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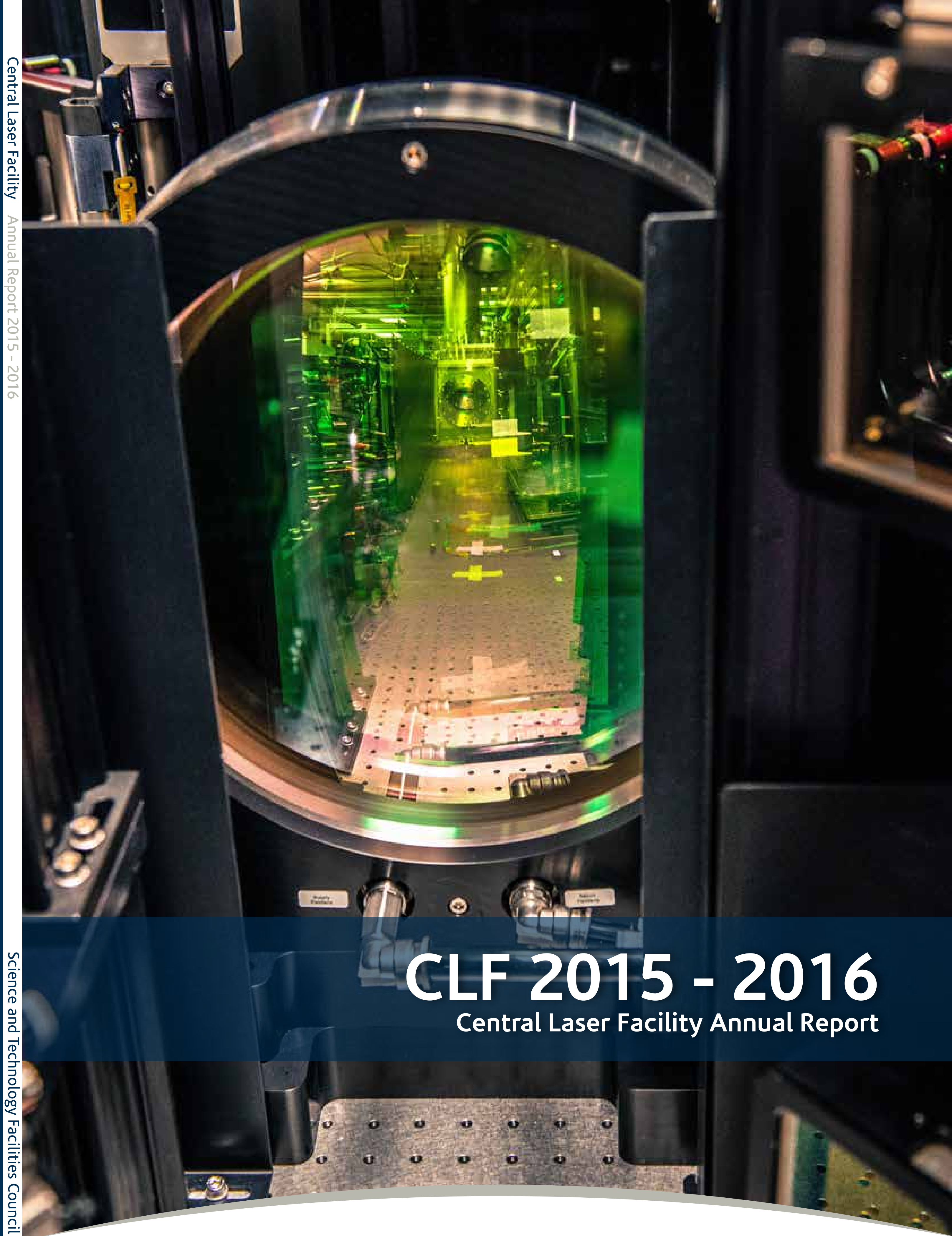
Boulby Underground Science Facility Boulby Mine, Cleveland.

Science & Technology Facilities Council

Central Laser Facility Annual Report 2015 - 2016

Science and Technology Facilities Council



CLF 2015 - 2016

Central Laser Facility Annual Report

Science & Technology Facilities Council

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The front cover shows Gemini laser amplifying crystal glows under irradiation with green lasers

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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 2015-16.

This year has seen an uplift in funding and consequently an uplift in the volume of user access we are able to offer, with the CLF's facilities still remaining heavily oversubscribed. The CLF and its community have continued to deliver scientific output and technical development of the highest order.

Vulcan – One of the main highlights this year was the publishing of the results from an experiment on the Petawatt facility, where a team from CLF / York used x-ray polarimetry diagnostics to measure the resistivity of a target heated to conditions similar to that found in brown dwarfs. The resistivity was found to be larger than existing models predicted, highlighting how current models are not adequate to explain the structure of such objects. The paper was published in Nature Communications.

Gemini continued to prove its unique capability as a driver for secondary sources for applications as well as fundamental science, yielding several high-impact papers this year in Nature-group journals and Physical Review Letters. These include the use of x-ray beams generated by Gemini for tomographic imaging of trabecular bone tissues and creating nearly charge-neutral electron-positron plasmas, recreating astrophysical phenomena observed in pulsars and quasars in the laboratory. Experiments in Gemini were also successful in accelerating electrons beyond 2GeV using the novel focusing geometry for the first time. The betatron x-rays generated in the process were used for high-resolution tomographic imaging of medical samples in this experiment.

Artemis continued to deliver experiments using XUV pulses to study electron dynamics, expanding the range of materials to include novel 2D materials and layered structures, with papers in the high-impact journals Physical Review Letters and Nano Letters. Artemis is building future capability by developing a few-cycle mid-IR source, which will enable generation of attosecond pulses at photon energies across the water window. The team showed that these few-cycle pulses can be further amplified, and are planning a power upgrade to the laser system, which will boost the flux of HHG available for experiments.

The CLF's facilities in the Research Complex at Harwell, Ultra and Octopus, were strengthened with the addition of new capabilities funded by the BBSRC in partnership with STFC.

Ultra – In 2015-16 access increased from 40 to 60 weeks per year through parallel operation of stations. The introduction of broadband infrared Surface Sum Frequency Generation (SSFG) has provided new facility capability. SSFG is a technique sensitive only to the vibrations of molecules at the monolayer level on surfaces and is being used to study the reactions during electro-catalysis.

Octopus biological imaging facility recruited two new scientists with expertise in super-resolution microscopy, to increase the amount of time delivered to users from 60 to 100 weeks per year. The new staff will allow parallel running of the Octopus stations, dealing with a serious oversubscription problem and making better use of the capital investment made in the facility by BBSRC, MRC, and STFC. A new single molecule localisation method suitable for mapping intermolecular separations was commissioned and made available for users.

The CLF's **Centre for Advanced Laser Technology and Applications (CALTA)** demonstrated world leading performance from its "DiPOLE 100" laser in October '15 with an output of 107J at 1Hz. This is the highest recorded pulse energy from a diode pumped laser of its type and a crucial milestone in the delivery of the £10M development contract for the HiLASE Facility in the Czech Republic. The system was dismantled and delivered to Prague in December and a joint STFC / HiLASE team has begun installing and commissioning the laser to its full 1kW specification in the new HiLASE facility building.

Design and component procurement of a second DiPOLE 100 laser (D-100X) is well advanced with assembly scheduled to commence in 2017. The system will be commissioned at CLF before delivery to Hamburg in mid-2018 as a joint EPSRC / STFC contribution to the European XFEL project as part of the international HiBEF consortium.

Economic Impact – This year CLF has continued to engage closely with industry and this has resulted in four companies gaining access to our facilities (Ultra, Gemini and Octopus). Additionally of particular note is the joint funding of a PDRA position with Johnson Matthey plc. This important step forward will enable much stronger links to be forged with both JM and wider industry.

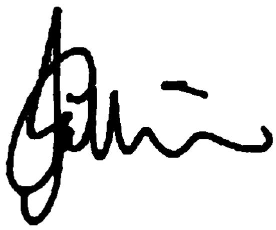
The year has been particularly productive in regards to Intellectual Property (IP) generation and protection, with a total of four patent applications filed. The IP reflects the broad range of sectors CLF covers and includes nuclear waste imaging, characterising ultra-short pulses, new laser alignment methods and novel biomarkers. CLF continues to take the lead in terms of invention disclosures and patent ideas submitted for review.

CLF's spin-out Scitech Precision Ltd. has grown this year and is now able to offer a laser micromachining service, having taken on two new members of staff and purchased laser processing equipment from a local company.

The communication of our work and its impact to non-scientific audiences is an increasing priority and the public profile of CLF continues to grow with a number of impact stories featuring in the mass media.

Finally, the close partnership the CLF has with its User Community has been central to our past success, and as we look forward, it is imperative that we collectively draw on that partnership to promote our collective success that is, in part, represented in this publication.

I hope that you enjoy reading it!



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 8 beam Nd:glass laser facility that operates to two independent target areas. The 8 beams can be configured in a number of combinations of long (>500ps) and short (<30ps) pulse arrangements.

Target Area Petawatt is Vulcan's highest intensity area, capable of 500J / 500fs 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 1ns. To complement the short pulse beamline, an additional 250J long pulse beam line as well as a variety of possible probe beams can be configured in the area. This year a new seed oscillator has been purchased to replace an obsolete laser; this will be installed in future maintenance weeks.

Target Area West is Vulcan's most flexible target area offering up to 8 long pulse beams or 2 short and 6 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 also be configured with all 8 beams in long pulse mode by using a compressor by-pass arrangement delivering a maximum of 2.5kJ 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. This year there has been substantial investment in diagnostics to provide a larger suite of optical diagnostics for the community that can be shared when operating parallel experiments.

Gemini

This high rep-rate Petawatt laser based on Ti:Sapphire technology has a unique capability to offer 2 synchronised beams, each with a power of 0.5 PW and a repetition rate of one shot every 20 seconds. The facility will enable interaction studies up to 10^{22} W/cm^2. F/20 and F/2 beam focusing options are available, with a built-in plasma mirror set-up in one beam line for high contrast pulse delivery. In recent years the contrast of the compressed pulses from Gemini has been improved to the point where it is good enough for all but the most sensitive experiments, and for those the dual plasma mirror system is available. Both Gemini beam lines use adaptive optics mirrors to ensure the focal spot optimization on a routine basis: this has had a significant impact in the experimental delivery. In addition this year we have implemented a longer focusing geometry (F/40) in Gemini. The focusing optic is a spherical mirror and an adaptive mirror is used to correct for the aberrations arising from the focusing optic. Along with improved focal spots, this has yielded 2.5GeV electron bunches with nC charges in a recent experiment in Gemini.

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 far-infrared to the XUV. The facility is configured flexibly for pump-probe experiments. Tuneable or few-cycle pulses can be used to generate ultrafast, coherent XUV pulses through harmonic generation or as pump and probe pulses. Two XUV beamlines lead to end-stations for atomic and molecular physics and condensed matter physics.

A new oscillator for the RedDragon was installed over summer 2015, and the long-term pointing stability of the laser is much improved. The stretcher and compressor gratings were also replaced in March 2016, the efficiency is now >70% and beam profiles are very good.

The Artemis lab has been re-arranged and the 45 degree table removed to provide a separate second XUV beamline, running parallel to the existing beamline. The new beamline consists of an HHG chamber, a flat-field spectrometer and a chamber for XUV imaging experiments. It provides increased space for filtering and beam separation.

The XUV monochromator has been upgraded with an additional grating at 830 lines/mm. This provides better energy resolution than the 300 lines/mm grating, but a factor of five less flux. For upcoming experiments, this will be compensated for by using 400 nm to generate the harmonics. On the monochromatised beamline, pump ellipticity measurements have now been implemented for users.

Octopus & Ultra (Research Complex)

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

In the dynamics area Ultra offers a state-of-the-art high power 10 kHz fsec / psec system combined with OPAs to generate pulses for a range of unique pump and probe spectroscopy techniques. It provides spectral coverage from 200-12000 nm and temporal resolution down to 50fs. This is used in the investigations of fast photodynamic processes in solids, solutions and gases. Its time resolved resonance Raman (TR^3) capability enables highly fluorescent samples to be studied using a 4ps optical Kerr shutter. The Time-Resolved Multiple-Probe Spectroscopy (TRMPS) facility links Ultra with a 1 kHz ultrafast laser spectroscopy system, giving a femtosecond to millisecond pump-multiple probe spectrometer. The BBSRC funded Ultra station, LIFEtime, is a high repetition rate system (100 kHz) offering TRMPS capability for the investigation of biological systems. 2DIR spectroscopy capability is also available.

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). 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. A Light Sheet Microscopy station has recently been commissioned and is now available for users.

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

Mechanical, electrical and computing support is provided for the operation of the laser facilities at the CLF, for the experimental programmes on these facilities and for the CLF's research and development activities. Mechanical and electrical CAD tools and workshop facilities enable a rapid response.

Theory and Modelling

The CLF offers to support scheduled experiments throughout the design, analysis and interpretation phases, if required and within the resources available. We support principal investigators in data interpretation via radiation hydrodynamics, particle-in-cell, hybrid and Vlasov-Fokker-Planck modelling capabilities, as well as providing access to large-scale computing. One- and multi- dimensional radiation-hydrodynamic and atomic physics tools have been renewed for a further year, as endorsed by the CLF User Forum. The CLF will continue to provide support for student training in plasma physics and computational methods, alongside opportunities for networking with colleagues. Extended collaborative placements within the group are particularly encouraged.

Target Fabrication

The CLF is supported by an on-site Target Fabrication capability that integrates high specification microtarget design and production in collaboration with the user community. The facility deploys a wide range of complementary fabrication techniques in house such as thin film coating, precision micro assembly, advanced characterisation and chemistry processes, and leverages the unique position within STFC to fund and access high precision micro machining and MEMS fabrication of target components. The facility is ISO9001 accredited and is leading the way in providing a high level of characterisation and traceability that is essential for targets fielded in cutting edge research. The CLF is also responsible for the delivery of targets for the academic access to 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.

This year the chemistry laboratory has been converted into a cleanroom providing an environment ideally suited to the production of low density foam and aerogel microtarget components. Further advances have also been made on a high accuracy wheel system populated with MEMS-produced targets for future use in the Gemini target for high repetition rate solid target experiments. This will continue to be developed.

Centre for Advanced Laser Technology and Applications (CALTA)

CALTA was established in 2012 to develop diode pumped solid state lasers (DPSSLs), capable of delivering high energy pulses at high repetition rate, and to exploit this new technology in applications including advanced imaging, materials processing, non-destructive testing and fundamental science.

CALTA has already won contracts and grants in excess of £26M and is currently constructing two 1kW lasers based on its proprietary "DiPOLE" architecture. One has already been delivered to the HiLASE Centre in the Czech Republic where it will be used for materials studies and laser peening. The other will be supplied to the European XFEL facility in Hamburg for integration within the "HiBEF" end station, where it will be used to compress material to high density and the extreme states produced will be diagnosed by the synchronised XFEL x-ray beam. Assembly of the system for HiLASE was completed in September 2015 at RAL and a crucial milestone reached in the project on 21st October with the achievement of 107J output at 1Hz from the final amplifier. Following delivery to Prague, a joint HiLASE / STFC team will begin installing and commissioning the laser to its full 1kW specification in the new HiLASE building.

Design and procurement of major equipment for the XFEL laser is well advanced and assembly will commence in 2017 with delivery to Hamburg anticipated in mid-2018.

Other activity within CALTA during the year included collaboration with CLF's High Power Laser Division on the development of ultra-broadband optical coatings to enable the generation of 20-30 fs pulses for the production of high energy x-rays, ions and neutrons for advanced imaging and security applications.

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.

Economic impact

Innovation, the exploitation of exciting new ideas in a timely and efficient manner is inherent within CLF. The delivery of high Economic Impact (EI) forms an integral component of the CLF strategic objectives. This year we have continued to engage closely with industry and this has resulted in four companies gaining access to our facilities (Ultra, Gemini and Octopus). Three of these companies came through direct commercial contracts for proprietary access and the fourth through peer review in collaboration with a University group. Of particular note is the joint funding of a PDRA position with Johnson Matthey. This important step forward will enable much stronger links to be forged with both JM and wider industry. Additionally CLF attracted funding through The Proof of Concept scheme operated by the Business and Innovation Department to develop new ideas and technology focussed on Laser Peening and a new VUV source for processing waste materials.

This year has been particularly productive regards Intellectual Property generation and protection with a total of four patent applications filed. The IP reflects the broad range of sectors CLF covers and includes nuclear waste imaging, characterising ultra-short pulses, new laser alignment methods and novel biomarkers. CLF continues to take the lead in terms of invention disclosures and patent ideas submitted for review. To broaden their market reach and activities portfolio, CLF spin-out Cobalt Ltd. has recently started working with STFC and two UK Universities, with funding from EPSRC on research that could lead to medical-grade systems that provide on-the-spot diagnosis of breast cancer and bone diseases such as osteoporosis. Whilst Scitech Precision Ltd. another CLF spin-out can now offer a laser micromachining service, having taken on two new members of staff and purchased equipment from a local company Micronanics.

Economic Impact

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Introduction

This paper highlights the key economic impact activities undertaken in the CLF for FY15/16. Throughout the year there has been significant work in cementing existing collaborations and establishing new relationships with industry and in raising awareness of CLF technology, techniques and capabilities in both national and international arenas.

Industry Engagement

This year we have continued to engage closely with industry and this has resulted in four companies gaining access to three of our facilities (Ultra, Gemini and Octopus). Three of these companies engaged through direct commercial contracts (proprietary access) and the fourth through peer review in collaboration with a University user group. Of particular note this year has been the establishment of a new PDRA scientist position in the LSF via joint funding through the Business and Innovations Department (BID) and Johnson Matthey. This important step forward will enable much stronger links to be forged with both Johnson Matthey and across wider industry.

Spin Out Companies

To broaden their market reach and activities portfolio, CLF spin-out Cobalt Ltd. has recently started working with STFC and two UK Universities on research that could lead to medical-grade systems that provide on the-spot diagnosis of breast cancer and bone diseases, such as osteoporosis, with funding from EPSRC. Scitech Precision Ltd. another CLF spin-out can now offer a laser micromachining service, after taking on two new members of staff and purchasing laser equipment from local company Micronanics.

Intellectual Property and Know-How

This year has been particularly productive with regards to Intellectual Property generation and protection with a total of four patent applications filed. This new IP reflects the broad range of sectors CLF covers and includes nuclear waste imaging, characterising ultra-short pulses, new laser alignment methods and novel biomarkers. CLF staff are highly creative and continue to take the lead in terms of invention disclosures and patent ideas submitted to STFC Innovations for review.

Proof of Concept Funding

The Proof of Concept (PoC) scheme is operated by the BID to develop new ideas and technology that have the potential to be commercialised either through future license deals or the formation of new spin-out companies. This year two new PoC proposals were funded. The first is focused on Laser Peening, a specialised surface treatment method for enhancing the fatigue life of engineering materials by applying a compressive stress that penetrates up to a few mm into the material. The project will design, build and demonstrate a laser peening capability based around the 10J, 10Hz DiPOLE laser developed and built by the CALTA team. There is potential for significant new IP enabled by some of the spatial and temporal characteristics of the DiPOLE laser pulses whilst the project also demonstrates the capability of DiPOLE type systems for industrial applications and processes. The project allows for collaboration across a number of new University groups including Coventry, Cranfield and Liverpool John Moores and importantly opens up new contacts with industry across the aerospace, defence and medical sectors.

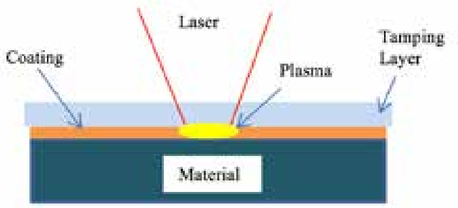

Figure1: Schematic of Laser Peening Process

A second PoC project builds on the knowledge and expertise of the plasma theory group at CLF and is funded to design and build a new, highly efficient vacuum ultraviolet (VUV) plasma source with potential applications in the processing of waste materials. The project allows the recruitment of a PDRA scientist to undertake the experimental work.

International Engagement

Projects funded under the Newton Fund with China (Laser Driven Sources for Medical Treatment and Imaging), India (Ionising Radiation Sources for Treatment and Imaging) and South Africa (Characterising Antibiotics, Water Treatment, Disease Diagnosis) are now fully underway. A number of trips are planned under this fund to explore future commercial and innovation opportunities.

EC H2020 funding has been secured under phase 1 of the Widespread Teaming Programme to work with the HiLASE Centre in the Czech Republic. This is a one year project to build a detailed and compelling Business Case for the future operation of the HiLASE Centre of Excellence. Work includes rigorous consultation with industry to produce a "user requirements" document. Outputs from the project will be used to generate the full proposal which will request significant funding (up to €50M funded jointly by both the EC H2020 programme and the Czech Ministry). This will be submitted under phase 2 of Widespread Teaming next year. Particular opportunities for CLF will be in the research and development of higher repetition rate DiPOLE (up to 100Hz) and higher pulse energies (beyond 150J per pulse).

Communication and outreach activities within the CLF

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Introduction

Public engagement encompasses outreach activities that 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 Central Laser Facility (CLF) delivers. UNESCO established 2015 as the International Year of Light and Light-based Technologies, providing many additional platforms on which to engage and inspire new audiences. Opportunities for communication and engagement in the reporting period 2015-2016 have been diverse, reaching across the UK. This year also saw the Harwell Open Week during which the CLF, along with all other major facilities onsite, opened their doors to school groups and the public for a week-long celebration of science, technology and engineering on the Harwell Campus.

INTERNATIONAL YEAR OF LIGHT 2015

International Year of Light

The CLF welcomed 2015 being named as the International Year of Light (IYOL) and Light-based Technologies - an opportunity to celebrate and educate about light and the photonics industry.

CLF staff attended the opening and closing ceremonies of IYOL 2015 where they were able to network with a range of key figures from the photonics sector.

International Year of Light

A "night sky laser" was deployed by the CLF as an unusual and unique means of stimulating interest in science. The bright green beam swept across the Harwell Campus in the early evenings throughout 2015 and projected logos onto the side of the Research Complex at Harwell Building. It could be seen as far away as Newbury.

SCIENCE UP CLOSE

Harwell Open Week

Harwell Open Week was held 8th – 11th July 2015 and welcomed around 18,000 visitors to the Harwell Campus, with ~ 16,000 on the Saturday alone. The week was the largest event at the site for 17 years and achieved an average customer satisfaction rating of 4.65 out of 5. 93% of visitors said they would recommend the event to a friend and 92% said they found out more about what people do at Harwell with 86% saying that the work STFC does is important to society. The event was a huge success thanks to the support and volunteering of over 1,000 STFC staff. A day for school groups was hosted on 8th July and saw students enjoying all the equipment and demonstrations on display. The CLF were centre-stage for two of the school workshops hosted by the central public engagement team. For key stage 3 students (age 11-14) the session included a visit to see the Vulcan and Gemini lasers up close, learning how they work and why we use them – from building stars to imaging bones. As well as touring the laser facilities, there was also a series

Harwell Open Week







Harwell Open Week

of hands-on activities and demonstrations, including a Jacob's ladder and bursting balloons with lasers, and the "Incredible Power of Light" roadshow. For key stage 5 students (age 16-18) the lasers in the Research Complex at Harwell, Octopus and Ultra, were visited as part of a workshop entitled "Stargazing in cells". Students toured the laboratories and laser facilities used for studying such diverse fields as alternative energy sources and structural analysis of bacteria. In addition, they ran a series of hands-on activities including extracting and amplifying DNA from strawberries. 9th July was reserved for corporate visitors and allowed for a day dedicated to communicating the science, innovation and opportunities for industry to engage with the CLF.

The Central Laser Facility opened doors to all of its facilities and engineering departments: Vulcan, Gemini, Artemis, Octopus and Ultra. The main public open day was held on Saturday 11th July 2015 where visitors got to learn all about lasers and the science they enable as well as have fun some with them along the way.

Many visited the heart of the Vulcan laser and walked through the laser bay which was made accessible especially for this day. A lucky group of 216 people were able to press the FIRE button for a (simulated) full power shot sequence with sirens blaring. We made science fun and a total of around 5000 people were able to see at least one of our lasers. Many had fun shooting 2500 balloons using a balloon-blasting laser built into a specially-made and interlocked enclosure. About 400 children found treasure looking through infrared viewers doing the lasers treasure hunt. Some even took a wander through the nano-quantum world, visiting Danceroom Spectroscopy, an interactive display where visitors could see themselves as energy fields in the quantum world. Children got the chance to dress up as a scientist, make their own laser targets and rather than eating marshmallows got to do a real experiment with them using vacuum equipment.

STFC Incredible Power of Light Roadshow

The CLF worked with the STFC events team to produce the “Incredible Power of Light” roadshow in time for the start of the International Year of Light 2015 (see annual report 2014-2015). In the reporting period 2015 - 2016 the roadshow was installed at the Scottish Parliament, Edinburgh, and the National Assembly for Wales, Cardiff, the ‘Science Lates’ event at the Science Museum, London, and was part of the Winchester, Durham, and Dundee science festivals. The exhibition has now visited a total of 13 venues, travelling 4,748 miles, and over 94 days captured the attention of around 69,371 people from all walks of life. For more information and details of how to book the “Incredible Power of Light” roadshow, please visit the STFC website: www.stfc.ac.uk/news-events-and-publications/events/stfc-events/stfc-s-incredible-power-of-light-roadshow/

Incredible Power of Light Roadshow

New outreach publications

A new version of the CLF highlights brochure was published in July 2015. "Central Laser Facility: Making Light Work" features short articles on CLF science, technology and engineering for a general audience. It captures the breadth of research and technology development carried out within the CLF across all disciplines of science - from fundamental explorative research to applied research aligned to the grand challenge solutions for societal benefit. A PDF copy can be found on our website: https://www.clf.stfc.ac.uk/Pages/Lasers_Brochure_2016.PDF and print copies are available on request.

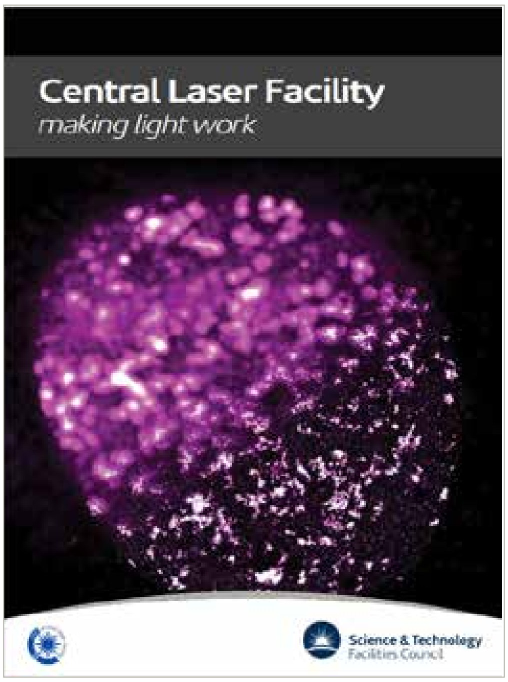
The STFC communications team commissioned science journalist Ben Gilliland to generate a booklet called "The Little Book of Big Lasers" pitched at a general public audience. The booklet includes layman introductions to lasers and laser light, descriptions of the CLF's lasers and includes examples of the research carried out at the CLF. The booklet is also suitable for school students and is available as PDF copy on the STFC website: www.stfc.ac.uk/files/educational-publications/little-book-of-big-lasers/ or print copies are available on request.

Continuing the good work

If you would like to work with us to promote your research or any aspect of CLF work, then please get in touch with Ceri Brenner (ceri.brenner@stfc.ac.uk). Whether it be through outreach events and activities, or via press releases and website content, we welcome collaboration on communicating CLF science.

Acknowledgements

We would like to thank all members of facility staff and the user community who participate in public engagement activities to help promote the laser science and engineering work of the CLF.



High Density Energy Science

High flux, beamed neutron sources employing deuteron-rich ion beams from D_2O-ice layered targets

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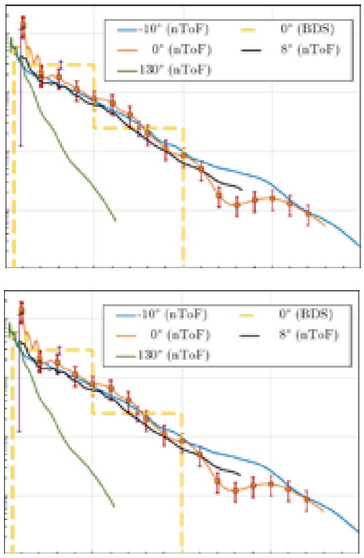
A bright, directional neutron source was produced by employing a laser-driven, deuteron-rich ion beam in a pitcher-catcher scenario. Au foils having a thin layer of D_2O ice at the rear side were irradiated by the petawatt arm of the Vulcan laser ($I \sim 2\times10^{20}$ Wcm^{-2}), producing a deuteron-rich, proton-free ion source. Neutrons of maximum energy up to 40 MeV and peak flux $\sim 2\times10^{9}$ n/sr were produced, preferentially emitted along the ion beam forward direction in a beam of ~70° (FWHM) cone. Simulations of the neutron generation via the d(d,n)^{3}He reaction considering the deuteron beam produced by the ice-layered targets is in a good-agreement with the experimental results.



Top: Neutron spectra, measured along different angles with respect to the laser axis, for the neutrons generated by a deuteron-rich ion source from an ice-layered target in a pitcher-catcher scenario. Bottom: Neutron beam profile experimentally measured by using a suite of neutron diagnostics (CR-39 nuclear track detector, neutron scintillators, and bubble detector spectrometers), compared to the numerical simulation of the neutron generation.

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Buffering and spectral control of protons accelerated from relativistically transparent thin foils

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B. Albertazzi, M. Nakatsutsumi, J. Fuchs *(LULI, Ecole Polytechnique)*
D. C. Carroll, G. Scott, D. Neely *(Central Laser Facility, STFC Rutherford Appleton Laboratory, UK and SUPA Department of Physics, University of Strathclyde)*
D. A. MacLellan, P. McKenna *(SUPA Department of Physics, University of Strathclyde)*
R. Heathcote, M. M. Notley *(Central Laser Facility, STFC Rutherford Appleton Laboratory, UK)*
P. Hilz, J. Schreiber *(Fakultat fur Physik, Ludwig-Maximilians-Universitat Munchen, and Max-Plack-Institut fur Quantenoptik)*
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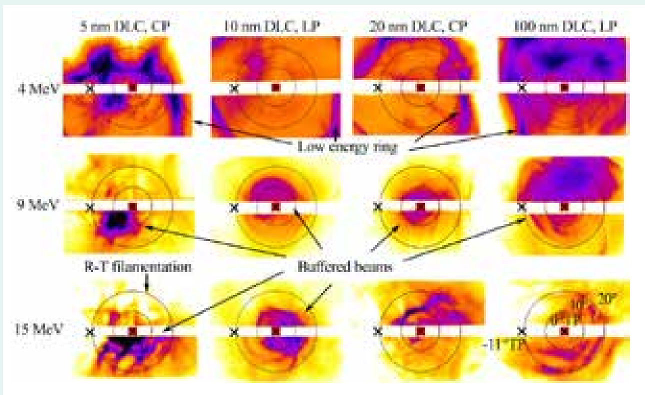
The generation of spectrally peaked ($\Delta E \sim 4$ MeV, $E \sim 8$ MeV), high charge (~50 nC) proton beams was measured from irradiation of ultra-thin carbon foils with the Vulcan Petawatt system [1]. A clear correlation was observed between the maximum carbon velocity and the proton spectral peak, indicating the protons are buffered ahead of the carbon species, preventing break up of the beam due to Rayleigh-Taylor-like instabilities. The beam divergence narrows down to ~8° with decreasing target thickness due to a space charge lens generated by pinched electrons in the relativistically transparent target.

[1] N. P. Dover et al., "Buffered high charge spectrally-peaked proton beams in the relativistic-transparency regime", New Journal of Physics 18, 013038 (2016).



Selected radiochromic film layers from stack diagnostic showing proton beam pattern at different energy bands for different target thicknesses. The low energy beam (top row) is dominated by an annular ring, whereas at high energy (middle/bottom row) a collimated beam appears along the laser axis.

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Laser-driven x-ray and neutron source development for industrial applications of plasma accelerators

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S R Mirfayzi, H Ahmed, A Alejo, S Kar *(Centre for Plasma Physics, Queen's University Belfast)*
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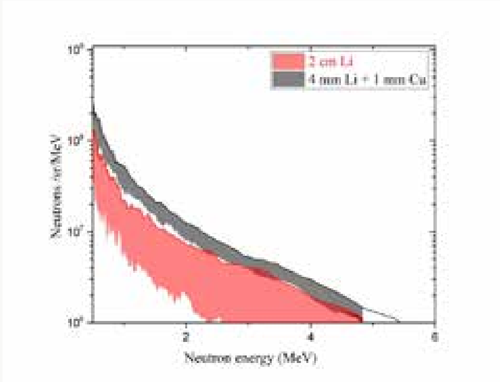
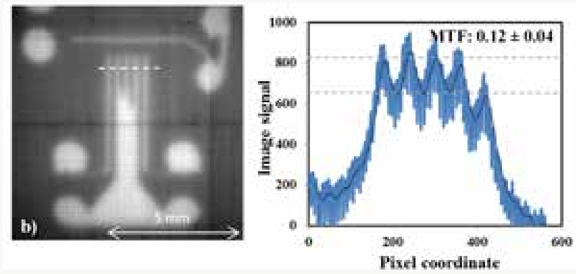
Pulsed beams of energetic x-rays and neutrons from intense laser interactions with solid foils are promising for applications where bright, small emission area sources, capable of multi-modal delivery are ideal. Possible end users of laser-driven multi-modal sources are those requiring advanced non-destructive inspection techniques in industry sectors of high value commerce such as aerospace, nuclear and advanced manufacturing.

We report on experimental work that demonstrates multi-modal operation of high power laser-solid interactions for neutron and x-ray beam generation. Measurements and Monte Carlo radiation transport simulations show that neutron yield is increased by a factor ~2 when a 1 mm copper foil is placed behind a 2 mm lithium foil, compared to using a 2 cm block of lithium only. We also explore x-ray generation and demonstrate imaging using a novel active detector with a 10 picosecond drive pulse in order to tailor the spectral content for radiography with medium density alloy metals.





Top: Measured neutron spectra for the two convertor designs, showing an enhancement in the neutron flux when a 4mm Li + 1mm Cu convertor is used compared to a bulk (2 cm) Li convertor. Bottom: Radiograph of a 5 mm thick tungsten plate wire cut with 200 micron width slits imaged using the CsI active detector under high magnification alongside a line profile of the area indicated by the dashed line used to calculate the modulation transfer function (MTF) of the image.

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Ion acceleration and plasma jet formation in ultra-thin foils undergoing expansion and relativistic transparency

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L. C. Stockhausen, R. Torres *(Centro de Laseres Pulsados (CLPU), Parque Cientifico, Salamanca, Spain)*
G. S. Hicks, N. P. Dover, Z. Najmudin *(The John Adams Institute for Accelerator Science, Blackett Laboratory, Imperial College London, UK)*
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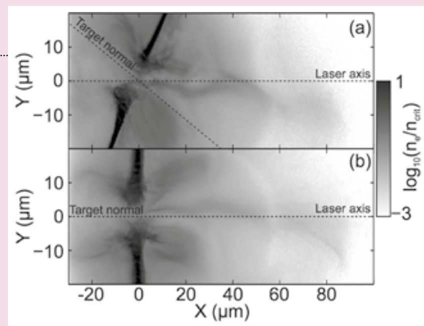
During the interaction of an ultra-intense laser pulse with an ultra-thin solid density target, the rapid heating to relativistic velocities and resulting decompression of plasma electrons can result in the target becoming relativistically transparent to the laser light. Within this regime, ion acceleration can be strongly affected by the transition from an opaque to a relativistically transparent plasma. Through the experimental measurement of the laser-accelerated proton beam at both near-normal laser incidence and at an incidence angle of 30, and through detailed particle-in-cell simulations, we identify characteristics which are consistent with the onset of three distinct ion acceleration mechanisms: sheath acceleration; radiation pressure acceleration; and transparency-enhanced acceleration. This latter acceleration mechanism, which occurs late in the interaction, is induced by the formation of a plasma jet propagating through the expanding ion population. The impact of laser incident angle on the formation of this plasma jet is investigated.



2D Simulation results showing electron density for a target initialised at (a) 0° and (b) 30° incident angle to the laser at an example time of 0.3 ps after the peak of the laser pulse has reached the target surface.

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Energy exchange via multi-species streaming in laser-driven ion acceleration

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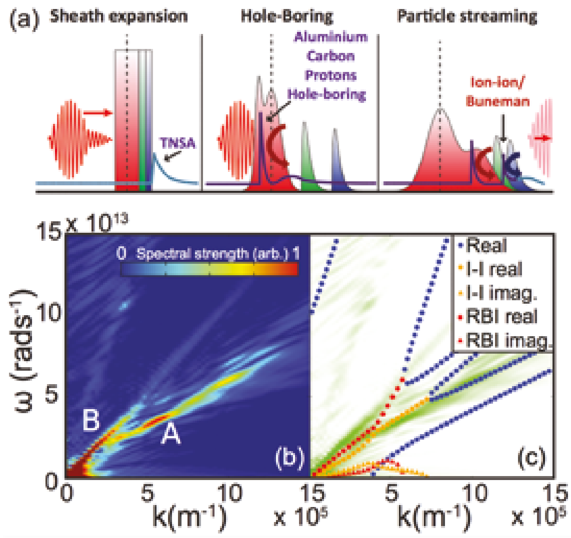
Throughout the interaction of an ultra-intense laser pulse with a thin foil, a variety of complex collective electron dynamics and multiple ion acceleration mechanisms can occur. This can lead to a multitude of charged particle populations overlapping spatially with differing momentum distributions. For certain scenarios, it is possible for this behaviour to induce streaming instabilities such as the relativistic Buneman instability and the ion-ion acoustic instability. Through the use of particle-in-cell simulations, the potential for these instabilities to grow and evolve is demonstrated. Energy-exchange via the ion-ion acoustic instability can occur between ion species if a population of ions can be accelerated to achieve sufficient momentum such that it can propagate through other more slowly expanding ion populations.



(a) Schematic illustrating the three-stages of the forward-directed ions of a 1D laser-acceleration simulation. (b) Spectral power from the 1D simulation as a function of frequency and wavenumber during the particle streaming stage (c) Analytic solutions to the combined dispersion relation for the ion-ion acoustic instability (I-I) and relativistic Buneman instability (RBI) for the averaged electron and ion densities and momentum over the same period as (b).

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The complex ion structure of warm dense carbon measured by spectrally resolved x-ray scattering

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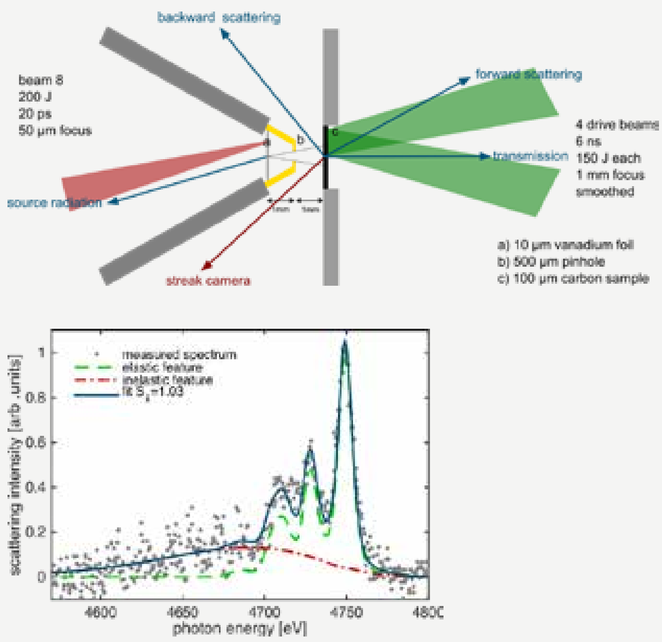
An improved understanding of carbon in the warm dense matter (WDM) regime has motivated an increasing number of experimental and theoretical studies, mainly driven by particular problems in planetary physics and inertial confinement fusion.

At CLF, we have performed measurements of the complex ion structure of warm dense carbon close to the melting line at pressures around 100 GPa. High-pressure samples were created by laser-driven shock-compression of graphite and probed by intense laser-generated x-ray sources with photon energies of 4.75 keV and 4.95 keV. High-efficiency crystal spectrometers allow for spectrally resolving the scattered radiation. Comparing the ratio of elastically and inelastically scattered radiation, we find evidence for a complex bonded liquid that is predicted by ab initio quantum simulations showing the influence of chemical bonds under these conditions. Using graphite samples of different initial densities, we demonstrate the capability of spectrally resolved x-ray scattering to monitor the carbon solid-liquid transition at relatively constant pressure of 150 GPa.



Top: Schematic of the experimental setup at Target Area West. Bottom: Spectrally resolved x-ray scattering from a carbon sample that was driven to a liquid state.

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Selective deuterium ion acceleration using the Vulcan Petawatt laser

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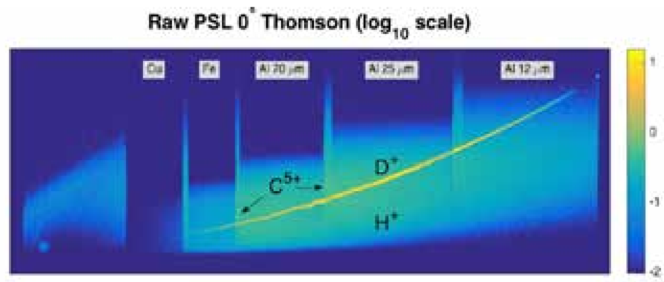
J Fuchs *(Laboratoire pour l'Utilisation des Lasers Intenses, École Polytechnique)*
A Kleinschmidt, M Roth *(Institut für Kernphysik, Technische Universität Darmstadt)*
Z Najmudin, H Nakamura *(Blackett Laboratory, Department of Physics, Imperial College)*
P Norreys *(Central Laser Facility, STFC Rutherford Appleton Laboratory, UK; Department of Physics, University of Oxford)*
M Olivier *(Department of Physics, University of Oxford)*
L Vassura *(Laboratoire pour l'Utilisation des Lasers Intenses, École Polytechnique)*
M Zepf *(Centre for Plasma Physics, School of Mathematics and Physics, Queens University Belfast; Helmholtz Institute Jena)*
M Borghesi *(Centre for Plasma Physics, School of Mathematics and Physics, Queens University Belfast; Institute of Physics of the ASCR, ELI-Beamlines Project)*
RR Freeman *(Physics Department, The Ohio State University)*

We report on the successful demonstration of selective acceleration of deuterium ions by target-normal sheath acceleration (TNSA) with a high-energy petawatt laser. TNSA typically produces a multi-species ion beam that originates from the intrinsic hydrocarbon and water vapor contaminants on the target surface. An ion beam with >99% deuterium ions and peak energy 14 MeV/nucleon is produced with a 200 J, 700 fs, >10^{20} W/cm^2 laser pulse by cryogenically freezing heavy water (D_2O) vapour onto the rear surface of the target prior to the shot. Within the range of our detectors (0°–8.5°), we find laser-to-deuterium-ion energy conversion efficiency of 4.3% above 0.7 MeV/nucleon while a conservative estimate of the total beam gives a conversion efficiency of 9.4%.



Raw Thomson parabola spectrometer data. The bright yellow line is the deuterium ion trace; a faint proton trace is also seen below; C ions are also present in the gaps of the heavy ion filters. The ratio of deuterium ions to protons is in excess of 99.9% demonstrating practically complete annihilation of the proton beam while achieving a bright deuterium ion beam.

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Effects of Pulse Duration, Energy and Target Type on the frequencies of Electromagnetic Pulses in a Petawatt laser system

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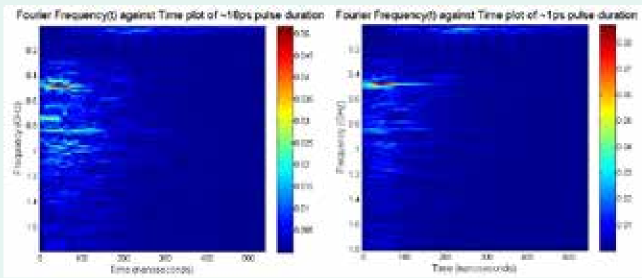
High powered laser-target interactions emitting Electromagnetic Pulses (EMP) has been an ongoing problem for laser systems such as Vulcan. Previous work has demonstrated that charged particles accelerated during the laser pulse draw a large return current from ground and into the target. These currents can generate bursts of EMP, with some measurements showing 2 main modes around 59 and 63MHz in Vulcan Petawatt. In this work the effect of laser pulse duration, energy and target type on the frequency of EMP was measured. A combination of B-dot, D-dot and Moebius loop detectors were used to obtain the data.

A wide range of responses and effects in the frequency modes of the EMP was found when changing the pulse duration, energy and target type. When lengthening the pulse duration there was a significant rise in the range of frequency modes seen. By increasing the energy of the pulse by an order of magnitude, we observed a large rise in the intensity and spectrum of frequencies. Changing to a trimmed target type decreased the EMP frequency intensity, although there are still traces of common frequency modes between the standard and trimmed target types.



Comparison of the 1 ps pulse (Right) and the 18ps pulse (Left) using a Nyquist Fourier Transform Program

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Measurement of the Angle, Temperature and Flux of Fast Electrons Emitted from Intense Laser-Solid Interactions

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V. Bagnoud, B. Zielbauer *(PHELIX Group, Gesellschaft fur Schwerionenforschung, Darmstadt)*

High-intensity laser-solid interactions generate relativistic electrons, as well as high-energy (multi-MeV) ions and x-rays. The directionality, spectra and total number of electrons that escape a target-foil is dependent on the absorption, transport and rear side sheath conditions. Measuring the electrons escaping the target will aid in improving our understanding of these absorption processes and the rear-surface sheath fields that retard the escaping electrons and accelerate ions via the Target Normal Sheath Acceleration (TNSA) mechanism.

A comprehensive Geant4 study was performed to help analyse measurements made with a wrap-around diagnostic that surrounds the target and uses differential filtering with a FUJI-film image plate detector. The contribution of secondary sources such as x-rays and protons to the measured signal have been taken into account to aid in the retrieval of the electron signal. Angular and spectral data from a high-intensity laser-solid interaction are presented and accompanied by simulations. The total number of emitted electrons has been measured as 2.6×10^{13} with an estimated total energy of 12±1J from a 100µm Cu target with 140J of incident laser energy during a 4×10^{20} W/cm^2 interaction.

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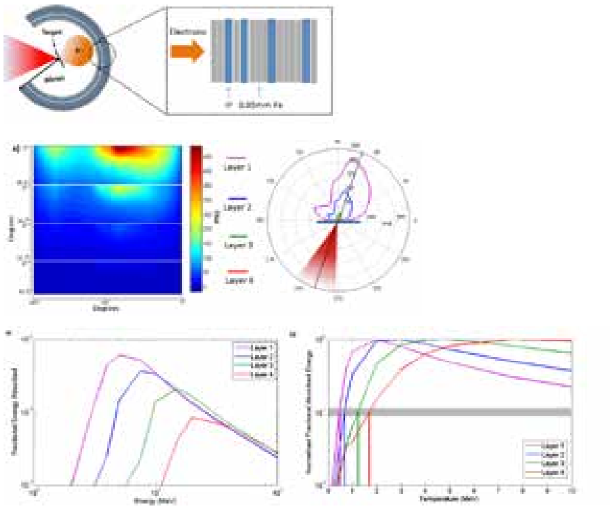

Top: Schematic of the diagnostic arrangement of Fuji BAS-TR Image Plate (IP) between 0.85mm Fe filter. Middle: The fractional absorption in the IP layers from mono-energetic electrons incident onto the array of Fe filters as a function of energy. Bottom: PSL signal from the remapped layers of IP between the Fe filtering from a 140J shot onto a 100µm Cu target and its corresponding polar plot.

Optimization of plasma mirror reflectivity and optical quality using double laser pulses

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R.J. Clarke, J.S. Green, R.I. Heathcote *(Central Laser Facility, STFC Rutherford Appleton Laboratory, UK)*
H.W. Powell, P. McKenna *(SUPA/Dept of Physics, University of Strathclyde, Glasgow, UK)*
T.D. Arber *(Department of Physics, University of Warwick, Coventry, UK)*
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Experimentally we have measured a specularly reflected energy fraction of 96% from a plasma mirror interaction, which was achieved by introducing a density scale length on the plasma mirror surface prior to the main pulse interaction. Experimentally, for a 1.054 µm wavelength laser, this scale length was estimated to be 0.1-0.3 µm, and this yields excellent agreement with particle-in-cell modelling that shows that absorption is minimised in scale lengths of preplasma of this order.

Further than this, an analytical model of the plasma mirror optical quality from interaction with a non-homogeneous preplasma is developed. This provides the understanding for control of the plasma mirror optical quality when fielded in the reflectivity enhancing regime. This again gives excellent agreement with experimental measurements, which show very good optical quality to be achieved in the regime where optimal reflectivity is achieved.

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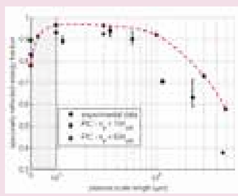
In this proof of principle experiment the preplasma was introduced by a collinear prepulse prior to the main pulse arrival. By triggering a plasma expansion on the plasma mirror surface using a non-collinear prepulse, a high reflectivity, high optical quality, contrast enhancing plasma mirror is a realisable and attractive optical component compared with the highly inefficient plasma mirror arrangements fielded until present.



The figure shows the experimentally measured plasma mirror reflectivity for the main pulse interaction, neglecting any contributions from the controlled prepulse, as a function of preplasma scale length. This is compared to the reflectivity measured in 1D collisional PIC modelling, which is shown for two maximum electron densities. Both clearly show an optimisation of the reflectivity for a finite scale length, and the full article provides the physical interpretation for these results.

Ellipsoidal plasma mirror focusing of high power laser pulses to ultra-high intensities

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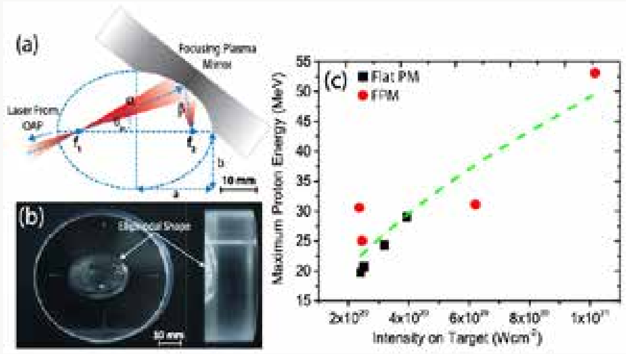
C. Armstrong, D. Neely *(SUPA/Dept of Physics, University of Strathclyde, Glasgow, UK; Central Laser Facility, STFC Rutherford Appleton Laboratory, UK)*
D. C. Carroll, S. J. Hawkes, R. J. Clarke,
(Central Laser Facility, STFC Rutherford Appleton Laboratory, UK)
D . J. Robertson *(Dept of Physics, Durham University, Durham, UK)*

This paper reports on the development of a small F-number focusing plasma mirror (FPM) capable of increasing the peak intensity achievable on the Vulcan-PW laser system. A factor of 2.5 reduction in focal spot size is achieved, compared to F/3 focusing using a conventional (solid state) optic, indicating a ×3.6 enhancement in peak intensity, accounting for changes in optic reflectivity and focal spot quality. An example use of the FPM in an investigation of laser-driven proton acceleration is demonstrated. An increase in the peak laser intensity from $3x10^{20}$ Wcm^{-2} to 10^{21} Wcm^{-2} is found to produce a factor of 2 increase in the maximum energy of sheath-accelerated protons from a thin foil positioned at the optic focus. This finding is consistent with sheath-acceleration intensity scalings. This study helps to bring plasma-based optical technology closer to maturity, with the aim of enabling the exploration of ultra-intense laser-plasma phenomena.



(a) Illustration of ellipsoidal focusing plasma mirror (FPM) concept. (b) Image of the manufactured FPM. (c) Plot of the max. proton energy achieved using either a FPM or flat PM.

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Dependence of target-rear-surface transverse plasma expansion on laser polarisation

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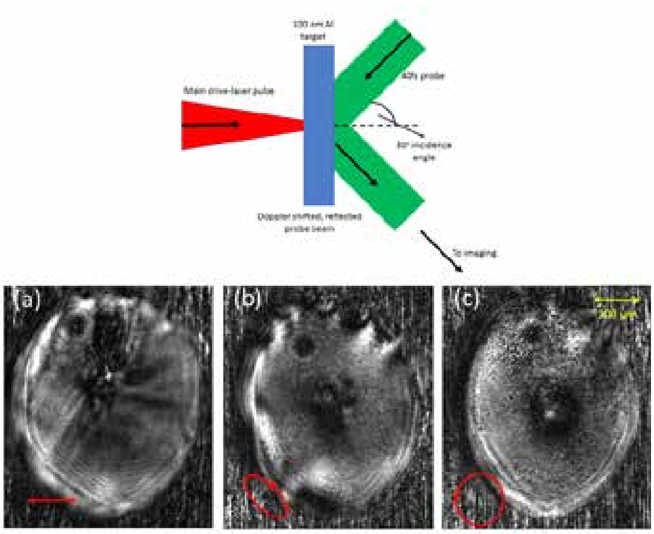
J. S. Green, S. Hawkes, D. C. Carroll, N. Booth, D. Neely *(Central Laser Facility, STFC Rutherford Appleton Laboratory, UK)*
M. Borghesi *(Centre for Plasma Physics, Queen's University Belfast, Belfast, UK)*

The dynamics of plasma electrons in ultrathin foil targets irradiated by intense (~6 x 10^{20} W/cm^2) laser fields is investigated experimentally. Through the use of optical probing techniques, the reflectivity of the rear surface of a target during a laser-foil interaction was characterised, enabling the target heating and plasma formation to be diagnosed, including observations of the lateral expansion of plasma.

Through variation of the laser optical polarisation incident on target, it is shown that plasma expansion is sensitive to the initial laser polarisation. Furthermore, we have observed that the lateral plasma velocity on the rear-surface of the target greatly increased when linearly polarised light was incident on the target front side.



(Top) Schematic of the experimental set-up.
(Bottom) Raw probe images of the target rear-surface for targets irradiated by (a) linear, (b) elliptical, and (c) circular polarised laser pulses. Images taken 3ps after main pulse arrived at the target.

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High resolution imaging of embryonic mouse samples with a laser-driven betatron x-ray source

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D. P. Norris, J. Sanderson, L. Teboul, H. Westerberg, M. Sandholzer, S. Johnson, Z. Szoke-Kovacs *(Mammalian Genetics Unit, MRC Harwell, Harwell Campus, UK)*
M. A. Hill, M. De Lazzari, J. Thomson *(CRUK/MRC Oxford Institute for Radiation Oncology, University of Oxford, Oxford, UK)*
D. R. Symes, D. Rusby, P. S. Foster, S. Botchway, S. Gratton *(Central Laser Facility, STFC Rutherford Appleton Laboratory, UK)*
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A radiographic imaging beamline was constructed around a laser wakefield-driven betatron x-ray source at the Gemini laser facility. Laser-wakefield acceleration is a compact plasma-based electron acceleration technique, capable of the production of GeV energy electron beams in an acceleration length of a few centimetres. The x-rays radiated by this electron beam are highly suitable for imaging purposes, investigated in this experiment through the radiography of embryonic mouse samples.

The x-ray source was found to be energetically stable to within 6% over hundreds of laser shots, with a characteristic energy of 18 keV. The average x-ray photon flux was above 10^6 photons/second/mrad^2, significantly brighter than laboratory-scale x-ray sources of similar resolution. This high flux facilitated the acquisition of hundreds of 2D radiographs in a short period.

The images were of high spatial resolution and signal-to-noise ratio, and represent an important step towards the routine application of laser-driven x-ray sources for preclinical imaging purposes.

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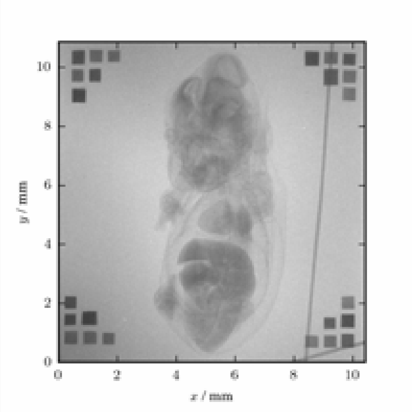

An exemplary radiograph of the mouse sample. Detector non-uniformities have been subtracted and hot pixels removed with a 3 x 3 median filter. The image has not been corrected for x-ray beam inhomogeneity, and so is indicative of the spatial profile of the x-ray beam during the experiment. The squares in each corner are elemental filters for the on-shot transmission spectroscopy, and the thin wires act as fiducials to account for the source motion.

Laser-wakefield accelerators as hard x-ray sources for 3D medical imaging of human bone

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R. L. Abel *(Department of Surgery and Cancer, MSk Laboratory, Imperial College London, UK)*
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D. R. Symes *(Central Laser Facility, STFC Rutherford Appleton Laboratory, UK)*

A bright μm-sized source of hard synchrotron x-rays (critical energy $E_{crit} > 30$ keV) based on the betatron oscillations of laser wakefield accelerated electrons has been developed. The potential of this source for medical imaging was demonstrated by performing micro-computed tomography of a human femoral trabecular bone sample, allowing full 3D reconstruction to a resolution below 50 μm. The use of a 1 cm long wakefield accelerator means that the length of the beamline (excluding the laser) is dominated by the x-ray imaging distances rather than the electron acceleration distances. The source possesses high peak brightness, which allows each image to be recorded with a single exposure and reduces the time required for a full tomographic scan. These properties make this an interesting laboratory source for many tomographic imaging applications.

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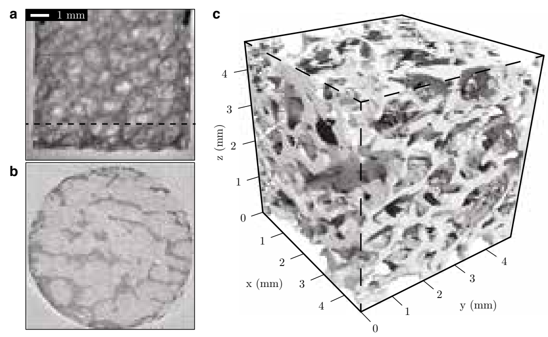


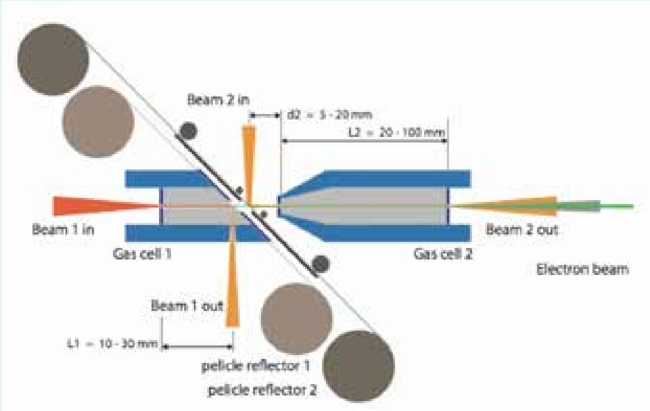
Tomographic reconstruction of trabecular bone sample: a, A raw image of the bone sample recorded on the x-ray camera. b, 2D reconstruction of a one-pixel high horizontal slice of the sample at the position indicated in a). c, Stacking together 1300 such slices generates a 3D voxel map of the bone sample. An isosurface marking the detailed structure of the bone surface is constructed, rendered using a ray-tracing method.

Modelling of a Plasma Mirror for a Laser Plasma Wakefield Staging Experiment

J.-N. Gruse, R. A. Watt, K. Poder, N. C. Lopes, S. Rozario, A. Sahai, J. C. Wood, J. M. Cole, S. P. D. Mangles and Z. Najmudin
(The John Adams Institute for Accelerator Science, Blackett Laboratory, Imperial College London)

The particle-in-cell EPOCH code was used to simulate the reflection of a high intensity laser pulse, ~$2x10^{18}$ Wcm^{-2}, corresponding to the Gemini laser pulse with a f/40 focusing parabola, from a 25 µm thick Kapton® tape featuring a preplasma formed by the laser pedestal. This is of interest for staging two gas cells in laser plasma wakefield acceleration to overcome the energy limitations due to depletion of the laser.

The tape was set 10 – 20 mm in front of the focal plane and the pre-plasma interaction was simulated with the hydrodynamics code FLAS. The resulting density distributions were used as inputs for EPOCH simulations to investigate the reflectivity of the s-polarised laser pulse off the tape for different tape positions. Additionally, an exemplary p-polarisation reflection was simulated to show the expected increased energy loss. It is found that reduced pre-ionisation results in higher reflectivity.



Staging two gas cells in laser plasma wakefield acceleration to overcome energy limitations.

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Optically controlled dense current structures driven by relativistic plasma aperture-induced diffraction

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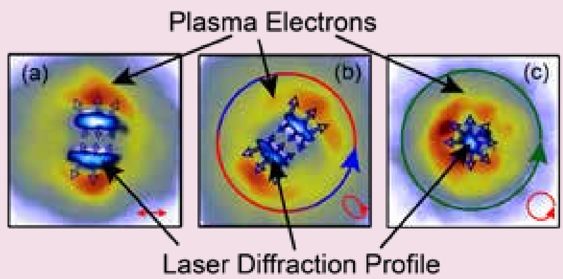
D. Neely *(Central Laser Facility, STFC Rutherford Appleton Laboratory, UK; SUPA Department of Physics, University of Strathclyde, Glasgow, UK)*
and Paul McKenna *(SUPA Department of Physics, University of Strathclyde, Glasgow, UK)*

In this work we show that an ultraintense laser pulse induces a 'relativistic plasma aperture' in a thin foil, and as a result undergoes the fundamental optic process of diffraction. Numerical investigations demonstrate that the plasma electrons collectively respond to the resulting laser near-field diffraction pattern (including angular frequency of rotation), producing a beam of energetic electrons with a spatial structure that can be controlled by variation of the laser pulse polarisation (see figure). The predicted electron-beam distributions are verified experimentally using the Gemini laser.

It is also shown that static electron-beam and induced-magnetic-field structures can be made to rotate at fixed or variable angular frequencies depending on the degree of ellipticity in the laser polarization. This new insight into relativistic transparency and charged particle dynamics is important for a wide variety of applications, including ion and radiation source development.



(a) 2D (Y-Z) plane showing laser light intensity and electron density for linear laser polarisation.

The hollow arrows illustrate the direction of the ponder-omotive force arising from the gradients in laser intensity. (b), same for elliptical polarisation. (c), same for circular polarisation.

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Plasma wakefield diagnostics with oblique crossing angle probe

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K. Glize, D. Symes, N. Bourgeois, R. Trines, R. Bingham, R. Pattathil
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F. Keeble, M. Wing *(University College London, Gower Street, London,UK)*
**authors contributed equally*

In this work, we present an experimental result from TA2 on capturing wakefields. The diagnostic was performed by sending a laser pulse as a probe crossing the wakefield at an oblique angle. This makes it possible to capture the wakefield at a certain position in plasma. Picture of modulations with similar wavelength with plasma wakefields are shown in the report. This experiment serves as a proof-of-concept of plasma wakefield diagnostics in a long plasma column and evolving wakefield, as in AWAKE experiment.

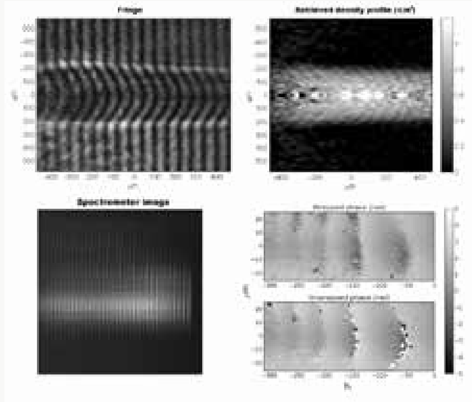

Figure 1. (Top, left) Mach-Zehnder interferometer result on the plasma density profile diagnostic. The modulation at the axis position in Figure (top, right) is due to the singularity near the axis in Abel inversion.
(Bottom, left) The spectrometer image of the spectral interferometry by the oblique angle probe pulses. (Bottom, right) The retrieved wrapped and unwrapped phase modulation when the plasma was present.

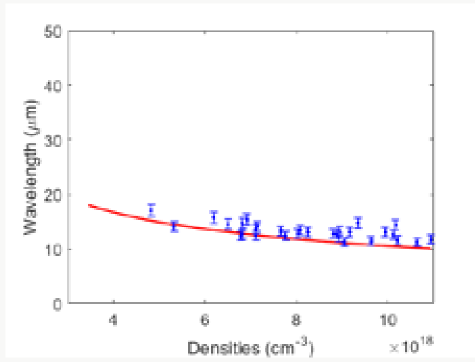

Figure 2. Plot of wakefield wavelengths against the plasma densities. The red line shows the theoretical wavelength.

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Measurement of the LWFA Betatron source length by cross-correlations over images of granular random targets

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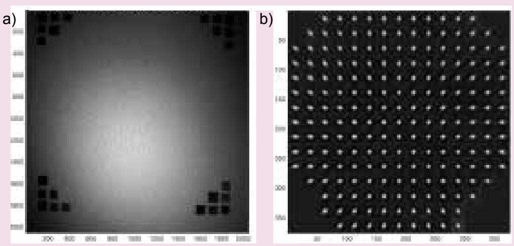
D. J. Chapman, M. E. Rutherford, D. Eakins
(Institute of Shock Physics, Imperial College London,UK)
D. R. Symes *(Central Laser Facility, STFC Rutherford Appleton Laboratory, UK)*

Electron beams being accelerated in laser driven plasma waves have micron size radial oscillations resulting in a forward flash of betatron radiation. In large laser systems like Gemini, it becomes very bright (>10^{12} photons per pulse), energetic (hard x-rays) and can be used for time resolved high-quality x-ray microscopy in absorption or phase-contrast.

A new method to characterize these x-rays beams was tested using Gemini. The blurring of an image of a random granular target (we used sand paper) is analysed and used to measure x-ray emission length and beam direction. The random but regular pattern of the target allows the image blurring to be mapped by autocorrelation of small samples of the image, and the emission length to be inferred. This diagnostic can be used to measure the blurring due to source length of a beamline in a single shot and to optimize the beamline for imaging with a reduced number of shots.



a) imaging of random granular target used to measure the blurring introduced by the x-ray emission length. b) montage of the image sample autocorrelations. We can see the autocorrelation in the centre of the beam presents a round shape corresponding to approximately the point spread function of the detector, but it becomes elongated with increasing radius due to the effect of the emission source length. This image is the extreme case for easy visualization of the effect. Using this diagnostic it is possible to optimize the beamline so this effect becomes negligible.

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Enhancement of laser wakefield acceleration generated electron beam energies on Gemini by employing f/40 focusing

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P. S. Foster, D. Rusby, D. R. Symes
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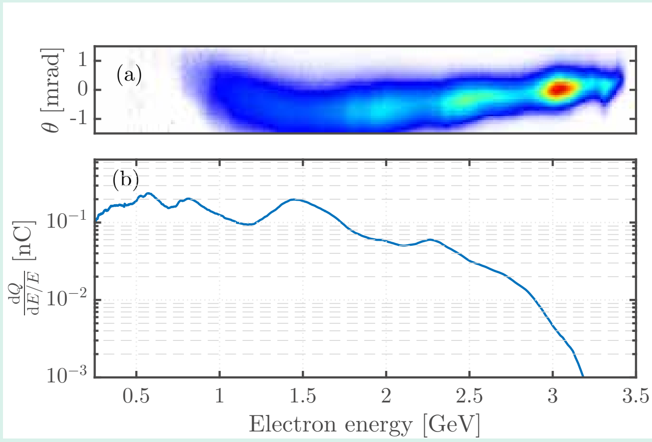
Experimental electron acceleration results from the 250TW Gemini laser system are presented. Driven by scalings for maximum energy gain in a single stage laser wakefield accelerator, an extended focusing geometry comprising of an f/40 spherical mirror was implemented. The new focal geometry allowed for maximum electron beam energies to be increased beyond 2 GeV; the peak beam energies were measured to be more than doubled compared to the previously used f/20 focusing geometry. Three-dimensional particle-in-cell simulations were performed to understand the increased energy gain. The simulations reveal that the increased energy gain is caused by very smooth self-focusing dynamics resulting from a large initial laser spot size. This leads to much less wake evolution, allowing the self-injected electrons to remain near the regions with the highest accelerating field for much longer.



High-energy electron beam measured with the f/40 focusing geometry. Panel (a) shows the raw data, highlighting the beam's very narrow (~1 mrad) divergence. The electron beam spectrum is plotted in Panel (b), emphasizing the multi-GeV energy scale acceleration.

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Investigating the effects of clustering in a laser wakefield accelerator

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L.Wilson, D, Rusby, E. Zemaityte, D. Neely, D. R. Symes, N. Booth, N. Bourgeois, O. Chekhlov, S. Hawkes, C. Hooker, R. Pattathil *(Central Laser Facility, STFC Rutherford Appleton Laboratory, UK)*
S. Dorking, D. Lockley, G. Cook, R. Deas
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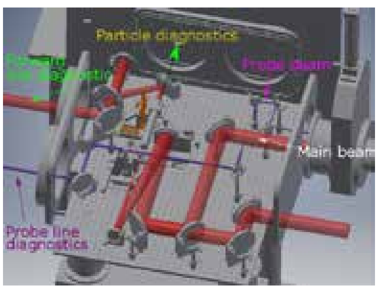
This report examines a new injection mechanism involving the ionization of clusters to generate electron beams in a self-guided laser wakefield accelerator. The experiment was performed using the Gemini (TA2) laser, which delivers 500 +/- 50 mJ, 45 +/- 5 fs into a 15 micrometre spot using an f/17 focusing geometry as can be seen in Figure 1. A cluster is a collection of small atoms or molecules which are locally at solid density. Methane readily clusters at room temperature in a gas jet and was chosen as the target gas for this experiment. The charge of the generated electron beam is observed to be greater by a factor of up to 2 on the beam profile monitor (Figure 2a) and up to 35 times on the electron spectrometer (Figure 2c). This novel injection mechanism provides a new way to control the charge of the electron beam in a wakefield accelerator.



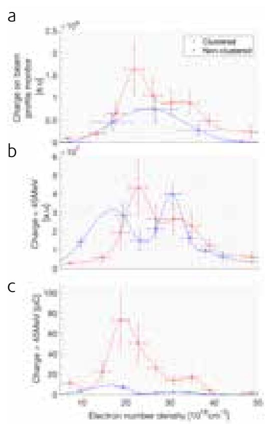


Figure 1 (left): Main chamber layout Figure 2 (Right): Comparison of beam charge between the clustered (red) & non-clustered (blue) on a) Beam profile monitor, b) Low energy electron spectrometer and c) High energy electron spectrometer.

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Density measurements in shock-compressed aluminium via betatron x-ray radiography

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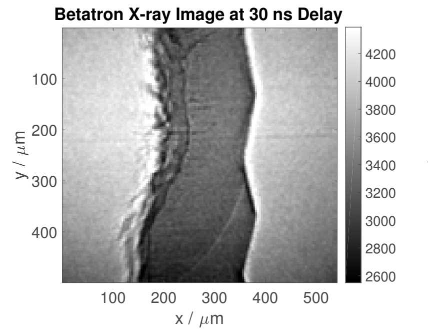
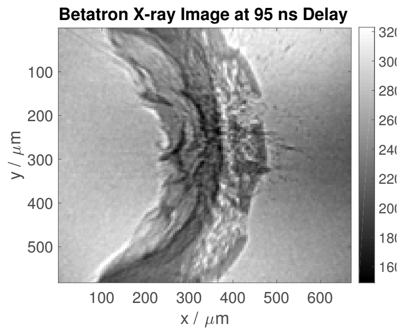
J. C. Wood, N. C. Lopes, K. Poder, S. P. D. Mangles, Z. Najmudin *(The John Adams Institute for Accelerator Science, Blackett Laboratory, Imperial College London, UK)*

A GeV level laser wakefield accelerator driven by the Gemini laser was used to produce a bright (> 10^7 photons/shot/mm^2 at the detector), hard (18.0 ± 0.6 keV critical energy) source of betatron x-ray radiation. The betatron pulse was used as an ultrafast, high signal to noise ratio probe of the subsurface physics of a laser driven shock wave in a solid density aluminium target. The target dynamics were imaged as a function of delay in the range 0-130 ns with a spatial resolution of approximately 4 µm. It is shown that quantitative density measurements of the shock-compressed material can be made with this source, and that this source is capable of directly measuring spall fracture at the mesoscale. Spatially-resolved measurements of density in materials under extreme conditions are important for validating equation of state models and understanding the phases of matter inside planets.





Top: High resolution betatron x-ray image of a double shock structure driven by a shaped laser pulse in to an aluminium target. Bottom: Betatron x-ray image taken at a later time showing that the material has spalled close to the rear surface.

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Calibration of the CLF Andor iKon Indirect Detection x-ray Camera

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R. J. Clarke, D. R. Symes *(Central Laser Facility, STFC Rutherford Appleton Laboratory, UK)*

To detect hard x-rays (>10 keV), systems based on indirect detection are common. In this scheme x-ray photons are absorbed by a scintillator, and the visible light produced is imaged onto a camera. For hard x-ray detection the CLF owns an Andor iKon L 936, which is a scientific CCD camera fibre-coupled to a structured 150 µm thick caesium iodide scintillator.

An important property to measure about an x-ray source is the amount of energy it emits. To enable the use of this camera for this measurement, a calibration was performed so that camera counts can be converted to x-ray energy deposited in the scintillator. The camera was exposed to a disk source of radioactive iron-55 with a known activity and x-ray spectrum. The camera produced 0.245 ± 0.002 counts per keV of energy deposited into the scintillator with a gain setting of 1x.

An Andor iKon L 936 indirect detection camera

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Laser-driven plasma acceleration in a regime of strong mismatch between the incident laser envelope and the nonlinear plasma response

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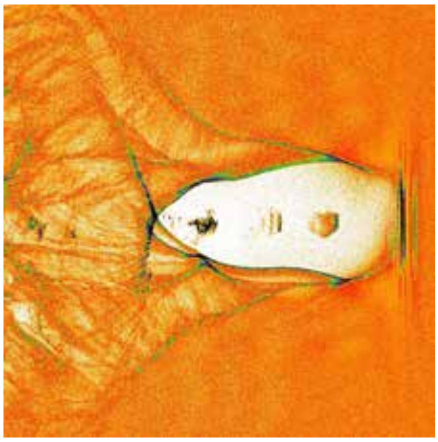
Laser-driven plasma wakefield acceleration of electrons in a strongly mismatched regime is explored and shown to have several advantages over the matched regime. Experimentally, larger laser focal spots of a high quality are much easier to produce and thus allow the plasma waves in this regime to have a high-quality transverse profile. An adjusted a0 model is presented to unravel the underlying laser-plasma dynamics while predicting the experiments more accurately. The injection events in this regime correspond to the formation of an optical shock. Its unbalanced radial and longitudinal ponderomotive force results in an elongated bubble that injects electrons with ultra-low emittance and high charge. Since laser slicing and bubble elongation are only activated over a small density range, the mismatched regime is useful only over a small density range. The triggering of optical shock also results in plasma fields as high as a TV/m, enabling multi-GeV electron beams in less than a centimetre.



A laser-driven plasma wakefield with an elongating bubble structure in the strongly mismatched regime driven in response to the unbalanced ponderomotive forces of the laser pulse driving it. The laser pulse enters an optical shock state triggered by its slicing due to the radial envelope oscillations changing the wake structure interacting with the head of the pulse. As the longitudinal ponderomotive force in the optical shock state is much higher than the radial force an asymmetry is induced in the electron trajectories, this results in the injection of an electron bunch with ultra-low emittance and high charge in the back of the bubble. This bunch gets accelerated to nearly 2.25GeV.

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Use of Raman Forward Scatter for seeding a Plasma Amplifier

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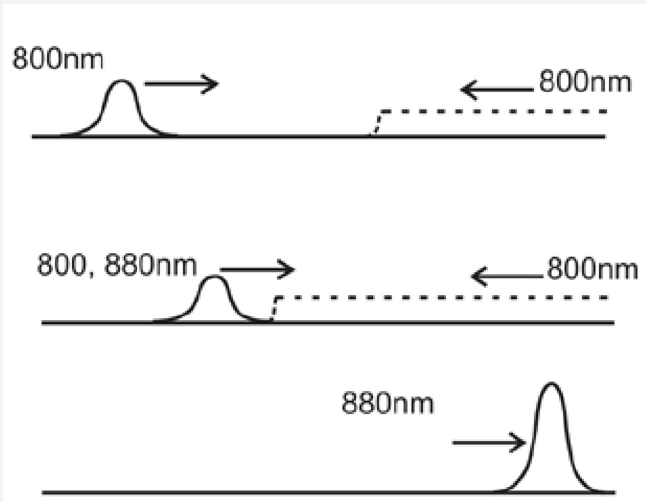
**These authors contributed equally*

Raman plasma amplifiers offer a promising new route to compress laser pulses to frontier powers, possibly into the UV range. Progress has been hampered by the requirement for a short, powerful seed pulse with a wavelength approximately 10% longer than the counter-propagating pump pulse. Here we investigate the generation of an effective seed pulse using Raman forward scatter in a pre-amplifier stage. The subsequent light was well characterised and had many desirable properties for a seed, once the remaining fundamental light has been spectrally filtered out. Furthermore, this technique allows a single laser system to generate both pulses. The feasibility is also assessed using a particle-in-cell simulation.



Schematic of the backwards Raman amplifier scheme, with seeding from forward scatter of a short pulse in an under-dense plasma.

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Enhanced Betatron Radiation from a Laser Wakefield Accelerator in a Long Focal Length Geometry

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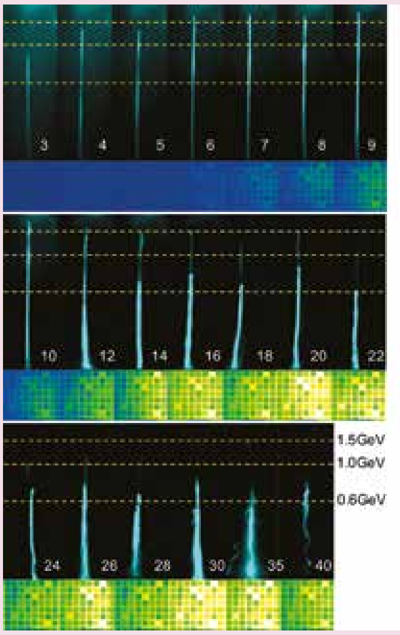
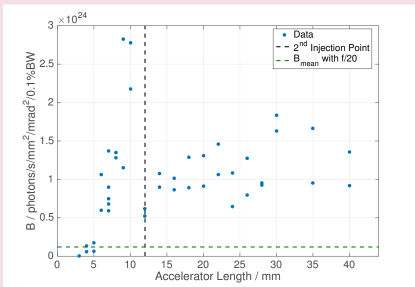
O. Kononenko, C. A. J. Palmer *(Deutsches Elektronen-Synchrotron, Notkestrasse 85, 22607 Hamburg, Germany)*
P. Foster, D. Rusby, D. R. Symes *(Central Laser Facility, STFC Rutherford Appleton Laboratory, UK)*
J. R. Warwick, G. Sarri *(Centre for Plasma Physics, Queen's University Belfast, Belfast, UK)*

By using a double focal length optic, a 6 m focal length *f*/40 optic compared to a 3 m *f*/20, it was shown that electrons from a self-guiding, self-injecting laser wakefield accelerator, driven by a 120 TW laser pulse, could be accelerated to 1.9 GeV while maintaining a source size below 0.5 µm. Dynamic evolution of the bubble size led to a secondary injection of a high charge per unit bandwidth electron bunch which increased the number of betatron radiation photons by a factor of five at moderate photon energies (~ 16 keV critical energy). By increasing the laser power to 240 TW the peak brightness of the betatron beam was increased to 3.8 x 10^{24} photons/s/mm^2/mrad^2/0.1%BW at 18 keV, with the whole beam containing 3 x 10^{10} photons above 1 keV.





Top: Electron spectra (black/blue) and betatron x-ray images (green) from an accelerator length scan, with length in mm denoted by the white numbers. The electron beam is dispersed vertically by energy. At 12 mm length a high charge per MeV electron beam was injected, which was correlated with a large increase in x-ray flux.

Bottom: Brightness as a function of accelerator length. The green dashed line shows the mean peak brightness with an f/20 geometry, which has been exceeded by a factor of more than 10 in this experiment.

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Dynamics and spectroscopy

Vibrational Fingerprinting of Protochlorophyllide Analogues and Implications for the Photochemical Synthesis of Chlorophyll

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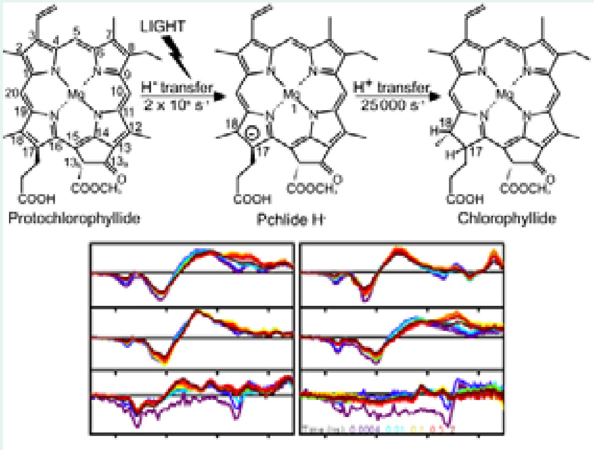
G. M. Greetham, M. Towrie *(Central Laser Facility, Research Complex at Harwell, Rutherford Appleton Laboratory, Harwell Oxford, Didcot, UK)*

A key regulatory step in the chlorophyll biosynthetic pathway is the reduction by the light-driven enzyme protochlorophyllide oxidoreductase (POR) of the C17-C18 double bond of protochlorophyllide (Pchlide) to form chlorophyllide (Chlide). In these experiments we have synthesized a number of Pchlide analogues that contain alterations at key mechanistic positions and used time resolved infra-red spectroscopy to understand how the structural changes affect the photochemical and excited-state properties of the Pchlide molecule that are so crucial for POR catalysis. The assignments we make provide direct confirmation of previous models for the involvement of specific vibrational modes in the excited state dynamics of Pchlide. More generally, these findings will now be crucial for mapping the coupling of any vibrational modes to the hydride and proton transfer chemistry in POR and for understanding the role of specific regions of the Pchlide molecule in POR catalysis.



The light-driven reduction of protochlorophyllide studied by time-resolved infra-red spectroscopy.

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Exploring DNA with 2D-IR – spectroscopy, dynamics and ligand binding

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P. M. Donaldson, G. M. Greetham, M. Towrie, A.W. Parker *(Central Laser Facility, Research Complex at Harwell, Rutherford Appleton Laboratory, Harwell Oxford, Didcot, UK)*

G.A. Burley
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The link between molecular structure and function is a central tenet of biology and an important basis for understanding biological mechanisms. Rather less well-studied however is the role played by molecular motion, and in particular structural fluctuations, in determining the functional behaviour of biomolecules. This gap in our understanding is particularly acute for DNA where the fundamental process of duplex unwinding invokes a level of dynamism not necessarily found in proteins.

Ultrafast 2D-IR spectroscopy offers the potential to provide bond-level structural insight into complex molecules, combined with sub-100 fs time-resolution enabling measurement of the molecular dynamics that underpin function. Here we present an overview of two recent studies exploiting 2D-IR to investigate the vibrational relaxation of DNA and the structural impact of ligand binding to double-stranded DNA, both in the solution phase.

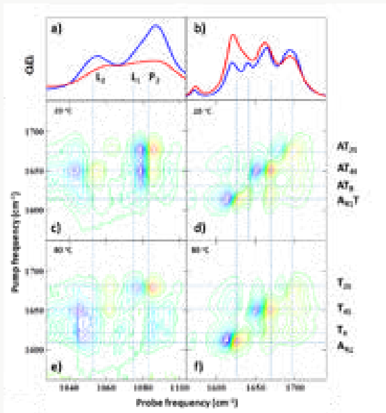

Figure: a) IR absorption spectra of AT 15-mer DNA in the backbone stretching region of the IR spectrum at 20˚C (blue) and 80˚C (red). b) IR absorption spectra showing vibrational modes of the bases at 20˚C (blue) and 80˚C (red). c-f) 2D-IR spectra showing results of one colour (d,f) and two color (c,e) experiments at 20˚C (c,d) and 80˚C (e,f).

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Observation of multiple steps in radical reactions on femtosecond to microsecond timescales

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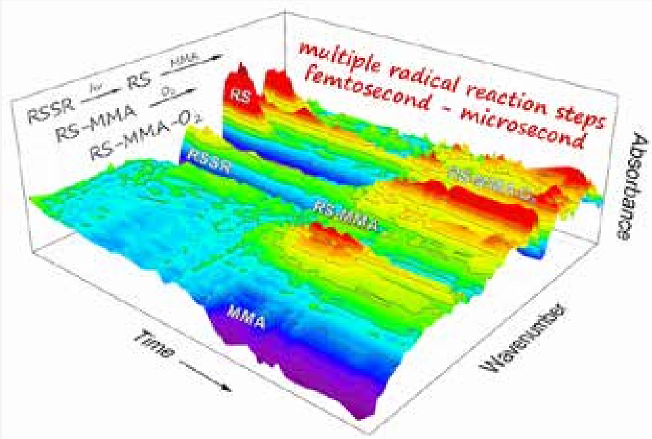
P.M Donaldson
(Central Laser Facility, Research Complex at Harwell, Rutherford Appleton Laboratory, Harwell Oxford, Didcot, UK.)

Free radical reactions in solution involve a complicated sequence of steps, which occur over a wide range of timescales. The initiation of the reactions by photochemical production of the free radicals can be complete in less than 1 picosecond, but subsequent steps require nanoseconds to microseconds to allow diffusion, encounters with co-reactants, and chemical reactions to occur. The LIFEtime facility at the CLF is well suited to observe these reactions because characteristic bands in the transient infra-red absorption spectra distinguish the intermediates involved in each reaction step, and measurements can be made over 9 orders of magnitude of time. We have studied the first steps in an example of the synthetically useful thiol-ene class of reactions in which a thiyl radical is generated by ultraviolet photolysis of a disulfide compound and adds to an alkene. The LIFEtime measurements successfully resolve the first three steps in the reaction sequence.



Transient IR spectra observing a thiol-ene reaction over femtosecond to microsecond timescales.

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Long-wavelength Laser-driven Ultrafast Magnetization Dynamics in Gadolinium

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C. Cacho, R. Chapman, E. Springate
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We studied the ultrafast laser-driven demagnetization of ferromagnetic gadolinium in time-resolved ARPES at the Artemis facility. Femtosecond excitation at 1300nm was followed by probing with 36eV high-order harmonic pulses. The 40-fs time resolution at Artemis revealed new aspects of non-equilibrium magnetism on the femtosecond timescale. In particular, d-band exchange splitting increased within the first 100fs after laser excitation as the majority spin component moved to higher binding energy. Further investigations will help to clarify whether this new observation is the signature of a coherent excitation of the exchange coupled 4f5d spins.

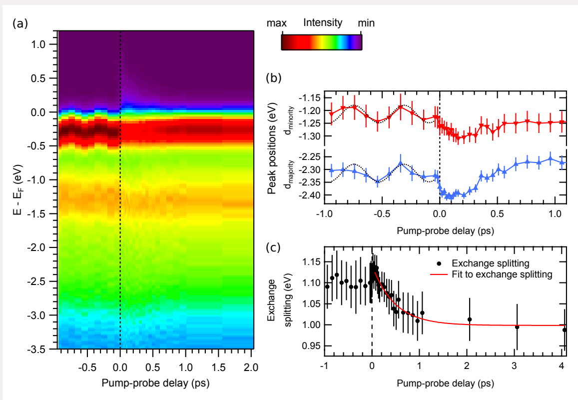

Figure 1: (a) Time-resolved photoemission spectrum. The strong feature at ≈0.3eV binding energy is the Gd(0001) surface state. Its oscillations result from ponderomotive acceleration of photoelectrons by the laser field. (b) Binding energy dynamics of the minority-spin (red) and majority-spin (blue) bulk d bands. The difference between them is the exchange splitting, shown in (c).

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Time resolved photoelectron imaging with an XUV high harmonic source

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O. Alexander, C. Cacho, E. Springate, R. T. Chapman
(Central Laser Facility, STFC Rutherford Appleton Laboratory, Chilton, Didcot, UK)
D. A. Horke *(Center for Free-Electron Laser Science, Deutsches Elektronen-Synchrotron DESY, Notkestrasse 85, 22607 Hamburg, Germany and The Hamburg Centre for Ultrafast Imaging, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany)*

We have performed a UV pump-VUV probe photoelectron imaging experiment on the photodissociation dynamics of CS2. The dynamics in the CS_2 molecule is initiated using a 70 fs 200 nm pump that populates the S_2 excited state of the molecule. Once in the excited state the molecule dissociates on a sub picosecond timescale leading to the formation of CS and S. The dynamics are probed by a delayed VUV probe at 15.5 eV. The probe is generated using high harmonic generation with a driving 400 nm pulse. The 15.5 eV harmonic is then separated from the other harmonic frequencies in a time preserving monochromator. The probe is then used to ionise both the excited state and remaining ground state population. Analysis of the changes in the resulting photoelectron images show features that correspond to ground state depletion and the delayed formation of the dissociation products.

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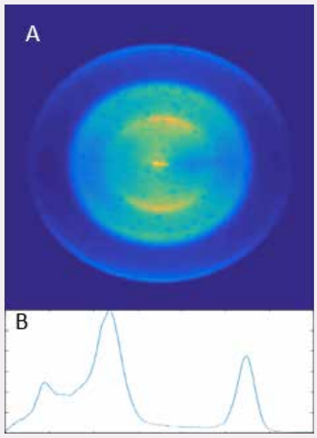

Photoelectron image (A) and spectrum (B) of CS_2 following excitation with UV (6.2 eV) and probing with XUV (15.5 eV) light.

Decay dynamics of conduction band electrons on hydroxylated TiO2

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C. Cacho, R. Chapman, E. Springate
(Central Laser Facility, STFC Rutherford Appleton Laboratory, Chilton, Didcot, UK)
H. H. Fielding *(Department of Chemistry, University College London, UK)*

We performed IR/UV-pump XUV probe experiments on a rutile TiO_2(110) surface. The pump energies, either larger or smaller than the band gap of rutile TiO_2, are chosen to distinguish the dynamics of different charge carriers. A trapping time of ~50 fs of electrons at the bottom of the conduction band is observed in the IR-pump XUV-probe measurements. In the UV-pumped measurements, the fast electron dynamics will also arise from electron trapping as it lies in a similar time scale. In addition, slow processes with lifetimes extending up to picoseconds can be understood under the scheme of trap-assisted recombination. This observation confirms the critical role of the band gap states to the annihilation of electrons and holes under low illumination conditions, which has long been proposed in photochemistry studies of TiO_2.

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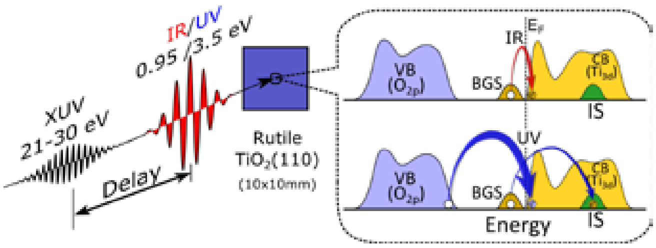


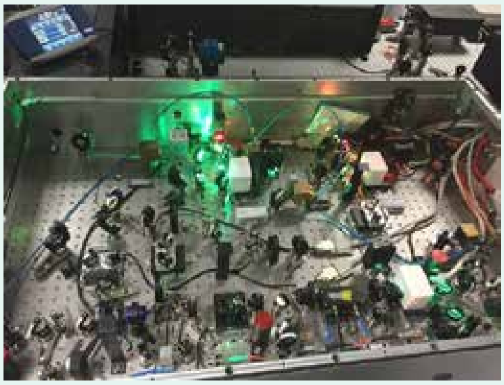
Schematic of the IR-/UV-pump XUV-probe experiments. The pump pulses are either 1300 nm (0.95 eV) or 350 nm (3.5 eV), which are followed by an XUV (21 and 30 eV, respectively) pulse with a controlled delay time. The IR pulse can create excitations from the BGS to the CB bottom, while UV can create excitations from the VB to CB bottom (big arrow) and from the BGS to a resonant intermediate state (IS) in the CB manifold (small arrow).

Laser Science & Development

ULTRA/ARTEMIS - 100 kHz High Power OPCPA Progress Report

E. Springate, M. Towrie, G. Greetham, A. Wyatt
(Central Laser Facility, Research Complex at Harwell, Rutherford Appleton Laboratory, Harwell Oxford, Didcot UK.)

This report provides the technical specification of the Fastlite 100 kHz high power optical parametric chirped-pulse amplifiers (OPCPA) system to be delivered to the CLF in June 2018. The CLF will use and develop the laser and OPCPA to generate light from the XUV to mid IR in the first phase in the bringing together of ULTRA and Artemis, and the provision of world leading pump probe facilities into the future.



The OPCPA

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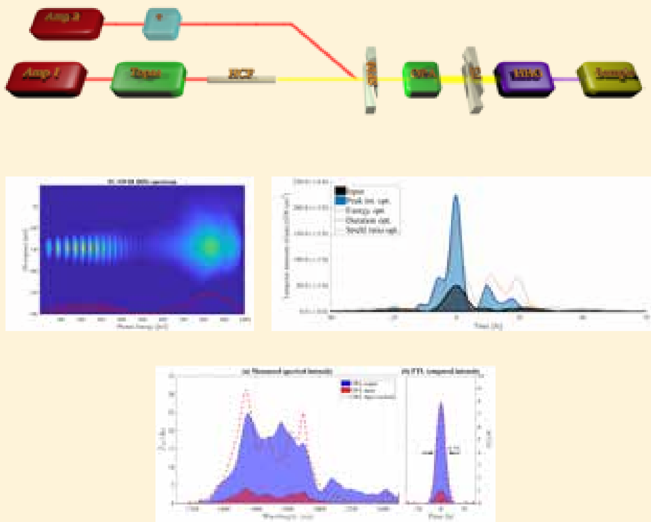
Short-Wave Infrared Few Cycle Pulse Generation and Characterization for High Harmonic Generation in the Water Window

A. S. Wyatt, A. J. H. Jones, R. T. Chapman, C. Cacho, E. Springate
(Central Laser Facility, STFC Rutherford Appleton Laboratory, Chilton, Didcot, UK)

P. Matía-Hernando, A. S. Johnson, D. R. Austin, J. P. Marangos, J. W. G. Tisch
(Blackett Laboratory, Imperial College)

We present developments of carrier envelope phase (CEP) stabilized short-wave infrared (SWIR) few-cycle pulses for driving high harmonic generation (HHG) for the production of extreme ultraviolet pulses in the water window (280-530eV). This spectral region has a wide range of applications in spectroscopy and element specific imaging due to the relatively high transmission in water, the presence of biologically important elements such as carbon (284eV), nitrogen (410eV) and oxygen (543eV) and the potential for nanometre spatial and attosecond temporal resolutions.

We present complete temporal characterization of the few-cycle pulses using a newly developed version of the dispersion scan technique utilizing third harmonic generation, allowing the source to be optimized and providing valuable information for the users. Initial experimental results show HHG of a continuous spectrum spanning up to ~150eV, with characteristic signatures of CEP effects. We also present a simple broadband amplification scheme to increase the few-cycle pulse energy to multiple millijoules to increase the harmonic flux.



Top: schematic of high-flux table-top source of water window harmonics. Middle left: high harmonic spectrum from few-cycle SWIR source; middle right: numerical modelling showing amplified temporal intensity from OPA; bottom: measured amplified SWIR pulse spectrum.

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A new long pulse beamline for the Gemini facility

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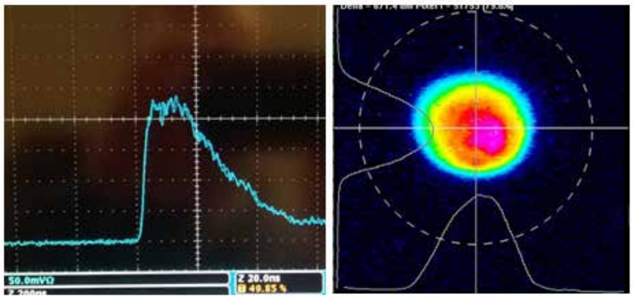
A new long-pulse beamline has been commissioned on the Gemini laser as an improved shock-driver beam. A single 1.053 micron beam from the north Quantel pump laser was sent directly to the target chamber, via one of the floor penetrations for auxiliary beams. The rise-time of the pulse was shortened to ≈1ns by a Pockels cell in the beam after the 9mm amplifiers. The output pulse energy measured after shaping was up to 50 joules, and the focal spot quality of the 50 mm diameter beam was confirmed to be suitable for driving shocks into solid targets. The delay of the laser Q-switch trigger was adjustable from the target area control room, allowing the timing of the shock to be controlled as an experimental parameter. The progress of the shock through the metal foil targets was imaged using Betatron x-rays from an electron beam driven by the south beam of Gemini.



Temporal (left) and spatial characteristics of a 50J pulse on the Gemini long-pulse beamline.

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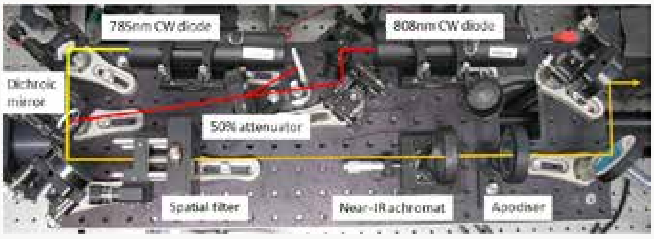
Recent Improvements to the Gemini Laser

C. J. Hooker, O. Chekhlov, C. D. Gregory, S. J. Hawkes, V. A. Marshall, B. T. Parry and Y. Tang
(Central Laser Facility, STFC Rutherford Appleton Laboratory, Chilton, Didcot, UK)

A number of improvements have been made to the Gemini laser, with the goal of making operations easier and enhancing the capabilities of the facility. A CW diode alignment beam combining two different wavelengths has been installed in LA2. The beam can be injected into either the TA2 or LA3 beamlines, to simplify the alignment of the pulse compressors. A pair of reflective polarisers with a throughput of 95% has been installed in the beamline to TA2, giving around 40% more energy on target. The slide-in beam attenuators in LA3 have been replaced with 1% transmitting mirrors to eliminate the scatter caused by the original lens-tissue versions, allowing good-quality focal spot measurements with the attenuated beams. Finally, rotating waveplates and polarisers have been installed at the output of the Gemini North and South amplifiers to provide precise energy control during shot runs.



Photograph showing the layout of the dual wavelength CW diodes in the Gemini front end room, with beam lines indicated.

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Software developments on Gemini

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In addition to the finer north and south amplifier energy control there have been a number of other developments in the software used in Gemini.

Operating system upgrade

We took advantage of the cessation of support for Windows XP to upgrade of all of our control and monitoring PCs to Windows 10. Many of these machines have been running since 2009, and unsurprisingly, the requirements for operations have altered considerably during this time, so the software was modified to streamline the process. We took the opportunity to add some useful features such as better configurability of parameters, and automatic switching of filters for cameras according to laser energy mode. We also replaced many of our outdated Firewire cameras with GigE equivalents, and are in the process of upgrading some of the original motion stages. Although this exercise has been complex and not straightforward, these changes will put us in a good position to continue to support the facility in the future.

User control and shot automation

A recent experiment in TA2 required a fairly fast (every few seconds) feedback loop between the Dazzler in the Gemini front end and a PC which analysed the parameters of the laser-produced electron beams, then modified the settings for the Dazzler to optimize the beam parameters. The most effective way of achieving this type of feedback was to allow the analysis software to "control" the main laser Control System, initiating shots via the PC that was performing the analysis. After some debugging the system worked well, and could potentially be expanded to include other semi-automated functionality. It is important to note here that the range of Dazzler parameters that the analysis software could apply was restricted to a relatively small range. This is because the pulses are delivered alternately to Target Area 2 and Gemini, and large changes to the Dazzler settings for the TA2 pulses can change the thermal conditions in the amplifiers, thereby affecting the pulses sent to Gemini.

Improvements in data analysis

One problem experienced by users is the synchronisation of their experimental data with laser diagnostics across multiple, embargoed, networks. To address this problem we recently installed a tool called DARB (Diagnostics, Analysis, Review and Backup), written in collaboration with the University of Strathclyde. DARB is described in more detail elsewhere.
As part of their on-going international scientific data curation programme, the Scientific Computing Department have upgraded the ICAT database on which eCAT is based to the latest version – version 4.8. One feature of this upgrade is the introduction of a more SQL-like query language which should enable more complex queries to be performed in the database rather than code, thus improving performance.

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Measurement of femtosecond-scale drift and jitter of the delay between the North and South Beams of Gemini

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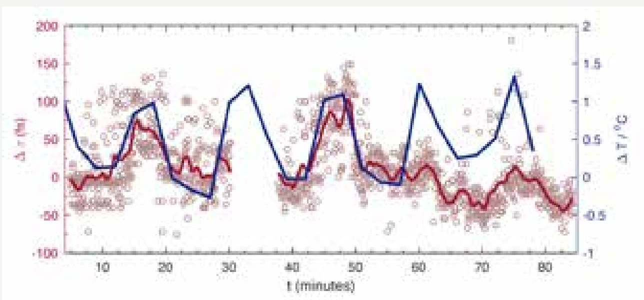
(John Adams Institute, University of Oxford, UK)
N. Booth, O. Chekhlov, C. D. Gregory, S. J. Hawkes, C. J. Hooker, B. Parry, Y. Tang
(Central Laser Facility, STFC Rutherford Appleton Laboratory, Chilton, Didcot, UK)

We describe an experimental technique for measuring femtosecond-scale drift and jitter in the delay between Gemini's North and South beams. This technique, based on spectral interference, was successfully employed in both an off-shot and on-shot capacity for an f/2-f/40 setup. However, the technique itself could be adapted with little difficulty to other focusing geometries.

The delay between the North and South beams was monitored over long periods with a precision of (10.3 ± 0.7) fs using both the off-shot and on-shot diagnostics. It was found that the delay oscillated on the scale of tens of fs over 10-20 minute timescales and correlated strongly with temperature variations of 1°C measured in the laser area.

The on-shot diagnostic showed good agreement with the off-shot measurements and could, in the future, be used in the development of an automated timing stabilization system.



Change in delay between North and South beams measured in TA3 (moving average in red line) against time compared to temperature measured in LA3 (blue line).

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Progress on delivery of a cross-polarised wave generation temporal filter for the Gemini laser

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O. Chekhlov, B. Parry, and P.P. Rajeev
(Central Laser Facility, STFC Rutherford Appleton Laboratory, Chilton, Didcot, UK)

We report on progress of work to integrate a temporal contrast enhancement unit in the Gemini laser system. The temporal filter (shown in the left-hand figure) comprises a specially designed double stage compressor and a cross-polarised wave generation (XPW) stage along with a hollow-core waveguide for spatial filtering. The system produces a pulse having a spectrum that is 35% broader than that of the seed and an overall energy conversion efficiency of 15%. The performance of the unit is thoroughly characterised in terms of the spatial and spectral characteristics of the seed and generated pulses. The characterisation and the dispersion tolerance of the system are investigated by employing a scanning routine with dispersion of three different orders. With an energy booster and a dispersion control unit, the system will be an intermediate stage that can contribute significantly in enhancing the temporal contrast and the spectral properties of the Gemini laser output.

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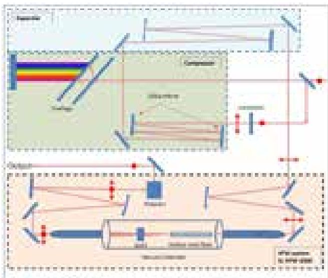

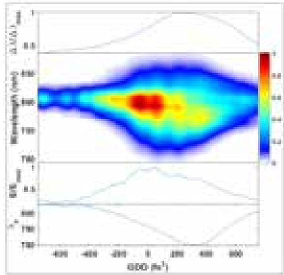

Left: Schematic of the experimental setup of the XPW generation system.

Right: The characteristics of the generated XPW pulse as a function of GDD of the input pulse. Δλmax is the maximum achievable bandwidth, E_{max} is the maximum achievable energy.

Magnetic Detection by Longitudinal and Transverse MOKE at Artemis

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J.-M. Mariot *(Université Pierre et Marie Curie, 75000 Paris, France)*

The understanding of ultrafast spin dynamics in ferromagnetic materials is attracting wide scientific interest owing to its potential applications for spintronics and high-density data storage. The use of a laser source to providing ultrashort pulses is very exciting as it offers the possibility to explore dynamics that operate on sub picosecond timescales, such as the photo-demagnetisation of a ferromagnet.

A Magneto Optical Kerr Effect (MOKE) detector has been built and commissioned at Artemis in order to study ultrafast demagnetisation. This new detector is compared to an existing demagnetisation detector, which uses Transverse MOKE, and results show that it can be used as a complementary diagnostic to the electron spectroscopy techniques.

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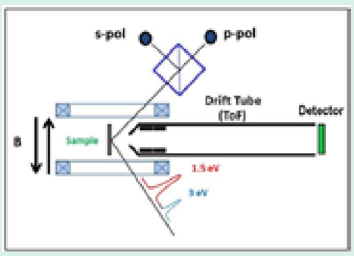

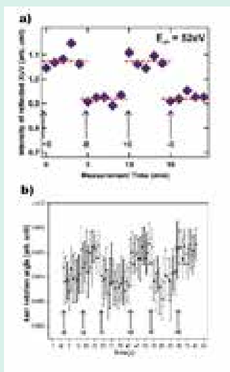

Top: Experimental chamber geometry configured for measuring L-MOKE
Bottom: a) Asymmetry in the reflected intensity for positive and negative magnetisations using T-MOKE. b) Kerr rotation for positive and negative magnetisations measured with L-MOKE.

Adhesive-free bonded crystalline Yb:YAG for high energy laser applications

M. De Vido, K. Ertel, J. Phillips, P. Mason, S. Banerjee, T. Butcher, J. Smith, C. Edwards, C. Hernandez-Gomez, J. Collier *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Chilton, Didcot, UK)*

D. Meissner, S. Meissner *(Onyx Optics, Inc., 6551 Sierra Lane, Dublin, CA 94568, USA)*

We report on the application of the adhesive-free bonding (AFB) technique to form Yb-doped crystalline Yttrium Aluminum Garnet (Yb:YAG) gain media slabs. We performed experiments to characterise mechanical strength, optical quality and laser-induced damage threshold (LIDT) of bonded substrates. We demonstrate that mechanical properties of bonded samples are similar to those of monolithic substrates. We show that the presence of a bonding interface does not introduce unwanted wavefront deformations and does not increase the probability of laser-induced damage onset. Results indicate that the AFB technique constitutes a viable alternative for producing large aperture gain media slabs required for high-energy laser systems.

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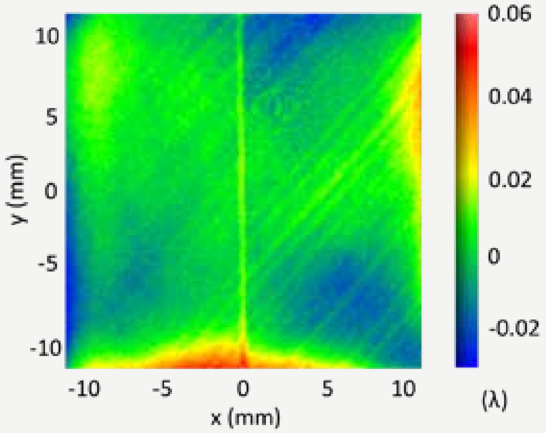

Fast Beam Stabilisation of a Large Diameter CW Laser in its Far Field Using 3 inch Piezo Mounted Mirrors

D. Shepherd, M. Galimberti, B. Parry, M. Harman, A. Frackiewicz, C. Hernandez-Gomez
(Central Laser Facility, STFC Rutherford Appleton Laboratory, Chilton, Didcot, UK)

We have successfully stabilised a CW beam in the far field at frequencies up to ~200 Hz, using a 3" mirror mounted on a piezo tip/tilt platform. The work is a step towards realising coherent combination of multiple large aperture beams as part of the HAPPIE project.

Key advances enabling the fast stabilisation were:

- The use of a hardware PID control loop with parameters optimised using a Monte Carlo method.
- The implementation of a custom vibration isolating mounting system for the piezo mirror.
- Hardware based pointing determination using fast quadcell photoreceivers.

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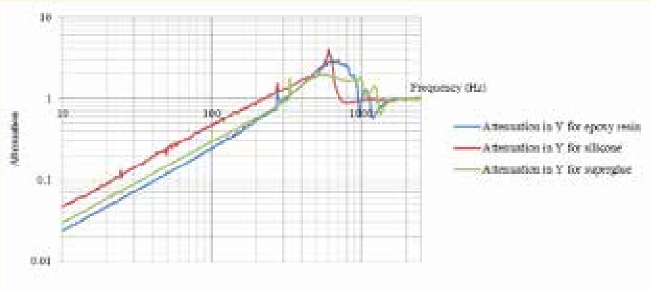

Attenuation of vibrations in the far field across a range of frequencies from 10 Hz up to 2500 Hz. Different adhesives for attaching the mirror substrate to the piezo platform produce varying responses.

20 W Upgrade to the ULTRA Facility

G. M. Greetham, N. Chandarana, I. P. Clark, P. M. Donaldson, E. Gozzard, I. V. Sazanovich and M. Towrie *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Chilton, Didcot, UK)*

The ULTRA facility has been upgraded by addition of a new 20 W Ti:Sapphire amplifier. Higher energy and better shot-to-shot stability of the new laser can provide improved signal to noise in experiments. Dedicated 2D-IR and SFG beamlines have so far increased the range of capabilities in the facility and enable additional parallel operations capability, to increase the throughput of number of weeks access available.

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Recent developments in the Thomson Parabola Spectrometer diagnostic for laser-driven multi-species ion sources

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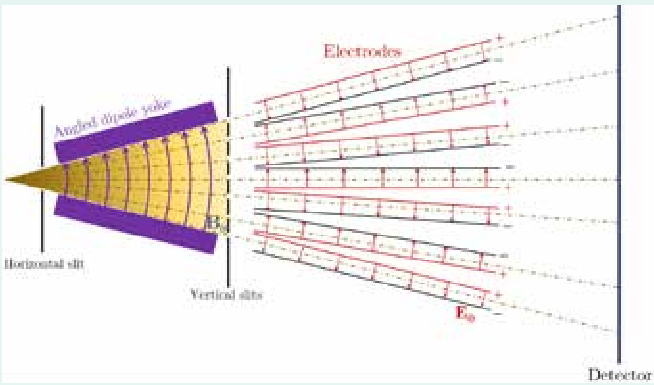
D.C. Carroll, R.J. Clarke, D. Neely, G.G. Scott
(Central Laser Facility, STFC Rutherford Appleton Laboratory, Chilton, Didcot, UK)
S. Kar *(Centre for Plasma Physics, Queen's University Belfast, UK and Central Laser Facility, Rutherford Appleton Laboratory, UK)*

Ongoing advances in laser-driven ion acceleration require modifications to the standard Thomson Parabola Spectrometer (TPS) arrangement in order to match the diagnostic requirements associated to the particular and distinctive properties of laser-accelerated beams. An overview of recent developments by our group of the TPS diagnostic, aimed to enhance the capability of diagnosing multi-species, high-energy ion beams, is presented. A recursive differential filtering technique was implemented at the TPS detector in order to facilitate the discrimination between ions with equal charge-to-mass ratio, allowing only the lightest of the overlapping ion species to reach the detector, across the entire energy range detectable by the TPS. In order to mitigate the issue of merging, and eventually overlapping, ion traces towards the higher energy part of the spectrum, an extended, trapezoidal electrode design was proposed and experimentally demonstrated, which enables a high energy-resolution at high ion energies without sacrificing the lower energy part of the spectrum. Finally, a novel multi-pinhole TPS design is discussed, that would allow angularly resolved, complete spectral characterization of the high-energy, multi-species ion beams.



Schematic top view of a large collection angle Multi-Pinhole TPS, capable of providing an angularly resolved, complete spectral characterization of high-energy, multi-species ion beams.

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Detector for imaging and dosimetry of laser-driven epithermal neutrons by alpha conversion

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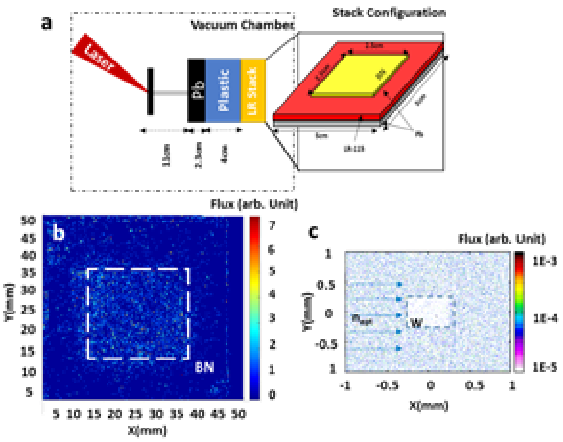
L. A. Wilson, C. Armstrong, R. J. Clarke, M. Notley, D. R. Rusby, D. Neely, C. M. Brenner
(Central Laser Facility, STFC Rutherford Appleton Laboratory, Chilton, Didcot, UK)
S. Ansell *(European Spallation Source, 22100 Lund, Sweden)*
N. M. H. Butler, A. Higginson, P. McKenna
(Department of Physics, SUPA, University of Strathclyde, Glasgow, U.K)
D. Raspino, N. J. Rhodes
(ISIS Facility, STFC Rutherford Appleton Laboratory, Chilton, Didcot, U.K)

In recent years the development of laser-driven neutron sources has demonstrated potentials for various applications in science, industry, security and healthcare. Neutrons generated from laser-driven neutron sources are typically in the MeV energy range known as fast neutrons. Although, fast neutrons are highly penetrating, for many applications lower energy neutrons (1 eV – 100keV) are required otherwise known as epithermal neutrons. Epithermal neutrons are highly suitable for radiographic applications due to their excellent capability to penetrate through many materials and reveal their compositions due to the strong difference in their material dependent scattering cross-sections.

Here we have presented an epithermal neutron imager based on detecting alpha particles created via boron neutron capture mechanism. The diagnostic mainly consists of a mm thick Boron Nitride (BN) sheet (as an alpha converter) in contact with a non-borated cellulose nitride film (LR115 type-II) detector. While the BN absorbs the neutrons in the thermal and epithermal ranges, the fast neutrons register insignificantly on the detector due to their low neutron capture and recoil cross-sections. The use of solid-state nuclear track detectors (SSNTD), unlike image plates, microchannel plates and scintillators, provides safeguard from the x-rays, gamma-rays and electrons.

The diagnostic was tested on a proof-of-principle basis, in front of a laser driven source of moderated neutrons, which suggests the potential of using this diagnostic (BN+SSNTD) for dosimetry and imaging applications.



Top: (a) showing the experimental setup inside the interaction chamber. The fast neutrons were generated by nuclear reactions in the catcher target induced by the MeV ions accelerated from the laser irradiated pitcher target. Epithermal neutrons produced by the plastic block were diagnosed by the BN+SSNTD stack as shown in (b). (c) Imaging capabilities, the FLUKA simulation done for tungsten, shows very good contrast because of the high neutron elastic cross section and atomic number for epithermal neutrons.

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Measurement of the x-ray emission source size from solid targets irradiated with intense laser pulses

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C.M. Brenner, D. Neely
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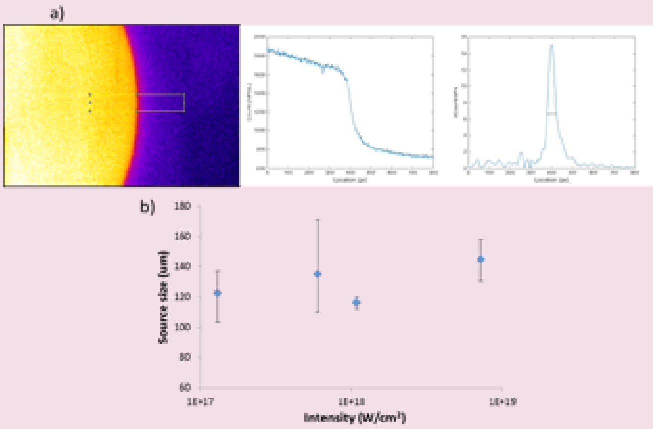
The x-ray source from a high intensity laser interaction with a solid target is key in both diagnosing the internal electron dynamics, and in the radiography of large scale industrial objects. By measuring the high energy x-ray source size (>100keV) from laser-plasma interactions we are able to infer valuable information about the dynamics of the hot electron beam traveling within the target, and determine a limit on resolution for industrial radiography. We present the design and first results from a novel penumbral measurement diagnostic, and detector stack capable of measuring the source size of high energy x-ray beams.

The penumbra of a shadow is a convolution of the source size, the object transmission, and the detector point spread function (PSF). Minimising these is key to achieving higher resolution measurements of the x-ray source. The report discusses the difficulties in achieving this for higher energy x-rays.



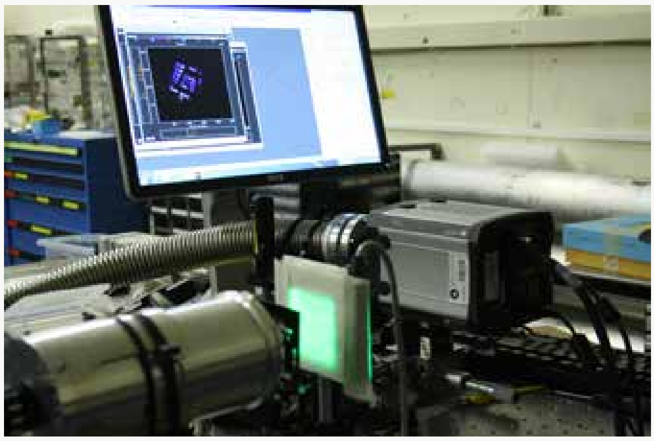
a) an example image cast by the penumbral aperture, with the two subsequent inlet graphs being a lineout and the gradient showing the source size b) shows the results from the defocus scan on 100μm tantalum, error bars shown account for the asymmetry of the source and variance in the source further corrections can be made by accounting for the point spread function (PSF) of the filter layers.

Contact: C.D. Armstrong (chris.armstrong@stfc.ac.uk)

Optimal resolution for a fibre bundle imaging system using a phosphorus based pinhole camera

M.E.Read, D.C.Carroll
(Central Laser Facility, STFC Rutherford Appleton Laboratory, Chilton, Didcot, UK)

An active pinhole camera has been developed which uses a phosphorus plate detector to convert the x-ray image into visible light. This light is imaged to a camera outside the vacuum chamber by a fibre imaging bundle system. In this report the imaging resolution of the lens and fibre bundle system is characterized. The lower resolution limit is found to be 0.75 cycles/mm; this means the smallest feature on the phosphorus that can be resolved is 670 microns. For a pinhole camera with x10 magnification this results in a resolution at the x-ray source of 67microns.



Equipment setup including back lighter, resolution target, cylinder, fibre and camera.

Contact: D.Carroll (david.carroll@stfc.ac.uk)

Surface roughness of NaCl coating used in thin film production

P. Ariyathilaka *(Scitech Precision Limited, STFC Rutherford Appleton Laboratory, Harwell Campus, Chilton, Didcot, Oxon, UK)*

D. Haddock *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Chilton, Didcot, UK)*

This report looks at the surface roughness of a salt (NaCl) coating. Salt coatings are widely used within Scitech Precision Ltd and the Target Fabrication Group at CLF as a release layer when creating thin film targets.

In this experiment salt was coated using thermal evaporation and a surface scan was done straight from the vacuum. A further scan was done after the coating had been left out in the atmosphere for a few days. Data was collected for a plain salt coating as well as a salt coating with an aluminium coating on top.

The surface scans were done using an Atomic Force Microscope (AFM) and the data analysed with Gwyddion, software dedicated to studying AFM images. The research showed that there was an increase of around 50% in the roughness of salt once left out in the atmosphere.

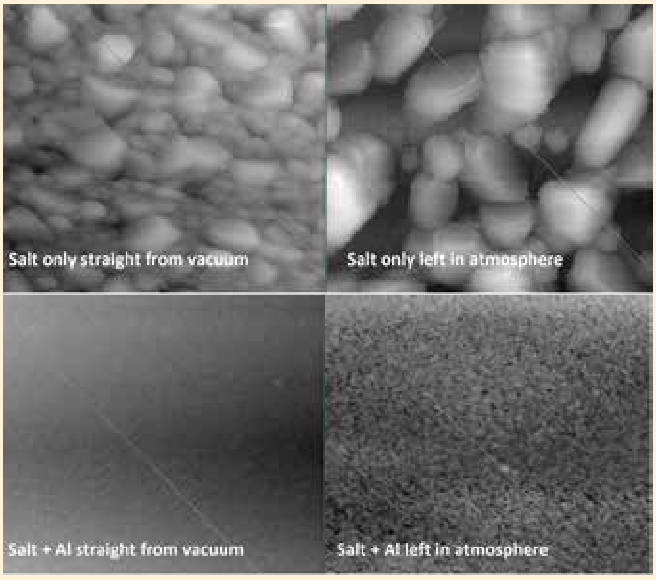


Figure showing the AFM scans of the salt and salt + aluminium coatings straight from vacuum and after being left in the atmosphere.

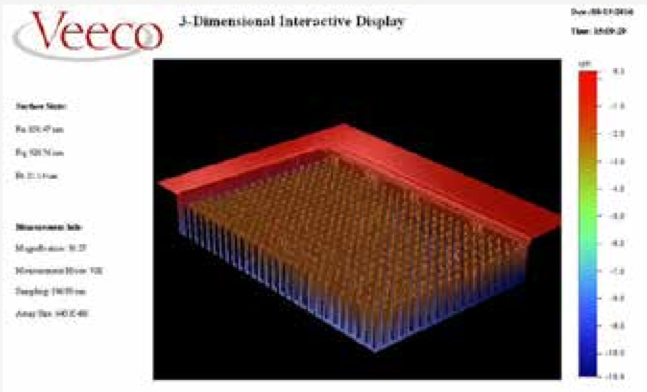
Contact: P. Ariyathilaka (pawala.ariyathilaka@scitechprecision.com)

MEMS Fabrication of Silicon Microwire Targets

G. Arthur *(Scitech Precision Limited, STFC Rutherford Appleton Laboratory, Harwell Campus, Chilton, Didcot, Oxon, UK)*

Some recent experiments at CLF have specified surface structures which give an increase in the absorption of the incident laser light. One of the best routes is to use MEMS-based fabrication to create regular arrays of close-packed micron-scale pillars (microwires), which give the desired optical behaviour. This manufacturing technique allows pillars, grating or similar structures to be defined over specific areas which are both highly uniform and scalable.

This paper describes the basic processes of MEMS-based fabrication and continues by outlining the process steps required to manufacture arrays of microwires over the required area. Microwire arrays, as seen in the figure, were successfully created and have been used in a recent experimental campaign.



Wyko white light interferometer scan of a 2μm microwire array target.

Contact: G. Arthur (graham.arthur@scitechprecision.com)

Target characterisation and pre-alignment for the HAMS high throughput targetry system

S. Astbury, C. Spindloe, N. Booth, M. Tolley, C. Gregory, E. Bryce
(Central Laser Facility, STFC Rutherford Appleton Laboratory, Chilton, Didcot, UK)
S. Karim *(Department of Mechanical, Materials and Manufacturing Engineering, University of Nottingham, UK)*

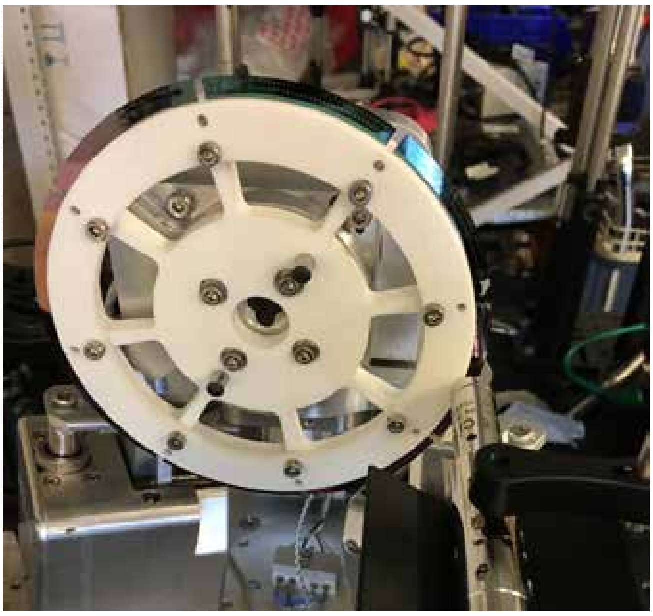
With more and more high repetition rate ultra-intense laser systems coming online, the necessity to increase solid microtarget production increases dramatically. The CLF have designed a High Accuracy Microtarget Supply (HAMS) system which is capable of mass production, rapid positioning, and in-situ focal distance measurement of MEMS-based targets for ultra-intense laser experiments.

This paper discusses the need and methods for pre-characterising silicon target sectors using a suite of measuring equipment available to the Target Fabrication Group at the CLF.

The surface roughness of silicon nitride targets, and the flatness and roundness of the interface wheel upon which they are mounted, is measured using white light interferometry, surface metrology probing and rotational scanning probing respectively.

Through use of Coordinate Measurement Machine (CMM), the alignment of target segments after wheel assembly has been characterised and segment deviation in the z-axis due to stresses in mounting are measured using a chromatic confocal displacement sensor.

Contact: S. Astbury (sam.astbury@stfc.ac.uk)

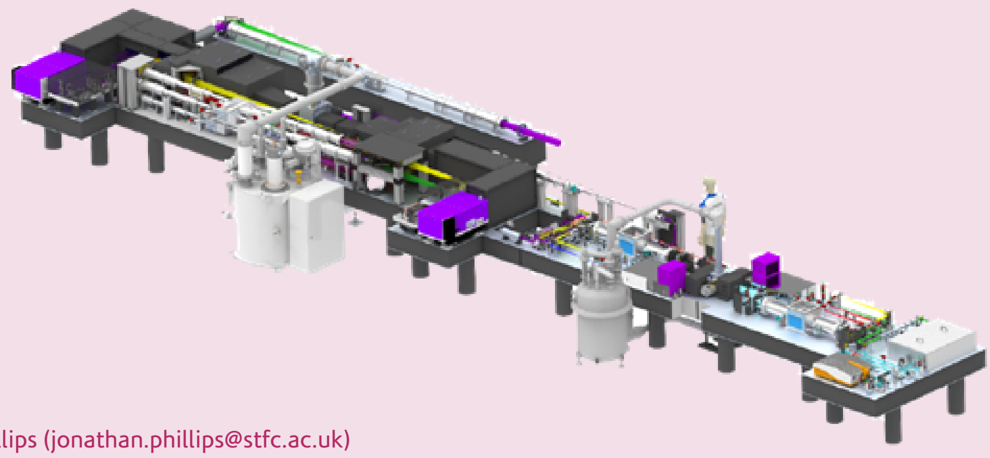


Chromatic confocal displacement setup on the HAMS interface wheel and silicon wafer target segments.

DiPOLE100 - World's first diode pumped kilowatt average power 100J-level Laser

J. Phillips, S. Banerjee, P. Mason, T. Butcher, K. Ertel, M. De Vido, J. Smith, I. Hollingham, B. Landowski, J. Suarez-Merchan, A. Thomas, M. Dominey, L. Benson, A. Lintern, B. Costello, S. Tomlinson, S. Blake, M. Tyldesley, C. Hernandez-Gomez, C. Edwards, T. Mocek, J. Collier
(Central Laser Facility, STFC Rutherford Appleton Laboratory, Chilton, Didcot, UK)
M. Divok, J. ilar, Mihai-George Muresan, A. Lucianetti, T. Mocek
(HiLASE Centre, Institute of Physics Dolnì Břežany, Czech Republic)

We report efficient and stable operation of world's first multi-joule DPSSL delivering 1 kW average power in 105 J at 10 Hz, confirming the energy scalability of multi-slab cryogenic gas-cooled amplifier technology. We also report on the commissioning of DiPOLE100 at the HiLASE Centre at Dolnì Břežany in the Czech Republic. The laser system, built at the Central Laser Facility (CLF), was dismantled, packaged, shipped and reassembled at HiLASE over a 12-month period by a collaborative team from the CLF and HiLASE.



Contact: J. phillips (jonathan.phillips@stfc.ac.uk)

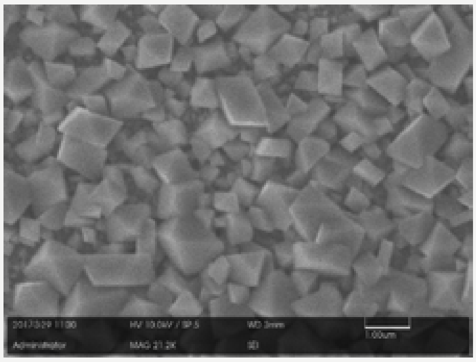
Factors Affecting the Quality of Electroplated High Power Laser Target Foils

A. Hughes *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Chilton, Didcot, UK)*

Experimental target design and production are key areas of research and development in the CLF Target Fabrication Group. Targets have always presented challenges in their fabrication and consequently new production techniques can improve precision and efficiency.

The work carried out in this report focuses on the factors affecting the thickness and quality of copper electroplated foils. This area of research is being carried out to investigate the possibility of generating intricate target designs through machining inexpensive materials, plating expensive metals on to the substrate, then removing the inexpensive substrate. Preliminary work has been carried out using electroplated copper, an inexpensive material but acting as a surrogate high value material, with the plan to apply the generic production principles to expensive metals as the research progresses.

This method of target production opens up the possibility of removing aspects of target assembly, removing adhesives from multi-component targets, and layering thin, structured metal foils without adhesives.



SEM image of copper surface formed on aluminium strip. Plating conditions: 18°C, 1mol dm^{-3} $CuSO_4$, not stirred throughout plating time, 10mA applied.

Contact: A.Hughes (Aasia.Hughes@stfc.ac.uk)

Commissioning of a new Diamond Turning Capability for STFC

C. Spindloe
(Central Laser Facility, STFC Rutherford Appleton Laboratory, Chilton, Didcot, UK)

M. Beardsley, M. Harris
(RAL Space, STFC Rutherford Appleton Laboratory, Harwell Campus, Chilton, Didcot, Oxon, UK)

The Central Laser Facility has invested in a new ultra-high precision lathe for the manufacture of high power laser target components and small optical elements for its programme. The machine, a Single Point Diamond Turning (SPDT) lathe, shown in the photograph, is one of the most technically advanced machining centres in the world and is able to machine components with surface roughnesses of ~ 1nm Ra. Through an existing and productive collaboration with RAL Space Precision Development Facility (PDF), where the equipment will be located, the CLF will be able to manufacture a new range of ultra-precise components, furthering its leading position within the community.

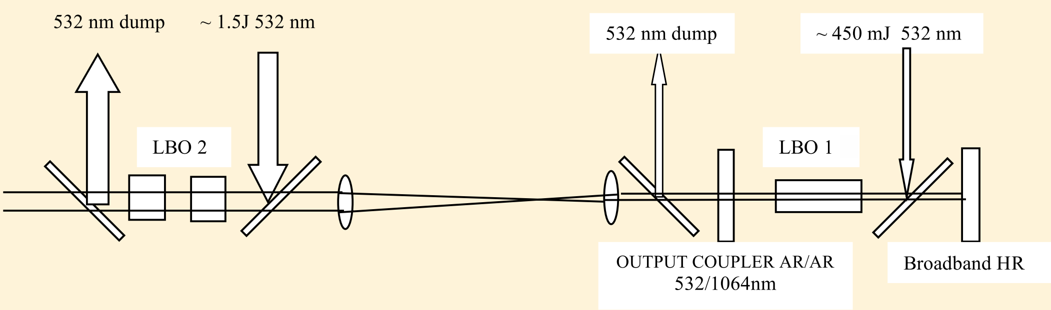
The Nanoform X Lathe

Contacts: C.Spindloe (Christopher.spindloe@stfc.ac.uk)

A stable ultra-broadband OPG/OPA source for the testing of 20 Petawatt Optical Parametric Chirped Pulse Amplifiers

W. Shaikh, P. Oliveira, I. Musgrave, M. Galimberti, A. Wyatt and C. Hernandez-Gomez
(Central Laser Facility, STFC Rutherford Appleton Laboratory, Chilton, Didcot, UK)

A LBO based OPG/OPA source is demonstrated with an energy exceeding 90mJ with a 6% RMS energy stability and tunability of 300nm between 750 to 1050nm. This novel source will facilitate the testing of MultiPetawatt OPCPA amplification schemes.



Contact: W. Shaikh (waseem.shaikh@stfc.ac.uk)

Frequency doubling experiments carried out on the DiPOLE-10 amplifier at CLF

J. Phillips, S. Banerjee, P. Mason, T. Butcher, K. Ertel, M. De Vido, J. Smith, A. Lintern, S. Tomlinson, M. Tyldesley, C. Hernandez-Gomez, C. Edwards, J. Collier
(Central Laser Facility, STFC Rutherford Appleton Laboratory, Didcot, UK)

We report on suitable crystals for second harmonic generation (SHG) energy at high repetition rates: 1 kW average power in 105 J at 10 Hz.

SHG of the DiPOLE laser is a crucial step in the realisation of a multi-Hz PW class laser, where the second harmonic (515nm) of DiPOLE will be used as a pump for a Ti:Sapphire or OPCPA system. The SHG experiments reported in this annual report were performed utilizing the DiPOLE-10 prototype laser system capable of generating 10J, 10Hz with pulse duration variable from 2ns to 10ns.

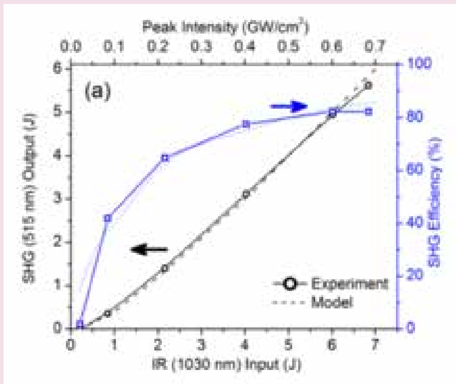


Figure: Type-I phase-matched SHG output energy and conversion efficiency in LBO crystal with 10mm square fundamental beam at 10Hz operation

Contact: J. phillips (jonathan.phillips@stfc.ac.uk)

Life and Science imaging

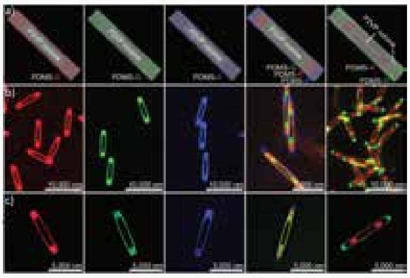
In-situ Visualization of Uniform Rectangular Platelet Micelles using Structured Illumination Microscopy

C. E. Boott, H. Qiu, Y. Gao, I. Manners *(School of Chemistry, University of Bristol, UK)*
S. E. D. Webb *(Central Laser Facility, Research Complex at Harwell, Rutherford Appleton Laboratory, Chilton, Didcot, UK)*

The realization of complex self-assembled structures in solution requires access to more advanced analytical techniques that permit the study of systems in their native environment. Current methods for micelle characterization either provide ensemble measurements (e.g. static light scattering or bulk fluorescence), possess limited resolution (e.g. laser scanning confocal microscopy, LSCM), or require the invasive removal of solvent prior to imaging (e.g. electron microscopy). Super-resolution fluorescence microscopy techniques offer an attractive solution to these problems.

We have successfully employed Structured Illumination Microscopy (SIM) to image nanostructures prepared from the living Crystallisation Driven Self-Assembly of fluorescent block copolymers. This technique enabled the study of the structures to be studied in their native environment at higher resolution than afforded by LSCM.

Contact: I. Manners (ian.manners@bristol.ac.uk)



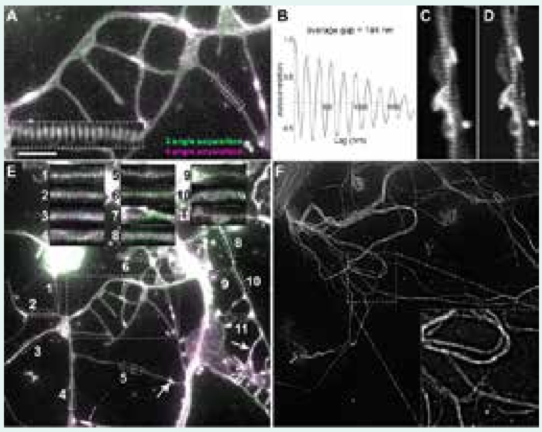
Uniform multiblock rectangular platelets selectively functionalized using fluorescent poly(ferrocenyldimethylsilane) BCPs. a) Schematic representations b) LSCM and c) SIM images of typical rectangular platelet block comicelles, with segregated regions composed of nonfluorescent poly(2-vinylpyridine) coronas and multiple dye-functionalized fluorescent poly(dimethylsiloxane) (PDMS) coronas. The PDMS coronas with red, green, and blue fluorescence are denoted as PDMS-R, PDMS-G, and PDMS-B, respectively. Figure reproduced with permissions from Science, 2016, 352, 697.

Structured illumination microscopy (SIM) as an approach to functionally dissect periodic membrane structures in neuronal axons

I. Hahn, A. Prokop *(Faculty of Biology, Medicine and Health, University of Manchester)*
S. E. D. Webb *(Central Laser Facility, Research Complex at Harwell, Rutherford Appleton Laboratory, Chilton, Didcot, UK)*

Axons contain parallel bundles of microtubules (MTs) that form their structural backbones and serve as life-sustaining transport routes. MT bundles are surrounded by regularly spaced actin rings termed periodic membrane skeleton (PMS) which were initially described in mammals. Their function was not known. We functionally dissected the structure and role of PMS by combining versatile Drosophila genetics with super-resolution microscopy.

Our combined approach using efficient super-resolution SIM imaging with versatile Drosophila genetics enabled us to functionally dissect PMS in axons. The advantage of SIM imaging is that it is fast and reliable and therefore ideally suited for quantitative analysis with very high sample numbers. This enabled us to apply a wide range of genetic and pharmacological manipulations and classify their affects using PMS abundance as readout. We could then apply our knowledge by showing a first functional relevance of PMS for MT bundles, MT dynamics, and even axon maintenance.



Superresolution images of Drosophila axons display PMS. (A) SIM image of SiR-actin–stained Drosophila primary neurons at 10 DIV; (B) Autocorrelation analysis showing the regular periodicity of the actin staining with a lag of 184 nm. (C, D) Axon visualized via STED shown as raw (C) and deconvolved (D) images. (E) Full SIM image of SiR-actin–stained neurons at 10 DIV

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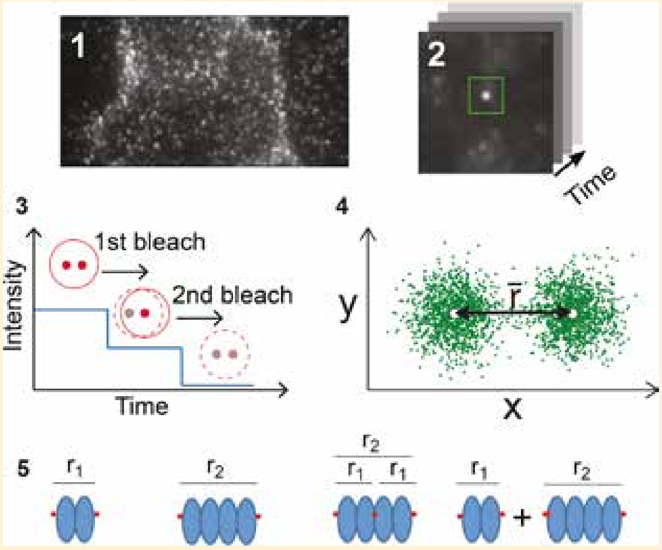
A.Prokop (andeas.prokop@manchester.ac.uk)

Determining the geometry of EGFR oligomers via fluorophore localization imaging with photobleaching

S.R. Needham, D. Korovesis, D.J. Rolfe, L.C. Zanetti-Domingues, C.J. Tynan, S.K. Roberts, M. Hirsch, T.Boyadzhiev, D.T. Clarke, M.L. Martin-Fernandez
(Central Laser Facility, Research Complex at Harwell, Rutherford Appleton Laboratory, Chilton, Didcot, UK)

Dimerisation, oligomerisation and clustering of cell surface receptors are recognized as important in the control of signalling processes. The epidermal growth factor receptor (EGFR, or HER1/ErbB1) is a cell surface receptor involved in many signalling pathways and which if dysregulated can lead to cancer. Using Fluorophore Localisation Imaging with Photobleaching (FLImP), a method developed by members of the OCTOPUS team, we probe the structure of inactive and ligand-induced EGFR oligomers measuring discrete pairwise separations between fluorophore conjugated HER1 Affibody or EGF.

Using FLImP we find that at physiological EGF concentrations, EGFR assembles into oligomers, as indicated by pairwise distances of receptor-bound fluorophore-conjugated EGF ligands. The pairwise ligand distances correspond well with predictions from structural models of EGFR dimers, tetramers, hexamers, octamers and decamers.



How to obtain separations with the FLImP method. (1) TIRF images are collected of fluorophore tagged ligand bound receptors and (2) spots of individual complexes are tracked to give intensity time courses. (3) Representation of a spot containing two fluorophore-conjugated ligands (red dots) where the intensity vs time trace shows two intensity levels which decays to zero in two bleaching steps. When one fluorophore bleaches (grey spot) the spots centroid position shifts. (4) A global least-squares seven-parameter-fit is used to identify the best intensity, x-y positions and the full-width at half-maximum of the point spread function for each fluorophore, from which their separation is calculated with a precision determined by the localization error; (5) Examples of the separations collected from a two-ligand dimer and tetramer, a three-ligand tetramer, and a mixture of a dimer and a tetramer.

Contact: S.R. Needham (sarah.needham@stfc.ac.uk)

Artemis operational statistics

R. T. Chapman *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*

The Artemis team delivered a total of nine user experiments from April 2015 to March 2016, as well as three weeks of development projects in partnership with facility users. In total, we delivered 99 days (20 weeks) of user access and twelve weeks of dedicated experiment setup. Table 1 shows the schedule for the year.

Week beginning	Experiment
30/03/2015	Set-up for Minns
06/04/2015	
13/04/2015	Minns 13220015
20/04/2015	
27/04/2015	Development
04/05/2015	
11/05/2015	Minns 13220015
18/05/2015	
25/05/2015	Laser service and maintenance
01/06/2015	
08/06/2015	Set-up for Moser, Schwenke, Thornton, Bertoni and Gierz
15/06/2015	
22/06/2015	
29/06/2015	Staff training
06/07/2015	Open Week
13/07/2015	Laser service and maintenance
20/07/2015	Set-up for Moser
27/07/2015	
03/08/2015	Moser 15120032
10/08/2015	
17/08/2015	Set-up for Schwenke
24/08/2015	Schwenke 15120043
31/08/2015	
07/09/2015	Thornton 13220017
14/09/2015	Set-up for Bertoni and Gierz
21/09/2015	Bertoni 15120037
28/09/2015	
05/10/2015	Gierz 15120027
12/10/2015	
19/10/2015	Changeover and bakeout
26/10/2015	
02/11/2015	Laser service and maintenance
09/11/2015	Set-up for Carley
16/11/2015	Carley 15120039
23/11/2015	
30/11/2015	Set-up for Brocklesby
07/12/2015	Brocklesby 16120012
14/12/2015	
21/12/2015	Christmas shutdown
28/12/2015	
04/01/2016	Engineering
11/01/2016	Development
18/01/2016	
25/01/2016	Laser Down
01/02/2016	Development
08/02/2016	Laser Down
15/02/2016	Set-up for Thornton
22/02/2016	Thornton 16120007
29/02/2016	
07/03/2016	Changeover
14/03/2016	Laser service and maintenance
21/03/2016	Engineering
28/03/2016	

Table 1. Artemis schedule for 2014-15.

Experiments and set-up

Six of the nine experiments in this reporting year were studies of time-resolved photoemission from condensed matter. Five of these used the angle-resolved photoemission chamber, and one used the ultrafast demagnetization chamber with time-of-flight detector. Of the remaining experiments, one was on time resolved photoemission in the gas phase, and the others on XUV coherent imaging. 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 2015-16 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.

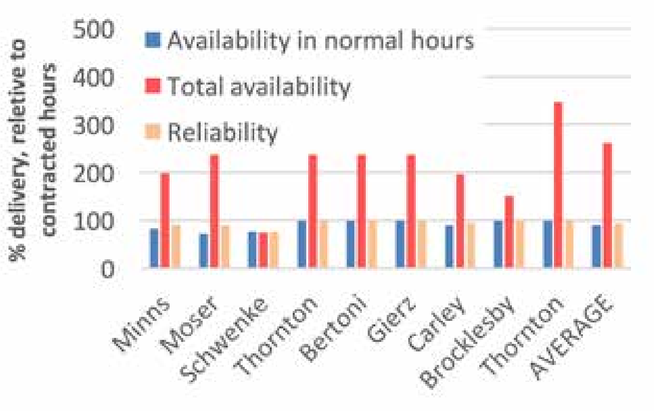


Figure 1. Availability and reliability for user experiments in 2015-16

The average availability is 262%, an improvement upon last year. We were able to deliver five experiments without losing any time at all to laser alignment, achieving 100% reliability and availability. The overall reliability has increased to 94% from 70% the year before.

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Gemini operational statistics 15/16

S. Hawkes *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*

During the reporting year, April 15 – April 16, a total of 5 complete experiments were delivered in the Astra-Gemini Target Area and 2 experiments in TA2. In total 29 high power laser experimental weeks were delivered the Gemini Target Area and 23 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 80% during normal working hours, rising to 136% with time made up from running out of normal working hours. The reliability of the Gemini laser was 87%. 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.

Two main system access slots were made available during the year. The first slot saw the replacement of the Astra amplifier 1 and 2 pump lasers for new Quanta Ray systems to address reliability, replacement of the LA2-LA3 transport relay pipe for a stainless steel version to improve optics lifetime and installation of an adaptive optic at the output of the Astra system. During this access period measurements were made of the full power Gemini focal spot in the target area.

The second system access period was used to install a new long pulse beamline for implementation as a shock driver for the April 2016 Eakins experiment. For further details of this installation see the article by Hawkes et al elsewhere in this report.

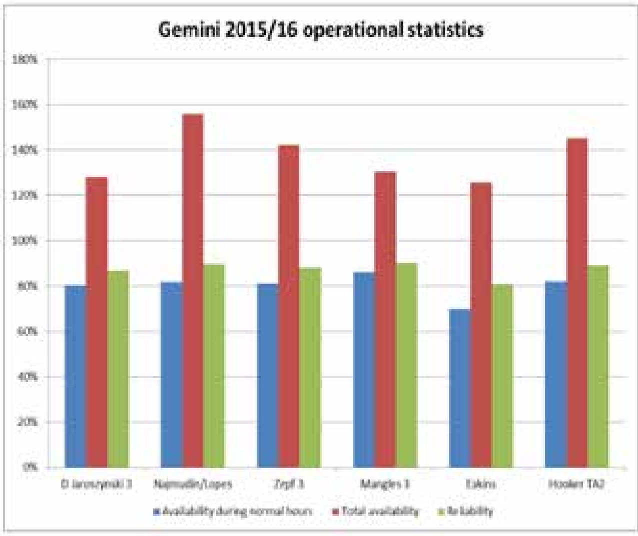

Figure 1. 2015/16 operational statistics

Week commencing	Gemini	TA2
30/03/2015		
06/04/2015		
13/04/2015	System access	
20/04/2015		
27/04/2015		
04/05/2015	Maintenance	
11/05/2015		
18/05/2015		
25/05/2015	Jaroszynski	
01/06/2015	15110013	Hooker
08/06/2015		15110002
15/06/2015		
22/06/2015		
29/06/2015	Open week prep	
06/07/2015	Open week	
13/07/2015		
20/07/2015	System access	
27/07/2015	Najmudin/Lopes	Hooker
03/08/2015	15110008/15110009	15110002
10/08/2015	System access	
17/08/2015		
24/08/2015		Hooker
31/08/2015	Najmudin/Lopes	15110002
07/09/2015	15110008/15110009	
14/09/2015		Extension
21/09/2015		
28/09/2015	Maintenance	
05/10/2015		
12/10/2015		System access
19/10/2015	Zepf	
26/10/2015	15110010	
02/11/2015		Hooker
09/11/2015		Extension
16/11/2015	Maintenance	
23/11/2015		Hooker
30/11/2015	Mangles	Extension
07/12/2015	15210013	
14/12/2015		
21/12/2015	Christmas 2015	
28/12/2015		
04/01/2016		
11/01/2016		
18/01/2016		Lead work
25/01/2016	System access	
01/02/2016		Engineering access
08/02/2016		
15/02/2016		Set up access
22/02/2016		
29/02/2016		
07/03/2016		
14/03/2016	Eakins	Commercial access
21/03/2016	15210011	
28/03/2016		

Figure 2. 2015/16 Gemini operational schedule

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Lasers for Science Facility

B. C. Bateman, D.T. Clarke *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*

OCTOPUS facility

In the reporting period (April 2015 to March 2016), 28 different User groups performed a total of 35 experiments. A total of 84 weeks' access was delivered to the UK User community including 4 weeks to European Users throughout the year. Biology and Bio-materials formed the majority of applications, see Figure 3.

A full breakdown of number of weeks applied for versus number of weeks scheduled is shown in Figure 1 indicating an oversubscription ratio of 1.57:1.

There were a total of 22 formal reviewed publications from this year's efforts.

ULTRA facility

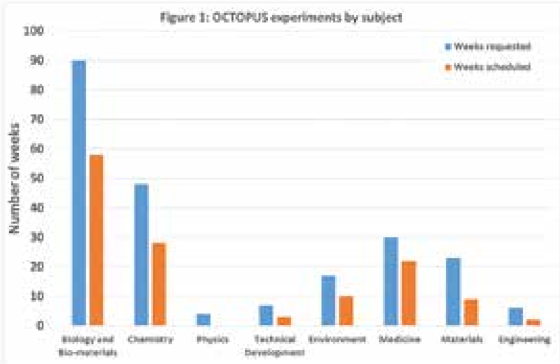
In the reporting period (April 2015 to March 2016), 18 different User groups performed a total of 22 experiments. A total of 51 weeks' access was delivered to the UK User community including 4 weeks to European Users throughout the year. Chemistry formed the majority of applications, see Figure 4.

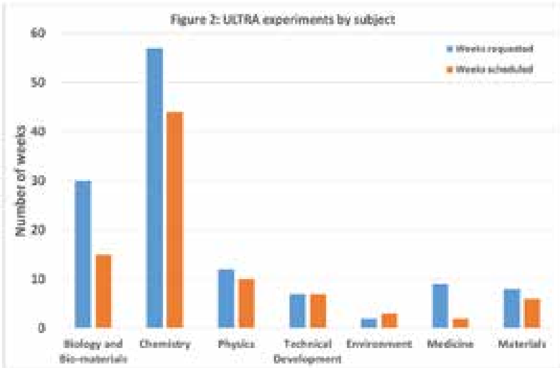
A full breakdown of number of weeks applied for versus number of weeks scheduled is shown in Figure 2 indicating an oversubscription ratio of 1.45:1.

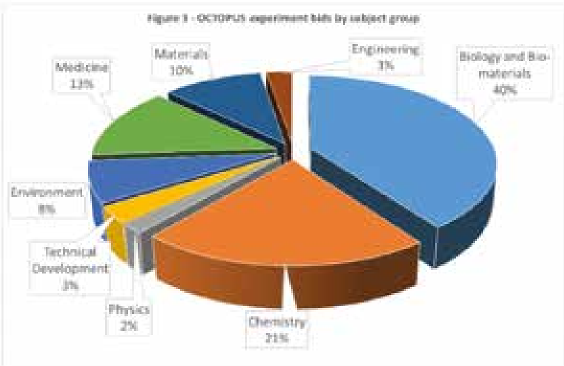
There were a total of 28 formal reviewed publications from this year's efforts.

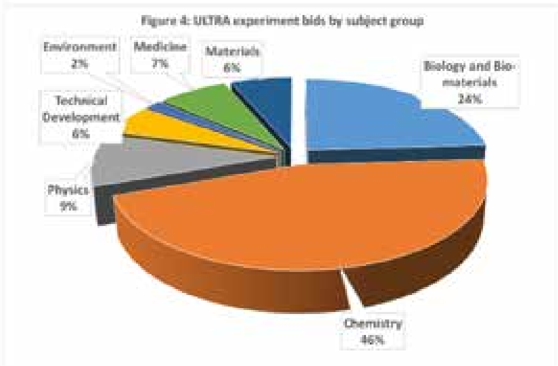
User satisfaction

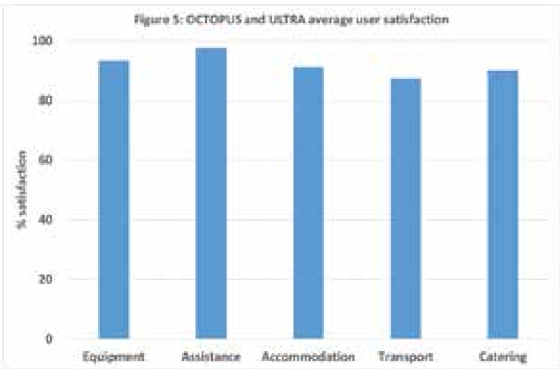
The average User satisfaction marks obtained from the scheduled Octopus and Ultra Users are shown in figure 5, with an average satisfaction of 91.9% across the categories. There were a total of 91 hours downtime reported over the combined 135 weeks of access.











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Vulcan Operational Statistics

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Introduction

Vulcan has completed an active experimental year, with 61 full experimental weeks allocated to target areas TAW and TAP between April 2015 and March 2016.

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

PERIOD	TAW	TAP
	2015	
04 May – 14 Jun	**T Dzelzainis** XUV probing of warm dense matter (112, 17, 84.8%) (89.7%, 111.3%)	**M Borghesi** High dose-rate effects in cell radiobiology employing ultrashort ion bursts (56, 3, 94.6%) (87.5%, 110.1%)
27 July – 30 Aug	**P McKenna** Fast electron transport in transient states of warm dense matter (101, 8, 92.1%) (84.1%, 116.5%)	**J Green** Resistive guiding and focusing of hot electrons in conical magnetic mirror targets (82, 9, 89.0%) (79.8%, 111.1%)
31 Aug – 13 Sep		**Plasma mirrors** (19, 1, 94.7%) (82.5%, 100.8%)
21 Sep – 25 Oct	**D Riley** K-edge shift under different plasma environments (122, 4, 96.7%) (75.3%, 128.9%)	**M Borghesi** High dose-rate effects in cell radiobiology employing ultrashort ion bursts (142, 6, 95.8%) (77.5%, 105.1%)
09/23 Nov – 13 Dec	**M Borghesi** Evolution of electrostatic and magnetosonic collisionless shocks in tenuous plasmas (143, 10, 93.0%) (89.8%, 119.0%)	**M Roth** Probing new laser driven ion acceleration shcemes with thin cryogenic targets (20, 4, 80.0%) (78.8%, 109.0%)
	2016	
11 Jan – 07/14 Feb	**M McMahon** Shock melting of cerium probed using single photon energy dispersive x-ray diffraction (99, 14, 85.9%) (86.1%, 116.4%)	**D Neely** Deuterium hydrogen composite beams for fast ignition (69, 11, 84.1%) (82.9%, 105.1%)
29 Feb –03 Apr	**G Gregori** Dynamics of hydromagnetic radiative shocks (87, 12, 86.2%) (83.5%, 108.3%)	P McKenna Collimated, high density jets of multi-MeV electrons from near-critical density targets (91, 9, 90.1%) (80.5%, 113.0%)

Table 1: Experimental schedule for the period April 2015 – March 2016

(Total shots fired, failed shots, reliability)

(Availability normal, additional hours)

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.

The total number of full disc amplifier shots that have been fired to target this year is 1143. Table 2 shows that this figure compares very favourably with recent years. 108 shots failed to meet user requirements. The overall shot success rate to target for the year is 91%, compared to 92%, 89%, 88% and 88% 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
11 - 12	641	54	92%
12 - 13	860	93	89%
13 - 14	1015	121	88%
14 - 15	1087	133	88%
15 - 16	1143	108	91%

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

The shot reliability to TAW is up very slightly at 90%, compared with 88% in 2013-14. The shot reliability to TAP is around 85%, down from 91% the previous year.

Analysis of the failure modes reveals that, as in recent years, the two overriding causes of failed shots are alignment and front end related issues. It is difficult to distinguish these two causes and we are in the process of commissioning high repetition rate diagnostics (camera-based energy monitors, spectrometers and autocorrelators) in the front end and throughout the laser area to identify and resolve specific sources of instability.

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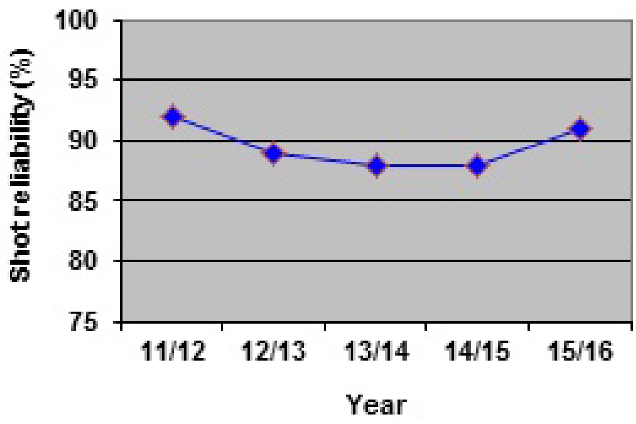

Figure 1. All areas shot reliability for each year 2011-12 to 2015-16

There is a requirement which was originally instigated for the EPSRC FAA that the laser system be available, during the five week periods of experimental data collection, from 09:00 to 17:00 hours, Monday to Thursday, and from 09:00 to 16:00 hours on Fridays (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 83.2% of the time during contracted hours, compared with 85.3% for the previous year. Although this figure is slightly down, the overall availability is slightly up from 111.9% in 2014-15 to 112.4% to all target areas. The time that the laser is unavailable to users is primarily the time taken for beam alignment at the start of the day.

Target Fabrication Operational Statistics

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RAL Experiments

Target Fabrication's support in the reporting period April 2015 to April 2016 was predominantly for Vulcan target areas, with only one of the 12 supported experiments in Gemini. Despite this, the number of supported experiments only decreased by one, a marked increase in the support required by Vulcan experiments. The Target Fabrication group supported a total of 4 experimental weeks for Gemini and 53 weeks for Vulcan. The total number of weeks support for solid target experiments was 57 weeks, down from 64 in the last reporting period. The Target Fabrication group also provided targets for two academic access experiments at AWE which are reported separately at the end of this report. 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 target numbers produced are shown in Table 1. The table is broken down into separate experiments and gives data on total target numbers produced and the subset consisting of high specification targets that have been produced. High specification targets are defined as targets that have taken significant highly skilled micro assembly or micromachining to be produced above and beyond typical target manufacture.

The total number of targets for use at RAL produced by the group in 2015-2016 was 2371 compared to 1937 in 2014–2015 and 2507 in 2013-2014. During 2015-2016 the number of high specification targets decreased from 87 to 77 accounting for 3% compared to 4% last reporting year.

Experiment	Targets Produced	High Specification Targets
0515 TAP	326	
50515 TAW	241	
0715TAP	113	40
0715TAW	235	
00915 TAW	220	11
1115 TAW	324	
0116 TAP	35	
0116 TAP	311	
0216 GTA	91	22
0216 TAW	243	
0316 TAP	139	
0416TAP	93	
TOTAL	**2371**	**77**

Table 1: Target production summary for 2015-2016. High specification targets include 3D micro-structures, low density targets and mass limited targets.

2) Target Categories

Targets can be separated into seven main categories as shown in Figure 1 and Table 2.

Ultra-thin foil targets are specified as having a thickness <500nm and 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; they 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. Foam targets are low density polymer structure manufactured through chemistry based techniques.

Target Category	Targets Produced 2015-2016	Targets Produced 2014-2015	Targets Produced 2013-2014
Ultra-thin Foil	197	530	679
Thick Foils	1349	708	685
Multi-layered Foils	605	500	653
Alignment	110	85	97
3D Micro-structures	99	82	334
Foams	0	5	33
Mass-limited	11	0	22
TOTAL	**2371**	**1937**	**2507**

Table 2: Target category summary for the last 3 reporting years. 3D micro-structures are targets that require micromachining or skilled micro-assembly. Mass-limited targets are targets designed to have minimal support structures

Figure 1: Targets delivered by type

It should be noted that figure 1 is not a reflection of staff effort. Assembly time for a single thick foil target is relatively short; for a batch of mass-limited targets, trials, manufacture and characterisation activities can amount to weeks of effort.

Each experiment usually requires similar targets with varying thickness, composition or geometry. For example: a thin foil experiment typically requests a thickness scan of a particular material. For foil experiments each thickness or composition change requires a separate coating run and for 3D experiments each geometry change requires a new assembly set up. Each change needs to be characterised and logged adequately. Within the total of 2371 targets there were 324 unique target variations which averages 7 targets per variation. Last reporting year the average number of targets per variation was 6. The flexibility provided by the group is a key capability of the CLF and enables the user community to fully utilize the limited time that is available during each experiment on both the Vulcan and Gemini laser systems.

3) 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 and is dependent on the type of experiment and also on experimental conditions such as diagnostic and laser performance. For this reporting period a total of 652 targets were modified or redesigned from the target list agreed upon in the planning stage. This makes up 27.5% of the total targets delivered. In the last reporting year the percentage was 25% and the year prior to that the modified percentage was 22%. As was the case last reporting year: three of the thirteen experiments accounted for the majority of the modified targets; in 0715TAW 84.6% of the total targets were modified, 79% for 1115TAW and 62% for 0915TAW. These three experiments were particularly demanding for Target Fabrication which often produced modified targets in less than a day. Target modifications required significant effort especially in the case of complete geometry change or alterations to coating specifications.

4) Adapting to Demand

The Target Fabrication group endeavors to be adaptable to the changing demands of the user community as experiments develop. Each experiment that is carried out often has widely varying target demands and as a result the group is constantly developing its capabilities.

For this and last two reporting years, foils have dominated the target types comprising just over 90% of the targets delivered. The large number of thick foil type targets can be attributed to the increased support of Vulcan target areas. In the last reporting year Target Fabrication supported many more Gemini experiments with ultra-thin foil requirements.

Ultra-thin and multilayer targets are reliant on coating plant capability and numbers are largely in line with the two previous years.

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 shot by the end of experimental campaign. Targets are collected shot targets totaled 288 accounting for 12.1% of the total targets made. In 2013-2014 a 16% return of un-shot targets was recorded, in 2012-2013 it was 19%, for 2011-2012 and 2010-2011 the proportion was 43% and 10% respectively.

Any un-issued or returned targets are carefully sorted and 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 contribute to their ability to adapt target designs quickly in response to experimental changes.

There has been a noticeable reduction in waste since the complete 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 the implementation (2009-2010, 2010-2011).

Approximately one percent of targets were returned as non-conforming under the QMS in this reporting period.

Orion Academic Access

The Target Fabrication Group has supplied targets to the AWE Orion academic access campaign for groups from the University of York and Imperial College London. In total 215 targets have been delivered for a total of 6 weeks access to Orion. The targets have been complex and have called for the implementation of a range of existing and new technologies including micromachining and gas filling of targets. Further work will be carried out to develop the technologies to enable new target types to be offered to CLF users.

External Contracts

Scitech Precision Ltd, (a spinout company from CLF Target Fabrication) has supplied micro-targets, specialist coatings and consultancy to a number of external contracts. In the year 2014-2015 a total of 53 contracts were completed for coatings, characterisation and also full target design and assembly. This is an increase from 44 in the previous year. The contracts were delivered to external facilities in countries including France, Germany, Italy, India and the US. In this reporting year Scitech Precision has supplied phase plates to LULI, LCLS, GSI and other large facilities.

Summary

Target Fabrication has supported 12 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. This year has seen a decrease in the total number of weeks supported at 57 but an increase in total target numbers to 2371 delivered. Over 90% of the targets delivered were foil type targets with an extremely high turnover of thick foils due to the higher than usual proportion of Vulcan experiments to Gemini.

The number of targets modified from initial target request in the experiments has continued to gradually climb from 22% in 2013-2014, 25% in 2014-2015 and 27.5% this reporting period. As with last reporting year the vast majority of modified targets were due to three experiments.

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CONFERENCE PROCEEDINGS

CALTA

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THESES

HIGH POWER LASER FACILITY

Meinecke, J
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Cross, J
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Hanton, F
Laser Ion Acceleration from Ultrathin foils and application to Radiobiology
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Crowston, R
The generation of upstream-propagating waves in astrophysically-relevant laboratory plasmas
PhD Thesis, University of York (2015)

Alraddadi, R
Modelling fast electron transport in solids and with application to Rayleigh-Taylor instability studies
PhD Thesis, University of York (2015)

Kettle, B
XUV Interaction with Warm Dense Matter
PhD Thesis, Queen's University Belfast (2015)

McKeever, K
Bremsstrahlung diagnostics for the study of x-ray emission from laser produced plasmas
PhD Thesis, Queen's University Belfast (2015)

Read, M
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Hicks, G
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Cole, J
Diagnosis and Application of Laser Wakefield Accelerators
PhD Thesis, Imperial College London (2015)

Gonzalez-Izquierdo, B
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Galinis, G
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Bainbridge, A
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LASERS FOR SCIENCE FACILITY

Delor, M
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Jones, S
Atmospheric reaction chemistry of cloud droplets and aerosol by laser tweezers and neutron scattering
PhD Thesis, Royal Holloway, University of London (2015)

Hill, R
Computational Studies of the Dynamics and Spectroscopy of Peptides
PhD Thesis, University of Nottingham (2015)

Ge, H
New Functionalised Carbon Based Nanomaterials for Biomedical Imaging Applications
PhD Thesis, University of Bath (2015)

Panel Membership and CLF Structure

LASERS FOR SCIENCE FACILITY ACCESS PANEL 2015/16

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ARTEMIS FACILITY ACCESS PANEL 2015/16

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VULCAN, ASTRA TA2 & GEMINI FACILITY ACCESS PANEL 2015/16

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Mr R. J. Clarke (Experimental Science Group Leader)
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Dr R. Pattathil (Gemini Group Leader)
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Dr D. Symes (Gemini Target Area Section Leader)
Central Laser Facility, Science & Technology Facilities Council

Dr N. Booth (Panel Secretary)
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CENTRAL LASER FACILITY STRUCTURE