMIS

DT Lloyd, AS Wyatt, R Chapman, C Thornton, P Majchrzak, A Jones, E Springate, K O'Keeffe
Quantum-Path-Sensitive Inline XUV Interferometry
High Intensity Lasers and High Field Phenomena 2018 (2018)

GEMINI

PA Walker, PD Alesini, AS Alexandrova, MP Anania, NE Andreev, I Andriyash, A Aschikhin, RW Assmann, T Audet, A Bacci, IF Barna, A Beaton, A Beck, A Beluze, A Bernhard, S Bielawski, FG Bisesto, J Boedewadt, F Brandi, O Bringer, R Brinkmann, E Brundermann, M Buscher, M Bussmann, GC Bussolino, A Chance, JC Chanteloup, M Chen, E Chiadroni, A Cianchi, J Clarke, J Cole, ME Couprie, M Croia, B Cros, J Dale, G Dattoli, N Delerue, O Delferriere, P Delinikolas, J Dias, U Dorda, K Ertel, A Ferran Pousa, M Ferrario, F Filippi, J Fils, R Fiorito, RA Fonseca, M Galimberti, A Gallo, D Garzella, P Gastinel, D Giove, A Giribono, LA Gizzi, FJ Gruner, AF Habib, LC Haefner, T Heinemann, B Hidding, BJ Holzer, SM Hooker, T Hosokai, A Irman, DA Jaroszynski, S Jaster-Merz, C Joshi, MC Kaluza, M Kando, OS Karger, S Karsch, E Khazanov, D Khikhlukha, A Knetsch, D Kocon, P Koester, O Kononenko, G Korn, I Kostyukov, L Labate, C Lechner, WP Leemans, A Lehrach, FY Li, X Li, V Libov, A Lifschitz, V Litvinenko, W Lu, AR Maier, V Malka, GG Manahan, SPD Mangles, B Marchetti, A Marocchino, A Martinez de la Ossa, JL Martins, F Massimo, F Mathieu, G Maynard, TJ Mehrling, AY Molodozhentsev, A Mosnier, A Mostacci, AS Mueller, Z Najmudin, PAP Nghiem, F Nguyen, P Niknejadi, J Osterhoff, D Papadopoulos, B Patrizi, R Pattathil, V Petrillo, MA Pocsai, K Poder, R Pompili, L Pribyl, D Pugacheva, S Romeo, AR Rossi, E Roussel, AA Sahai, P Scherkl, U Schramm, CB Schroeder, J Schwindling, J Scifo, L Serafini, ZM Sheng, LO Silva, T Silva, C Simon, U Sinha, A Specka, MJV Streeter, EN Svystun, D Symes, C Szwaj, G Tauscher, AGR Thomas, N Thompson, G Toci, P Tomassini, C Vaccarezza, M Vannini, JM Vieira, F Villa, C Wahlstrom, R Walczak, MK Weikum, CP Welsch, C Wiemann, J Wolfenden, G Xia, M Yabashi, L Yu, J Zhu, A Zigler
Horizon 2020 EuPRAXIA design study
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LASER DEVELOPMENTS

J Smith, TJ Butcher, PD Mason, KG Ertel, S Banerjee, M De Vido, OV Chekhlov, M DivokÃ½, J Pilar, W Shaikh, C Hooker, C Hernandez-Gomez, CB Edwards, JL Collier, A Lucianetti, T Mocek, PJ Phillips, WA Clarkson, RK Shori
100J-level nanosecond pulsed Yb:YAG cryo-cooled DPSSL amplifier
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P Navratil, O Slezak, J Pilar, KG Ertel, M Hanus, S Banerjee, PJ Phillips, J Smith, M De Vido, A Lucianetti, C Hernandez-Gomez, CB Edwards, JL Collier, T Mocek, PD Mason, M DivokÃ½, TJ Butcher, WA Clarkson, RK Shori
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G Korn (Ed.), LO Silva (Ed.), B Rus, P Bakule, D Kramer, J Naylon, J Thoma, M Fibrich, JT Green, JC Lagron, R Antipenkov, J Bartoníček, F Batysta, R Baše, R Boge, S Buck, J Cupal, MA Drouin, M Ďurák, B Himmel, T Havlíček, P Homer, A Honsa, M Horáček, P Hríbek, J Hubáček, Z Hubka, G Kalinchenko, K Kasl, L Indra, P Korous, M Košelja, L Koubíková, M Laub, T Mazanec, A Meadows, J Novák, D Peceli, J Polan, D Snopek, V Šobr, P Trojek, B Tykalewicz, P Velpula, E Verhagen, Š Vyhlídka, J Weiss, C Haefner, A Bayramian, S Betts, A Erlandson, J Jarboe, G Johnson, J Horner, D Kim, E Koh, C Marshall, D Mason, E Sistrunk, D Smith, T Spinka, J Stanley, C Stolz, T Suratwala, S Telford, T Ditmire, E Gaul, M Donovan, C Frederickson, G Friedman, D Hammond, D Hidinger, G Chériaux, A Jochmann, M Kepler, C Malato, M Martinez, T Metzger, M Schultze, P Mason, K Ertel, A Lintern, C Edwards, C Hernandez-Gomez, J Collier
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PLASMA PHYSICS

D Del Sorbo, DR Blackman, R Capdessus, K Small, C Slade-Lowther, W Luo, MJ Duff, APL Robinson, P McKenna, Z Sheng, J Pasley, CP Ridgers
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ULTRA

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VULCAN

DR Rusby, C Brenner, C Armstrong, L Wilson, R Clarke, A Alejo, R Deas, P McKenna, S Kar, D Neely
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INDIVIDUAL CONTRIBUTIONS AND COLLABORATIVE SCIENCE

AG Ghita, N Stone, P Matousek
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THESES

ARTEMIS

Smith, A
High energy and high intensity probes of chemical dynamics
PhD Thesis, University of Southampton (2017)

Cabo, A
Two-Dimensional Materials: From Basic Research in Transition Metal Dichalcogenides to Technique Development for Graphene Applications
PhD Thesis, Aarhus Universitet (2017)

Hernando, P
Attosecond pump-probe methods for measurement of molecular hole dynamics
PhD Thesis, Imperial College London (2017)

GEMINI

Kasim, M
Quantitative optical probing of plasma accelerators
PhD Thesis, University of Oxford (2017)

Scullion, C
Investigation of ion acceleration from solid targets driven by ultrashort laser
PhD Thesis, Queen's University Belfast (2017)

VULCAN

Sadler, J
Optimisation and applications of Raman plasma amplifiers
PhD Thesis, Imperial College London (2017)

Raten, N
Complex phase space representation of plasma waves: theory and applications
PhD Thesis, University of Oxford (2017)

Ceurvorst, L
Relativistic channeling with applications to inertial confinement fusion
PhD Thesis, University of Oxford (2017)

Robinson, T
Optically levitated targets as a source for high brightness x-rays and a platform for mass-limited laser-interaction experiments
PhD Thesis, Imperial College London (2017)

Lowe, H
Development of a multi keV x-ray backlighter source based on laser irradiation of extended cluster gases
PhD Thesis, Imperial College London (2017)

Giltrap, S
Laser-plasma interaction experiments using high energy, high contrast OPCPA lasers
PhD Thesis, Imperial College London (2017)

Padda, H
Intra-pulse dynamics of laser-driven ion acceleration in ultra-thin foils
PhD Thesis, University of Strathclyde (2017)

Wilson, R
On the role of focal spot size in ultra-intense laser-solid interaction physics
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Butler, N
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PhD Thesis, University of Strathclyde (2018)

Alejo, A
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ULTRA

Coulter, P
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PhD Thesis, University of Bristol (2018)

Koyama, D
Ultrafast photochemical reaction dynamics of aromatic sulphur compounds in solution
PhD Thesis, University of Bristol (2017)

Neri, G
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PhD Thesis, University of Liverpool (2016)

Gurung, S
Biophysical & crystallographic studies of DNA i-motifs
PhD Thesis, University of Reading (2018)

Hithell, G
Studies of the structure and ultrafast dynamics of DNA using 2D-IR spectroscopy
PhD Thesis, University of Strathclyde (2017)

Spall, S
Rhenium and manganese Ð-diimine tricarbonyls as CO2 reduction catalysts : insights from novel ligand design
PhD Thesis, University of Sheffield (2017)

Cletheroe, L
Photosensitizing diiron hydrogenase mimics: excited state dynamics
PhD Thesis, University of Sheffield (2017)

Skewring, J
Development of luminescent transition metal complexes for correlative light and electron microscopy and super resolution microscopy
PhD Thesis, University of Sheffield (2017)

McKenzie, L
Novel transition metal complexes for use as photosensitizers in photodynamic therapy
PhD Thesis, University of Sheffield (2017)

OCTOPUS

Shephard, R
The study of atmospheric reaction chemistry of cloud droplets and aerosol by application of optical trapping and neutron and X-ray scattering
PhD Thesis, Royal Holloway (2017)

Panel Membership and CLF Structure

LASER FOR SCIENCE FACILITY ACCESS PANEL 2017/18

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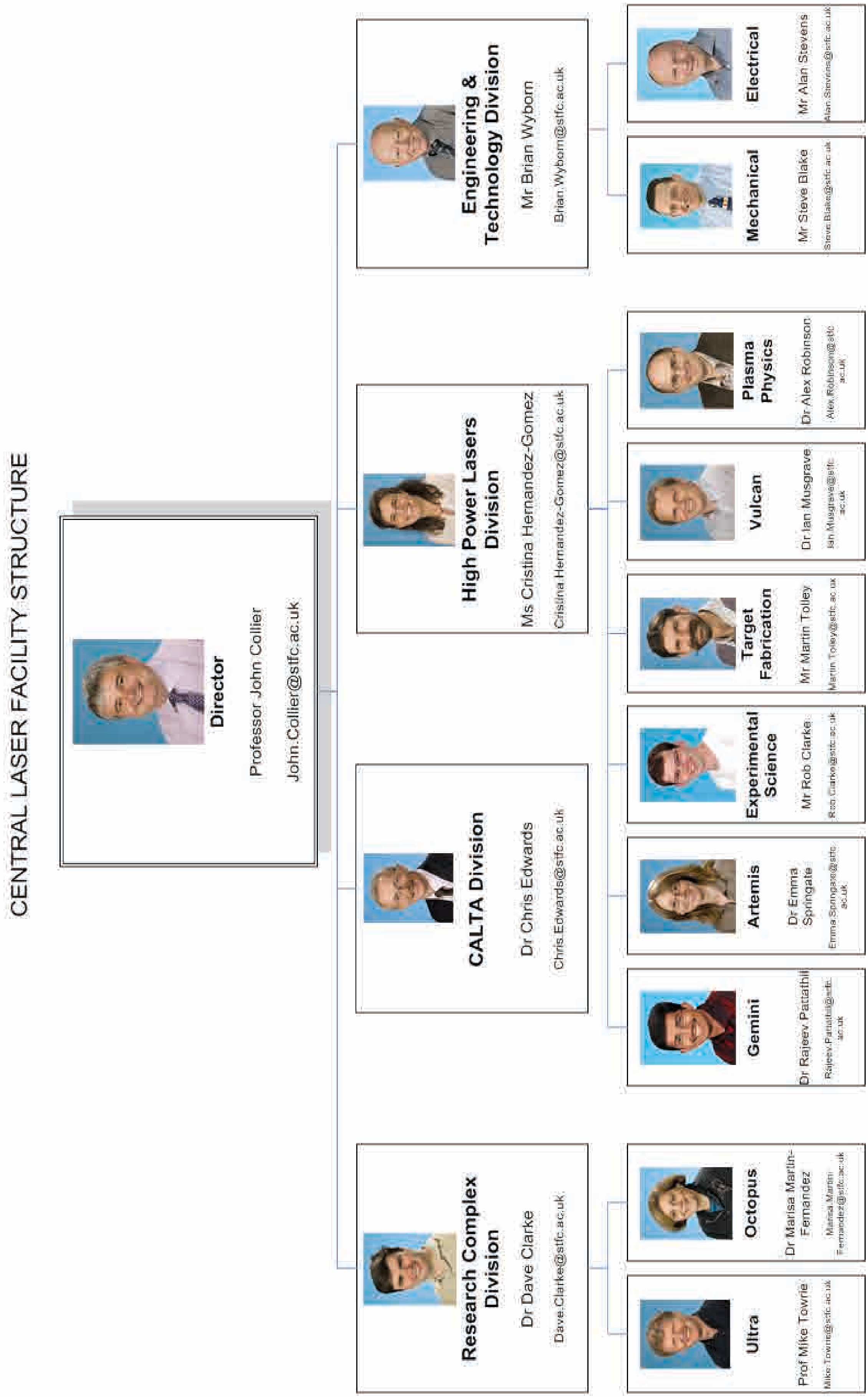
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