CLF 2014 - 2015

Central Laser Facility Annual Report

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

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This annual report for the Central Laser Facility (CLF) at the STFC Rutherford Appleton Laboratory provides highlights of the scientific and technical research which has been carried out by users of the Facility and its staff over the financial year 2014-15.

Despite its ongoing operation within the constrained environment set by the Large Facilities Funding Model (LFFM), the CLF and its community have continued to deliver scientific output and technical development of the highest order. User volume has increased again despite the financial constraint and the CLF's facilities remain heavily oversubscribed.

- **Vulcan** – This year saw one of the Vulcan Target Area West experiments enter into the Institute of Physics Physics World Top 10 achievements of 2014. The experiment, led by Professor Gianluca Gregori from Oxford University was designed to investigate magnetic field generation within supernova remnants. The group collided high-turbulence plasmas driven by the long pulse beamlines and was originally published in Nature Physics.
- **Gemini** – Gemini continued to prove its unique capability as a driver for secondary sources for applications. Scientific highlights include two high impact results that appeared in Physical Review Letters. In one of them an international team used the Gemini laser pulses to accelerate a dense relativistic electron sheet formed between two few-atoms thick foils. The coherent motion of this sheet gives rise to a bright, isolated half-cycle pulse in the XUV. In another, a Queen's University Belfast-led team produced gamma-ray beams in the multi-MeV range with highest peak brilliance ever generated in a laboratory - three orders of magnitude higher than conventional bremsstrahlung x-ray sources – using nonlinear-Thompson scattering of one beam of Gemini off a 0.5 GeV electron beam produced by the other.
- **Artemis** - Artemis continued its successful string of experiments looking at electron dynamics in graphene, with high–impact publications in Physical Review Letters and Nano Letters, including investigations of how graphene can be tailored to potentially act as a semiconductor and as a more efficient solar cell. A collaboration using an Artemis end-station at Diamond Light Source achieved a first with measurements of time-, spin- and angle-resolved photoemission. Artemis can now offer shorter pulses to users, and this year measured sub-10 fs electron dynamics combined with sub-eV energy resolution, and developed a source of few-cycle pulses in the infrared.

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** - The "LIFEtime" instrument on Ultra uses new laser technology to extend the Time-Resolved Multiple Probe spectroscopy idea first developed on Ultra, to enable the monitoring of processes on timescales from femtoseconds to milliseconds in the same experiment.
- **Octopus** – Octopus benefited from the addition of a new super-resolution microscope, that offers Stimulated Emission Depletion (STED) Microscopy, capable of a spatial resolution of 50 nm. This complements the MRC-funded super-resolution microscope that was commissioned for users early in the year.

Science highlights included work on polymer–fullerene heterojunctions, from a team using Ultra involving the University of Cyprus, Imperial College, the University of Montreal and the CLF, published in Nature Communications.

Some of the CLF's spectroscopy techniques found unusual applications, with Spatially Offset Raman Spectroscopy being used to investigate evidence for bone diseases in the remains of Henry VIII's sailors from the Mary Rose. Raman spectroscopy techniques were also used in a collaboration between Durham University and the CLF, investigating medieval manuscripts at Durham's World Heritage Site in Palace Green Library, Durham Cathedral. The aim of the project was to identify the pigments used in a range of manuscript books of Northumbrian origin or provenance, dating from the 6th to 12th century. Non-destructive spectroscopy techniques are ideal for studying these delicate, precious samples.

The CLF has continued to work on essential technology for the 20 PW upgrade to Vulcan. Even though the availability of capital to enable this project to proceed still remains elusive, the CLF is determined to remain in a position to be able to start construction immediately should it appear. CLF has also continued to invest in next generation laser, target and diagnostic technology as well as continuing its development of large scale computing in support of its programmes.

In terms of economic impact, this has been a very successful year with a number of high impact activities. In particular the ground-breaking experimental run in Vulcan TAW demonstrated the capabilities of Laser Driven Sources for imaging of industrially relevant complex samples, engaging with companies from Aerospace, Energy, Security & Defence and Advanced Manufacturing sectors. The work provides a platform to build a solid case for future funding to fully develop this key area of impact for CLF. New contracts with industry have been won this year enabling access to Vulcan and Ultra, providing industry with the opportunity to access state-of-the-art laser systems to develop their own products, processes and technologies whilst generating additional income for the department. On the IP front several new ideas are in the early evaluation stage, including a new device for short pulse diagnostics, a novel alignment process for high power laser systems and new methods for nuclear waste imaging.

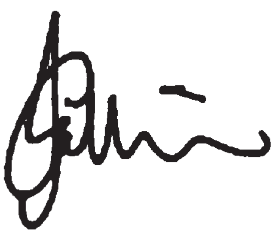
CLF's spinout company Cobalt Light Systems has continued to grow and expand its range of products. They have recently won a number of awards including the prestigious Royal Academy of Engineering MacRobert Award and the Queen's Award for Enterprise. Cobalt also recently topped the Sunday Times BT Business SME Export Track 100. CLF spinout Scitech Precision Ltd combines expertise in micro-assembly and micro-engineering with extensive insight into the physics behind high power laser science. New opportunities exist for high repetition rate target positioning and target supply. Plans to ensure Scitech continues to grow and flourish will be stepped up in 2015.

The CLF's Centre for Advanced Lasers and Applications (CALTA) has successfully completed seven milestone deliverables for the D-100 laser (1032nm, 100J, 2-10ns, 10Hz) due for delivery to the Czech Republic "HiLASE" facility in Dolni Brezany during 2015. The milestones completed include; demonstration of the main pre-amplifier (1032nm, 7J, 10ns, 10Hz) for a period of forty eight hours, high efficiency (>75%) frequency conversion (SHG) of the output of the main pre-amplifier and demonstration of the 100J power amplifier laser diode pump system. The successful delivery of these milestones has significantly increased the profile of the CLF as a leader in this "ground breaking" DPSSL technology.

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

Director, Central Laser Facility

Overview of the Central Laser Facility (CLF)

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

Vulcan

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

Target Area Petawatt is Vulcan's highest intensity area, capable of 500 J /500 fs pulses focused to 10^{21} W/cm^2. The ps OPCPA front end ensures that the ASE contrast of the PW system is better than 10^{10}. To complement the short pulse beamline, an additional 250 J long pulse beam line, as well as a variety of possible probe beams, can be configured in the area. This year we have been investigating the contrast and have identified a number of pre-pulses that were caused by post-pulses in the OPCPA pre-amplifier. These have been removed by the use of wedged optics.

Target Area West is Vulcan's most flexible target area, offering up to eight long pulse beams, or two short and six long pulse beams. The two short pulse beams operate independently and can be configured so that one operates at 80-100 J / 1 ps (10^{20} W/cm^2) and the other one either at 80-100 J / 1 ps or at 300 J / 10 ps in flexible geometries. This year the mirror mounts on the CPA beam lines have been modified as part of the continuing work to improve focal spot quality.

In addition, there has been substantial investment in the long pulse provision in TAW, by upgrading the final lens focusing mounts and by installing a compressor by-pass arrangement to enable TAW to be used with all eight beams in long pulse mode. The maximum energy that can be delivered is 2.5 kJ when all eight beams are configured for long pulse operation. 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 we have worked on improving the stability of the long pulse shaping system employed in TAW and have improved the pulse to pulse energy stability to ~5%.

Gemini

This high rep-rate Petawatt laser based on Ti:Sapphire technology has a unique capability to offer two synchronised beams, each with a power of 0.5 PW and a repetition rate of one shot every 20 seconds. The facility enables interaction studies up to 10^{22} W/cm^2. F/20 and F/2 beam focusing options are available as standard, with a built-in plasma mirror set-up in one beam line for high contrast pulse delivery. There have been several improvements on the temporal contrast of Gemini pulses in recent years; this year has seen the implementation of a transmission grating-based stretcher in Gemini in order to improve its coherent contrast. There has also been a major improvement in the focal spot quality obtained in Gemini. A new wavefront diagnostic technique after the farfield, along with the versatile deformable mirrors, has yielded ~60% encircled energy in a two micron spot for F/2 focusing. As a result of these improvements, the maximum proton energies obtained in Gemini have increased significantly.

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 can be used as pump and probe pulses.

Two XUV beamlines lead to end-stations for atomic and molecular physics and condensed matter physics. One beamline contains a monochromator to select a single harmonic from the spectrum while preserving the 30 fs pulse length. Wavelength selection on the second beamline is obtained through filtering and multilayer mirrors.

Artemis offers a variety of end-stations for time-resolved spectroscopy and imaging. The UHV end-station offers time-and angle-resolved photoemission spectroscopy (ARPES). A second UHV chamber for time-resolved photoemission on magnetic samples has been commissioned. This chamber is equipped with a low noise level electron time-of-flight analyser, magnetisation coils and MOKE. The atomic and molecular physics end-station contains a velocity map imaging detector and differentially pumped gas source. A coherent XUV imaging chamber with multilayer focusing mirrors and sample positioning has also been installed.

This year the development work on Artemis has continued to focus on widening the range of experiments offered. We have continued to develop gas-phase photoelectron spectroscopy experiments with XUV probes, and have now increased the XUV flux at target by a factor of 30, by using the second harmonic at 400 nm as the HHG drive pulse. The hollow fibre pulse compressor was recommissioned this year and used to obtain sub-10 fs temporal resolution and sub-eV energy resolution in a NIR-pump XUV-probe photoelectron spectroscopy experiment on graphene. We have also started a development in collaboration with Imperial College on few-cycle idler pulses at 1.8 micron, to be able to generate harmonics in the water window.

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 fs / ps system combined with OPAs, to generate pulses for a range of unique pump and probe spectroscopy techniques. It provides spectral coverage from 200-12,000 nm and temporal resolution down to 50 fs. This is used in 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 4 ps 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. A new BBSRC-funded Ultra station, LIFEtime, has recently been installed and is currently being commissioned using selected projects. Capital funding has been provided to upgrade the Ultra system with a new 20 W laser that will improve performance for a number of techniques, and enable parallel operation, allowing Ultra operations to be increased from 40 to 60 user weeks per year. A technician is being recruited to support the increased level of operation.

In the imaging area, the Octopus cluster offers a range of microscopy stations linked to a central core of pulsed and CW lasers providing ‘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); and single molecule Alternating Laser Excitation (ALEX) in both confocal and TIRF modes. 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. Additional funds have been made available to increase the number of user weeks offered by Octopus from 60 to 100 per year. To support the higher level of operations, two new Link Scientists have been appointed, with expertise in super-resolution microscopy.

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 will offer to support scheduled experiments throughout the design, analysis and interpretation phases, if required and within the resources available. We offer hydrodynamic, particle-in-cell, hybrid and Vlasov-Fokker-Planck modelling capabilities, and access to large-scale computing. Parallel computing resources include the SCARF system, and the CLF purchased assets, LEXICON 1 and LEXICON 2. In early 2016 we anticipate the commissioning of a new asset, SCARF-MAGNA-CARTA, which will be a 256 core resource. New 1D and multi-dimensional radiation-hydrodynamic and atomic physics tools have been renewed for a further year, as endorsed by the CLF User Forum. Student training in computational methods, and opportunities for networking with colleagues, will continue to be provided. Extended collaborative placements within the group are particularly encouraged.

Target Fabrication

A high capability target fabrication facility is operated within CLF, delivering advanced microtargetry to experiments. The facility offers a wide range of integrated target production techniques, such as microassembly, thin film coating (including ultrathin carbon), and low density foam production. Many microcomponents are produced in collaboration with the STFC micromachining and MEMS facilities. Multiple characterisation techniques underpin all microtarget production and R&D programmes. Target Fabrication continues to be ISO9001 accredited. Commercial access to target fabrication capabilities is available to external laboratories and experimentalists via the spin-out company Scitech Precision Ltd.

As the result of a sustained R&D programme over the last year, it is now possible to offer cryogenic deuterium film ice targets. During the reporting year a dedicated chemistry laboratory, operating under cleanroom conditions, has been commissioned. The new laboratory has allowed a wider range of low density polymer targets to be offered at much higher yields. Additionally chemistry-based techniques have been extended to produce ultrathin (few nm) plastic films. We have developed a programme to address high repetition rate requirements, HAMS (high repetition rate microtargetry system), which aims to integrate microtarget mass production and rapid positioning.

Centre for Advanced Laser Technology and Applications (CALTA)

CALTA is a new STFC/CLF Centre that is charged with driving forward next generation laser technology, principally focused on the industrial and commercial application of high power lasers and the by-products of interactions (e.g. super bright, high energy photons, electrons, ions, etc). At its heart is a campaign to develop advanced, proprietary diode-pumped laser technology (DiPOLE) and associated multi-PW component technology that has been pioneered within the CLF in recent years. The main activity within DiPOLE is the development of a scalable diode-pumped solid state laser (DPSSL) concept that is capable of delivering kJ-level pulses at a repetition rate of 10 Hz or above. A conceptual design of a cryogenic Yb:YAG amplifier has been developed that can be scaled to kJ energy levels and beyond, due to its geometry, unique laser design and cooling technique.

A lower-energy DiPOLE prototype amplifier system has been built and is currently operational, routinely delivering 7 J /10 Hz with good energy stability. This year CALTA has focused on the delivery of a £10.3M contract to supply a 100 J DiPOLE to the HiLASE project in the Czech Republic. The system has been built in a CLF cleanroom and commissioning has started. The aim is to demonstrate base line design and then to ship the system to the HiLASE team for installation and final commissioning on their premises in the Czech Republic.

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 Laser Lab-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.

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 and the overall delivery plan.

This year we have generated impact by:

- A ground breaking experimental run in Vulcan TAW, demonstrating the capabilities of Laser Driven Sources for the imaging of complex samples, relevant across a number of industrial sectors;
- Engaging and partnering with industry by winning contracts with companies to enable access to our facilities;
- Winning bids through H2020 for Widespread and Teaming, and the Newton Fund for collaborations with China, India and South Africa;
- Filing new patents in the area of super-resolution molecular imaging;
- Building and supporting our spin out companies;
- Engaging with the public, in particular through *International Year of Light* activities.

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

Economic Impact

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Introduction

This paper reviews some of the important economic impact activities for FY14/15. This has been a successful year, with a number of high impact activities. In particular, the ground-breaking experimental run in Vulcan TAW demonstrated the capabilities of Laser Driven Sources for imaging of industrially relevant complex samples and was a great success. The work provides a platform to build a solid case for future funding to fully develop this key area of impact for CLF.

Industry Engagement

The year focused on building relationships with a number of industrial sectors. Meetings and tours of the facilities were conducted throughout the year with companies in aerospace, medical, materials and advanced manufacturing, which have sown the seed for potential new collaborations and projects in the future. Initial discussions with Johnson Matthey Ltd to co-fund a postdoctoral researcher to work in CLF on commercial projects are promising.

I have been invited to give the keynote presentation at the 5th International Conference on Laser Peening to be held in April 2015 in the US. This is a very important application area for our DiPOLE laser platform. The ability to shape laser pulses in both space and time is expected to generate new IP and know-how in this area, opening new exploitation opportunities for DiPOLE across a broad spectrum of industry sectors. Further to visits to CLF, I have also organised, chaired and presented at a number of conferences, workshops and exhibitions throughout the year.

Winning Contracts and External Funding

New contracts with industry have been won this year enabling access to Vulcan and Ultra. This generates additional income and provides industry with the opportunity to access state-of-the-art laser systems to develop their own products, processes and technologies. Also CLF was successful in the Phase 1 bid for funding through the H2020 Widespread and Teaming initiative. Here, funding is allocated for one year to establish a business plan for teaming with the HiLASE facility in the Czech Republic. This project will further our industrial outreach and engagement, whilst providing new opportunities for developing and exploiting CLF technology.

CLF was also successful in three bids to the UK Government's Newton Fund. We have established projects in China, India and South Africa which will run over the next 4-5 years. The projects provide the opportunity to look for new exploitation routes for the DiPOLE technology, in addition to enhancing the impact of our science and technical capability overseas.

CLF continues to work closely with all three ELI pillars and discussions have started for the development (phase 1) and supply of the L2 beamline to ELI-Beamlines in the Czech Republic.

Demonstrating Capability

In March this year we conducted a milestone experiment in Vulcan TAW to demonstrate Laser Driven Sources Imaging of industrially relevant samples. The programme, part funded through STFC BID, engaged companies from Aerospace, Energy, Security and Defence, and Advanced Manufacturing all of whom were actively involved and supplied samples for tests. In addition two new University groups (Bristol and Cambridge) came on board and worked closely together with the University of Strathclyde and Queen's University Belfast.

The outputs from this experimental run will be used to build a robust case for funding to further develop this important activity.

Spin Out Companies

Cobalt Light Systems Ltd has continued to grow and expand its range of products. They have recently won a number of awards including the RAE MacRobert award and the Queen's Award for Enterprise, and recently topped the Sunday Times BT Business SME Export Track 100.

Scitech Precision Ltd combines expertise in micro-assembly and micro-engineering with extensive insight into the physics behind high power laser science. New opportunities exist for high repetition rate target positioning and target supply. Plans to ensure Scitech continues to grow and flourish will be stepped up in 2015.

Intellectual Property and Know-How

The Octopus team filed a new patent in the area of super-resolution molecular imaging this year.
The transmission grating patent filed previously by the Gemini group is under review by patent office examiners at PCT stage. The Microwave VUV project, funded through STFC's Proof of Concept fund, is progressing well now that the new postdoctoral researcher is in place.

Several new ideas are in the early evaluation stage, including a new device for short pulse diagnostics, a novel alignment process for high power laser systems, and new methods for nuclear waste imaging.

Generating impact is an on-going and evolving activity, and in CLF we will continue to grow industrial engagement, build and demonstrate our capability, and drive innovation through our knowledge and ideas.

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 2014-2015 have been diverse, reaching across the UK and even further beyond. They range from the STFC 'Power of Light' roadshow, to supernova science on Vulcan being highlighted by the Institute of Physics as a top 10 physics story for 2014, to a news story on CLF spinout Cobalt Light Systems reaching millions across global news media.

INTERNATIONAL YEAR OF LIGHT 2015

International Year of Light

The CLF was involved in many public outreach events this year in celebration of the *International Year of Light and Light-based Technologies* (IYL 2015). The UK's first official event took place in early January 2015 with an evening of laser science talks, co-hosted by the CLF at the Ace Hotel in London. Photographs and a report of the event can be found on the IYL 2015 UK blog website: http://light2015.org.uk/bringing-the-power-of-lasers-to-the-public/.

Ceri Brenner demonstrating on the CLF exhibition stand at the Manchester Museum of Science and Industry

A CLF exhibition stand was the central feature of an IYL 2015 event hosted by the Photonics KTN at the Manchester Museum of Science and Industry (MOSI). Coverage of the day is featured heavily in the MOSI's promotional film for their public interaction days: https://youtu.be/21JQIFlGyqk.

CLF director John Collier co-presented an IYL 2015-themed Talking Science public lecture, *The Light Fantastic*, in which the science explored at Diamond Light Source, CLF and RAL Space was presented to a packed lecture theatre at RAL.

A 'night sky laser' has been 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 onto the side of the *Research Complex at Harwell* building.

STFC 'Incredible Power of Light' Roadshow

The CLF obtained funding for and built a roadshow, the 'Incredible Power of Light'. The roadshow tour began in February 2014, visiting Northern Ireland Science Festival in Belfast, the Big Bang Fair in Birmingham, and Stargazing Live in Leicester.

Further dates booked for the remainder of 2015 included visits to the Scottish and Welsh Parliaments, the 'Science Lates' event at the Science Museum, and the Winchester, Durham, and Dundee science festivals. The exhibition has visited a total of 10 venues, travelling 3,936 miles, and over 85 days captured the attention of around 64,309 people from all walks of life.

The roadshow in full swing during the busy schools days at the Big Bang Fair in the NEC arena in Birmingham.

Demonstrating how adaptive optics work to correct beam spots (top left); a life-size replica of the Vulcan laser amplifier is used to introduce how to align laser beams (top right); the roadshow installed in the foyer of the Scottish Parliament building in Edinburgh (bottom left); and the spatially offset Raman spectroscopy demonstration kit (bottom left), which allowed visitors to scan shampoo bottles and displayed live data.

The exhibition was kitted out with impressive demonstration pieces, developed by CLF staff. This included a Vulcan laser bay walk through, with a full-scale interactive amplifier set-up, and a SORS demo kit actively reading the contents of identical shampoo bottles coupled to an easy-to-follow computer interface displaying the extracted spectra. Also on show was a live demonstration of adaptive optics generating a perfect spot, laser trapping apparatus, and a laser communications demonstration beaming camera information above the exhibition to a readout screen several metres away.

Hitting the headlines

Press releases are a great tool for communicating CLF science as, if they are successfully picked up by news media, they can reach large audiences very quickly. This year has seen a boost in the number of press releases generated and published by the STFC press office, with a total of 14 press releases generated.

Several of these stories were picked up by many other news outlets. For example, a story on rickets in 16th century sailors on the Mary Rose was given coverage by *BBC Breakfast news* (average 1.5M viewers), the *BBC website*, the *Daily Mail* (circulation 1.8M) and the *Telegraph* (circulation 545,000). The 'singing stars' story, on sound wave generation from hot dense laser plasmas, was covered in the *Mirror, Daily Mail*, *Washington Post* and 40 other outlets. Other stories were taken up by specialist trade media, such as a graphene computer chips story which appeared across nine specialist sites including Electronics Weekly.

The STFC media team achieved global media coverage for a story on CLF spinout company Cobalt Light Systems winning a prestigious engineering award. The story was covered by major broadcasters and newspapers across the world, including BBC Breakfast news, Fox news, The Times, Daily Mail and The Independent. Over five million people are estimated to have seen or read the story. Another popular press release came from an experiment carried out with the Vulcan laser to study the physics within supernova blast waves. The story was covered by Daily Mail online and was subsequently picked up by the Discovery Channel, who filmed within the Vulcan laser bay and Target Area West for an episode of *How the Universe works*. The Institute of Physics named the supernova experiment paper in their top 10 list of physics news for 2014.

Our science was featured in specialist laser and physics news websites, including *The Engineer* (feature article on the laser for HiLase) and *Laserlab Forum* (double-page spread on graphene experiments at Artemis and several other articles).

Maintaining a close working relationship with the RAL press officers has been key to getting these press releases as accurate and clear as possible. Their advice to us, and the wider CLF user community, is that aligning the date of the press release with a paper publication or grant announcement is absolutely crucial to attract high impact coverage, so we would like to encourage our users to let us know as early as possible if your CLF-related work could be press release material. Contact ceri.brenner@stfc.ac.uk for any enquiries or further information.

We also regularly update the CLF website newsreel with science stories of experiments and related publications, as well as community announcements. The CLF website is designated as a scientific interaction site; therefore coverage can include more technical detail than in wider public news articles. We use this platform to communicate and celebrate CLF work that has made it into high impact journals such as *Physical Review Letters* or *Nature,* for example, and especially when results obtained at the CLF appear on journal front covers. Over the last year, the CLF published 38 news stories.

Visits and tours

The CLF continues to welcome visitors and host tours around the facility. Over the reporting period, 1,627 people have visited the CLF, an increase of more than 30% over last year's total. This included 10 relatively large, centrally-organised group visits to the CLF for Education and Public Access days, and 87 smaller, less formal groups of tours for stakeholders, campus partners, MPs, funding agencies, scientists, etc.

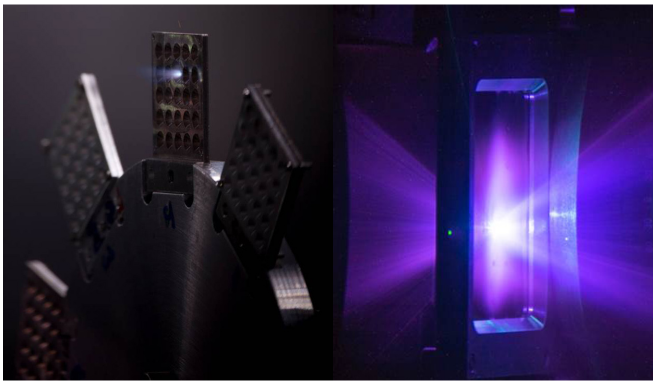
Great use has been made of the CLF Visitor Centre as a venue for hosting meetings and introductory talks, and as a starting point for group tours, which has enabled an increase in capacity for visitors. As well as promoting the CLF effectively, the Centre is reducing the number of interruptions to facility operations for lab tours.

Artist Research Residency

An artist research residency has been initiated this year, in collaboration with and funded by two renowned organisations in the artworld, ArtQuest and The Arts Catalyst. Over 60 applications from professional UK visual artists were received for the *Beamtime* residency, which supports the artist to visit the CLF for a period of 10 days spread over three months, to engage with both the science and the scientists in order to inspire their creative work. Coverage of Alistair McClymont's residency has so far been documented on his blog page and in an interview with Vice magazine, in which he states *"My goal is to interpret and represent the beauty of the science here in some way. The perceived gulf between scientists and artists is completely false. In many ways, they are very similar kinds of people: we question the world around us, interpret, and present our results. The paradigms are normally quite different."*
Alistair engaged with research teams working on experiments with the Gemini and Vulcan lasers, and actively participated by aligning and triggering SLR cameras to photograph the laser-target interaction. His imaging diagnostic proved very useful in providing an additional viewpoint of the front surface interaction, as well as generating stunning plasma photos. A public talk event was held at Somerset House in London, during which Alistair and Ceri Brenner discussed the project and the engagement experience to an audience of Arts Catalyst followers. Alistair's blog, in which he captures thoughts and experiences during the residency, can be found here:

http://studio.alistairmcclymont.com/tagged/beamtime

Inspiring the next generation



Capturing the flash of a plasma from the Gemini laser (left) and the Vulcan laser (right). Credit: Alistair McClymont

A large part of public engagement is dedicated to inspiring the next generation into science, technology, engineering and maths (STEM) subjects, to ensure the UK has the skillset to continue its strong heritage in this area, as well as transfer these valuable skills into other sectors.

Work experience is a very effective way in which the CLF is able to reach out to young people interested in science and engineering. Normally occurring over the summer, sixth-form and undergraduate students are matched with a CLF supervisor to carry out a project lasting up to eight weeks. Over the reporting period, the CLF has hosted 21 school students in the facility, a 50% increase on last year, through the RAL work experience placement scheme. The feedback is very positive, with those answering 'How well were your tasks explained?' giving an average 4.4 out of 5, and over 80% indicating that the placement has influenced their career decision.

The CLF's plasma physics group hosted a number of eight-week summer and work experience students. PhD students studied parametric amplification in plasma, and worked on channelling and hole-boring for fusion energy research. First-year undergraduate students from the Universities of Manchester and Oxford ran super-computer models of laser-plasma interactions. They also gained experience with the computer program LabView for data acquisition and analysis. A returning under-graduate summer placement made strong headway in computer simulations of 10 PW laser-plasma interactions. They continue their university education invigorated by the experience of working in a cutting-edge research laboratory.

The CLF took part in the UK's first Conference for Undergraduate Women in Physics, by giving the keynote talk during their visit to RAL and with a panel member during the careers Q&A session.

Plasma physics group summer students alongside Alex Robinson and Raoul Trines.

There still remains much participation by CLF staff in the STEM ambassador scheme, which includes visits to local schools and career events. For example, Ceri Brenner gave the keynote talk during the University of Birmingham's 'Girls in STEM' day, with a talk titled 'STEM has impact for life'. She was also invited to a school in London to speak to the whole of year 9 and year 10 year groups on the subject 'Lasers and Super Exciting Research'.

The CLF continues to participate in the Engineering Education Scheme, run by the UK's Engineering Development Trust, which introduces sixth formers to the world of engineering via a programme of joint projects between participating schools and institutions.

Community engagement

Two CLF staff won major prizes this year. Prof Tony Bell was awarded the 2014 Hoyle medal and Prize by the Institute of Physics. Prof Pavel Matousek and spin-out company Cobalt Light Systems won the Royal Society of Engineering's MacRobert Prize. At least 16 CLF staff hold joint appointments or visiting positions with academic and industrial partners, or are Fellows of learned societies.

As well as making regular scientific presentations as part of the CLF's core science mission, facility staff are involved in the organization and direction of national and international scientific meetings. The CLF has been responsible for organising and hosting a number of conferences and user meetings throughout the year, including the Laserlab Foresight workshop 'Lasers for Life', hosted at the Royal Society in London, attended by almost 150 people.

The CLF continues to host the High Power Lasers (HPL) Community Meeting, and the HPL and Artemis user forums. CLF maintains links with the Culham Plasma Physics Summer School, and has organised for lectures to be hosted at RAL along with tours of the CLF for all of the 60 PhD students involved.

The CLF publishes its Annual Report covering all of the scientific and technical activity of the department over the year. This report is circulated to more than 500 recipients around the globe, as well as appearing online. To reduce publishing costs, the full articles are available to download from the CLF website, with a printed collection of article summaries.

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 Intensity/Energy Science

XUV collisional absorption of warm dense aluminium

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G. O. Williams, S. Künzel, M. Fajardo *(GoLP/Instituto de Plasmas e Fusão Nuclear, Lisboa, Portugal)*
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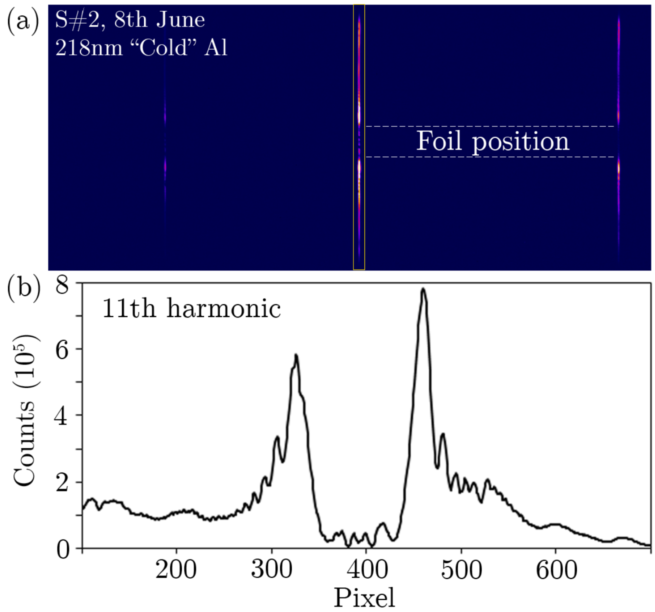
This report describes an experiment to measure the collisional absorption of warm dense matter (WDM) aluminium in the XUV regime. Thin aluminium sample foils were radiatively heated to WDM conditions using adjacent palladium heater foils. A separate high harmonics probe, generated using the short pulse beam 7 and an argon gas jet, was used to test the resulting target absorption.

The chosen photon energies of the harmonics probe make collisional absorption the dominant process for transferring energy to the target. This process is theoretically challenging, and experimental evidence can help to verify the conflicting models currently published.



A 'cold' data shot (#2, 8th June) for a 218 nm Al sample.
(a) Raw flatfield spectrometer data with the 9th, 11th and 13th order harmonics visible. The spatial position of the foil has been highlighted.
(b) Lineout of the 11th harmonic across the spatial direction.

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Phase transitions in shock-compressed bismuth identified using single photon energy dispersive x-ray diffraction

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A. Higginbotham *(Dept of Physics, University of York, UK)*
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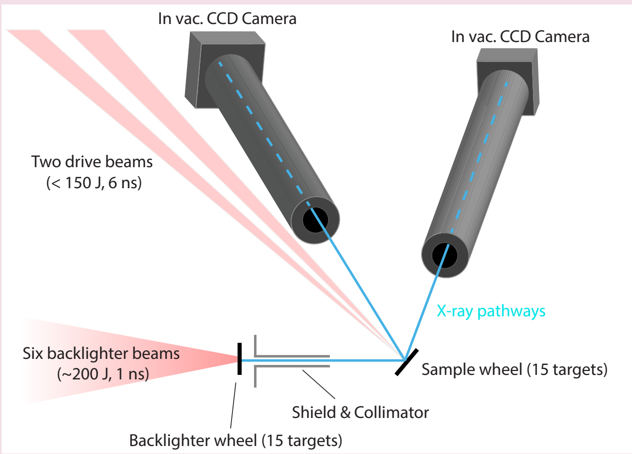
Dynamic compression of materials using high-power laser facilities allows access to extreme P-T states that lie well beyond the current limits of diamond anvil cell techniques. However, collecting x-ray diffraction data from samples at such conditions is extremely difficult, as the very high laser intensities used to drive the metallic foil that produces the nanosecond-duration x-ray source creates a hostile environment, in which the x-ray noise from the drive lasers generates very large backgrounds that can eclipse any diffraction signal from the sample. Here we present evidence for phase transitions in shock-compressed bismuth using the, relatively new, Single Photon Energy Dispersive X-Ray (SPEDX) diffraction technique. Experiments were performed on the Vulcan laser at the Central Laser Facility.

We observe diffraction from the (110) bcc peak of Bi-V, and, from its measured lattice parameter, the sample's pressure was determined to be approximately 16 GPa, the maximum pressure at which the peak was observed. This could indicate a lower estimate of shock melting for bismuth, thought to lie between 16 and 24 GPa.

These experiments are crucial for improving the quality of observed x-ray diffraction of a sample in the extreme (and hostile) conditions generated during laser shock compression.



Experimental set-up within the target chamber.

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X-ray scattering at breakout from warm dense iron

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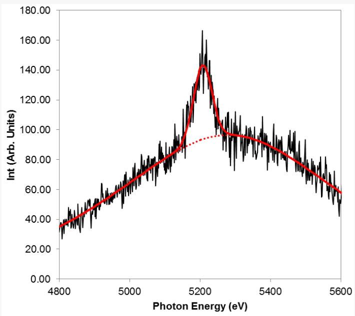
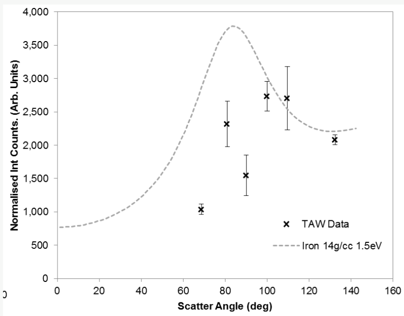
E. Tubman, C. D. M. Murphy, N. Woolsey *(Dept of Physics, University of York, UK)*

The study of warm dense matter using x-ray scattering techniques has proven to be a valuable technique for characterization of these dense, transient plasma states. Considerable interest has been focused on the study of relatively light elements such as hydrogen and lithium, up to carbon. Carbon and hydrogen are interesting in particular, as they are thought to be present, under warm dense conditions, in the cores of Jovian mass planets. There is, however, major motivation to extend research to heavier elements such as iron, as not only is iron thought to be present in the core of Earth and the rocky planets of our own solar system, but also in many so called 'super earths' which have recently been discovered. Accurate planetary modelling will require an in-depth understanding of how iron behaves under the extreme temperatures and pressures at the heart of an Earth-mass planet.

In this article we present initial results from an experiment undertaken at the target area west laboratory, to measure the angularly resolved x-ray scattering cross-section of iron under extreme pressure and temperature, similar to that of the Earth's core. The experiment employed a novel geometry, which allowed us to probe much more uniform samples of iron than previously possible.





Left: Example of a typical data shot on one of the scattering spectrometers. Data shown here was collected at a scattering angle of 68.6°±6.0°.

Right: Comparison of experimental results of the scattering power to an estimate based upon calculating the ionic structure factor using an HNC model with a screened Yukawa potential and calculating ionic form factors using the approach of Pauling.

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Neutron production from ultrathin foils by radiation pressure driven ions

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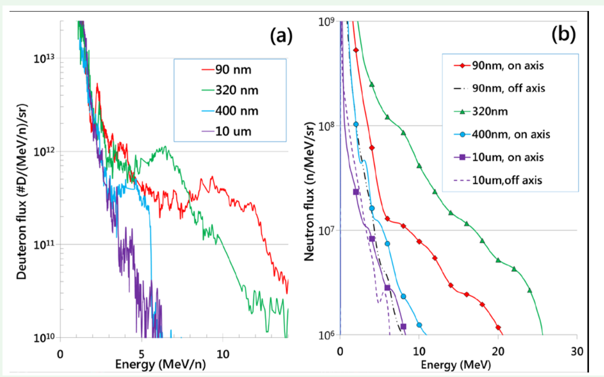
An ultra-short burst of fast neutrons would have a wide range of applications in science, industry, healthcare and security. However, the limitation in accessing large neutron facilities has led to an increasing interest in finding table-top sources. Laser-driven ion accelerators have been investigated as a possible solution, mainly by using the ions accelerated via the Target-Normal Sheath Acceleration (TNSA) mechanism impinging on suitable neutron converter targets. Despite being a robust mechanism, TNSA exhibits a slow ion energy scaling with respect to the incident laser intensity ($E_{ion} \propto \sqrt{I_L}$), with a beam predominantly formed by protons, reducing the range of possible nuclear reactions involved in the neutron generation.

Here we report on the neutron generation using radiation-pressure driven ion acceleration (RPA). This mechanism holds the advantage of generating higher energy ion beams, including heavy ions, with high laser-ion conversion efficiency and low divergence. Unlike typical experiments, where a secondary converter target is needed, a high-flux, directional neutron beam was produced from the primary target itself when the RPA mechanism was involved.



(a) Appearance of narrow-bandwidth features in the deuterium spectra as the thickness is reduced.
(b) Variation of the neutron spectrum depending on the target thickness, showing improved neutron generation when RPA is the dominant mechanism.

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Modelling the effect of laser focal spot size on sheath accelerated protons in intense laser-foil interactions

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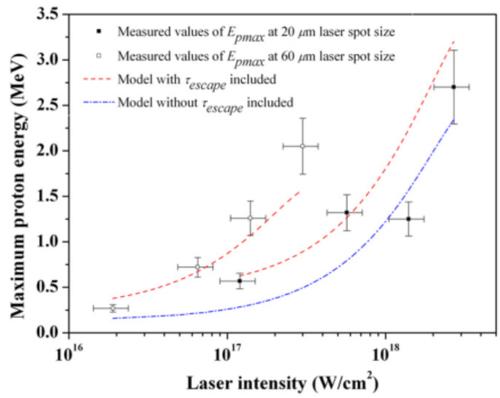
P. McKenna
(Dept of Physics, University of Strathclyde, Glasgow, UK)

We present an approach to modelling the effect of the laser focal spot size on the acceleration of protons from ultra-thin foil targets irradiated by ultra-short laser pulses of intensity 10^{16}–10^{18} W/cm^2. The importance of including lateral expansion of hot electrons at the rear surface of a thin foil irradiated by an intense laser pulse in modelling ion acceleration is demonstrated, with the introduction of an additional term in the definition of the ion acceleration time. This additional escape time term, τ_{escape}, accounts for the time it takes for laterally-transporting hot electrons to escape the accelerating sheath area on the rear surface. In the case of a large focal spot diameter (> 20 µm) this term is significant compared to laser pulse durations of < 50 fs, and is a dominating factor in defining the acceleration time. An approach that combines the modified acceleration time with a plasma expansion model, along with calculations for the hot electron temperature and density, is used to model the maximum proton energy and is found to be in good agreement with experimental results. Further experimental investigation at large focal spot sizes, and various laser and target parameters, would be very useful in order to verify that the modelling approach presented in this paper can be expanded beyond the specific irradiation conditions described in this study.



Measured values of E_{pmax} plotted as a function of peak laser intensity compared to model calculations, with and without inclusion of the τ_{escape} term in equation. At each focal spot size, the laser intensity was varied by varying the laser energy only, while keeping the laser pulse duration constant throughout.

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Proton activation history on the Vulcan high-intensity petawatt laser facility

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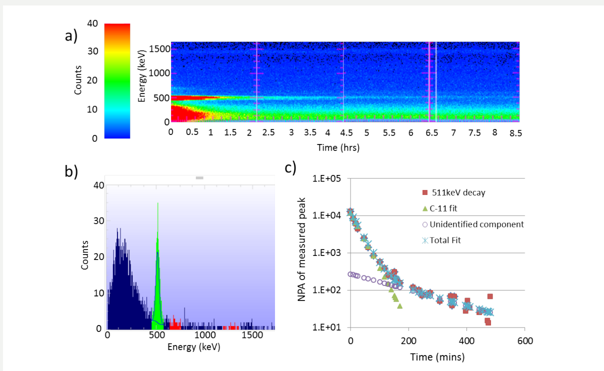
High-intensity lasers are an effective source for the acceleration of high-energy particles. Using different interaction configurations, they can be optimized for the acceleration of electrons, protons, heavy ions, high-energy photons, or neutrons. However, laser facilities operating at intensities in the region of 10^{19} W/cm^2 or above can easily generate levels of activity that must be both monitored and controlled to mitigate unwanted exposure to personnel. The knowledge of radiation source terms, through both experiments and modelling, is now well understood and for the most part can be dealt with through the use of shielding and specialized beam dumps. Shielding to ensure the safety of personnel has always been a critical requirement, and is a fundamental step within the design phase.

Unlike most other particle accelerators, most high-power laser facilities are still accessed by personnel post-shot with few or no capabilities for remote handling. As a result, the secondary activation and control of components that lie around the interaction is of great importance to safety. In this paper, we present a 10-year history of activation data on the Vulcan petawatt facility, and discuss the primary sources of activation and the potential impact on future laser facilities.



Measured decay products from an activated plasma mirror from Target Area Petawatt. Data is taken using a Scionix 2" NaI detector coupled to a Canberra Osprey MCA running in Multi-spectral scaling (MSS) mode.
a) MSS buffer data showing full spectrum against elapsed time (from measurement start)
b) Snapshot of the spectrum showing the 511 keV peak from the β+ decay
c) Plotted net peak area (NPA) of the 511 keV decay with associated fit for the ^{11}C decay and a presently unidentified component with an approximate half life of 2.3 hours

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Tunable mega-ampere electron current propagation in solids by dynamic control of lattice melt

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M. P. Desjarlais *(Sandia National Laboratories, New Mexico, USA)*
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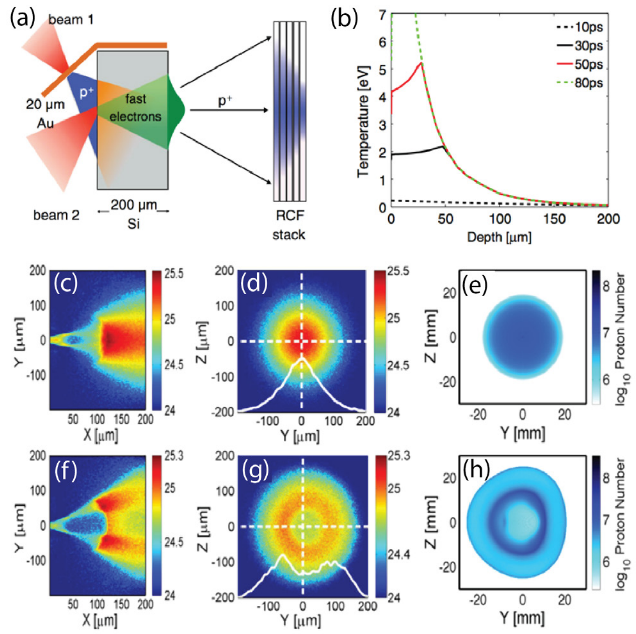
This report describes a numerical and experimental investigation into the effect of resistivity gradients, produced by lattice melting in solid targets, on the generation of resistive magnetic fields and the transport of fast electrons. A proton beam produced in separate laser-solid interaction is used to heat the target isochorically, melting the target lattice in a tunable manner, whilst a separate pulse drives fast electrons through the sample. These tailored heating profiles result in the generation of resistively generated magnetic fields, enabling the fast electron current propagation to be manipulated.

In this way, critical properties of the fast electron beam, such as its divergence, spatial profile and symmetry, may be actively tailored without the need for complex target geometries.



(a) Experimental layout
(b) Temperature profile within the Si target resulting from the proton-driven heating, at given times (t_{heat}) after the arrival of the most energetic protons. Side and front view of electron density (m^{-3}) in initially unheated (c-d) and proton heated (f-g) silicon. (e) and (h) are the corresponding modelled proton-spatial intensity maps arising from the rear-surface density profiles in (d) and (g), respectively.

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Characterization of laser-driven proton beams from near-critical density targets using copper activation

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High-energy proton beam acceleration from near-critical density plasma targets was characterized using a copper activation diagnostic. Both the proton spectra and beam profile were measured using this technique. Very-low density foam targets were used to produce plasma densities of between $0.9n_c$ and $30n_c$, where n_c is the critical plasma density.

An increased laser-accelerated hot electron density at the rear target-vacuum boundary was implied for the lowest density targets from the observed enhanced proton acceleration. Channel formation and collimation of the hot electrons inside the target lead to this increase. Particle-in-cell simulations demonstrate the correlation between the channel depth and longitudinal electric field strength in support of the experimental observations.

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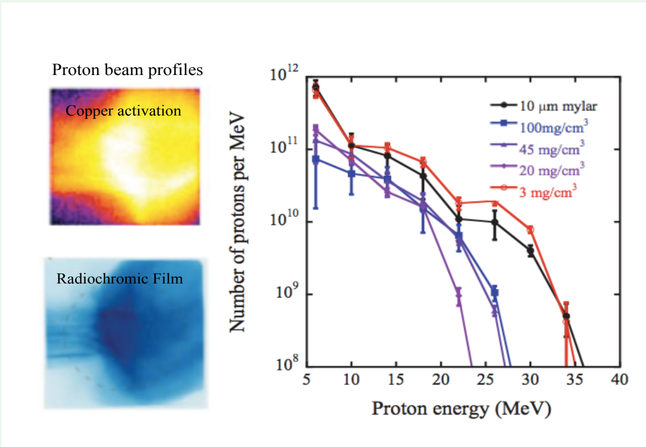

(Left) Proton beam profiles recorded using: (top) the copper activation stack and imaged post-shot using image plate detectors; and (bottom) directly on the radiochromic film stack layers for a 20 mg/cc foam target.
(Right) The proton spectra extracted from the copper activation stacks for different density targets.

Evidence of locally enhanced target heating due to instabilities of counter-streaming fast electron beams

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Understanding the dynamics of counter-streaming fast electron beams is important for a variety of research fields, including laser-driven x-ray and particle sources, the fast ignition approach to inertial confinement fusion, and astrophysical phenomena.

An experimental study aimed at investigating the role of instabilities in a system of counter-streaming fast electron beams was performed. The fast electron beams were generated through double-sided irradiation of a layered target foil. X-ray spectroscopy of the emission from the central Ti layer showed a higher temperature for double-sided irradiation with respect to single-sided irradiation. Simulations suggest that the locally enhanced target temperature in the case of counter-streaming fast electron beams might be attributed to the current-filamentation instability.

The counter-propagating scheme is a promising candidate for the efficient generation of hot dense matter, which is of great interest for the study of radiative and transport processes in inertial confinement fusion and astrophysical research.

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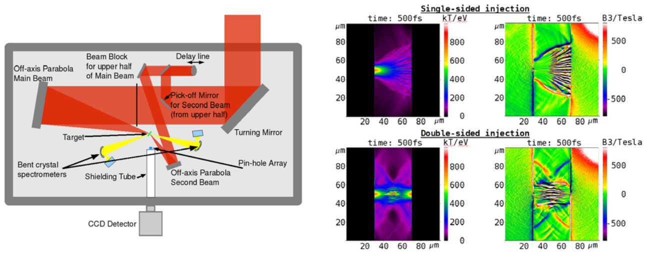

Left: Schematic of the experimental setup.
Right: Temperature (left) and magnetic field (right) maps at 500 fs, as obtained from LSP simulations for a single electron beam (top) and for two counter-propagating electron beams (bottom) in a 40 μm thick target. The total energy injected into the target is the same in both cases.

Laser pulse propagation and enhanced energy coupling to fast electrons in dense plasma gradients

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X. H. Yuan *(University of Strathclyde, Glasgow, UK; State Key Laboratory of Transient Optics and Photonics, Xian Institute of Optics and Precision Mechanics, Chinese Academy of Sciences, People's Republic of China)*
M. Burza, C-G. Wahlström *(Dept of Physics, Lund University, Sweden)*
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X. X. Lin, Y.T. Li *(Beijing National Laboratory of Condensed Matter Physics, Institute of Physics, People's Republic of China)*

We demonstrate, experimentally and via particle-in-cell simulations, that there is an optimum density gradient for efficient energy coupling to electrons in the interaction of an intense (10^{20} W/cm^{-2}), picosecond laser pulse with a dense plasma. This optimum occurs due to strong self-focusing and channelling, which drives absorption over an extended volume in the plasma. At longer density gradients the laser quickly filaments, resulting in a decrease in overall laser energy coupling.

The results show that, by dynamically controlling the plasma density gradient, it is possible to significantly enhance the laser energy absorption and coupling to fast electrons.

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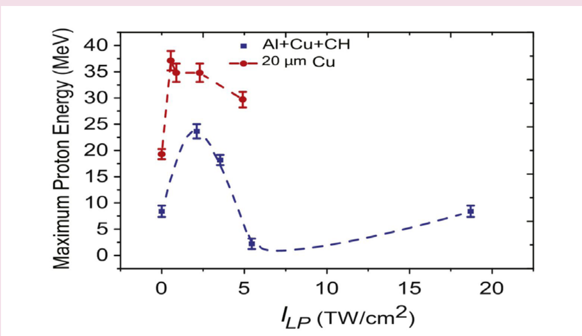
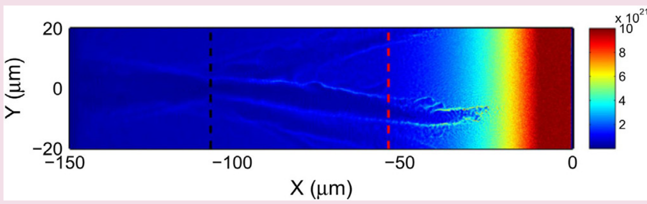


Maximum proton energy as a function of laser intensity, I_{LP}, for a 123μm Al-Cu-CH and 20μm Cu target.



2D PIC simulation results showing electron density, n_e, in units of cm^{-3} after 1500 fs.

Proton acceleration enhanced by a plasma jet in expanding foils undergoing relativistic transparency

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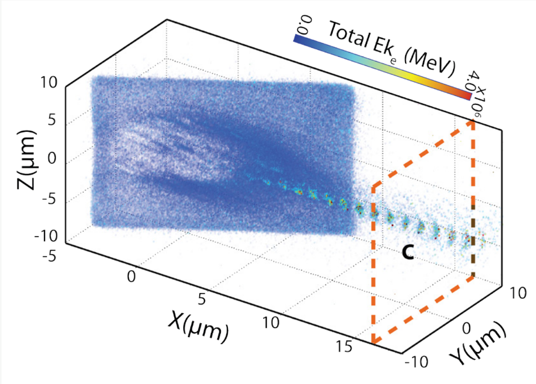
G. Hicks, N.P. Dover, Z. Najmudin *(Imperial College London, UK)*
D.R. Rusby, D.C. Carroll, R.J. Clarke, I.O. Musgrave, D. Neely *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*
S. Kar, M. Borghesi *(Queen's University Belfast)*

The Target Area Petawatt laser was used to investigate experimentally ion acceleration on thin foils(≤40 nm in thickness), with 2D and 3D particle-in-cell simulations used to aid understanding of the internal particle and field dynamics. The protons, accelerated by target normal sheath acceleration (TNSA) and radiation pressure acceleration (RPA) mechanisms, were angularly separated and identified through their signature features observed via a spatial-intensity distribution measurement.

A high-energy proton population with low divergence is detected when the target becomes relativistically transparent due to heating and expansion. The simulations indicate that, in these conditions, a plasma jet is formed at the rear of the target, expanding into the sheath-accelerated proton layer.
This jet is supported by a self-generated azimuthal magnetic field, and the electrons contained within are accelerated to super-thermal energies directly by the propagating laser pulse. The propagation of these electrons through the ion layers enhances the energy of the nearby protons. By adding a controlled pre-pulse, it is possible to demonstrate the sensitivity of this jet formation and energy enhancement to the rising edge profile of the laser pulse.



3D PIC results showing the total electron energy contained within the formed plasma jet.

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Influence of low-temperature resistivity on fast electron transport in solids: scaling to fast ignition electron beam parameters

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Numerical investigation of the definitive role played by low temperature electrical resistivity is conducted by 3D hybrid particle-in-cell simulation, both in the sub-kJ and kJ regimes applicable to lab experiments and fast ignition relevant parameters respectively.

Calculations provide resistivity profiles for both ordered and disordered cases, and these are used (alongside intermediate cases between these) for simulation to assess the sensitivity of fast electron transport to both the magnitude of resistivity, and the shape of the resistivity-temperature profile. It is found that the magnitude and profile shape both strongly affect the resistively-generated magnetic fields and, thus, the fast electron transport pattern. The scaling of these results to the giga-ampere currents relevant to fast ignition schemes is also addressed.

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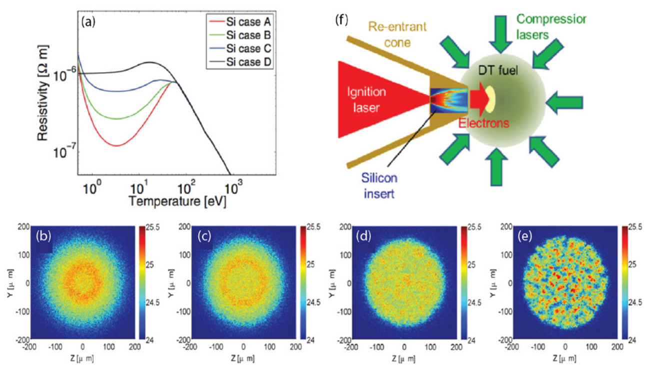

(a) Calculated resistivity-temperature curves for ordered (case A) and disordered (case D) and two intermediate cases (cases B, C). A transition from an annular to a filamented electron beam transport pattern is observed with decreasing degree of lattice order (b) case A, (c) case B, (d) case C, and (e) case D.
(f) Potential usage of cone FI target scheme with a silicon insert to induce an annular fast electron beam transport.

A Freon™-filled bubble chamber for the spectra measurement of ultrashort gamma ray bursts

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Recently, many experiments have demonstrated that bright ultrashort gamma-ray bursts can be generated from the interaction of high-power lasers with plasma . These bursts, typically with sub-picosecond duration, are very promising light sources for ultrafast gamma-ray radiography. However, their short pulse duration also poses challenges on the measurement of the spectra. Conventional solid-state spectrally-resolved detectors are unsuitable, because the pulse durations of these bursts are orders of magnitude shorter than the response time of the detectors. Here we report a novel Freon™-filled bubble chamber detector for the spectra measurement of ultrashort gamma-ray bursts in the range of 0.4 - 4 MeV. This detector was used in a Gemini campaign in January 2015. It simultaneously recorded thousands of bubble traces created by scattered Compton electrons. By analyzing the length and angle of the traces, the gamma-ray spectra can be convoluted in the range of 0.4 - 4 MeV with high efficiency and resolution.

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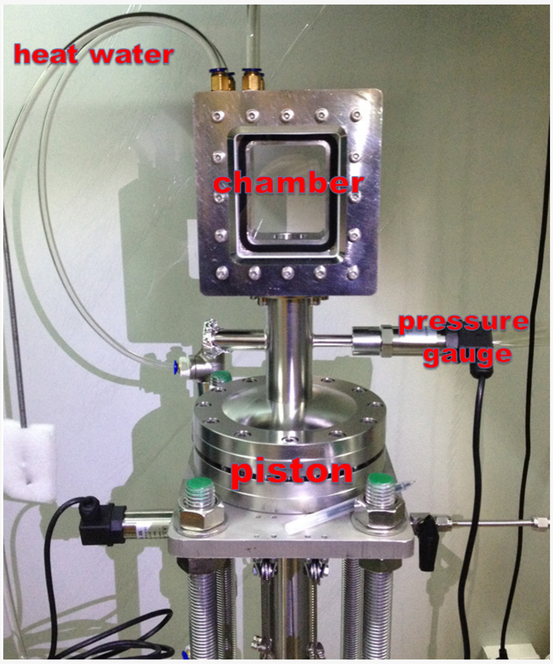

Photograph of the detector, with components labelled

Ultrafast imaging of laser-driven shocks using betatron x-rays from a laser wakefield accelerator

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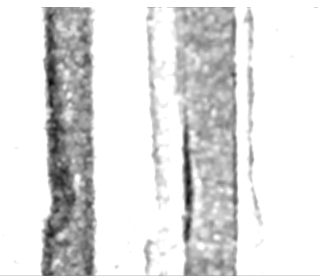
Laser wakefield accelerators have been shown to produce electron beams of GeV energy, with energy spreads of a few percent in plasma lengths of approximately 1 cm. They also produce a beam of hard, bright x-rays, referred to as 'betatron radiation', with intensity high enough for single shot imaging and a few fs duration, making them a highly interesting source for applications. The micron scale source size permits high resolution imaging in a compact geometry.

We present measurements of the x-rays, indicating that their spectral flux is described by a synchrotron spectrum with critical energy 25±5 keV and that they come from a micron sized source. $7\pm3 \times 10^9$ photons are produced per shot with a narrow divergence, allowing single shot high magnification x-ray imaging. By imaging a shock travelling at ~6 km s^{-1}, we have demonstrated the potential of this femtosecond x-ray source for observing rapidly evolving phenomena at high resolution.



X-rays generated by a laser wakefield accelerator, known as betatron x-rays, were used to image laser-driven shocks in silicon travelling at speeds of approximately 6 km s^{-1}. The left and right images show the shock propagation in untamped and tamped 50 micron thick silicon.

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A laser-driven pulsed x-ray backscatter technique for enhanced penetrative imaging

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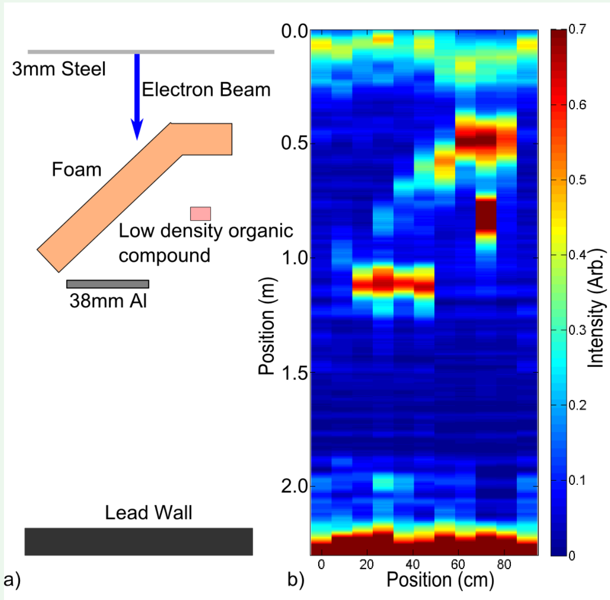
X-ray backscatter imaging can be used for a wide range of imaging applications, in particular for industrial inspection and portal security. The application of this imaging technique to the detection of landmines is currently limited, due to the surrounding sand or soil strongly attenuating the 10 s to 100 s of keV x-rays required for backscatter imaging. Here, we introduce a new approach involving a 140 MeV short-pulse (<100 fs) electron beam generated by laser wakefield acceleration to probe the sample, which produces bremsstrahlung x-rays within the sample, enabling greater depths to be imaged.

An x-ray backscatter image of an array of different density and atomic number items is demonstrated. The use of a compact laser wakefield accelerator to generate the electron source, combined with the rapid development of more compact, efficient and higher repetition rate high-power laser systems, will make this system feasible for applications in the field.



An array of objects, including 38 mm thick Al, 0.14 m thick insulation foam, and a low-density organic compound are shown.
a) Diagram of the set-up of an array of test objects.
b) Example of an x-ray backscatter image of the object array shown in a).

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Interactions of relativistic electron-positron bunches with ambient plasmas in a regime relevant to the study of astrophysical jets

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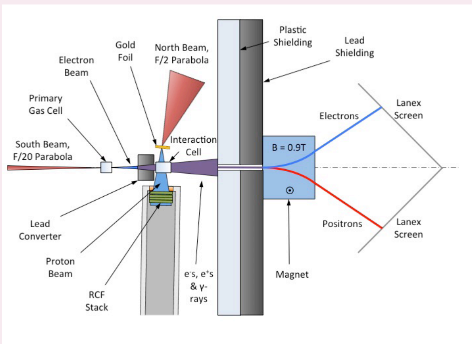
Neutral electron-positron plasmas (EPPs) are theorised to play a major role in astrophysical phenomena, such as Active-Galactic Nuclei, Pulsars and Gamma-Ray Bursts (GRB).

It is thought that the magnetospheres associated with compact rotating astrophysical objects (black-holes, neutron stars) are teeming with EPPs, which are ejected in polar outflows and relativistic jets. These highly-collimated jets travel light years beyond their host galaxy's boundaries, and produce a termination shock via their interaction with the intergalactic medium (IGM). It is theorised that this EPP/IGM interaction is responsible for the generation of strong, long-lived magnetic fields conducive to the generation of GRBs.

In this experiment, a relativistic neutral EPP was generated and subsequently propagated through an electron-ion plasma, in a regime pertinent to the study of astrophysical jets. Preliminary analysis indicates beam filamentation, which produces multi-Tesla magnetic fields consistent with the generation mechanism thought to occur at the termination shock of astrophysical jets.



Schematic of the experimental layout. Outside of the experimental plane, and not shown in the figure, is a collection optic used to image the rear surface of the interaction cell to observe the beam profile.

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High order harmonics from relativistic electron spikes

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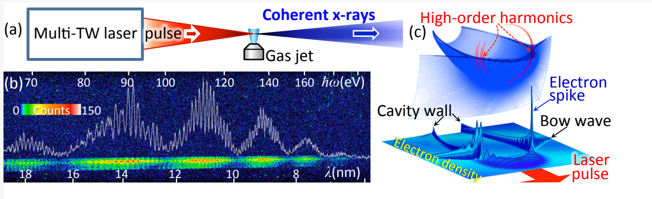
High-order harmonic generation is one of the most fundamental processes of nonlinear optics. The spatial and time coherence of high-order harmonics allows the tightest focusability and generation of ultrashort pulses required for applications. Various nonlinearities produce high-order harmonics in a wide range of laser-matter interaction regimes. We provide a detailed description of experiments performed with the J-KAREN and Gemini lasers, where we discovered a new regime of relativistic high-order harmonic generation by multi-terawatt femtosecond lasers in gas targets. The coherent x-rays, consisting of hundreds of even and odd harmonic orders, were generated with both linearly and circularly polarized pulses, and reached the 'water window' spectral range. The results were explained using particle-in-cell simulations and catastrophe theory. We give a comprehensive account of simulations and the harmonic generation mechanism, and model where a tightly-focused laser in plasma forms structurally stable electron spikes coherently emitting high-order harmonics.

Our work paves the way towards a bright coherent x-ray source based on compact lasers and accessible, repetitive, and debris-free gas jet targets. Such a source will be crucial for fundamental research and numerous applications requiring pumping, probing, imaging of microscopic objects, and for attosecond science.



New regime of high-order harmonic generation by relativistic-irradiance (>10^{18} W/cm^2) laser focused into a gas jet target. (a) Experimental set-up: Multi-terawatt (10-120 TW) femtosecond (30-50 fs) laser pulses focused into a helium gas jet target (~10^{19} cm^{-3}) produce bright coherent x-rays, consisting of hundreds of even and odd harmonics. (b) Typical single-shot raw data and its lineout. (c) 3D particle-in-cell simulation, demonstrating high-order harmonic generation by the sharp oscillating electron density spikes appearing at the joint of boundaries of wake and bow waves excited in tenuous plasma by the laser pulse.

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Ultrahigh brilliance multi-MeV gamma-ray beams from nonlinear relativistic Thomson scattering

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The generation of high-quality, multi-MeV gamma-ray beams is an important field of study, pertinent to fundamental research, cancer radiotherapy, active interrogation of materials, and radiography of dense objects. Several mechanisms for generating such gamma-ray beams have been proposed, including bremsstrahlung emission, synchrotron emission, Compton scattering, and in-flight positron annihilation. Bremsstrahlung sources are the most commonly used technique (particularly in medicine), but the generated γ-rays have a broad divergence, which, in conjunction with the source size, place a limitation on the peak brightness.

Here, we report on the generation of a high-quality γ-ray beam through the scattering of an ultrarelativistic electron beam in the field of a relativistically intense laser ($a_0 \approx 2$). The generated γ -ray beam is of narrow divergence (< 2.5 mrad), multi-MeV (6 to 18 MeV), and has ultrahigh peak brilliance (> 1.8 x 10^{20} photons s^{-1} mm^{-2} 0.1% BW).

The reported brilliance is the highest ever achieved in the multi-MeV regime that, coupled with the ultra-short duration of the γ–ray beam (~10 fs), makes this a unique source for practical applications.

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Plasma-optics pushes the limit of laser-driven ion acceleration

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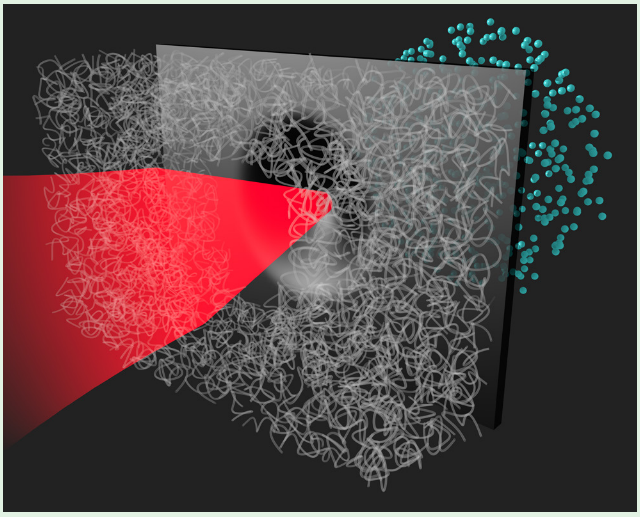
The enormous force from radiation pressure exerted onto a nanometer thin, diamond–like carbon (DLC) foil by a high intensity laser pulse can enhance efficient acceleration of carbon ions. Kinetic energies up to 30 MeV were reached in our initial experimental demonstration of this novel radiation pressure acceleration (RPA) scheme in 2009. Those studies revealed grand technological challenges posed by current laser technology in our pursuit of peak intensities well beyond 10^{21} W/cm² with ideally abrupt temporal profiles.

Current experimental results reveal that near-critical plasmas, due to the intensity-dependent relativistic mass-increase of the electrons, can form strong nonlinearities that tightly focus the laser to a near-diffraction limited spot size and temporally steepen the pulse front. This novel relativistic plasma-optic effect has been realised with more sophisticated targetry - depositing micrometer thin carbon-nanotube foam onto DLC target foils in LMU's DLC-factory. These multi-layer targets were tested in a collaborative laserlab-europe experiment at STFC Rutherford Appleton Laboratory's Gemini laser, which brought together researchers from Germany, the UK, Spain and China. RPA of carbon ions up to 240 MeV kinetic energy has been achieved.

This recent accomplishment is an important milestone for our research focus on laser-driven ion acceleration at the Munich Centre for Advanced Photonics (MAP Centre of Excellence Cluster), with promise for extending kinetic energies to the GeV level for envisioned applications at the Centre for Advanced Laser Applications (CALA) in Munich.



(Artist's impression, courtesy of Isabella Cortrie, LMU)

The laser pulse from one of the Gemini-arms is focused onto Carbon-Nanotube (CNT) foam – DLC composite targets. Within the CNT-foam plasma with near-critical electron densities, the laser undergoes relativistic self-focusing and pulse-front steepening on micrometer length scales before it impinges onto 10 nm thin DLC-foil. Due to the substantially decreased focal spot paired with the steep rise, radiation pressure acceleration becomes more effective.

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Dynamics and spectroscopy

Dynamics of chemical and photochemical reactions in solution

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The solvent environment plays a crucial role in many synthetic, biological, and photochemical processes, through its influence over the thermodynamic properties of the reaction. Favourable solvation of reaction intermediates can accelerate reaction rates by reducing the heights of energy barriers along reaction pathways, thereby promoting certain chemical outcomes at the expense of others.

Our research seeks to better understand this influence at the molecular level in both unimolecular and bimolecular reactions. The various relaxation and reaction pathways (including bond-breaking and bond-forming events, interaction of reactive species with the solvent, and dissipation of energy) exhibited by photoexcited molecules are probed by transient absorption spectroscopy, which allows the populations of reactants, intermediates, and products to be followed on femtosecond to picosecond timescales. By comparing the dynamics exhibited by reactions in the gas and solution phases, evidence is obtained for the influence exerted by the solvent on chemical mechanisms.

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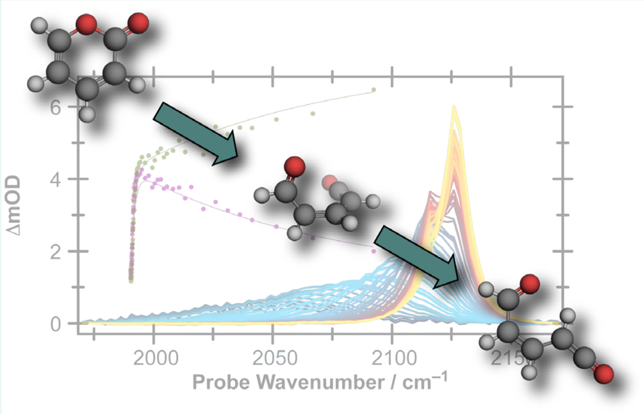

UV laser pulses induce ring-opening in cyclic organic molecules

Femtoseconds to seconds transient IR study of BLUF domain function utilizing unnatural amino acid substitution

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The BLUF (Blue Light Using Flavin) domain of the AppA photosensor was studied from femtoseconds to minutes. The key Y21 residue was probed by exchanging tyrosine for fluorotyrosines. The fast photochemical kinetics were only slightly perturbed, suggesting a weak dependence on Y21 pK_a and redox potential. The recovery kinetics were, however, altered by factors of >3000, indicating a role for proton transfer in the activated complex.

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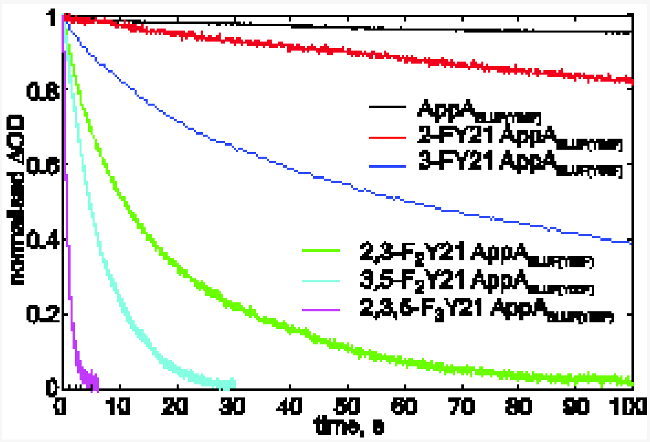

Dependence of the slow recovery kinetics for different fluorotyrosines

Resolution of the complete proton relay cycle in the green fluorescent protein with femtosecond to microsecond transient infra-red

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The time-resolved multiple probe spectroscopy (TRMPS) method was used to measure the complete femtosecond to 100 nanosecond proton transfer cycle in the green fluorescent protein. Mutagensis was used to alter the structure of the proton wire and to probe the effect on the dynamics.

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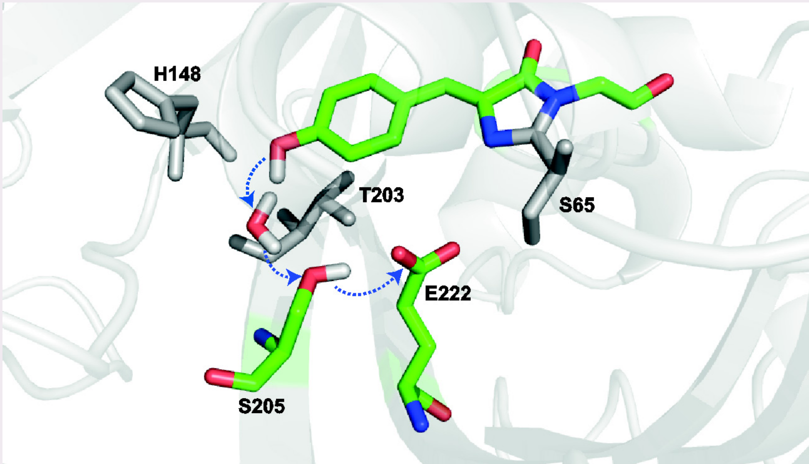

The structure and pathway of proton motion in the GFP proton wire

Time-resolved studies of guanine photo-oxidation by a DNA-bound Ru(II) complex in solution and crystal states

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Photo-sensitised oxidation of guanine is an important route to DNA damage, with possible applications in phototherapeutics. Such photodamage often occurs via one-electron photo-oxidation of guanine. In solution, an understanding of the process requires reliable knowledge of where and how the sensitiser is bound in DNA, a non-trivial matter due to the array of binding sites in a typical sequence. We have overcome this by performing ultrafast time-resolved infrared (TRIR) spectroscopy on photo-excited crystals of photosensitisers bound to DNA, whose structure has been determined by x-ray crystallography.

This pioneering approach has been used to determine the forward (1/500 ps^{-1}) and reverse (1/10 ns^{-1}) rate of photo-induced electron transfer for a reaction site whose molecular environment has been defined to 1.2 Å resolution. It also leads us to propose a specific guanine site of oxidation, and reveals similarities between the dynamics in the crystal state and the solvent medium.

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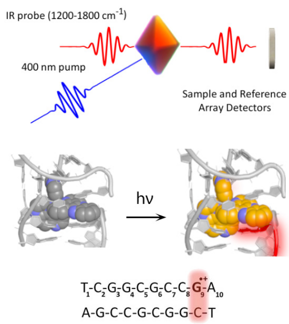

Experimental overview: Visible excitation and TRIR probing of crystals of Λ-$[Ru(TAP)_2(dppz)]^{2+}$ bound to $\{TCGGCGCCGA\}_2$ leading to identification of the site of photo-induced guanine oxidation.

Observing the photochemistry of [FeFe]-hydrogenase sub-site analogues from femtosecond to milliseconds

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The LIFEtime spectrometer has been used to study the photochemistry and dynamics of synthetic compounds that structurally mimic the active site of [FeFe]-hydrogenase enzymes. Experiments aimed at understanding the effect of ultraviolet excitation of these species on femtosecond to picosecond timescales has shown that the dominant photochemical process is carbonyl ligand photodissociation to create a coordinatively unsaturated Fe-centre.

Here, the extended temporal range offered by the time-resolved multiple probe spectroscopy (TRMPS) methodology is exploited to extend our investigations to include the diffusive phenomena occurring on nanosecond to microsecond timescales following excitation, which could be key to hydrogen-generation by these species.

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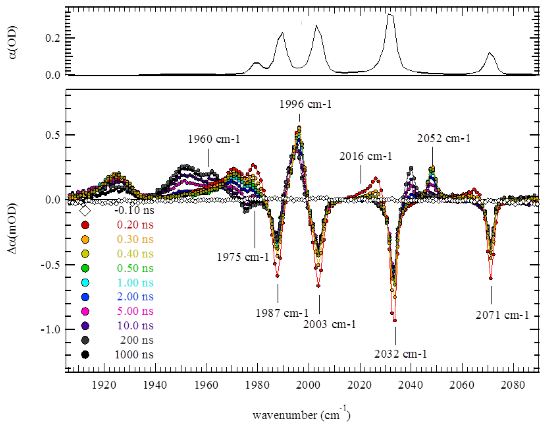

Time resolved infrared spectra of (μ-S(CH$_2$)$_3$S)Fe$_2$(CO)$_6$ in heptane solution, obtained using the LIFEtime spectrometer operating in TRMPS mode.

UV laser spectroscopy of mass-selected ionic liquid building blocks in the gas-phase

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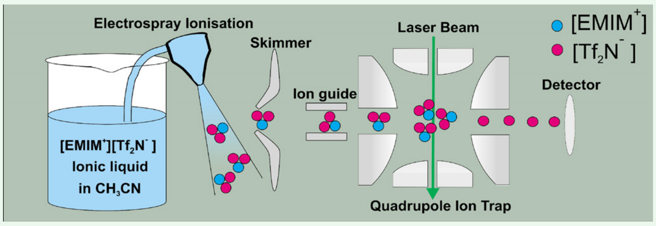
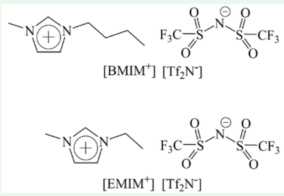
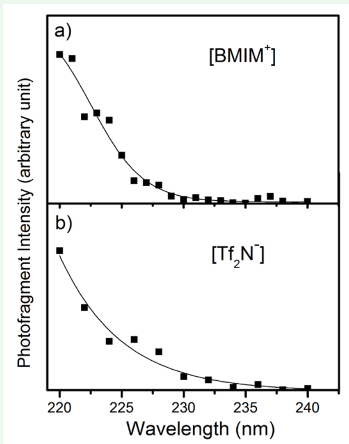
This work reports the application of laser photodissociation spectroscopy to study the electronic spectra of aggregate clusters of the components of ionic liquids in the gas-phase. These spectra have been recorded in a custom-adapted commercial mass spectrometer, which incorporates a laser interface. The ionic liquid aggregates are introduced to the gas-phase by electrospray ionization. The spectra obtained are the first UV laser action spectra of mass-selected gas-phase ionic liquid aggregates, i.e. $[BMIM^+]_n[Tf_2N^-]_m$ and $[EMIM^+]_n[Tf_2N^-]_m$ where n ≠ m and n, m = 1,2. Each aggregate cluster displays a spectral maximum absorption at 220 nm, the high energy limit scanned. However, the anionic and cationic aggregate photofragmentation cross-sections are notably different, indicating distinctive decay mechanisms.

Our spectra compare well to spectra of gas-phase ionic liquids obtained by other methods, indicating the utility of our technique as a facile route to obtaining gas-phase electronic spectra of isolated ionic liquids.







Top: Schematic representation of the experiment, illustrating production of ionic liquid aggregates by electrospray, and laser photodissociation spectroscopy within an ion trap.
Left: Structures of the (top) $[BMIM^+][Tf_2N^-]$, and (bottom) $[EMIM^+][Tf_2N^-]$ ionic liquids.
Right: Cluster laser photofragment action spectra of a) $[BMIM^+]$ from the $[BMIM^+]_2[Tf_2N^-]$ cationic aggregate, and b) $[Tf_2N^-]$ from the $[BMIM^+][Tf_2N^-]_2$ anionic aggregate.

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Peroxy radical photolysis in the near UV

M.A. Blitz, T. Ingham *(School of Chemistry, University of Leeds, UK)*

The hydroxyl radical (OH) is the most important species in atmospheric chemistry as it is the primary reagent for initiating reactions. However, in pristine, forested environments (low ozone and low NOx) the predicted OH concentration can be too low by up to an order of magnitude. A potential source of this missing OH is from the photolysis of peroxy radicals, which are much less reactive than OH and are present in much higher concentrations.

To test this hypothesis, the NSL2 laser was used to photolyse peroxy radicals (RO_2) in the near UV (300 – 350 nm).
The peroxy radicals were flowed into a low-pressure cell, especially designed to measure the OH radical with great sensitivity via fluorescence.

OH was detected from the photolysis of peroxy radicals found in forested environments. The observed efficiency of OH generation in the near UV suggests this is a significant additional source of atmospheric OH.

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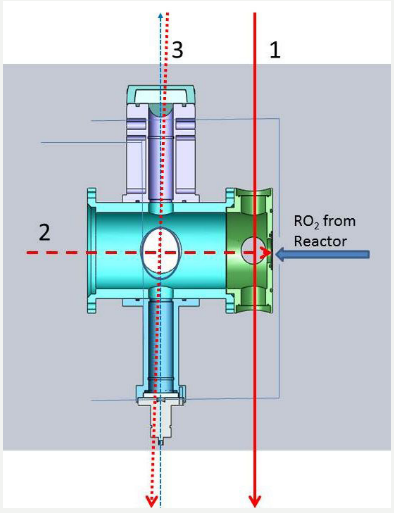


A solid model drawing of the photolysis cell. RO_2 radicals flow through the pinhole and are photolysed in the near UV with the NSL2 laser system using three geometries (in red), before OH is detected via the second laser (blue).

Ultrafast transient absorption spectroscopy of size-controlled colloidal nanocrystals for hydrogen generation with an inverse conical taper

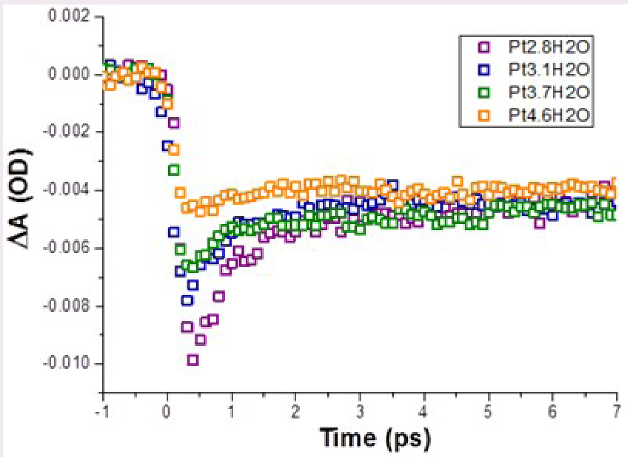
F. Jaeckel *(Dept of Physics, University of Liverpool, UK)*
W. Li *(The University of Liverpool, UK; Chemical Engineering and Applied Chemistry, Aston University, Birmingham, UK)*

Solar hydrogen is currently receiving considerable attention as a potential component of a green and sustainable future energy mix. Catalyst-decorated colloidal semiconductor nanocrystals are studied as a potentially inexpensive, scalable means for photocatalytic hydrogen generation, offering wide control over their optical and electronic properties.

We have recently shown that size-controlled quantum confinement in Pt-decorated CdS nanospheres can be used to control the internal quantum efficiencies for hydrogen generation, i.e. smaller nanocrystals show higher efficiencies [1].

Here, we use ultrafast transient absorption spectroscopy to address the underlying mechanism in detail. Transient absorption traces of size-controlled Pt-decorated CdS nanospheres (see Figure) exhibit accelerated dynamics for smaller nanocrystal sizes, which is indicative of faster and thus more efficient charge separation, consistent with the observed increases in quantum efficiencies for smaller nanocrystals. This additional understanding is an important step towards the rational design of quantum confined colloidal photocatalysts.

[1] W. Li, F. Jaeckel et al. Nanoscale 2015, 7, 16606-16610.



Transient absorption spectroscopy of size-controlled Pt-decorated CdS SNCs, showing size-dependent charge carrier dynamics.

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Recent developments towards time-resolved electron diffraction at York

J. P. F. Nunes, M. S. Robinson, P. D. Lane, D. A. Wann *(Dept of Chemistry, University of York, UK)*

An apparatus has been built to allow time-resolved electron diffraction (TRED) experiments to be performed in the UK for the first time. These experiments allow for the structures of small molecules to be resolved and for their dynamics to be probed in real-time.

The Wann group TRED apparatus electron gun produces short electron bunches using the third harmonic of an 800 nm femtosecond laser focused onto a gold photocathode. This ultrafast electron beam is then used as a probe in pump-probe experiments.

Since its commissioning in 2013, the TRED apparatus at York (left-hand figure) has been used to record time-averaged electron diffraction data for both polycrystalline (right-hand figure) and gas-phase species, and preliminary time-resolved experiments showed a sub-picosecond time-resolution. The apparatus has recently been fitted with a purpose-built solenoid lens, capable of reducing the diameter of the electron beam by 30%, improving the spatial resolution of experiments.

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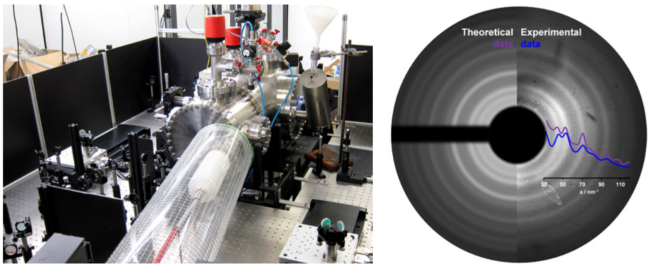

Left: The TRED apparatus at York.
Right: Comparison between theoretical and experimental diffraction patterns and diffraction data, collected from a 20 nm-thick polycrystalline platinum sample.

Ultrafast non-radiative decay of neutral amino acids: phenylalanine and tryptophan

S. De Camillis, J. Miles, G. Alexander, I.D. Williams, J.B. Greenwood
(Centre for Plasma Physics, Queen's University Belfast, UK)

The aromatic amino acids tryptophan, tyrosine and phenylalanine are critical building blocks of proteins. The fluorescence they produce when irradiated with mid-ultraviolet light is widely exploited to track the activity of proteins in cells. Tryptophan has the strongest fluorescence, while it is very weak in phenylalanine.

In this study we have used ultraviolet and visible femtosecond laser pulses to excite these molecules and probe the ultrafast processes by which this energy is subsequently dissipated. In phenylalanine we show that there is a relaxation process lasting 300 femtoseconds, which quickly quenches the absorbed ultraviolet energy by converting it to vibrational energy before any light can be emitted. A similar but much weaker process was found in toluene, the sub-unit of phenylalanine which absorbs ultraviolet light. These results help to explain why phenylalanine fluoresces weakly compared with other molecules like tryptophan and toluene.

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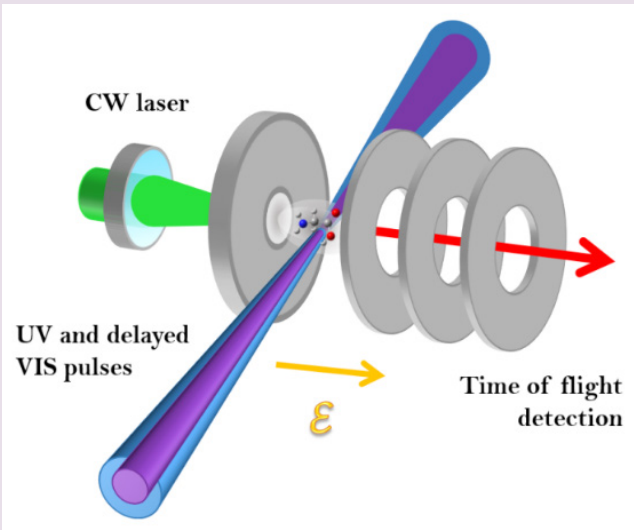

Schematic representation of the experiment. Femtosecond ultraviolet and visible laser pulses were focused into the interaction chamber, where they were absorbed by the molecules to form positive ions. By analysing the masses of the ions produced for different delays between the two laser pulses, the ultrafast dynamics were observed.

Circular dichroism in the ion yields of amino acids

J. Miles, L. Casey, S. De Camillis, G. Alexander, I. D. Williams, J. B. Greenwood
(Centre for Plasma Physics, Queen's University Belfast, UK)

Molecules which are non-superposable mirror images are termed chiral, with left- and right-handed versions known as enantiomers. As nature uses only one enantiomeric type for its building blocks, e.g. proteins and DNA, chirality is an integral part of biology functions. Therefore discrimination of different enantiomers is important for understanding the origins of life and efficacy of drugs in disease treatment.

In the present study, a femtosecond laser with circular polarisation has been used to discriminate between the enantiomers of the amino acid phenylalanine, by resonantly ionising the molecules and detecting relative yields of the ions produced. As this process is very efficient, it could enable different enantiomers to be detected with much higher sensitivity than is currently possible with conventional techniques.

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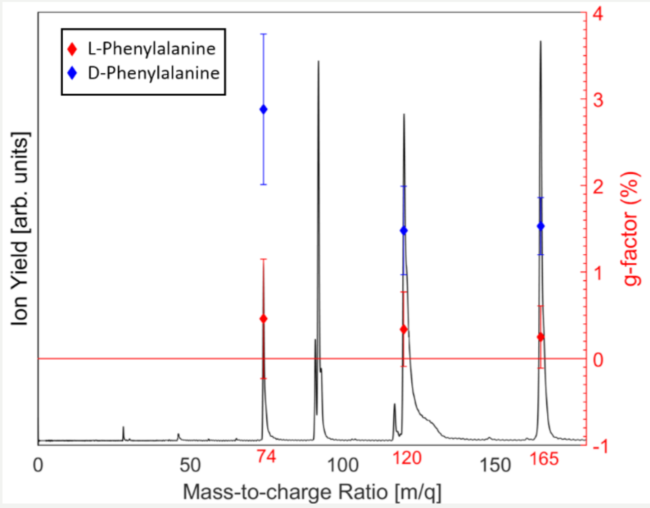
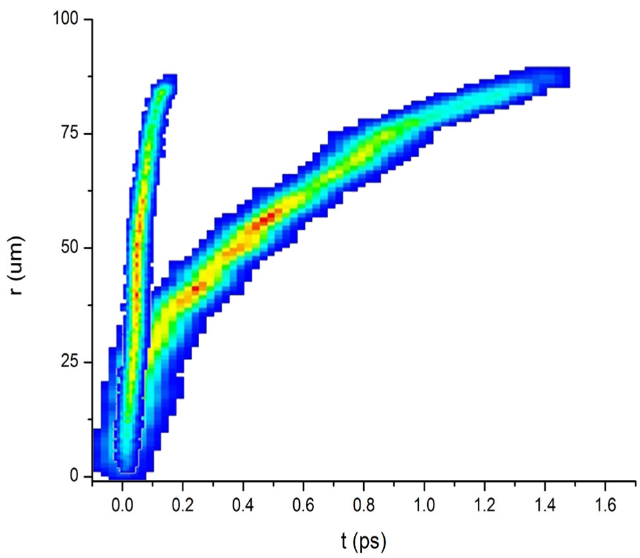


Mass spectra obtained from irradiating left- (blue) and right- (red) handed phenylalanine with circularly polarised femtosecond laser pulses. The difference in ion yields was used to distinguish the enantiomers.

Developing a next generation ultrafast electron microscope

C.W. Barlow Myers, P.L. Campbell, W.A. Bryan *(Dept of Physics, Swansea University, UK)*

We present a novel concept for a femtosecond electron microscope, capable of both diffractive and holographic imaging. Incorporated in the concept is the reduction of the three main sources of temporal broadening: geometric, space-charge, and energy broadening. Using a Nanoscale Metal Tip (NSMT) as our photoemitter, the focusing and collimation of ultrafast pulses is demonstrated with a lens located behind the emission site. This allows for an ultra-compact experimental design, reducing both broadening from path length differences and energy bandwidth effects.



An illustration of the influence of geometric broadening upon ultrafast electron pulses and how this may be combatted using an increased electron energy and magnetic focusing or collimation in the vicinity of the electron source. Shown are the distributions of two electron pulses overlaid on the same time-scale, comparing a pulse energy of 300 eV without magnetic focusing, with a 25 keV pulse with magnetic focusing following propagation of 7 mm. Allowing the beam to diverge (i.e. without lens) extends the temporal profile of the pulse to 1.5 ps. Catching the beam before it naturally expands is essential in reducing geometric broadening, facilitating pulses well below 100 fs.

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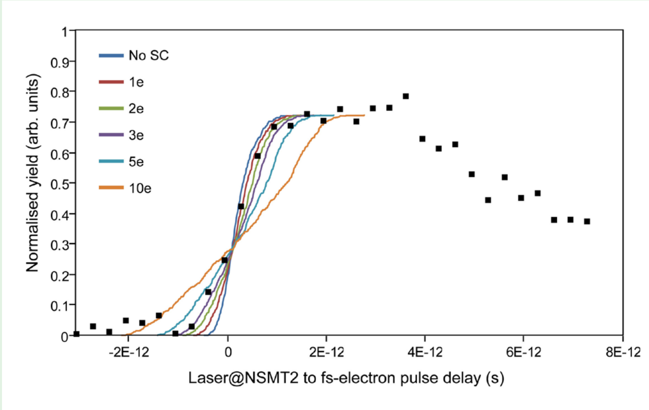
Time-resolved microscopy with femtosecond few-electron pulses

W. A. Bryan, C. W. Barlow-Myers *(Dept of Physics, Swansea University, UK)*
A. R. Bainbridge *(Accelerator Science & Technology Centre, STFC Daresbury Laboratory, Cheshire, UK)*

We have demonstrated a new form of electron microscopy, whereby a femtosecond laser pulse is used to generate bunches of a few electrons per shot. Keeping the number of electrons low prevents the mutual Coulomb repulsion from dominating, hence delivering as short a pulse as possible to the object being.

Here we use our femtosecond electron point-projection microscope to observe the evolution of charge at the apex of a metal tip, which comes to a point tens of nanometres across. By illuminating this nanotip with a second laser pulse, we are able to spatially and temporally image the evolution of the charge. The technique demonstrated here opens the door to time-resolved imaging of very rapid processes in conductors, dielectrics and insulators, which has significant relevance to the next generation of light-driven optically-coupled electronics.



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The graph shows a comparison between the measured temporal response of our nanoscale conducting object (black squares) with simulations of the cumulative electron density as a function of delay. The zero-delay point is identified through the use of the optical delay between the two laser pulses and confirmed by simulations. The cumulative electron flux is compared directly to the sequential image difference. No space-charge (SC) is the case whereby the geometric and bandwidth stretch of the electron pulse limit duration at the target and 1e to 10e are the predictions with full three-dimensional space charge calculations. It is clear that this observation is consistent with an electron flux of between one and three electrons per pulse on average. The best fit electron pulses in the presented experimental data have a standard deviation of approaching 100 fs, which is among the fastest ever observed.

Ultrafast electron flux calibration for nanoscale dynamic imaging

W. A. Bryan *(Dept of Physics, Swansea University, UK)*
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Femtosecond pulses of electrons combine the short wavelength characteristics of transmission electron microscopy with the temporal resolution afforded by pump-probe measurements on ultrafast timescales. The ideal operational mode is when each electron pulse contains, on average, less than one electron per shot. This requires highly sensitive diagnostic tools.

Here we show that, using a low-flux source of secondary electrons which diffuse over our detector, we can observe single arrival events: when scaled up to the exposure time when performing femtosecond electron microscopy, this allows us to determine the number of electrons per pulse with high fidelity. We also present the degree to which the electron trajectories through our instrument agree with numerical modelling.

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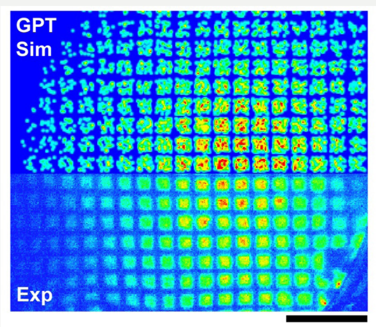

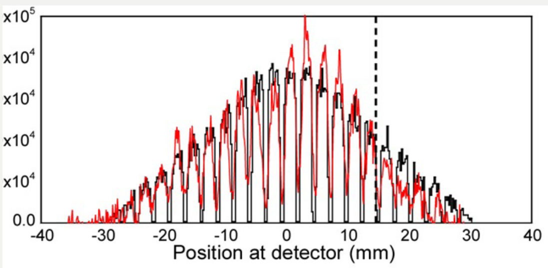

(Left top) General Particle Tracer (GPT) simulation of the propagation of a femtosecond electron pulse through a 300 mesh TEM grid placed 5 mm from our femtosecond electron source.
(Left bottom) Experimental observation of the same configuration. Scale bar is 15 mm at the detector plane. The strong agreement between experiment and simulation illustrates how we are able to quantify the propagation of our electron pulses through our instrument.
(Right) A direct comparison between the GPT model (black) and experimental measurements (red) as a slice through the data presented to the left.

Investigating the ultrafast recovery of the charge density wave phase in 1*T*-$TiSe_2$

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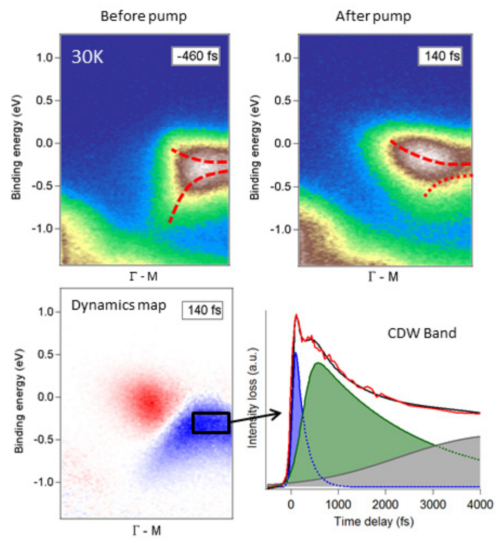
M. Hoesch *(Diamond Light Source, Didcot, UK)*
C. Cacho, E. Springate, R. Chapman *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*

In this experiment, we have used time- and angle-resolved photoemission spectroscopy to address the longstanding debate about the origin of the charge density wave (CDW) phase in 1*T*-$TiSe_2$, a prototypical example of complex solid state material. We studied the recovery dynamics of both the low temperature CDW phase and its fluctuation phase at higher temperatures.

For the first time we observed a complex sequence of three different timescales in their recovery dynamics and associated them to different electronic and lattice degrees of freedoms. Furthermore, by tuning the excitation photon energy close the energy size of the CDW gap in this system, we discovered a non-trivial dependency of the amplitude of these different components. This promises deeper insights into the mechanisms of the CDW phase, the interplay of the different degrees of freedom, and emphasizes the importance of tuning the pump photon wavelength to specific energies relevant for the investigated system.



(Top) Time-resolved photoemission intensity maps of the charge density wave phase of 1T-$TiSe_2$ near the border of the Brillouin zone. (Bottom left) Difference intensity map, emphasizing the induced dynamics. (Bottom right) Transient intensity loss of the CDW band, showing the three timescales in its recovery dynamics.

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Unveiling the role of the Mott-like electronic excitations in high-temperature superconductors by time-resolved photoemission

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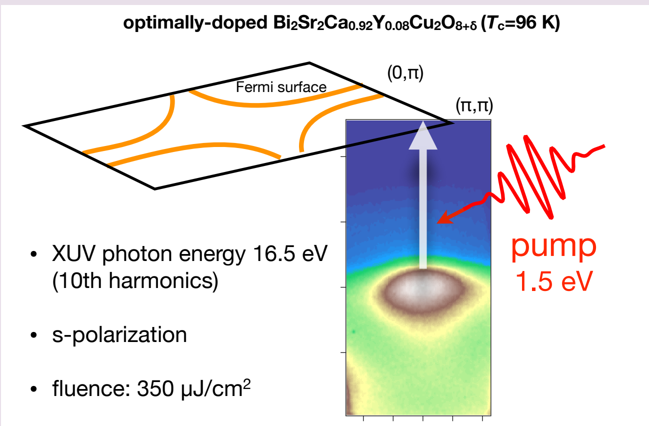
A. Damascelli *(Dept of Physics & Astronomy, University of British Columbia, Vancouver, Canada)*

The interplay between superconductivity and the high-energy electronic excitations related to the Mott physics remains one of the unsolved problems in the physics of copper oxides.

Here we perform time-resolved angle-resolved photoemission spectroscopy (trARPES) measurements, with high temporal resolution and XUV photon energy, to investigate the ultrafast dynamics of the oxygen bands in superconducting $Bi_2Sr_2Ca_{0.92}Y_{0.08}Cu_2O_{8+\delta}$ for the first time. The results unveil a non-trivial excitation pathway, which results in the long-lived trapping of holes in the oxygen O-$2p_\pi$ bands, probably under the form of localized polarons. The energy of the ultrafast modification of the O-$2p_\pi$ bands is of the order of the charge-transfer transition, which is strongly affected by the onset of superconductivity.

Our results underscore the crucial role of the photoinduced, long-lived non-thermal states in pump-probe experiments on copper oxides. This experiment also paves the way to the new era of trARPES on cuprates, in which the ultrafast electron dynamics will be mapped over the entire Brillouin zone.



Cartoon of the XUV time-resolved ARPES experiment on Bi2201. The pump excitation at 1.5 eV photon energy creates a non-thermal electronic distribution characterized by an excess of holes in the O-$2p_\pi$ oxygen bands and of electrons in the conduction band. Snapshots of the relaxation process are taken by XUV probe pulses ($h\nu$=16.5 eV) that photoemit electrons at a kinetic energy $E_{kin}=h\nu-\Phi$, where Φ is the work-function of the material.

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Ultrafast free carrier dynamics in single layer MoS_2

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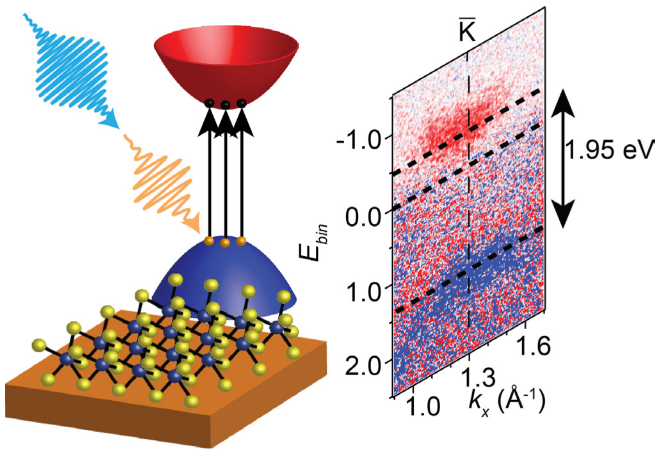
The interplay between free carriers and bound excitons completely specifies the optical properties of semiconductors. The recently discovered class of single layer semiconducting transition metal dichalcogenides may be excellent candidates for new optoelectronic technologies, due to the presence of strongly bound excitons with remarkable properties. However, the properties of free carriers in these materials have remained unknown, because the strong exciton lines mask the free carrier signal altogether in all-optical experimental techniques.

Using time- and angle-resolved photoemission spectroscopy (trARPES) at the CLF Artemis facility for a single layer of MoS_2 contacted to a metal, we were able to measure the dynamics of free carriers directly for the first time. This allowed us to map out a direct band gap of 1.95 eV in single layer MoS_2, and we observed that carriers are extracted by the metal contact on an ultrafast femtosecond timescale. Such ultrafast extraction by the metal contact is essential for applications that seek to exploit the properties of free carriers in MoS_2, since they must be extracted before they decay via lattice vibrations or defects.



(Left) Pump-probe experiment on single layer MoS_2 on Au(111). The pump pulse creates free carriers (electrons and holes) around the parabolic valence and conduction band edges of MoS_2.
(Right) The excited state signal recorded with a high harmonic probe beam, revealing the photoexcited carriers and the direct band gap of single layer MoS_2.

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Life & Science Imaging

Fast confocal fluorescence lifetime imaging

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Fluorescence lifetime imaging microscopy (FLIM) is a powerful and widely applied advanced microscopy technique, particularly in the biological sciences. In a standard single beam laser scanning microscope arrangement, acquisition times are typically of the order of 3 - 5 minutes, which represents a significant limitation when dynamic information is sought in a biological experiment. We have recently shown that acquisition times can be significantly reduced by the use of a scanning multiphoton multifocal arrangement, in which an array of beamlets is scanned across the sample and the fluorescence is imaged onto a single photon avalanche diode (SPAD) array detector.

In this report we demonstrate one-photon excitation multibeam confocal laser scanning microscopy as a method for rapid FLIM, with low laser powers and acquisition times two orders of magnitude shorter than conventional time-correlated single photon counting (TCSPC) based laser scanning FLIM. This reduction in acquisition time will enable real-time monitoring of intracellular processes, including protein-protein interactions.

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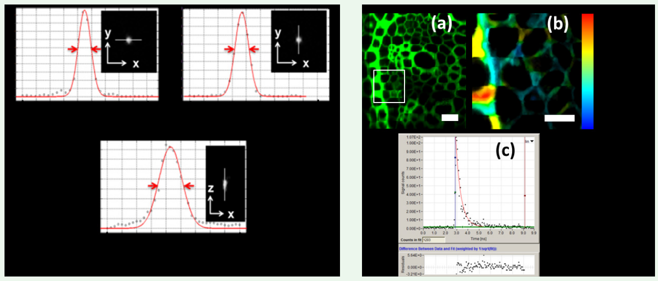

(Left): Optical resolution measurements of a 175 nm green microsphere.
(Right): (a) Fluorescence intensity image of convallaria section recorded using an array of 15x13 beamlets (b) 8x8 beamlet TCSPC FLIM image measured in 2 s corresponding to the ROI shown by the white box in (a). Scale bar 10 μm. (c) Representative decay curve from 3x3 pixels in the time-resolved image.

Multiplexed label-free detection of single proteins

A. Sebesta, A. Weigel, P. Kukura *(Physical & Theoretical Chemistry Laboratory, University of Oxford, UK)*

Optical detection of single molecules usually relies on the fluorescent properties of the molecule or on the introduction of a fluorescent label. Recently, alternative approaches eliminating the need for labels were introduced, using the local refractive index sensitivity of surface plasmon resonances for sensing. Protein sensing down to the single molecule level was shown. These breakthroughs were achieved either by total internal reflection type dark field microscopy, or with photothermal microscopy using photoinduced heat dissipation to generate a refractive index contrast.

These methods exclusively relied on the readout of one gold nanoparticle sensor at a time. However, it would be desirable to extend these techniques to allow for multiple-particle read out and thus simultaneous observation of multiple events for implementing next-generation clinical diagnostic assays. Schemes based on plasmon resonance shift detection of multiple particles were presented only recently, using either time gated events like a spatial light modulator in the conjugate image plane as a form of complex slit, sample scanning, or pure intensity readout to reach their multiplexing capabilities.

Here, we present a novel wide-field detection scheme, which allows simultaneous monitoring of the surface plasmon resonance of multiple gold nanorods. It directly records 2D spectrally dispersed images of gold nanorod samples. The spectra are corrected via an overlapped particle image that correlates the particle positions to the reference slit position, allowing us to use the full 2D space of the sensor. We present an unprecedented low noise fluor, allowing us to observe single protein particle binding events with high signal-to-noise ratios.

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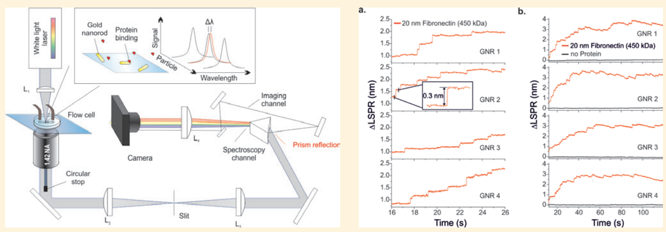


(Left): Experimental setup of the dark field microspectroscope.
(Right): Time-dependent surface plasmon resonance shift for protein free (black) and 20 nM Fibronectin solution (red).
A magnified region shows clear single protein binding steps, the inset emphasizes the unprecedented single to noise ratio (a).
The full trace shows the saturation behavior after 1 minute (b).

FRET-FLIM as an approach to validate proteomics datasets

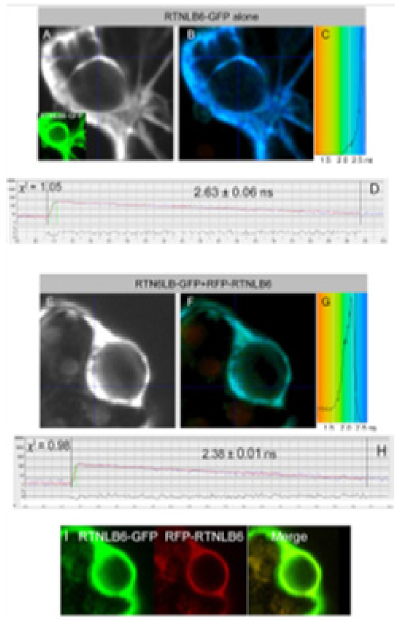
C. Hawes, V. Kriechbaumer *(Dept of Biological and Medical Sciences, Oxford Brookes University, Oxford, UK)*
S. Botchway *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*

The cortical endoplasmic reticulum (ER) in plants is pleomorphic and structured as a tubular network capable of morphing into flat cisternae, mainly at three-way junctions, and back to tubules. Plant reticulon (RTNLB) proteins tubulate the ER by dimer- and oligomerization, creating localised ER membrane tensions that result in membrane curvature. Some RTNLB ER-shaping proteins are present in the plasmodesmal (PD) proteome [1] and may contribute to the formation of the desmotubule, the axial ER-derived structure that traverses primary PD [2]. Here we investigate the binding partners of two PD-resident reticulon proteins, RTNLB3 and RTNLB6, which are located in primary PD at cytokinesis [2].

We used a dual approach to identify interacting partners of RTNLB3 and RTNLB6 [1,2]. First, GFP-immunoprecipitation assays coupled to mass spectrometry, to identify proteins potentially binding to RTNLB3 and RTNLB6 was performed. Second, a detailed FRET-FLIM (Förster Resonance Energy Transfer by Fluorescence Life Time Imaging Microscopy) analysis was conducted with the identified proteins, to confirm prey-bait interactions in vivo.

Our mass spectrometry interaction data identified a large percentage (40%) of ER proteins, including other RTNLB family members. However, we also found a relatively large number (25%) of proteins present in the published PD proteome [1], and a surprisingly high proportion (35%) of plasma membrane proteins. Of the PD-resident proteins we identified, a significant number were shown previously to be targets of viral movement proteins (MPs). Additional proteins identified suggested roles for RTNLBs in transport and pathogen defence. We suggest that RTNLBs may play key roles in anchoring and/or signalling between the cortical ER and PM. This proteomics data was subsequently validated through in vivo assessment of interactions by FRET-FLIM analysis.

References: [1] Fernandez-Calvinoet al, 2011
[2] Knox et al, 2015



FRET-FLIM analysis of RTNLB6 without an interaction partner (A-D) or RTNLB6 dimerization (E-I).

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Theory & Computation

Rate coefficients in a degenerate plasma produced by short wavelength lasers

V. Aslanyan, G. J. Tallents *(York Plasma Institute, University of York, UK)*

We have constructed a collisional-radiative model, with rate coefficients calculated using the Fermi-Dirac energy distribution function for free electrons. This allowed us to compare how the steady-state and time-evolved ionization fraction in plasmas vary from calculations, assuming the usual Maxwell-Boltzmann electron distribution, for different laser intensities.

We have found that, although the Fermi-Dirac distribution makes little difference for plasma conditions close to local thermodynamic equilibrium, the presence of strong photoionizing radiation, such as that from a short wavelength laser, creates dense and degenerate electrons. The evolution of a degenerate plasma may differ significantly from a classical plasma.

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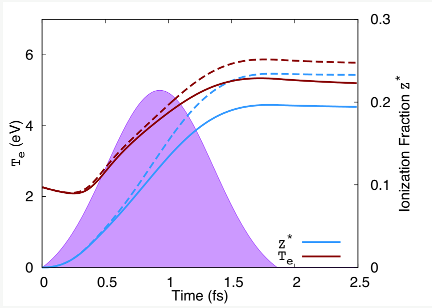

Ionization fraction and temperature evolution of diamond as it is subjected to a pulse of short wavelength radiation (photon energy – 14 eV, duration – 1 fs, peak intensity – 10^{14} W cm^{-2}). The dashed lines assume a Maxwell-Boltzmann electron distribution, while the solid lines assume a Fermi-Dirac distribution.

Shrinking the angular distribution of fast electrons via wires with an inverse conical taper

A.P.L. Robinson, H. Schmitz *(Plasma Physics Group, CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*

We report on our recent studies of targets that exploit resistivity gradients to guide fast electrons and which incorporate an inverse conical taper. This is perhaps the simplest geometry that is interesting in terms of its ability to reduce the angular spread of the fast electrons. We also show how this can be applied to wire heating and the remarkable improvement that including even a slight inverse conical taper can yield.

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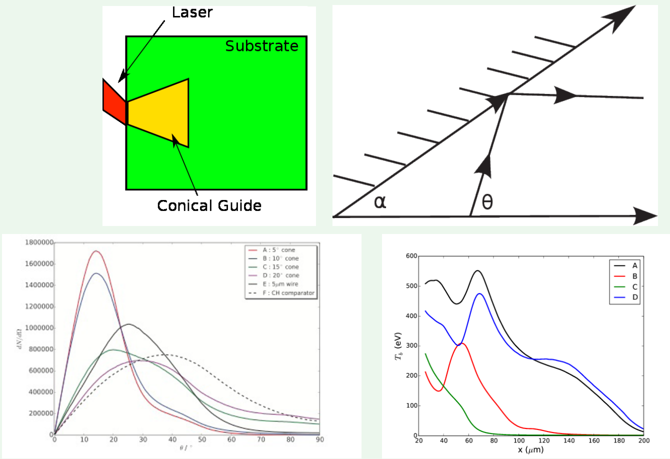

Top left: Schematic plot of wire with inverse conical taper.
Top right: Schematic plot of reflection from oblique plane.
Bottom left: Angular distribution of fast electrons from different simulations. Legend indicates type of guide element used in each simulation. Distributions are calculated at 3 ps (substantially after end of injection).
Bottom right: Lineouts (along guide axis) of background electron temperature (eV) in simulations with different wire targets, with/without inverse conical tapers.

The effect of superluminal phase velocity on electron acceleration in a powerful electromagnetic wave

A.P.L. Robinson *(Plasma Physics Group, CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*
A.V. Arefiev, V.N. Khudik *(Institute for Fusion Studies, The University of Texas, USA)*

We have derived an analytic solution for the problem of a single electron in an electromagnetic (EM) plane wave of arbitrary strength and arbitrary phase velocity. The solution has been checked against direct numerical integration. From this analytic solution we can begin to understand the extent to which EM dispersion (and thus superluminal phase velocities), due to either plasma dispersion or wave-guiding, affects direct laser acceleration (DLA).

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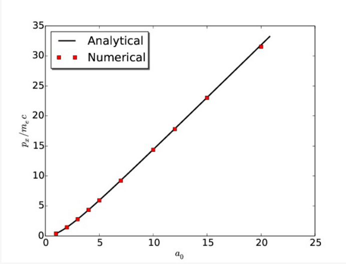

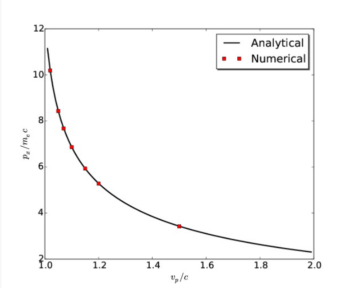

Top: Peak longitudinal momentum p_x from a series of numerical calculations in which a_0 is varied for v_p = 1.15c against the predictions of equation 16:

$$\frac{p_{\parallel}}{m_e c} = \tilde{p}_x = \frac{\sqrt{u^2 + a^2(u^2-1)} - u}{u^2-1}$$

Bottom: Peak longitudinal momentum p_x from a series of numerical calculations in which v_p is varied for a_0 = 5 against the predictions of equation 16.

Anisotropic cooling of electron beams interacting with intense laser pulses

A. Noble, S.R. Yoffe, D.A. Jaroszynski *(SUPA/Dept of Physics, University of Strathclyde, Glasgow, UK)*

With the advent of a new breed of high power laser facility, it is essential to understand the dynamics of relativistic electron beams interacting with ultra-intense laser pulses, such as the reduction of their momentum spread. We have explored a prime example of such effects, namely the radiative reduction of momentum spread, or beam cooling.

Ignoring radiation reaction, there is no beam cooling: electrons emerge from the pulse with their initial momentum spread. The situation is changed when radiation reaction is included. According to the classical theory, interaction with the pulse causes significant beam cooling, which is equally partitioned between transverse and longitudinal directions. Including quantum effects changes things once again, with a reduction in beam cooling, and a breaking of the symmetry between longitudinal and transverse directions, with the transverse cooling lying closer to the classical case, and the longitudinal cooling more resembling the case with no radiation reaction. In all cases there is isotropy within the transverse plane, the polarisation of the laser pulse playing no role.

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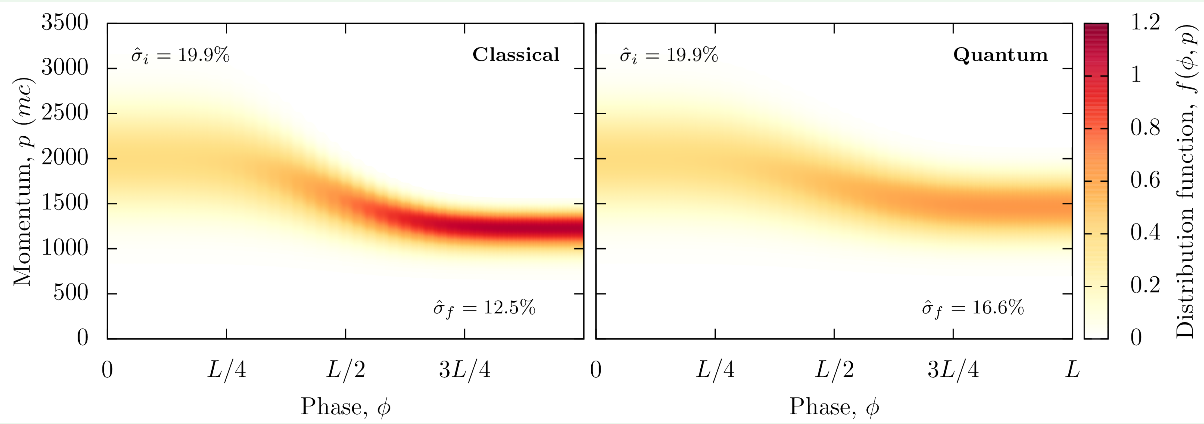


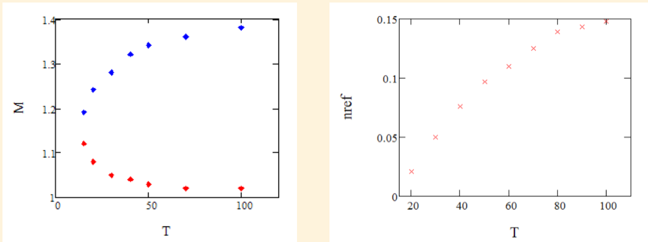
Longitudinal cooling of a 1 GeV electron beam colliding with a 2 x 10[21] W/cm[2] laser pulse.

Weak collisionless shocks in laser plasmas

R.A. Cairns *(University of St Andrews, Fife, UK)*
R. Bingham *(University of Strathclyde, Glasgow, UK; CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*
R. Trines *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*
P. Norreys *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK; Dept of Physics, University of Oxford, Oxford, UK)*

Last year we described a theory of low Mach number laminar collisionless shocks, and their possible relevance to observed localized high electric fields in laser compressed pellets and experiments on ion acceleration. Here we have extended our earlier work to look at more general properties of these structures, in order to obtain the parameter domain within which they exist and some scaling laws. In a single species plasma, there are two parameters that determine the structure: the ratio of electron to ion temperature, and the Mach number.

The accompanying figures shows the domain of existence of the structures, with a minimum temperature ratio of just under 15 and a widening range of Mach numbers above this value. Within this range, a fairly small fraction of the ions is reflected, while above the maximum Mach number we expect a more complicated structure, with a large fraction of the ions reflected.



Left: Upper (blue) and lower (red) limits of the allowed Mach number range, estimated by numerical trial and error for a range of electron/ion temperature ratios.
Right: The reflected ion density as a function of temperature at the maximum Mach number.

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Single shot quantitative and spatially resolved plasma wakefield diagnostics

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R. Bingham, R. Trines *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*
M. Wing *(Dept of Physics & Astronomy, University College London, UK)*

Plasma wakefield accelerators are promising technology to accelerate particles within a distance up to three orders of magnitude shorter than conventional accelerators. However, only a few techniques exist to diagnose the plasma wakefields, and none of them can be used to quantitatively measure the amplitude of the wakefield in spatially-resolved manner. We propose a method to diagnose the plasma wakefield's parameters using photon acceleration. In this technique, a laser pulse that could cover several plasma wavelengths is fired into the wakefield. Inverting the measured frequency modulation profile of the pulse yields the density profile of the wakefield at the interaction point. By introducing a crossing angle the interaction point can be chosen, thus making it possible to diagnose the wakefield at certain positions in the plasma.

Simulations were performed to check the accuracy of the measured wakefield amplitude compared with the actual amplitude. Most of these results agree qualitatively and quantitatively, with a relative error less than 10% for various tested wakefield amplitudes, crossing angles and probe frequencies. This technique opens up new possibilities for qualitative and quantitative diagnostics of plasma wakefield density at chosen positions in a plasma.

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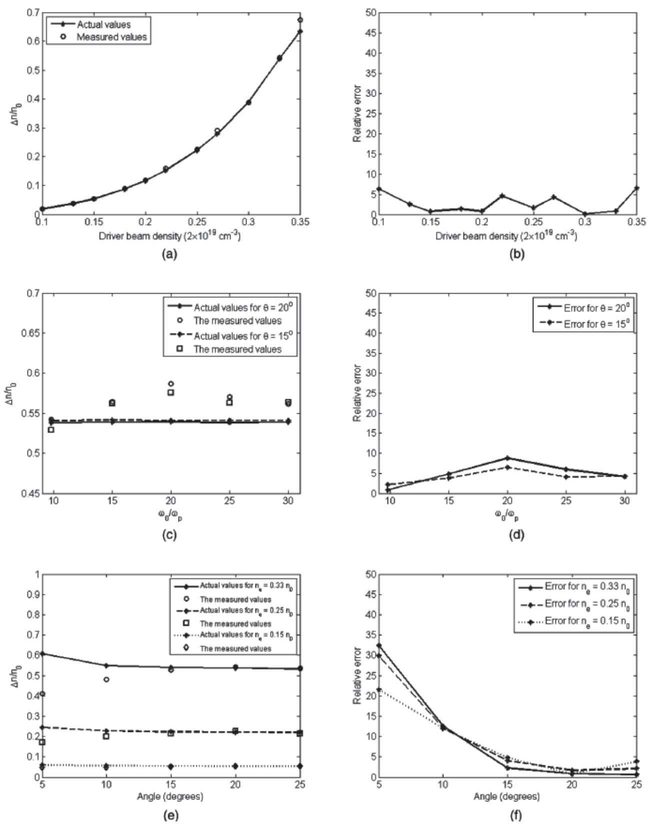

Comparison of the amplitude values between the measured and actual density profiles for (a) various peak driver beam density values and (b) the relative errors, (c) various probe frequencies and (d) its relative errors, and (e) various crossing angles with (f) its relative errors.

Measuring radiation reaction in laser-electron beam collisions

T. G. Blackburn
(Dept of Physics, Chalmers University of Technology, Gothenburg, Sweden)

Using today's high-power laser facilities, it is possible to detect quantum radiation reaction in the collision of a GeV electron beam and an intense laser pulse. Experimental signatures of radiation reaction will be the substantial yield of >10 MeV gamma rays and the reduced energy of the electron beam. This will still be evident even if that electron beam is accelerated by a laser wakefield, and so has a broad initial energy spectrum with a large low-energy tail.

We can exploit the fact that the diameter of the laser pulse will be smaller than that of the electron beam, and consider the latter's energy spectrum per unit cross-sectional area. As shown in the figure, there will be a prominent depletion zone in the areal energy spectrum if the beams collide successfully.

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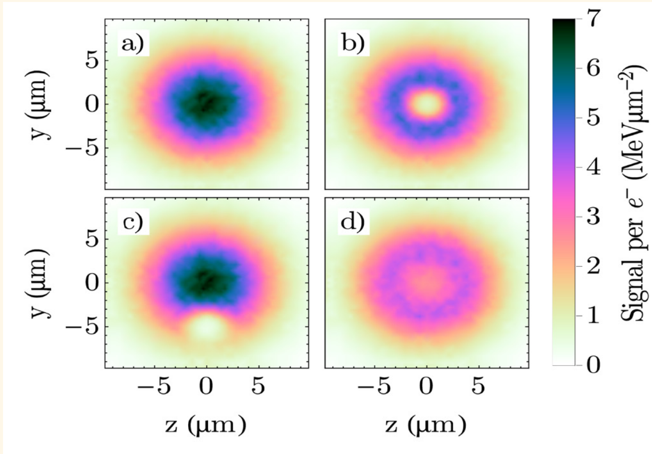

The energy carried by the electron beam, per particle per unit cross-sectional area a) prior to the collision with the high-intensity laser pulse, and immediately after a collision at b) Δx = Δy = 0, c) Δx = 0, Δy = 5 μm and d) Δx = 50 μm, Δy = 0.

Exploiting the self-similar nature of Raman and Brillouin scattering

R. M. G. M. Trines *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*

Raman and Brillouin amplification are two schemes for amplifying and compressing short laser pulses in plasma. Depending on the laser and plasma configurations, these schemes could potentially deliver the high-energy, high-power pulses needed for inertial confinement fusion, especially fast-ignition fusion.

Analytical self-similar models for both Raman and Brillouin amplification have already been derived [1,2], but the consequences of this self-similar behaviour are little known and hardly ever put to good use. In this paper, we will give an overview of the self-similar laws that govern the evolution of the probe pulse in Raman and Brillouin amplification. We will then show how these laws can be exploited, in particular regarding the parameters of the initial probe pulse, to control the properties of the final amplified probe and improve the efficiency of the process.

[1] V.M. Malkin, G. Shvets and N.J. Fisch, Phys. Rev. Lett. 82, 4448 (1999).
[2] A.A. Andreev et al., Phys. Plasmas 13, 053110 (2006).

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Simulations of nanosecond laser self-focusing and channelling in under-dense magnetised plasmas

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R. J. Kingham *(Blackett Laboratory Imperial College London, UK)*
P. A. Norreys *(Clarendon Laboratory, University of Oxford, UK; CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*

Magnetic fields – both applied and self-generated – are increasingly relevant to laser-plasma interactions, because of the potential benefits to ICF and plasma waveguide applications. Electron transport dynamics in magnetised plasmas are intricate, as heat-flow and B-field evolution feedback onto each other. To investigate laser self-focusing dynamics in such systems, two existing codes – CTC, a fluid code, and IMPACT, a VFP code – have been augmented with a paraxial wave solving module.

The fluid simulations of beam propagation through magnetised plasmas show significant changes in the electron density profile. These changes result in laser beam defocusing when Nernst advection is accounted for (see figure). Matching simulations using IMPACT, however, indicate that non-local effects are present and the fluid code can overestimate Nernst advection under these conditions. This highlights the need for appropriate heat flux and magnetic flux limitation.

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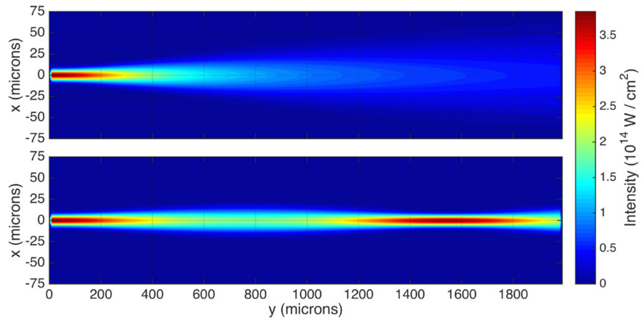

Laser intensity profiles from the fluid code CTC with Nernst advection enabled (upper) and disabled (lower). The laser defocuses after ~350 ps with Nernst advection accounted for,whereas without the beam is channelled over a distance of 2 mm.

The effect of lattice structure on fast electron transport in dual layer solid targets

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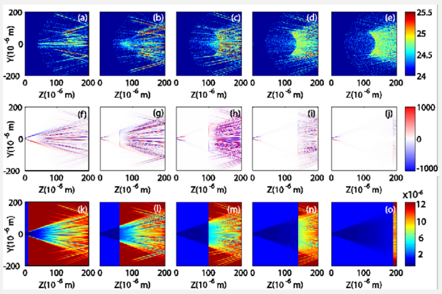
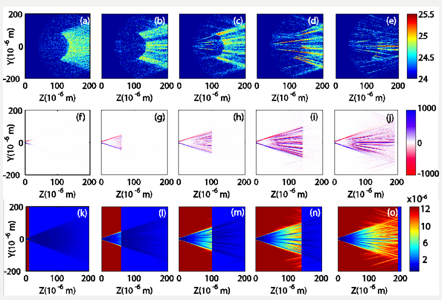
D. R. Rusby, G. G. Scott, D. Neely *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*
M. P. Desjarlais *(Sandia National Laboratories, Albuquerque, USA)*
B. Zielbauer, V. Bagnoud *(PHELIX Group, GSI Hemholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany)*

The influence of lattice structure and low-temperature electrical resistivity on the transport of fast electrons in solids is numerically investigated using 3D hybrid particle-in-cell (PIC) simulation. Simulations of dual layer targets comprising ordered and disordered carbon allotropes, show the effect of electrical resistivity in layered targets that do not exhibit a change in atomic number across the layer boundary.





Our numerical investigation implies that there is a minimum propagation distance of approximately 60 μm of vitreous material (and an implied minimum growth-time), required to allow resistive magnetic fields to evolve to the extent that resistive filamentation of the fast electron beam is observed. In addition, the presence of carbon with disordered lattice structure generates strong filamentary effects, with little dependence on its location within a dual layer target, when its thickness is of the order of 60 μm or greater.

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Top: Zephyros simulation results for double layer targets with vitreous carbon as the front layer and diamond as the rear.
TOP ROW: Log_{10} fast electron density maps (m^{-3}), in the [Y-Z] mid-plane, for: (a) LF =10 μm; (b) LF =50 μm; (c) LF =100 μm; (d) LF =140 μm; (e) LF =190 μm;
MIDDLE ROW: Corresponding 2D maps of the magnetic flux density (B_x component in Tesla);
BOTTOM ROW: Corresponding 2D maps of electrical resistivity (Wm).

Bottom: Zephyros simulation results for double layer targets with diamond as the front layer and vitreous carbon as the rear.
TOP ROW: Log_{10} fast electron density maps (m^{-3}), in the [Y-Z] mid-plane, for: (a) LF =10 μm; (b) LF =50 μm; (c) LF =100 μm; (d) LF =140 μm; (e) LF =190 μm;
MIDDLE ROW: Corresponding 2D maps of the magnetic flux density (B_x component in Tesla);
BOTTOM ROW: Corresponding 2D maps of electrical resistivity (Wm).

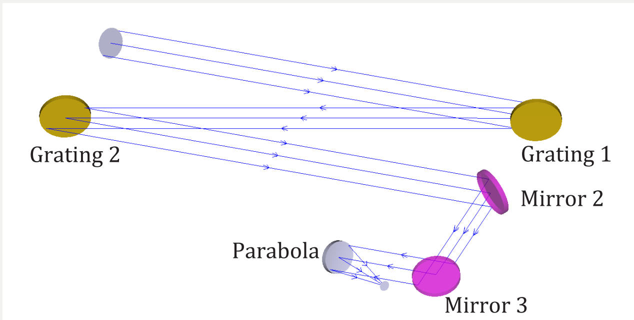
Development

Laser beam collimation effects on large CPA compressors

R. Heathcote, M. Galimberti, R. J. Clarke, T. B. Winstone, I. O. Musgrave, C. Hernandez-Gomez *(CLF, STFC Rutherford Appleton Laboratory, Didcot UK)*

Modelling and analysis have been performed to show a link between laser collimation tolerances and dispersion effects in chirped pulse amplification (CPA) compressors. These show that an uncollimated beam can present itself as residual dispersion in a CPA system, which will have adverse effects on laser power and intensity if uncorrected.

The techniques of shearing interferometry and beam propagation over large distances for setting beam collimation have been assessed for their limitations in measuring wavefront radii. An analysis of the sensitivity of CPA systems to non-collimated beams has been studied. This effect has been practically demonstrated for a high-power Nd:glass laser and the best techniques for alignment are discussed.



Zemax models of the Petawatt beamline

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Laser shock peening of Si_3N_4 ceramics: experimental set-up and general effects

P. Shukla, J. Lawrence *(Laser Engineering & Manufacturing Research Group, University of Chester, UK)*

For over two decades, laser shock peening (LSP) or laser peening has been an established technique for the surface treatment of metals and alloys, due to the known benefits offered by the process. In particular, the technique offers: increased compressive residual stress; reduction in friction and wear; surface topography changes; and an increase in hardness.

LSP of advance ceramics is, however, unreported and requires much development. Physical characteristics prevent ceramics from behaving in the same way as metals when exposed to short pulses of laser energy, such that mechanical yielding and plastics deformation is difficult to introduce. As a result, the benefits from LSP found with metals/alloys are not common with hard brittle materials, such as ceramics. It is, therefore, of great interest to investigate LSP of ceramics, to understand the short pulse laser-material interaction, and the surface and bulk property modification.

Our work is a first step towards developing a laser peening technique for ceramics, intended to provide greater understanding of the science behind the technique, particularly for ceramics, by analysing mechanical, physical, and internal aspects of the material. Our goal is to apply the successful technique to engineer (strengthen) components from range of industrial sectors. We present details of the experimental set-up of our research using the EPSRC-funded ultra-high power (10 J) Nd:YAG laser (NSL4) system.

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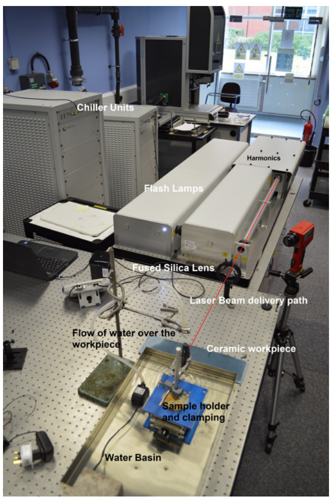
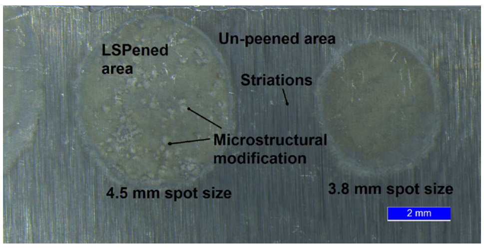




Left: Set-up of LSP experiments.
Right: Optical image of two different regions post-LSP, with an indication of a microstructural modification. As-received surface (left) and post-LSP surface (right) of Si_3N_4 advanced ceramic.

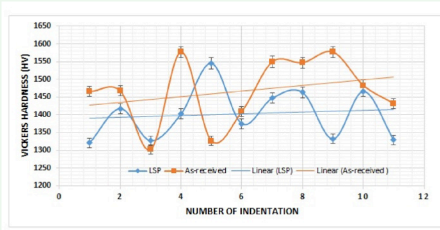
Alteration of fracture toughness (K_{Ic}) of Si_3N_4 advanced ceramics by laser shock peening

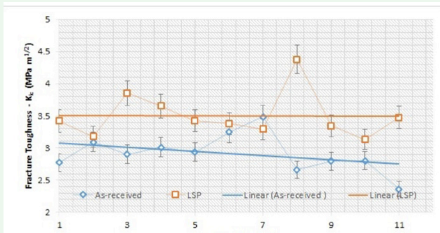
P. Shukla, J. Lawrence *(Laser Engineering & Manufacturing Research Group, University of Chester, UK)*

Lasers are known to influence the surface properties of ceramics materials in general. This study is a continuation of our work in laser shock peening (LSP) of Si_3N_4, initiated to study the effects on the surface hardness and the surface fracture toughness (K_{Ic}).

For a number of years, LSP has been an established technique for the surface treatment of metals in particular. However, LSP of advanced ceramics remains an under-developed process for a number of reasons, including brittleness and the ceramic being prone to cracking. It is, therefore, of great interest to study the effects of laser LSP of advanced ceramics, to gain a better understanding of the short pulse laser-material interaction and the changes in physical and internal properties.

Silicon nitride (Si_3N_4) ceramics are some of the most widely used advanced ceramic materials in industry, with diverse applications across many sectors including automotive, motorsports, military, aerospace and space. For many of these high demand industrial applications, fracture toughness is an essential property, and ceramics in general have a low fracture toughness compared with that of metals and alloys. Crack sensitivity and low K_{Ic} could limit the use of Si_3N_4; however, its applications have gradually increased as a result of the desirable physical properties and longer functional life which gives it a commercial advantage over the conventional materials in use. With that said, an increase in the K_{Ic} would lead to an enhancement in the functional life and performance of Si_3N_4 components. Our work with the LSP technique aims to result in increased K_{Ic}.





Surface hardness (top) and K_{Ic} (bottom) of the Si_3N_4 advanced ceramic after LSP

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Progress on positioning of solid targets for Gemini

D. R. Symes, N. Booth, M. Baraclough, G. Indorf, P. Oliver, G. G. Scott, D. Neely, C. Spindloe, R. I. Heathcote, R. J. Clarke, P. S. Foster, C. D. Gregory, P. P. Rajeev
(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)

Experiments on Gemini require target positioning with micron accuracy to achieve the highest intensity. Our standard method is to backlight the rear surface of the target with an LED through the microscope objective used to image the focal spot. We demonstrate some enhancements to this alignment technique ensuring that we can achieve accurate positioning, even using challenging materials such as ultrathin 10 nm carbon foils and polished silicon wafers. The focal spot camera has been modified to include a lower magnification (10x) mode, and a laser focusing onto the rear surface of the target to complement our standard LED backlighting. We also discuss characterisation of the motorised stages commonly used in the CLF, which we have measured using a confocal sensor capable of detecting sub-micron motion. Each stage has advantages and drawbacks, and we point out some improvements that are needed to the drive system to optimise the positioning performance.

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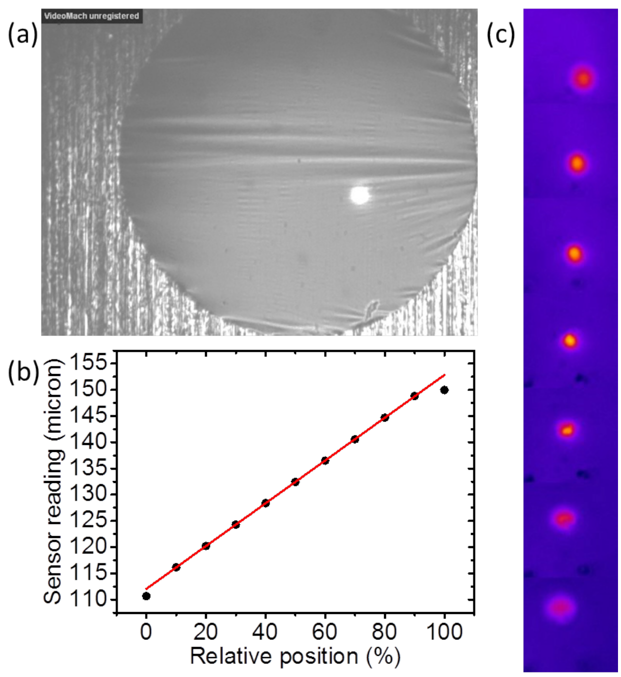


(a) Image of a 10 nm carbon foil backlit with an LED at 10x magnification.
(b) A focusing laser has been added to the camera arrangement and can be used for micron-accurate positioning.
(c) A closed loop piezoelectric motor can be used for extremely accurate motion over a range of 25 microns.

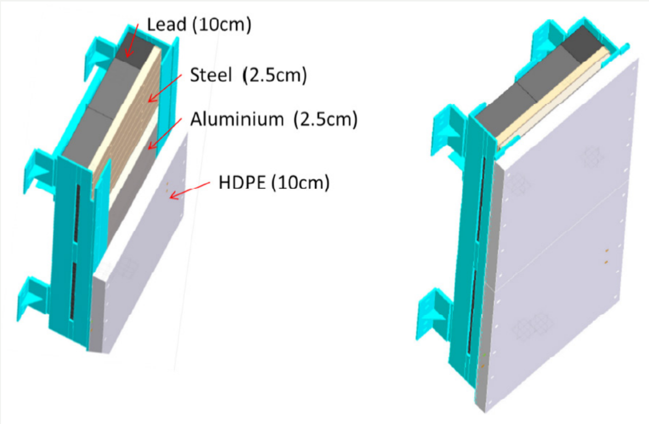
Increased radiation shielding in Gemini Target Area 3

R. J. Clarke, R. I. Heathcote, D. R. Symes, P. S. Foster, P. P. Rajeev, S. Blake, S. Spurdle, P. Brummitt, D. Neville *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*

K. Poder, N. C. Lopes *(The John Adams Institute for Accelerator Science, Blackett Laboratory, Imperial College London, UK)*

The success of laser wakefield acceleration on Gemini has led to a steady increase in electron energies over recent years. Experiments are now routinely generating GeV electron beams with a high repetition rate (1 shot / 20 seconds) for many hours continuously. In order to resolve the highest energies of over 1 GeV, a strong magnetic field is required, which sweeps some of the electrons above the original lead shielding wall on the North side of TA3. These advances have necessitated a review of the radiological shielding in the bunker.

Here we report the calculations carried out to determine the required shielding enhancement, and how these enhancements have been carried out. First, we added extra layers to the main shielding wall in the forward beam path; second, we installed a permanent lead wall inside TA3, covering the area directly above the beam path. This shielding is sufficient for current experimental demands.



Engineering drawing of the frame that has been installed in Gemini TA3 to hold extra lead shielding vertically above the electron beamline.

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Optimisation of the *f*/2 Gemini focal spot using full beam adaptive optics

C.D. Gregory, D.R. Symes, M. Baraclough, T. Anderson, S.J. Hawkes, C.J. Hooker, O. Chekhlov, B. Parry, Y. Tang, N. Booth, P.S. Foster, P.P. Rajeev
(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)

A new optimisation method for the Gemini *f*/2 parabola has been adopted. The standard focal spot camera has been modified in order to both image the focus of the laser, and measure the wavefront quality with a HASO sensor (a commercial Shack-Hartmann sensor from Imagine Optic). These measurements are made simultaneously and in real-time, whilst adjusting a full-aperture adaptive optic in either closed- or open-loop correction mode. In addition, an ImageJ macro has been written that allows rapid, quantitative characterisation of the focal spot using a number of standard metrics. In a recent experiment using this optimisation scheme, a wavefront flatness of $< \lambda/20$ was achieved, with the corresponding focal spot containing $> 58\%$ energy in its $1/e^2$ radius of 1.6 μm.

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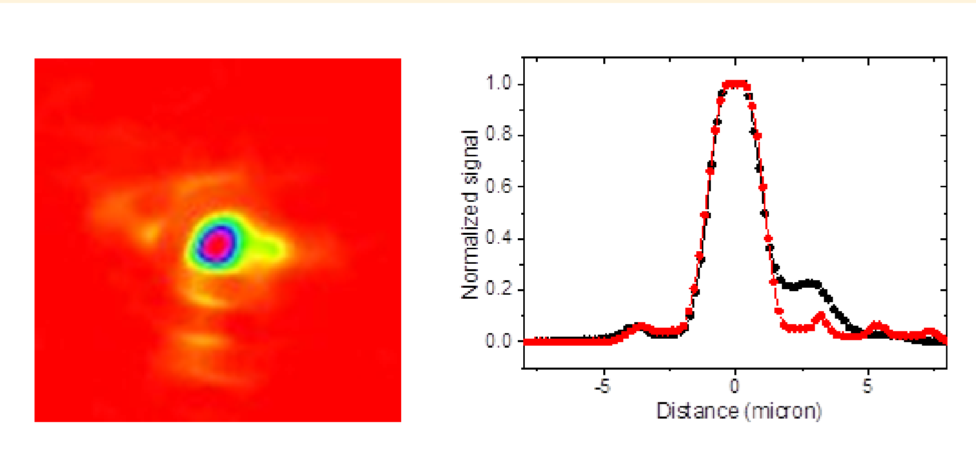

Focal spot of the pulsed beam using an adaptive optic and f/2 parabola.

An adaptive optic in the Astra laser

C. J. Hooker, B. T. Parry, C. D. Gregory *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*

An adaptive optic (AO) has been installed at the output of Amplifier 3 in the Astra laser, to control the wavefront before the beam is split to ATA2 and Gemini. The AO is a dielectric-coated, bimorph-type deformable mirror, coated on both sides to maintain an acceptable level of flatness. It has 31 actuators in a circular pattern, 19 of which are inside the area of the beam. The wavefront is measured in the beam transmitted through a good-quality turning mirror after the AO, using a HASO wavefront sensor from Imagine Optic in a plane conjugate to the AO. The dominant error in the beam is astigmatism due to the four oblique passes of the 800 nm beam through the Ti:sapphire crystal. The AO has been able to reduce the wavefront error from typically 0.6 wave to better than 0.06 wave P-V and 13 nm RMS.

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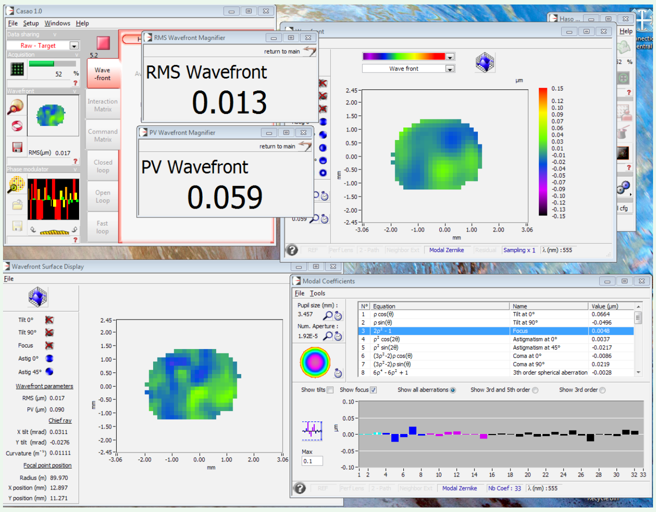

Screenshot from the AO control program, showing a well-corrected beam from Amplifier 3.

A transmission grating pulse stretcher for contrast enhancement of Gemini

Y. Tang, O. Chekhlov, S.J. Hawkes, C.J. Hooker, J.L. Collier, P.P. Rajeev *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*

Studies of contrast on the Gemini laser showed that a contrast feature around the main pulse (the pedestal) originates in the pulse stretcher. Use of transmission gratings in a test set-up reduced the pedestal by a factor of almost 100 compared to reflection gratings. We therefore built a new stretcher for the Gemini laser using two transmission gratings, and took advantage of the change to design better mountings for all the optics in the stretcher, to improve stability and ease of alignment.

The stretcher was commissioned in September 2014. For reasons we have not yet discovered, the expected improvement in contrast did not materialise, and we are planning further studies to understand this. However, the transmitted spectrum of the new stretcher is wider by around 8 nm, and this has led to compressed pulses as short as 35 fs for the first time on Gemini.

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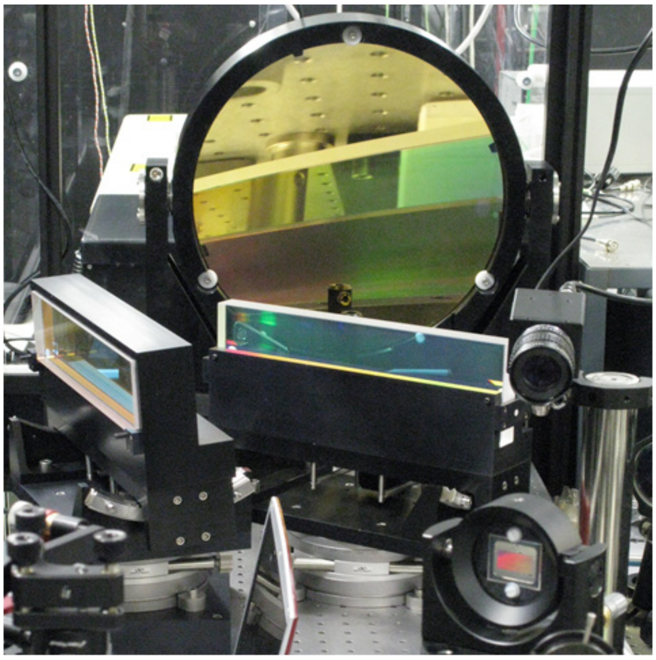

The new Gemini stretcher. The small first grating is in the foreground. Behind are the second grating and the spherical mirror, with the flat rear mirror on the left.

Facility development update: The Kerr-gated Raman/ ultrafast time-resolved fluorescence instrument

I. V. Sazanovich, G. M. Greetham, B. C. Coles, I. P. Clark, P. Matousek, A. W. Parker, M. Towrie *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*

The Kerr-gating beamline has been developed for 10 kHz repetition rate and implemented in the Ultra facility.
The instrument provides efficient rejection of the emission background in Raman experiments, and offers a capability to carry out broad-band TRF experiments with ultrafast temporal resolution. The upgraded set-up demonstrates 40% gate opening efficiency and ~ 4 ps gate width when CS_2 is used as Kerr medium, and covers > 3000 cm^{-1} in one frame with ~ 15 cm^{-1} spectral resolution in the Raman experiments, with the dark noise of ~ 6 counts rms in 10 s acquisition.

The top figure shows the Kerr-gate schematic. The bottom figure demonstrates the power of the Kerr-gate, showing the spectrum of Fluorescein dye in ethanol with and without the gate. Without the gate (blue line), emission completely obscures the Raman signatures, but with the gate (red line), the Raman lines of the solvent are easily observed.

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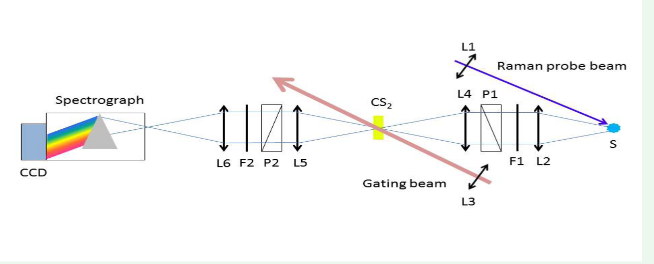

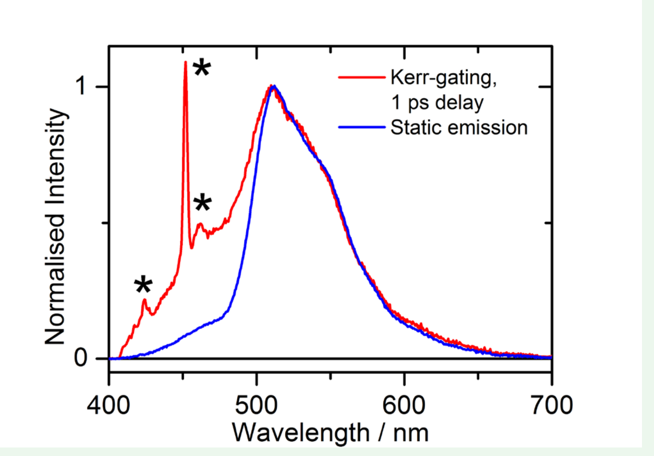

Top: Schematic diagram of the Kerr-gate, where: S is the sample; L1 – L6 are lenses; F1, F2 are cut-off filters; P1, P2 are polarisers; and CS_2 is the Kerr cell filled with carbon disulfide.
Bottom: Comparison of the Kerr-gated spectrum taken at 1 ps time delay (red line) from Fluorescein in ethanol, with the reconstructed steady-state spectrum from the same sample (blue line). Both spectra have been normalized to the peak intensity of fluorescence.

Time-resolved multiple-probing experiments on Ultra

G.M. Greetham, P.M. Donaldson, C. Nation, I.V. Sazanovich, I.P. Clark, A.W. Parker, M. Towrie *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*

D.J. Shaw *(SUPA/Dept of Physics, University of Strathclyde, Glasgow, UK)*

Early experiments on the new BBSRC- and STFC-funded Ultra-LIFEtime system are presented. The dual ytterbium-based amplifier laser's application to time-resolved multiple-probing experiments is described. These measurements show IR spectral changes from chemical and biological molecular dynamics over more than 10 orders of magnitude in time, from femtoseconds to seconds.

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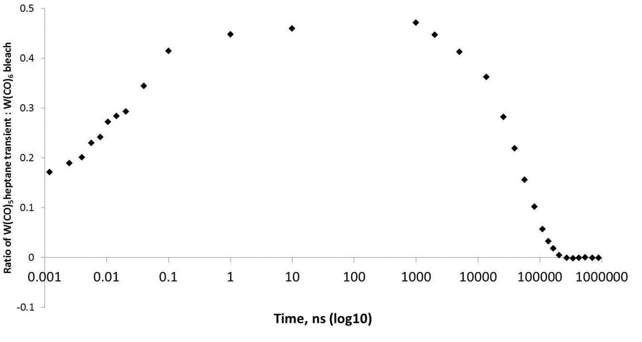


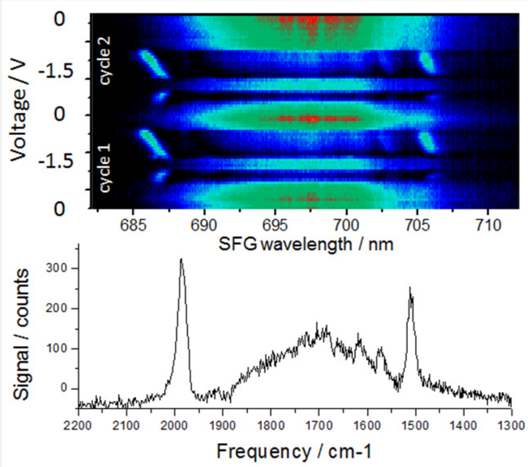
Orders of magnitude in time

Surface specific IR-Visible sum frequency generation on Ultra

P.M. Donaldson *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*
A.J. Cowan, G. Neri, J.J. Walsh *(Dept of Chemistry, University of Liverpool, UK)*

Infrared-Visible surface specific sum frequency generation (IR-Vis SFG) measurements were made available to users on Ultra for the first time. The method's unique advantage is that it gives vibrational spectra of molecules at interfaces with incredible sensitivity and selectivity. The broad infrared bandwidth, flexible femtosecond-picosecond synchronised amplifiers, and high repetition rate of ULTRA, were used to give a sensitive IR-Vis SFG platform.

The Cowan Group from the University of Liverpool applied IR-Vis SFG on Ultra to study electrochemical catalyst reactions at metal electrodes. In particular, the Group is interested in catalysts that enhance carbon dioxide reduction to carbon monoxide; a process with important industrial applications. By controlling the voltage applied to the electrodes, IR-Vis SFG was used to observe the arrival of the catalysts on the electrode surface and the subsequent chemical changes with applied voltage.



Voltage-cycled electrochemical interface IR-Vis SFG signal from a Mn(bpy)(CO)3(Br) solution

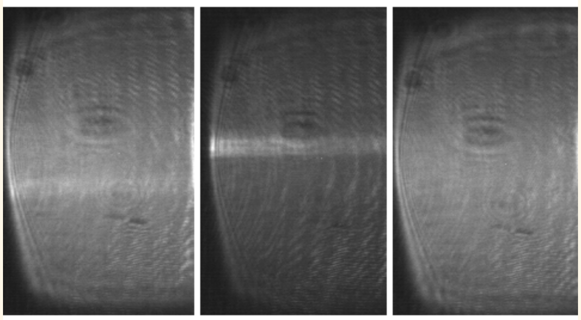
Contact: P. M. Donaldson (paul.donaldson@stfc.ac.uk)

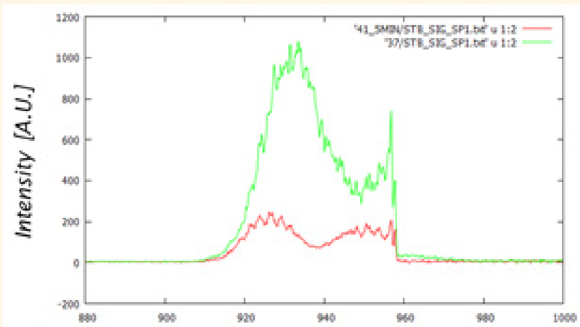
Performance of the rod amplifier chain for the 20 PW Component Test Lab

A. Boyle, M. Galimberti, P. Oliveira *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*

OPCPA-based laser systems are capable of producing high contrast, high peak power amplification whilst maintaining the large bandwidth required for short pulses of a few tens of femtoseconds. This makes the technology the ideal candidate for future multi-petawatt facilities, such as the proposed Vulcan 20 PW upgrade.

The 20 PW Component Test Lab (CTL) OPCPA pump laser was fired and 20 J of green, 527 nm, was achieved at 59% conversion efficiency. Initially this was used to find the phase matching angle of 80% deuterated DKDP (left-hand figure). OPCPA was then demonstrated using a seed beam, 40 nm bandwidth centred at 940 nm, in collinear alignment to achieve OPCPA. The seed beam was amplified from 40 mJ to 0.9 J and the full bandwidth was sustained (right-hand figure).





Contact: A. Boyle (alexis.boyle@stfc.ac.uk)

Left: Three NF images showing the phase matching scan. The left-hand and middle images show a narrow stripe corresponding to 0.01 degree acceptance angle; the right-hand image shows the NF after precise tuning.
Right: Seed beam from 20 PW front end (red). Amplified seed using OPCPA in 80% DKDP (green).

Development of the laser diagnostics for Vulcan

M. Galimberti, A. Boyle, A. Kidd, A. Jenson, A. Moss, D. Pepler, D. Shepherd *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*

F. Barnsley, K. Phipps *(Scientific Computing Dept, STFC Rutherford Appleton Laboratory, Didcot, UK)*

At the Vulcan facility, users are continually requesting improvements to the laser diagnostic systems. The main requests are to:

- implement a view tools to the users and operators of all the diagnostics data;
- improve reliability of the diagnostics;
- implement automatic data;
- concentrate all the important information on one screen;
- implement loop stabilization;
- provide after shot data analysis; and
- record more metadata related to the shot.

To address these issues, a new diagnostic architecture was required (left-hand figure) with an upgrade of the software. This architecture includes automatic alignment and loop stabilization, automatics saving and data analysis, centralized error reporting, and 'out of window' parameter checking. It also integrates the capability to catalogue the data using an ICAT system, and then to make it accessible via eCat, which enables the data to be displayed, searched and downloaded (right-hand figure).

The new system is currently under test and will be released next year.

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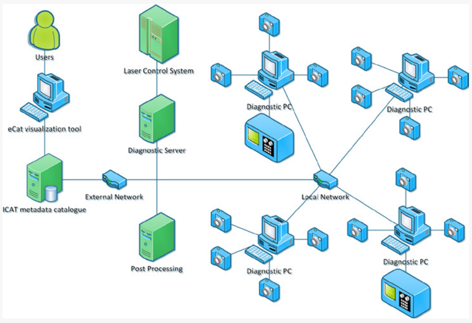
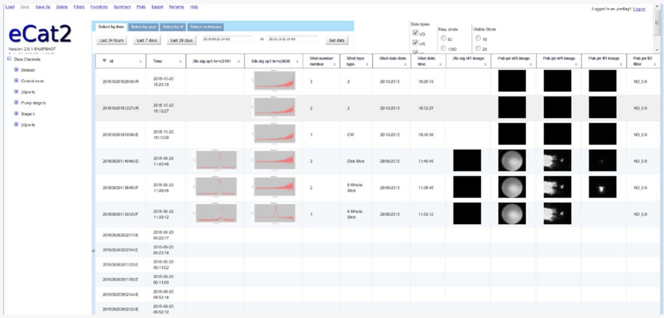


Diagnostic architecture



Screenshot of eCat web page

Development of GRENOUILLE analysis tools

M. Galletti *(INFN - LNF, Frascati, Italy)*
M. Galimberti, A. Boyle, P. Oliveira *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*
D. Giulietti *(Physics Department of the University and INFN, Pisa, Italy)*

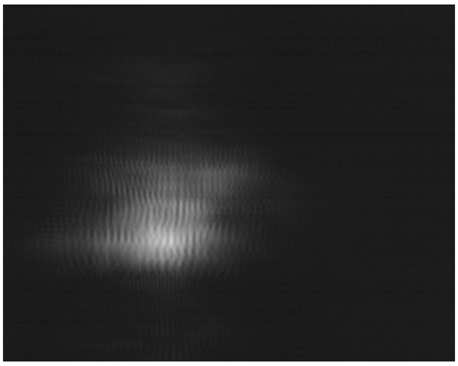
The characterization of ultra-short high-power laser pulses has always been a challenge. One of the most promising techniques is GRENOUILLE, which is considerably more sensitive and extremely easy to set-up and align than previous techniques. Here we present the development of the analysis software for GRENOUILLE data.

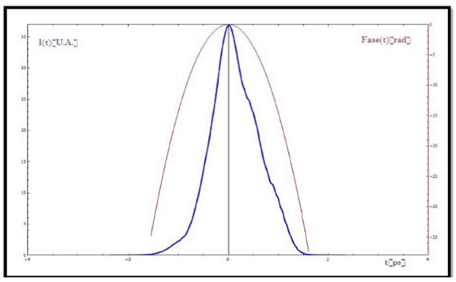
This innovative analysis program is based on the acquisition of an experimental image, which will be cleaned up and calibrated before being used.

Starting from an arbitrary pulse, we create a simulated image and compare it to the experimental data. By using a minimisation algorithm to change the arbitrary pulse, we minimise the distance between the two images, obtaining the laser pulse shape.

The software has been tested on experimental images acquired in the Target Area Petawatt at the Vulcan Facility at STFC RAL (see figures).

The results have been compared to those for a standard single-shot autocorrelator, showing good agreement. The new software will be integrated into the diagnostic system at Vulcan.





Top: GRENOUILLE image. Bottom: Reconstructed pulse

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Image Plate scanner calibrations

M. M. Notley, D. Carroll, R. J. Clarke, D. Rusby, D. Neely *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*

The FUJI Image Plate and associated scanning machine FLA5000 are regularly used at the Central Laser Facility to record and read data from high power laser interaction experiments. The image plates (IP) available (MS, SR, and TR types) are all sensitive in varying degrees to ionising radiation (for example, x-rays, electrons and protons) and are used to detect and record information, while the scanner is used to read and digitize it.

Investigations have taken place using an Fe55 source and test objects (pinhole arrays and a test grid) to verify the linearity of response, noise levels and resolution limits of the FLA5000 scanner in combination with MS, SR and TR-type IPs. The full report details the specific tests carried out and the results.

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Characterization of x-ray lens for use in probing high energy density states of matter

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H. W. Doyle *(First Light Fusion, Yarnton, UK)*
D. C. Carroll, C. Spindloe *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*
M. Calvert, D. Riley *(School of Mathematics and Physics, Queen's University Belfast, UK)*
I. J. Kim, C. H. Nam *(Centre for Relativistic Laser Science, Institute for Basic Science, Gwangju, Korea)*

We outline the use of an x-ray polycapillary lens to focus divergent laser-produced x-ray sources to high intensities, thus achieving an improvement in signal-to-noise ratio compared to conventional backlighter techniques.

In the experiment, line emission produced by driving a titanium backlighter target is focused by the lens and the output characterized. We find that our setup is equivalent to placing the backlighter target 3 mm from the sample with a 600 μm diameter pinhole.

The lens therefore enables the placement of the backlighter target at a much larger distance from the sample to be studied and, therefore, has the ability to greatly improve the signal-to-noise ratio on detectors in high energy density physics experiments. We demonstrate this with two simple diffraction experiments using pyrolytic graphite and polycrystalline aluminium.

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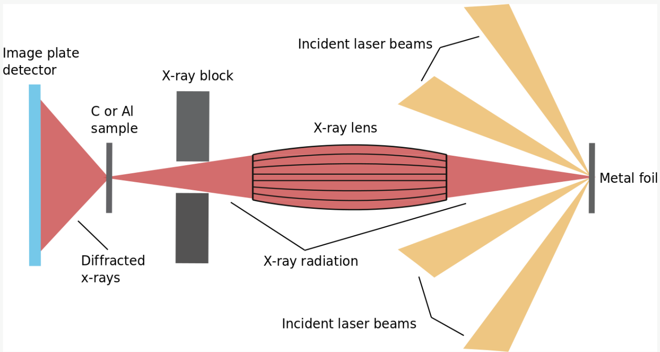

Top-down view of the experimental setup. The incident laser beams drive the He-α transition in the titanium foil on the right hand side of the diagram. The resulting line radiation is focused by the x-ray lens onto the target. The x-rays are diffracted according to Bragg's law and are detected by the image plate. The distance between the titanium target and the sample is 242.3 mm.

DARB: An automated system for diagnostic handling, analysis, review and backup of laser plasma experimental data

R.J. Gray, P. McKenna *(Dept of Physics, University of Strathclyde, Glasgow, UK)*
R.J. Clarke *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*

Through a collaboration between the University of Strathclyde and the CLF, an automated system called DARB has been developed for storing, analyzing, visualizing and backing up data produced during laser-plasma experiments.
This current version is able to operate in a fully hands-off mode, enabling researchers to transfer effort from labour-intensive data registration to data analysis, ideally improving scientific outcomes for laser-plasma experiments. Close integration with the RAL based ECAT data system will be added in the future.

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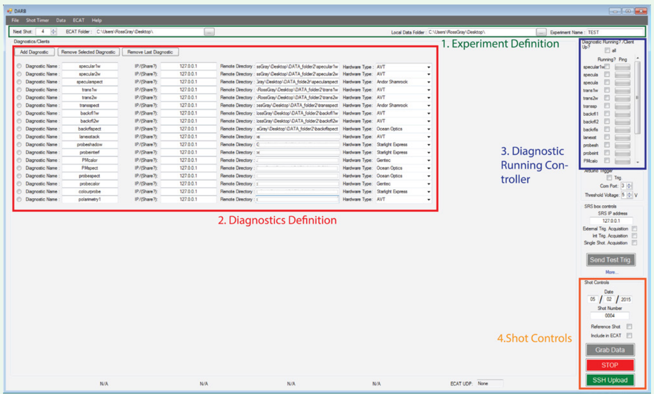


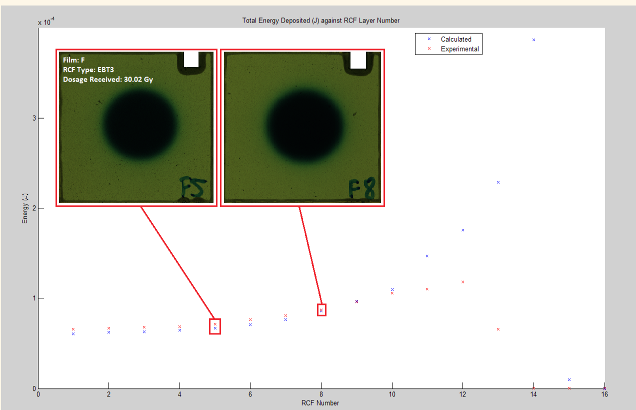
Graphical user interface for DARB software package:
(1) Definition of the experiment name and data folder
(2) Definition of diagnostic name, client IP address, and remote data directory
(3) Activation of diagnostic and ping of remote client
(4) Grab data command.

Validity of the analysis of radiochromic film using MATLAB Code

S.J. Millington, D.C. Carroll, J.S. Green *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*

A series of MATLAB (MATrix Laboratory) code has been written, to create and use calibration files to extract data from radiochromic film (RCF) when used as a diagnostic in laser target interactions. Two types of RCF – HDV2 and EBT3 – were given known dosages of protons at the Birmingham cyclotron, and the data was extracted using the MATLAB code before being compared to data calculated by SRIM (Stopping Ranges in Ions and Matter) software to determine the validity of the code.

The code was tested against single proton energy stacks, as well as a range of proton energies provided by the use of a modulation wheel. The energy deposited, as calculated by the MATLAB code, fit the SRIM calculations more accurately for EBT3 than for HDV2. It was concluded that the test did not provide a fair assessment of the code's ability to generate proton spectra, as the calibration tests did not fit the assumptions made by the code.



Contact: S. J. Millington (samuel.millington@stfc.ac.uk)

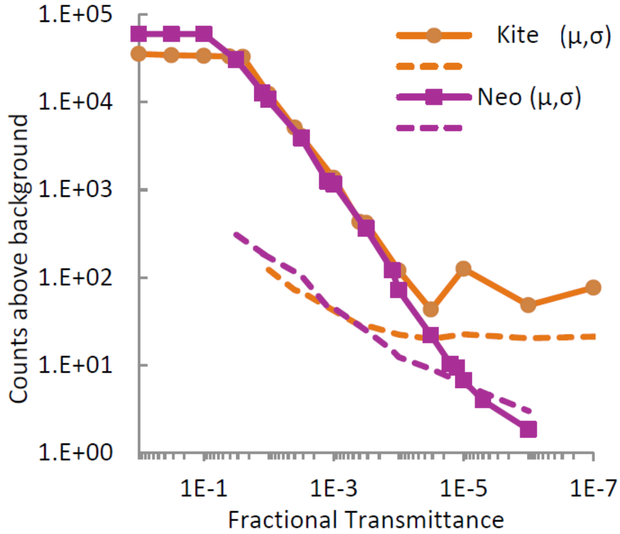
Total energy deposited in active layer (J) against RCF active layer number.
The red displays the experimental data output by the Matlab code, and the blue displays the calculated data output from SRIM software. Overlaid are two pieces of RCF used in the calibration tests, linked to their corresponding data points. Both pieces have been exposed to 30.02 Grays.

Comparison of Cameras: Dynamic Ranges and Sensitivities of optical CCDs.

P. Oliver, A. Horn, R.J. Clarke, D. R. Rusby, G. Scott, L. A. Wilson, D. Neely
(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)

Cameras are used for collecting light and imaging in a wide range of diagnostics. This report details properties and characteristic features of a range of different cameras used in experiments, including charge coupled devices (CCD), electron multiplying charged coupled devices (EMCCD), and complementary metal–oxide–semiconductor (CMOS). The dynamic range and linearity of the cameras are compared, and the different components of noise and their levels for each camera are studied.

Contact: L. A. Wilson (lucy.wilson@stfc.ac.uk)



Linearity curve for Raptor kite EMCCD and Andor Neo CMOS cameras.

Camera operational characterisation: Stingray F-033 and Imaging Source USB DFK 23U274

I. Arteaga, L. A. Wilson, R. J. Clarke, G. Scott, P. Oliver, D. Neely
(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)

Two CCD cameras were characterised to test linear response, dynamic range and background counts. The cameras studied were a monochrome Stingray F-033 and a colour Imaging Source (IS) DFK 23U274.

Uniform green light was shone onto the CCDs, and the fractional transmittance was varied by placing different ND filters in front of the chip. Several pictures were taken for each optical density, and mean counts and standard deviation were recorded for each picture.

It was found that the Stingray had a better linear response to incident light as well as larger dynamic range.

The IS camera was found to have a large increase in background counts due to warming of the camera over use, generating random counts within the CCD chip.

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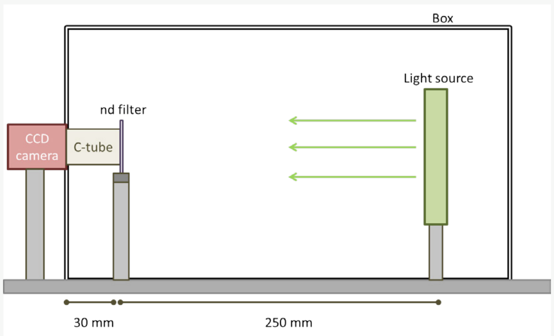

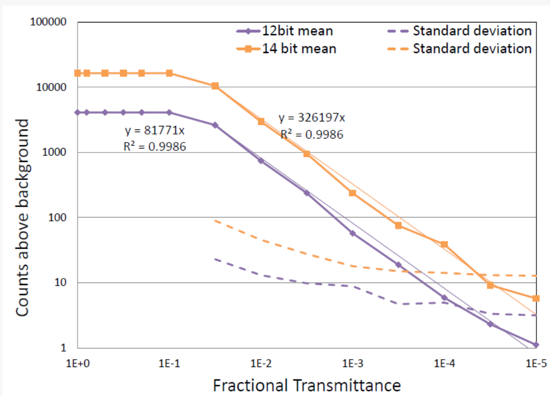

Top: Diagram of the experimental set up.
Bottom: Linearity plot of mean counts and standard deviation vs fractional transmittance of Stingray F-033 at 12 bit and 14 bit

Tip Enhanced Raman Spectroscopy for high power laser target applications

E. Crane *(ECE Paris, France)*
D. Haddock, A. Parker C. Spindloe, M. K. Tolley *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*

The Target Fabrication Group at the Central Laser Facility, in collaboration with Professor Tony Parker, has developed Tip Enhanced Raman Spectroscopy (TERS). TERS is a new characterisation technique that combines the molecular bonding information provided by Raman Spectroscopy with the high spatial resolution offered by Atomic Force Microscopy (AFM). Combining the two techniques allows users to gain information on the chemical bonding nature of a material on the scale of tens of nanometers.

When laser light is incident on a gold-coated AFM tip, there is a large enhancement of the signal from the molecules touching the tip. This signal can be detected by the Raman Spectrometer, providing chemical bonding information for a very small area, just a few tens of nanometers in size. This TERS technique is being developed to provide advanced characterisation information to support the Target Fabrication Group's production of Diamond-Like Carbon and similar materials.

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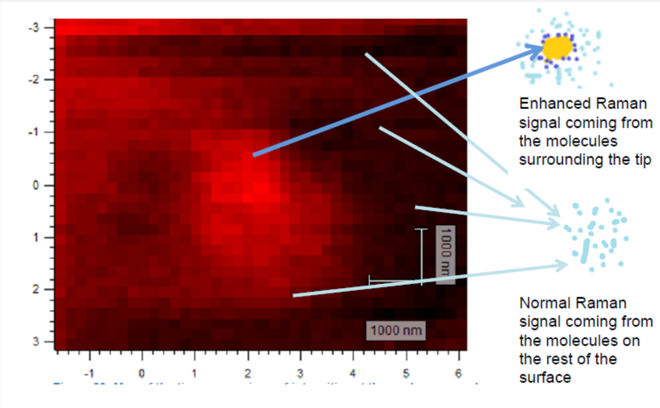
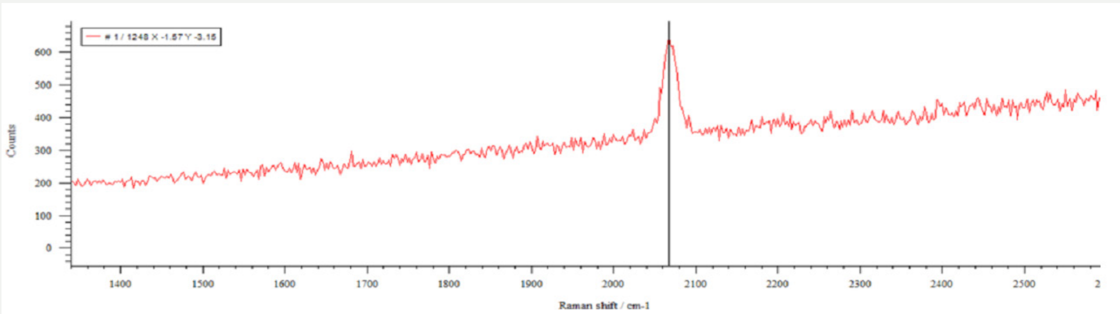


Above: Each pixel represents the intensity of the Raman Spectroscopy signal at the point shown in the spectrum below. Below: The map is the area around a gold coated AFM tip in contact with HCM Rotaxane. The centre of the image clearly shows enhancement of the Raman signal in close proximity to the tip.



Delivery of targets to the 2015 Orion academic access campaign

C. Spindloe, P. Brummitt, D. Wyatt, I. East, M. K. Tolley *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*
J. Foster, E. Gumbrell, R. Charles, P. Graham, J. Firth, J. Skidmore *(AWE, Reading,UK)*
F. A. Suzuki-Vidal, G. Swadling *(Plasma Physics group, Blackett Laboratory, Imperial College London, UK)*
E. Tubman, N. Woolsey *(York Plasma Institute, University of York, UK)*

This paper describes the range of targets that have been produced by the Target Fabrication Group in the CLF, for the academic access experiments on the Orion laser facility at AWE during 2015.

The experiments were carried out by academic groups from the University of York and Imperial College London, with different target designs required for each campaign. During the reporting period, a large number of high specification targets and backlighters have been delivered, and a number of new technologies have been developed to support the programme. This paper reviews the assembly processes, thin film requirements and micro-machining processes needed to produce the targets. Also discussed is the implementation of a gas fill system to produce targets that have an internal fill of gas from 0.3 bar to 1 bar, and the challenges that are posed by such a targets.

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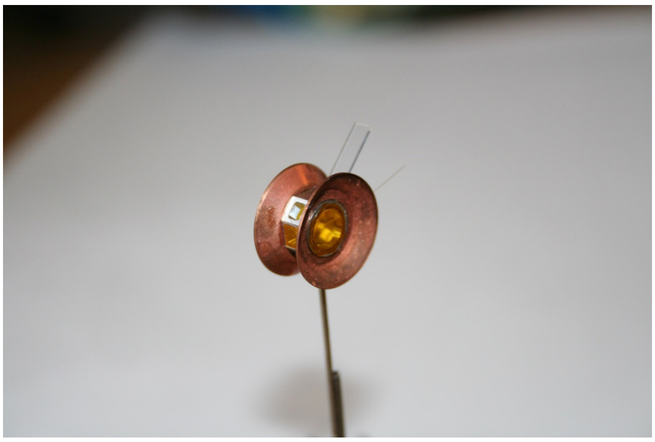

The gas filled target for the Imperial College London experiment in 2015.

Recent developments in the manufacture of cryogenic deuterium target

S. Astbury, D. Carroll, R. Clarke, S. Crisp, P. Holligan, S. Hook, D. Neely, P. Rice, C. Spindloe, S. Spurdle, T. Strange, M. Tolley, S. Tomlinson *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*

Targets made of cryogenic deuterium/hydrogen ice films are currently of significant interest for high power laser experiments. The CLF has been researching and developing a target system to produce thin films of hydrogen and deuterium ice to deliver such targets.

This paper describes developments in the cryogenic target system design including radiation shielding, coldhead and growth chamber redesigns. Operating methodology issues are also discussed. Refinements of the system resulted in the ability to grow deuterium ice films of the order of several hundred microns thick, with survivability in excess of 14 hours.

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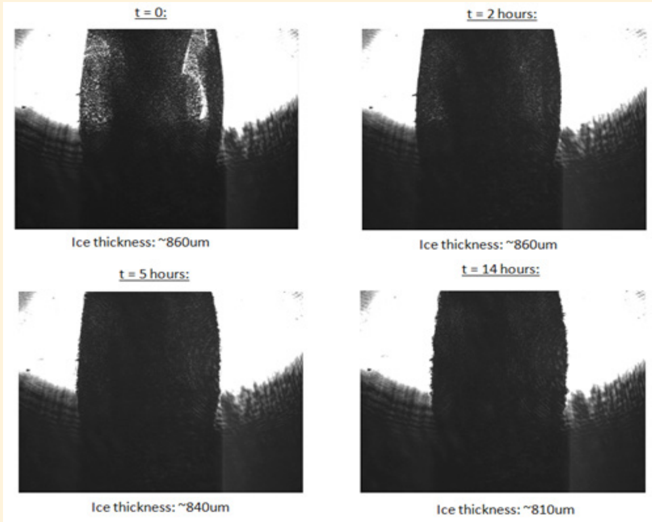


Time-lapse sequence of deuterium ice over 14 hours

The problem with silicon

M. Notley, R. Clarke, R. Heathcote, I. East, D. Haddock, C. Spindloe, M. Tolley
(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)
G. Arthur *(Scitech Precision Ltd, Harwell Science and Innovation Campus, Didcot, UK)*

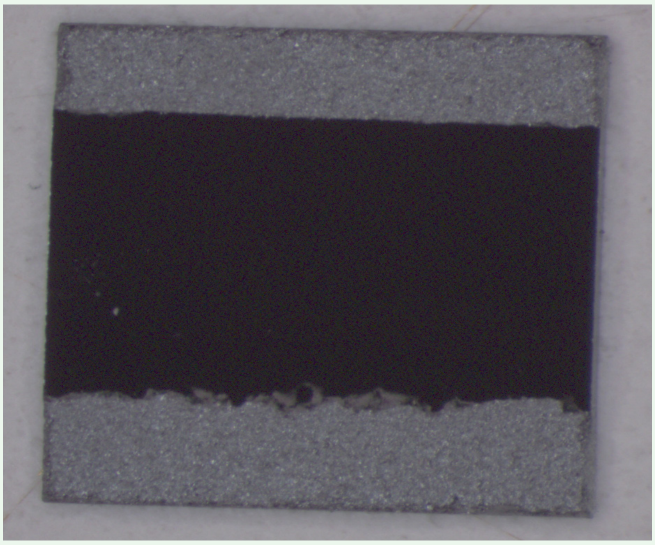
Precise alignment of laser targets, to within Rayleigh range of experiment focusing optics, can usually be achieved by retro imaging[1]. This involves collecting light that scatters off a target from an alignment beam, re-imaging it, and setting the image to be at its smallest size when the target is at the focus of the alignment beam. This has become the standard way to make sure that targets are at focus on experiments using the Vulcan High Power Laser Facility, and is relied upon to guarantee the highest intensity is present on the target. The precision needs to be within the Rayleigh range (30 μm) for the F#3 focusing optics that are used.

Silicon targets are now regularly used in plasma interactions for their lattice structure and resistivity properties[2]. Silicon, however, presents alignment procedure issues with retro-imaging, due to highly polished, flat surfaces and high transmission to the laser light employed (1053 nm) at alignment beam intensities (mW). This polished surface means that silicon targets do not diffusely reflect, giving a very low scatter signal, and rendering retro imaging very difficult to achieve.

This report presents a method and results to mitigate these issues.

References

[1] D. Carroll CLF annual report 2011-2012, 'An imaging system for accurate target positioning for fast focusing geometries'
[2] D.McLellan et al PRL 113 185001 (2014)



Silicon target after solution applied.

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A dedicated target fabrication laboratory for low density materials, polymers and novel materials

A. Hughes, C. Whyte, C. Spindloe, D. Haddock, M. Tolley *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*

W. Nazarov *(School of Chemistry, St Andrews University, Fife, UK)*
G. Arthur *(Scitech Precision Ltd, Harwell Science and Innovation Campus, Didcot, UK)*

This paper describes the capabilities of the recently opened, fully-refurbished chemistry laboratory in the Central Laser Facility within the Target Fabrication Group. The laboratory is dedicated to the production of low density materials, polymer thin films and other novel chemistry-based target components, including electroplating, to deliver to the high power laser programs that are run by STFC.

For a number of years, there has been an increasing demand for low density materials as target components, with foams being the most requested type. A dedicated laboratory for the production of such targets will enable target quality to be increased, and also allow the development of new and more complex materials. This article presents the current capabilities of the laboratory, together with the initial results of the production and characterisation of low density polymeric foams and thin polymer films.

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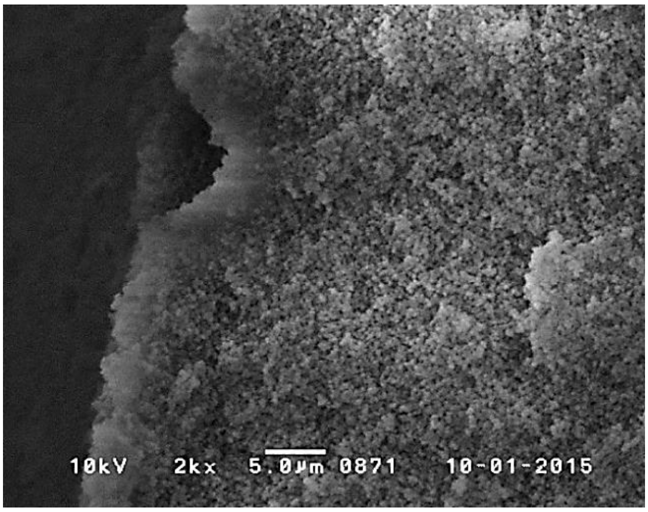

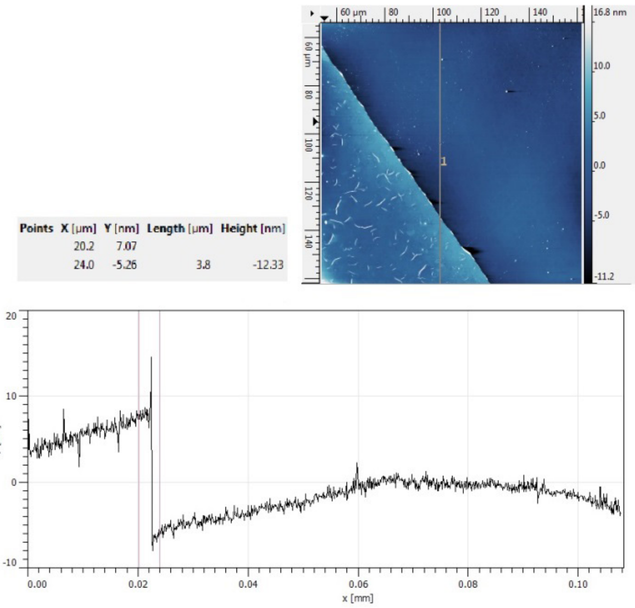

Top: 100mg/cc foam, Au coated, x2000 mag. Image used to characterise pore size used.
Bottom: An AFM scan of a 12 nm thick Formvar film mounted on a silicon wafer.

Artemis operational statistics

E. Springate *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*

The Artemis team delivered a total of seven user experiments from April 2014 to March 2015, as well as two weeks of development projects in partnership with facility users. In total, we delivered 24 weeks of user access and seven weeks of dedicated experiment set-up. Table 1 shows the schedule for the year.

<table>
<tr><th>Week beginning</th><th>Experiment</th></tr>
<tr><td>31/03/14</td><td></td></tr>
<tr><td>07/04/14</td><td>Set-up for Schwenke</td></tr>
<tr><td>14/04/14</td><td></td></tr>
<tr><td>21/04/14</td><td>Development</td></tr>
<tr><td>28/04/14</td><td>Schwenke 13220007</td></tr>
<tr><td>05/05/14</td><td rowspan="2">Laser down</td></tr>
<tr><td>12/05/14</td></tr>
<tr><td>19/05/14</td><td rowspan="2">Laser service and maintenance</td></tr>
<tr><td>26/05/14</td></tr>
<tr><td>02/06/14</td><td>Set-up for Cacho</td></tr>
<tr><td>09/06/14</td><td rowspan="4">Cacho 13220002</td></tr>
<tr><td>16/06/14</td></tr>
<tr><td>23/06/14</td></tr>
<tr><td>30/06/14</td></tr>
<tr><td>07/07/14</td><td rowspan="2">Engineering</td></tr>
<tr><td>14/07/14</td></tr>
<tr><td>21/07/14</td><td rowspan="2">Hollow fibre re-commissioning</td></tr>
<tr><td>28/07/14</td></tr>
<tr><td>04/08/14</td><td rowspan="3">Set-up for Gierz, Monney, Giannetti and Ulstrup</td></tr>
<tr><td>11/08/14</td></tr>
<tr><td>18/08/14</td></tr>
<tr><td>25/08/14</td><td></td></tr>
<tr><td>01/09/14</td><td rowspan="3">Gierz 13220018</td></tr>
<tr><td>08/09/14</td></tr>
<tr><td>15/09/14</td></tr>
<tr><td>22/09/14</td><td>Laser service and maintenance</td></tr>
<tr><td>29/09/14</td><td></td></tr>
<tr><td>06/10/14</td><td>Laser service and maintenance</td></tr>
<tr><td>13/10/14</td><td rowspan="2">Monney 13220016</td></tr>
<tr><td>20/10/14</td></tr>
<tr><td>27/10/14</td><td>Development</td></tr>
<tr><td>03/11/14</td><td rowspan="2">Giannetti 13220003</td></tr>
<tr><td>10/11/14</td></tr>
<tr><td>17/11/14</td><td>Set-up for Schwenke</td></tr>
<tr><td>24/11/14</td><td rowspan="4">Schwenke 13220007</td></tr>
<tr><td>01/12/14</td></tr>
<tr><td>08/12/14</td></tr>
<tr><td>15/12/14</td></tr>
<tr><td>22/12/14</td><td rowspan="2">Christmas shutdown</td></tr>
<tr><td>29/12/14</td></tr>
<tr><td>05/01/15</td><td></td></tr>
<tr><td>12/01/15</td><td rowspan="4">Ulstrup 13220013</td></tr>
<tr><td>19/01/15</td></tr>
<tr><td>26/01/15</td></tr>
<tr><td>02/02/15</td></tr>
<tr><td>09/02/15</td><td>Laser down</td></tr>
<tr><td>16/02/15</td><td>Set-up for Thornton</td></tr>
<tr><td>23/02/15</td><td>Laser service and maintenance</td></tr>
<tr><td>02/03/15</td><td rowspan="3">Thornton 13220017</td></tr>
<tr><td>09/03/15</td></tr>
<tr><td>16/03/15</td></tr>
<tr><td>23/03/15</td><td>Development</td></tr>
</table>

Table 1. Artemis schedule for 2014-15.

Experiments and set-up

Six of the seven 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. The remaining experiment was 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 2014-15 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.

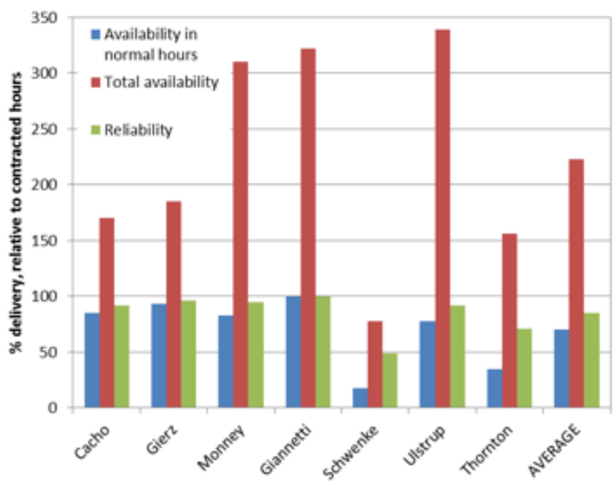

Figure 1. Availability and reliability for user experiments in 2014-15.

The average availability is 223%, very similar to last year. We were able to deliver one two-week experiment without losing any time at all to laser alignment, achieving 100% reliability and availability. However, the overall reliability has dropped from 85% to 70%, because we struggled to deliver two experiments – one due to laser problems (failure of the chiller for the oscillator) and one with faulty XUV filters.

Over the past year, we had two extended periods when the laser was down – both due to problems with the cryogenic cooling and chillers. As a result, we had to change the Ti:Sa crystals in both cryo-heads and lost a total of four weeks' delivery time.

Refurbishment and re-commissioning

The XUV monochromator was refurbished early in the year, with new toroidal mirrors and gratings, which restored the throughput and energy resolution.

The hollow fibre pulse compressor was re-commissioned and used to obtain sub-10 fs temporal resolution and sub-eV energy resolution in a NIR-pump XUV-probe photoelectron spectroscopy experiment on graphene [1]. This was our first test of the XUV monochromator's performance with <25 fs pulses. We were able to change between good temporal resolution and good energy resolution straightforwardly, which was vital to the interpretation of these ultrafast measurements.

Development

This year, development work on Artemis has continued to focus on widening the range of experiments that we can offer.

We started a development project in collaboration with Imperial College on generation of few-cycle pulses at 1.7 micron. It has been shown that the idler from a commercial OPA can be coupled into a hollow fibre to produce few-cycle IR pulses, which can be used to generate harmonics in the water window [2]. Similar technology is now being transferred from Imperial College to Artemis. In the first two weeks of effort here, we completely upgraded the fibre system (Figure 2), showed that we could achieve sufficient spectral broadening to get pulses below 10 fs (Figure 3), and built diagnostics.

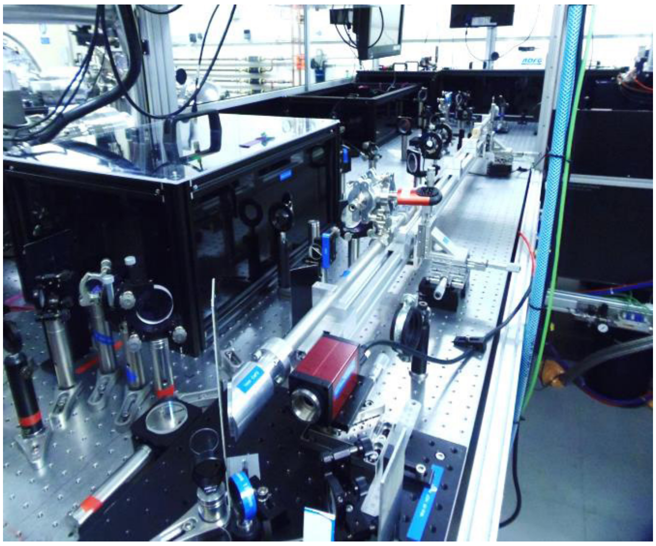

Figure 2. Hollow fibre system for generating few-cycle pulses from the idler of the optical parametric amplifier.

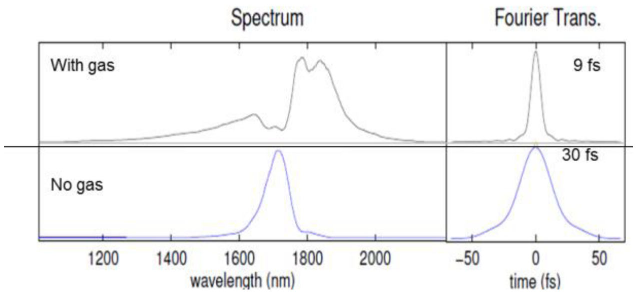

Figure 3. Left: Spectra at the exit of the hollow fibre showing broadening when filled with gas (top), compared to unbroadened spectrum with no gas (bottom).
Right: The corresponding panel shows the corresponding Fourier transform pulsewidths.

We have also continued to develop gas-phase photoelectron spectroscopy experiments with XUV probe, which had previously suffered from low count rate. Last year we installed a molecular beam source to increase the gas density at target. This year, we increased the XUV flux at target by a factor of 30, by using the second harmonic at 400 nm as the HHG drive pulse. Tests incorporating both these improvements showed that the image acquisition time is now sufficiently short to make these experiments feasible, and a proposal was scheduled by the Facility Access Panel.

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2. S. L. Cousin, F. Silva, S. Teichmann, M. Hemmer, B. Buades, and J. Biegert, "High-flux table-top soft x-ray source driven by sub-2-cycle, CEP stable, 1.85-μm 1-kHz pulses for carbon K-edge spectroscopy", Optics Letters 39, 5383 (2014).

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Gemini operational statistics 14/15

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

During the reporting year, April 2014 to March 2015, a total of six complete experiments were delivered to the Astra-Gemini Target Area. In total, 31 high power laser experimental weeks were delivered to the Gemini Target Area, with the delivered schedule presented in Figure 2.

The availability of the Gemini laser system (delivery to the Gemini Target Area) was 84% during normal working hours, rising to 158% with time made up from running outside normal working hours. The reliability of the Gemini laser was 91%. An individual breakdown of the availability and reliability for the six 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 system access slots were made available during the 14-15 operational period. During the first, the entire Femtolasers front end was replaced, including the Synergy oscillator and multi-pass amplifier. The oscillator was replaced with a turnkey Integral Element pro system, which is intended to reduce the system start-up time and is, in principle, a hands-free oscillator. During the second access period, a transmission grating stretcher was installed. This new stretcher was used successfully for the Sarri, Ma and McKenna experiments, and is now the permanent pulse stretcher of the Gemini system (see article in this report by Chris Hooker et al).

Other system developments during the year included the replacement of the Amplifier 1 continuum pump laser for a Quanta Ray system, and the replacement of the Amplifier 2 pump laser for a new, higher energy, Quanta Ray system. All of the 10 Hz multi-pass amplifiers are now pumped by Quanta Ray systems.

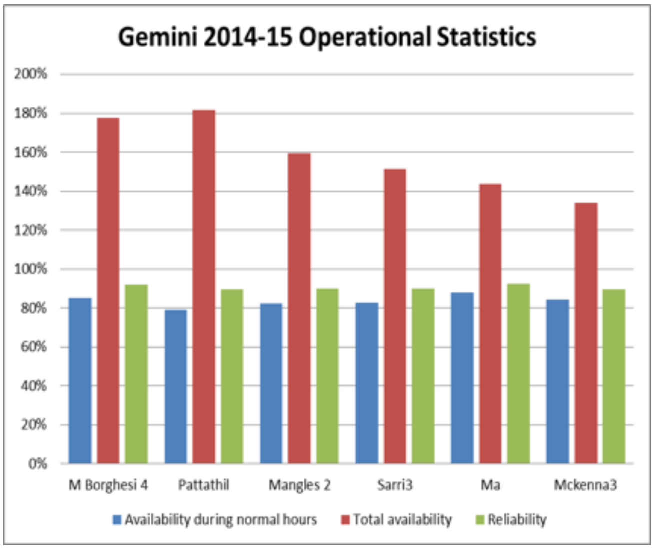

Figure 1. 2014/2015 operational statistics

Contact: S. Hawkes (steve.hawkes@stfc.ac.uk)

31/03/2014	06/04/2014	
07/04/2014	13/04/2014	System Access
14/04/2014	20/04/2014	
21/04/2014	27/04/2014	
28/04/2014	04/05/2014	
05/05/2014	11/05/2014	Set up
12/05/2014	18/05/2014	
19/05/2014	25/05/2014	
26/05/2014	01/06/2014	Borghesi
02/06/2014	08/06/2014	13210014
09/06/2014	15/06/2014	
16/06/2014	22/06/2014	
23/06/2014	29/06/2014	Set up
30/06/2014	06/07/2014	
07/07/2014	13/07/2014	Pattathil
14/07/2014	20/07/2014	13210031
21/07/2014	27/07/2014	
28/07/2014	03/08/2014	
04/08/2014	10/08/2014	Compressor works
11/08/2014	17/08/2014	13210031 (ext.)
18/08/2014	24/08/2014	Quantel Service
25/08/2014	31/08/2014	
01/09/2014	07/09/2014	Mangles
08/09/2014	14/09/2014	13210021
15/09/2014	21/09/2014	
22/09/2014	28/09/2014	
29/09/2014	05/10/2014	
06/10/2014	12/10/2014	
13/10/2014	19/10/2014	System Access
20/10/2014	26/10/2014	
27/10/2014	02/11/2014	
03/11/2014	09/11/2014	Maintenance
10/11/2014	16/11/2014	
17/11/2014	23/11/2014	
24/11/2014	30/11/2014	Sarri
01/12/2014	07/12/2014	13210063
08/12/2014	14/12/2014	
15/12/2014	21/12/2014	
22/12/2014	28/12/2014	Christmas
29/12/2014	04/01/2015	
05/01/2015	11/01/2015	Set up
12/01/2015	18/01/2015	
19/01/2015	25/01/2015	
26/01/2015	01/02/2015	Ma
02/02/2015	08/02/2015	13210052
09/02/2015	15/02/2015	
16/02/2015	22/02/2015	Maintenance
23/02/2015	01/03/2015	
02/03/2015	08/03/2015	McKenna
09/03/2015	15/03/2015	13210040
16/03/2015	22/03/2015	
23/03/2015	29/03/2015	

Figure 2. 2014/2015 Gemini operational schedule

Lasers for Science Facility

B. C. Coles, I. P. Clark and D.T. Clarke *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*

RAL-based experiments

In the reporting period (April 2014 to March 2015), 32 different user groups performed a total of 39 experiments in the Octopus and Ultra facilities laboratories at RAL. A total of 5,623 hours laser time was delivered to the UK user community and European users throughout the year, with 216 hours downtime. Biology and bio-materials formed the majority of the applications (see Figure 1).

A full breakdown of number of weeks applied for versus number of weeks scheduled is shown in Figure 2, indicating an oversubscription ratio of 1.96:1. The RAL-based schedule is shown in Table 1. The average user satisfaction marks obtained from the scheduled users are shown in Figure 3, with an average satisfaction of 92.5% across all categories.

There were a total of 52 formal reviewed publications produced from the year's efforts.

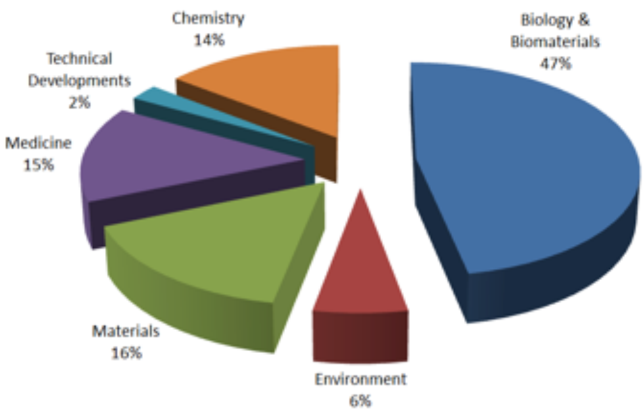

Figure 1. RAL-based bids by subject group

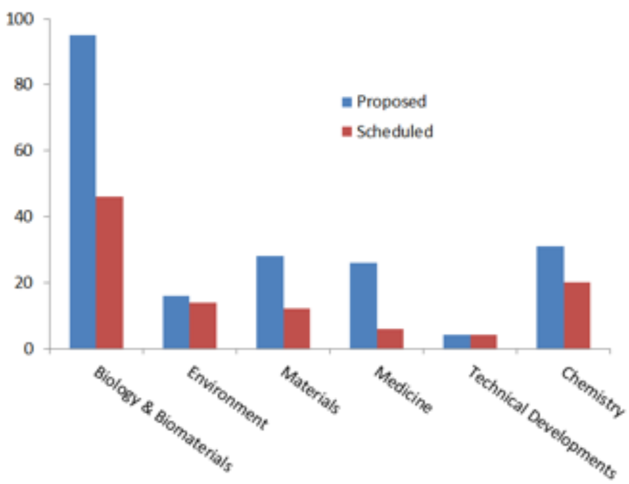

Figure 2. RAL-based experiments by subject

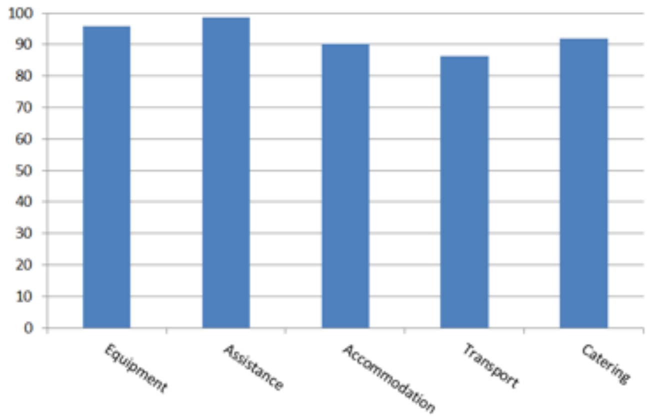

Figure 3. RAL-based average user satisfaction scores

Loan Pool

Throughout 2014/15, the Laser Loan Pool continued to provide laser loans to the UK research community. The facility delivered 328 weeks of laser time in the reporting period, supporting 16 research groups through 17 laser loans, and its work lead to the publication of 10 articles in peer reviewed journals within 2014/15. The ratio of weeks applied for versus weeks scheduled was 2.5:1 and the downtime was approximately 10 %.

At the end of 2014, EPSRC announced that it would no longer fund the Loan Pool, so this was the last full year of operation. To ensure that the community benefits from the assets of the loan pool, an open call was issued for bids from groups wishing to permanently house the loan pool lasers. The assessment process was underway at the time of writing.

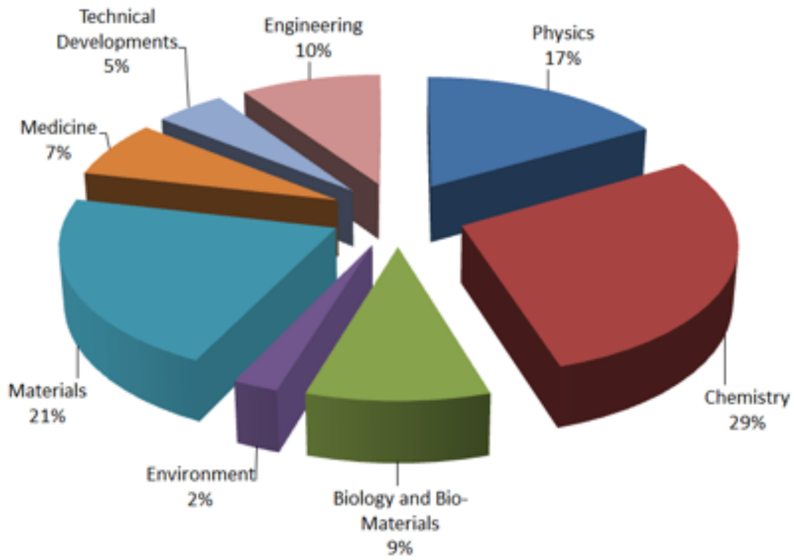

Figure 4. Loan Pool bids by subject group

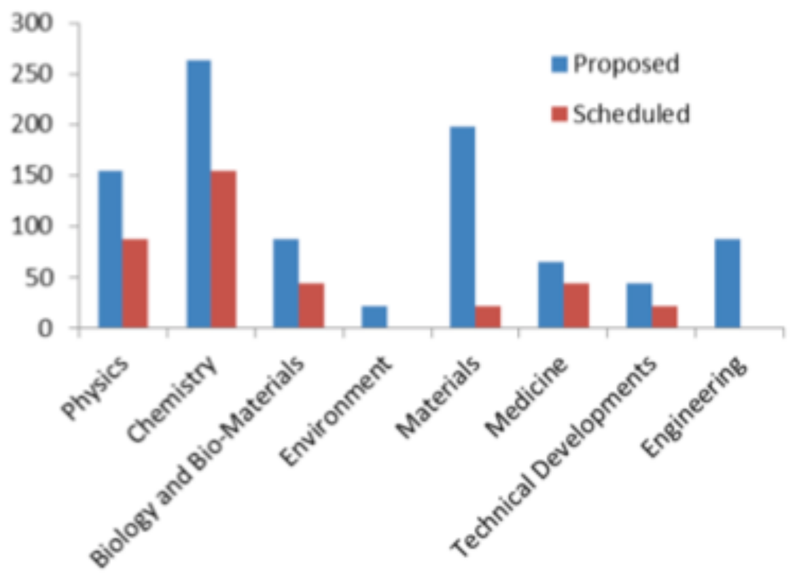

Figure 5. Loan Pool experiments by subject

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Target Fabrication

D. Haddock, C. Spindloe & M. K. Tolley *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*

RAL Experiments

A total of six Gemini and seven Vulcan experiments were supported by the Target Fabrication Group in the reporting period April 2014 to April 2015. The total number of experiments supported increased by three in this reporting period compared with the last. The Target Fabrication Group supported a total of 30 experimental weeks for Astra Gemini and 34 weeks for Vulcan. The total number of weeks support for solid target experiments was 64 weeks, up from 50 in the last reporting period. The Target Fabrication Group also provided targets for two academic access experiments at AWE, which are reported separately within this publication. This report does not include support for other areas of the CLF including Artemis and the LSF.

Target Numbers

For the reporting year, the total number of targets produced is 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 micro-machining to be produced, above and beyond typical target manufacture.

The total number of targets for use at RAL produced by the Group in 2014-2015 was 1,937 compared to 2,507 in 2013–2014 and 1,801 in 2012-2013. During 2014-2015, the number of high specification targets decreased from 334 to 87, accounting for 4% compared to 13% in the last reporting year. The drop can be accounted for by the fact that there were no experiments in this reporting year fielding mass-limited targets, the most popular high specification target last year.

Experiment	Targets Produced	High Specification Targets
0514 GTA	86	5
0614 GTA	73	
0814 GTA	76	20
0814 TAP	165	
0914 TAP	174	8
0914 TAW	240	
1114 GTA	54	
1114 TAW	166	54
1114 TAP	229	
0115 GTA	8	
0115 TAW	330	
0315 GTA	146	
0315 TAW	190	
TOTAL	1942	87

Table 1: Target production summary for 2014-2015. High specification targets include 3D micro-structures, low density targets and mass-limited targets.

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 <500 nm and require a skilled micro-fabricator to assemble them; thick foils make up the rest of the 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 often involve 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 2014-2015
Ultra-thin Foil	530
Thick Foils	708
Multi-layered Foils	500
Alignment	85
3D Micro-structures	82
Foams	5
Mass-limited	0

Table 2: Target category summary. 3D micro-structures are targets that require micro-machining or skilled micro-assembly. Mass-limited targets are targets designed to have minimal support structures.

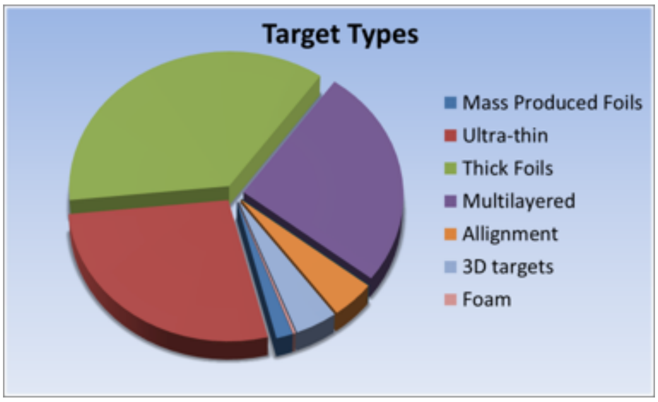

Figure 1: Target delivery summary by type

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; however, for a batch of five foam 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.

Within the total of 1,942 targets, there were 330 unique target variations, which averages six targets per variation. 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 Astra Gemini laser systems.

Experimental Response

It is seen as a significant strength of the Target Fabrication Group 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 can differ, 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 489 targets were modified or redesigned from the target list agreed upon in the planning stage, which makes up 25% of the total targets delivered. In the last reporting year the percentage was 22%, and in the year prior to that the modified percentage was 33%. Three of the thirteen experiments in this reporting period used 347 modified targets; in 0914TAP, 71% of the total targets were modified, 48% for 0914TAW and 75% for 0315GTA. These three experiments were particularly demanding for the Target Fabrication Group, which often produced modified targets in less than a day. Target modifications required significant effort, whether for complete geometry change or alterations to coating specifications.

Adapting to Demand

The Target Fabrication Group endeavours 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.

Foils have dominated the target types during this reporting year and the last, comprising just over 90% of targets delivered.

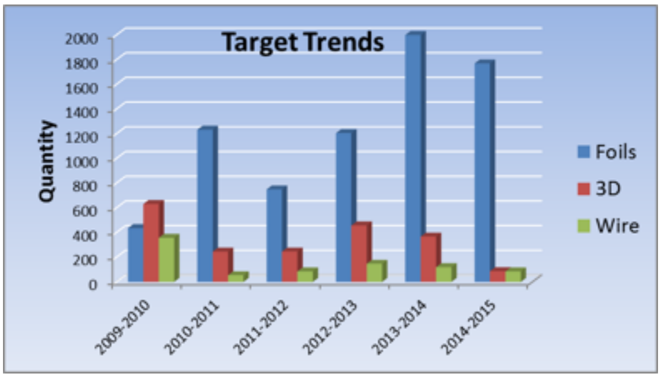

Figure 2: Target numbers produced by type. Foil targets encompass ultra-thin foils, thick foils and multilayered foils. 3D targets include microstructures and foams. Wire targets include alignment and mass-limited targets.

Ultra-thin and multilayer targets are reliant on coating plant capability and have made up over half of the delivered targets. Multilayered targets have been particularly popular, with four experiments requesting over 50% of their targets with coated layers. This is in contrast to last year where there was only one experiment that requested the vast majority of the multilayered targets (1113TAW).

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 at the end of the experiment period and logged. Returned un-shot targets totalled 313, accounting for 16% of total targets made. In 2012-2013 a 19% return of un-shot targets was recorded, in 2011-2012 it was 10%, while for 2010-2011 and 2009-2010 the proportion was 23% and 43% 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 contributes 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 the years before the implementation (2009-2010, 2010-2011).

Less than one percent of targets were returned as non-conforming under the QMS in this reporting period. This number is likely to be inaccurate, as user requests often fail to properly record non-conformities, and instead request additional targets. The Target Fabrication Group is working to improve the recording of these by working with user groups to keep records of which targets they do no use due to non-conformities.

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 six 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 the CLF Target Fabrication Group) 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, characterization, and also full target design and assembly, an increase from 44 in the previous year. The contracts were delivered to external facilities in countries including France, Germany, Italy, India and the USA. In this reporting year, Scitech Precision has supplied phase plates to LULI, LCLS, GSI and other large facilities.

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Vulcan Operational Statistics

A.K. Kidd and T.B. Winstone *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*

Introduction

Vulcan has completed an active experimental year, with 46 full experimental weeks allocated to target areas TAW (Target Area West) and TAP (Target Area Petawatt) between April 2014 and March 2015.

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 is the availability of the laser to target areas during normal operating hours and outside hours operations.

	2014	
07 Apr – 25/18 May	**D Riley** XUV probing of warm dense matter (72, 9, 87.5%) (88.2%, 115.4%)	**S Kar** A novel scheme for simultaneous focusing, energy selection and post-acceleration of TNSA proton beam (113, 17, 85.0%) (73.3%, 108.4%)
28 July – 31 Aug	**M Roth** Probing new laser driven ion acceleration schemes with thin cryogenic targets (47, 9, 80.9%) (90.4%, 101.7%)	
22 Sep – 26 Oct	**G Gregori** Laboratory study of carbon white dwarf crystallization using high power lasers (99, 9, 90.9%) (87.9%, 114.8%)	**N Woolsey** Extreme X-ray radiation fields created during an ultra-intense laser-solid interaction (93, 9, 90.3%) (82.8%, 109.7%)
10/17 Nov – 21 Dec	**D Riley** Structure of warm dense matter (155, 18, 88.4%) (89.2%, 117.7%)	**P McKenna** Towards mono-energetic ion acceleration via shocks driven by tailored laser (125, 28, 75.8%) (78.3%, 109.0%)
	2015	
26 Jan – 15 Feb	**M McMahon** Probing ramp compressed metals using single photon energy dispersive X-ray diffraction (147, 11, 92.5%) (92.3%, 113.6%)	
9 Mar – 22 Mar	**DSTL** (100, 6, 94.0%) (94.9%, 119.4%)	
23 Mar – 5 Apr	**C Brenner** X-ray imaging with laser sources (136, 17, 87.5%) (83.2%, 113.7%)	

Table 1: Experimental schedule for the period April 2014 – March 2015

(Total shots fired, failed shots, reliability)

(Availability normal, additional hours)

The total number of full disc amplifier shots that have been fired to target this year is 1,087. Table 2 shows that this figure compares very favourably with recent years. 133 shots failed to meet user requirements. The overall shot success rate to target for the year is 88%, compared to 89%, 92%, 89% 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
10 - 11	764	87	89%
11 - 12	641	54	92%
12 - 13	860	93	89%
13 - 14	1015	121	88%
14 - 15	1087	133	88%

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.

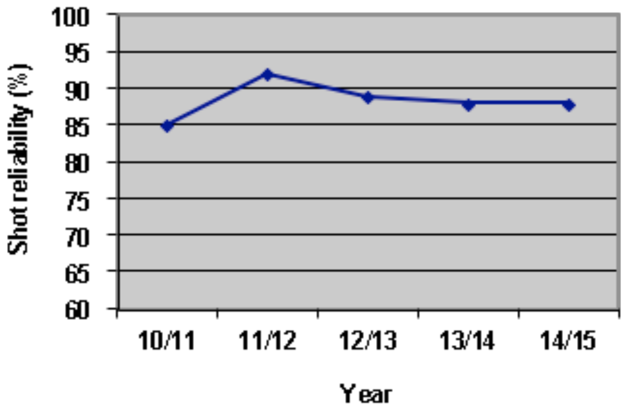

Figure 1. All areas shot reliability for each year 2010-11 to 2014-15

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 experimental period). The laser has not always met the start-up target of 09:00, 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 85.3% of the time during contracted hours, compared with 78.8% for the previous year. Although this is encouraging, the overall availability is down from 119.2% in 2013-14 to 111.9% 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.

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CONFERENCE PROCEEDINGS

ARTEMIS

Isabella Gierz, Matteo Mitrano, Hubertus Bromberger, Andrea Cavalleri, Cephise Cacho, Richard Chapman, Emma Springate, Stefan Link, Ulrich Starke
Controlling Dirac Carrier Dynamics in Graphene via Phonon Pumping
International Conference on Ultrafast Phenomena 2014 – P2.48 (2014)

Cephise Cacho, Jesse Petersen, Isabella Gierz, Haiyun Liu, Stefan Kaiser, Richard Chapman, Edmond Turcu, Andrea Cavalleri, and Emma Springate
Mid-IR Pump, EUV Probe Femtosecond Time-and-Angle-Resolved Photoemission Spectroscopy
International Conference on Ultrafast Phenomena 2014 – P1.35 (2014)

CALTA

J. Phillips, S. Banerjee, P. Mason, J. Smith, M. Sawicka, M. Divoky, K. Ertel, T. Butcher, M. de Vido, T. Davenne, M. Fitton, O. Chekhlov, J. Greenhalgh, W. Shaikh, O. Wagner, C. Hernandez-Gomez, and J. Collier
Frequency Doubling at 7J of a High Energy, High Repetition Rate DPSSL System
CLEO: Applications and Technology 2014 – JW2A.70 (2014)

T. Butcher, P. Mason, S. Banerjee, J. Pilar, M. Divoky, J. Smith, M. De Vido, J. Phillips, K. Ertel, O. Chekhlov, S. Tomlinson, W. Shaikh, J. Greenhalgh, I. Musgrave, C. Hernandez-Gomez, and J. Collier
Front End Design for a Temporally and Spatially Shaped 100 J Diode-Pumped Solid-State Laser
Advanced Solid-State Laser Conference 2014 – ATh2A.50 (2014)

Jodie Smith, Jonathan Phillips, Klaus Ertel, Paul Mason, Saumyabrata Banerjee, Tom Butcher, Mariastefania De Vido, Justin Greenhalgh, Cristina Hernandez-Gomez, and John Collier
Dark-Field and Laser Performance Diagnostics for a 100J 10Hz Amplifier System
International Committee on Ultra Intense Lasers Conference (2014)

P. D. Mason, S. Banerjee, K. Ertel, P. J. Phillips, O. Chekhlov, M. De Vido, T. Butcher, W. Shaikh, J. Smith, S. Tomlinson, M. Galimberti, C. Hooker, R. J. S. Greenhalgh, C. Hernandez-Gomez, and J. Collier
Pump Laser Design for a 10 Hz PW Class Laser System
International Committee on Ultra Intense Lasers Conference (2014)

Saumyabrata Banerjee, Klaus Ertel, Paul Mason, Jonathan Phillips, Jodie M Smith, Mariastefania De Vido, Thomas Butcher, David Richards, Justin Greenhalgh, Cristina Hernandez-Gomez, and John Collier
DiPOLE: A 10 J, 10 Hz multi-slab cryogenic gas cooled Yb:YAG amplifier
6th EPS-QEOD Europhoton, Neuchatel, Switzerland (2014)

GEMINI

S. Mangles, M. S. Bloom, J. Bryant, J. M. Cole, A. Doepp, S. Kneip, H. Nakamura, K. Poder, M. J. Streeter, J. Wood, R. Bendoyro, J. Jiang, N. C. Lopes, C. Russo, O. Chekhlov, K. Ertel, S. J. Hawkes, C. J. Hooker, D. Neely, P. A. Norreys, P. P. Rajeev, D. R. Rusby, R. Scott, D. R. Symes, J. Holloway, M. Wing, and J. F. Seely
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Reducing the contrast pedestal in CPA lasers
International Conference on Ultra-Intense Lasers, ICUIL Goa, India (2014)

THESES

HIGH POWER LASER FACILITY

Dance, R
Measurement and Modelling of Fast Electron Transport in Solid Materials
PhD Thesis, University of York (2014)

Powell, H
Ion Acceleration in Ultrathin-foils Undergoing Relativistic Induced Transparency
PhD Thesis, University of Strathclyde (2014)

MacLellan, D
Effect of Electrical Resistivity on Fast Electron Transport in Relativistic Laser Plasma Interactions
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Scott, G
On the use of multiple high intensity laser pulses in ion acceleration experiments
PhD Thesis, University of Strathclyde (2014)

Fox, T
Strong Shock Wave Generation by Fast Electron Energy Deposition in Shock Ignition Relevant Plasmas
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Foster, P
Characterisation of Plasma Mirror Activation and Laser-Driven Ion Studies
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Rittershofer, W
Laser Wakefield Acceleration in Tapered Plasma Channels: Theory, Simulation and Experiment
PhD Thesis, University of Oxford (2014)

Ulstrup, S
A Direct Investigation of the Electronic Structure of Graphene - Tunability, Many-Body Interactions and Ultrafast Dynamics of Dirac Fermions
PhD Thesis, Aarhus University (2014)

Peli, S
Unfolding the ultrafast interplay between delocalized wavefunctions and localized electronic interactions in quantum correlated materials
PhD Thesis, Università degli Studi di Milano (2015)

Panel Membership and CLF Structure

LASERS FOR SCIENCE FACILITY ACCESS PANEL 2014/15

REVIEWERS

Professor R. Perutz FRS (Panel Chairman)
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University of Edinburgh

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Radcliffe Department of Medicine
University of Oxford

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Department of Physics
University of Strathclyde

Professor C. Kaminski
Department of Chemical Engineering and Biotechnology
University of Cambridge

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University of Oxford

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University of Bristol

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Dr S. Quinn
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MRC

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Professor M. Towrie (Molecular & Structural Dynamics)
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Dr M. Martin-Fernandez (Functional Bio-systems Imaging)
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Dr C. Stubbs (Panel Secretary)
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ARTEMIS FACILITY ACCESS PANEL 2014/15

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Université de Genève, Switzerland

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University of Duisburg-Essen, Germany

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Optoelectronics Research Centre
University of Southampton

Professor S Dhesi
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Dr R. T. Chapman (Artemis, AMO and Imaging)
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VULCAN, ASTRA TA2 & GEMINI FACILITY ACCESS PANEL 2014/15

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Professor S. Rose (Panel Chair)
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Imperial College London

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Professor P. Gibbon
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Forschungzentrum Julich, Germany

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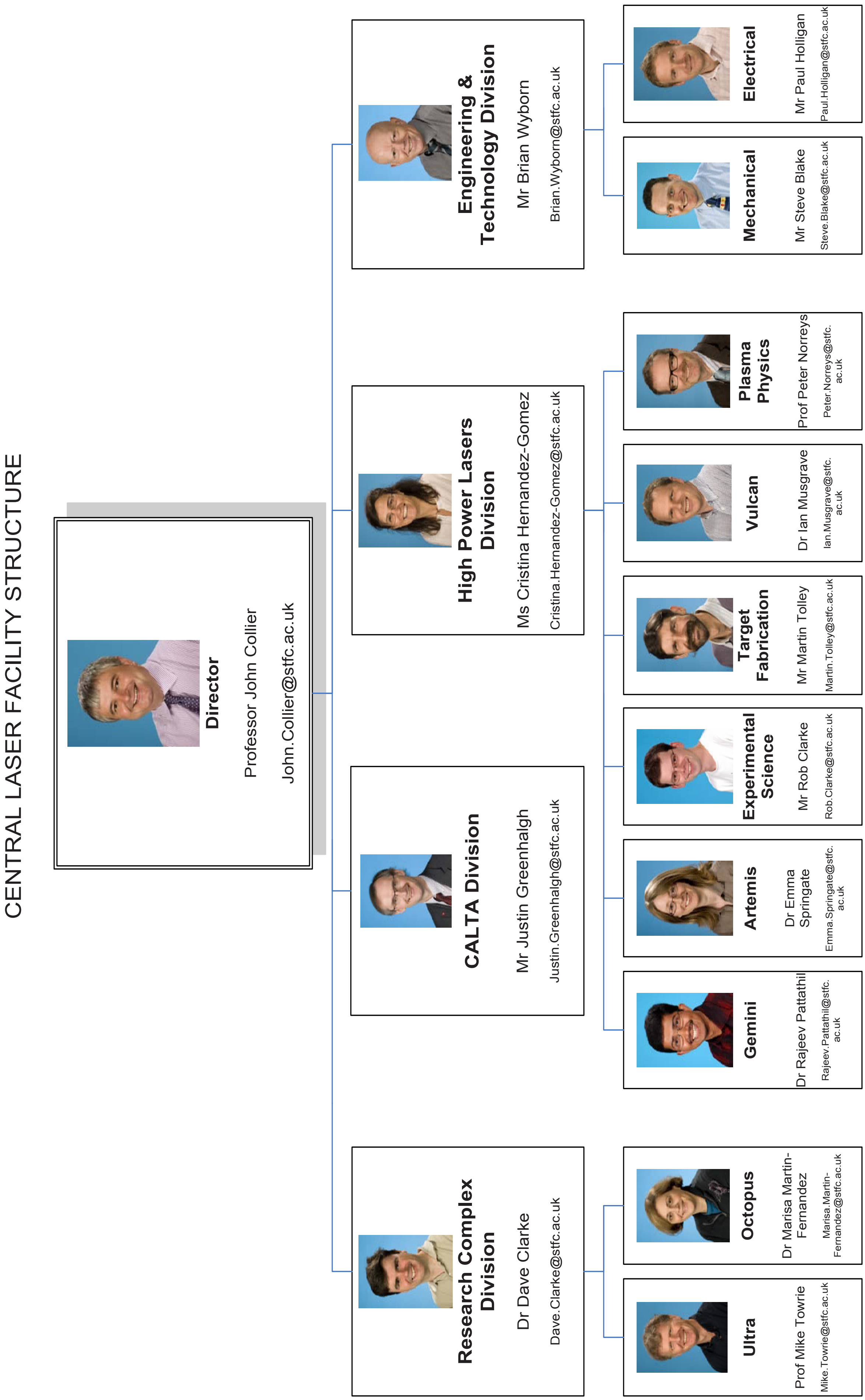
Mr R. J. Clarke (Experimental Science Group Leader)
Central Laser Facility, Science & Technology Facilities Council

Dr R. Pattathil (Gemini Group Leader)
Central Laser Facility, Science & Technology Facilities Council

Dr D. Symes (Gemini Target Area Section Leader)
Central Laser Facility, Science & Technology Facilities Council

Dr N. Booth (Panel Secretary)
Central Laser Facility, Science & Technology Facilities Council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