CLF 2013 - 2014

Central Laser Facility Annual Report

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The front cover represents a programme of work in ULTRA studying dynamic effects in DNA crystals and in solution.

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Foreword

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This annual report for the Central Laser Facility (CLF) at the STFC Rutherford Appleton Laboratory provides highlights of the scientific and technical research which has been carried out by users of the Facility and its staff over the financial year 2013-14.

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** – A new OPCPA pre-amplifier has been commissioned to replace the original pre-amplifier that had been in service for over 10 years. It has resulted in increased reliability and reduced downtime.

- **Gemini** – delivered 35 weeks of cutting-edge science in the last year (its highest number yet), along with 12 weeks of access in its Target Area 2. Experiments performed in this period have produced high impact scientific results, including those published in Nature Communications and Physical Review Letters and the first ever tomographic imaging of a human bone tissue using a laser-generated betatron source.

- **Artemis** – experiments on Artemis are continuing to reveal the potential of graphene as a material for electronics and optoelectronics. Femtosecond pulses of extreme-ultraviolet light are used to capture the electron dynamics at the Dirac cones in graphene, responsible for its extraordinary electronic properties. The measurements show that a population inversion can be produced in graphene, using an infrared laser as a pump – a surprising result as graphene lacks a band-gap. The second laser amplifier was upgraded this year for higher pulse energies. The experimental capabilities have also been extended, adding end-stations for ultrafast demagnetisation and coherent imaging, and a differentially-pumped gas source for the AMO end-station.

- **Ultra** – The time resolved vibrational facilities on ULTRA have addressed many fundamental molecular dynamic problems spanning the physical and biological sciences. This year the construction of the LIFEtime instrument will build on recent ULTRA developments that open up new studies on protein function and DNA damage that span timescales over 10 decades of time from 200 fs to milliseconds.

- **Octopus** – All the super-resolution microscopes funded by BBSRC and MRC have been commissioned, and have been used for a number of user programmes. For example, the first installation in the UK of a STORM microscope capable of rapidly acquiring two-colour, 3D super-resolution images has provided images of the cytoskeleton at 50 nm resolution at 0.5 Hz. Adaptive optics has been applied to single molecule tracking for the first time in TIRF imaging and this is one of the building blocks of a new project that has started to combine multifocal techniques, adaptive optics and STORM super-resolution imaging, with the goal of achieving 20x20x20 nm resolution in whole cells. Finally, a recent collaboration with Unilever, funded through STFC's Collaborative R & D scheme, is investigating the structure of human tyrosinase using single-molecule techniques.

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.

The CLF have a strong and impressive background in Economic Impact, providing solutions to industry and making a positive difference to society. There has been significant work establishing new relationships with industry and in raising awareness of CLF technology, techniques and capabilities at national and international level. Funding made available through STFC's Business and Innovations Directorate enabled access to OCTOPUS for two companies, Evotec and Unilever, whilst a direct commercial contract with DSTL lead to a successful campaign in Gemini. The CLF's "Universal Motor Controller", developed through STFC Proof of Concept funding has progressed into a fully operational "demonstration kit". The technology allows the "plug and play" control of any motor type through an easy to use web based interface and will shortly feature in mainstream outlets.

CLF's spinout company Cobalt Light Systems has successfully deployed its non-invasive bottled liquid screener Insight100 across EU airports. Its scanners are now operational at 8 out of 10 largest EU airports and 65 EU airports in total. The deployment represents the first phase of the lift of the restriction on carrying liquids on the board of plane. The instruments are used to scan medical essentials such as baby milk or medicine taken on board and duty free items in transfers. The technology is also deployed at 9 out of 10 of the largest pharmaceutical companies in quality control applications. The CLF spinout Scitech Precision Ltd continued to sell microtargets and phase plates to an increasing number of international customers.

CLF's Centre for Advanced Lasers and Applications (CALTA) has successfully completed its first major contract and is progressing well with its second, to deliver a 100J version of the DiPOLE laser to the HiLASE project in the Czech Republic. CLF has also been awarded a grant to supply a similar laser system to the XFEL project as a UK contribution in kind, and other systems are in discussion.

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

Target Area Petawatt is Vulcan's highest intensity area it is capable of 500J/500fs pulses focused to 10^{21} W/cm^2. The ps OPCPA front end ensures that the ASE contrast of the PW system is better than 10^{10} at 1ns. To complement the short pulse beamline, an additional 250J long pulse beam line as well as a variety of possible probe beams that can be configured in the area. This year a new OCPA pre-amplifier has been commissioned to replace the original system, this new pre-amplifier is capable of higher pulse energies and has an improved energy stability.

Target Area West is Vulcan's most flexible target area offering up to 8 long pulse beams or 2 short and 6 long pulse beams. The two short pulse beams operate independently and can be configured so that one operates at 80-100 J / 1 ps (10^{20} W/cm^2) and the other one at either at 80-100 J / 1 ps or at 300 J / 10 ps in flexible geometries. 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 8 beams in long pulse mode The maximum energy that can be delivered is 2.5KJ when all 8 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.

Gemini

This high rep-rate Petawatt laser based on Ti:Sapphire technology has a unique capability to offer 2 synchronised beams, each with a power of 0.5 PW and a repetition rate of one shot every 20 seconds. The facility will enable interaction studies up to 10^{22} Wcm^{-2}. F/20 and F/2 beam focusing options are available, with a built-in plasma mirror set-up in one beam line for high contrast pulse delivery. In recent years the contrast of the compressed pulses from Gemini has been improved to the point where it is good enough for all but the most sensitive experiments, and for those the dual plasma mirror system is available. This year has seen the implementation of adaptive mirrors on both Gemini beam lines. One is a commercially made mirror while the other is a home-built one. This installation has streamlined focal spot optimization on a routine basis, which had a significant impact in the experimental delivery. In addition, to increase the reliability of the Gemini facility the oscillator that seeds Astra-Gemini has been replaced by a Femtolasers Integral Element Pro, which is a sealed, turnkey system with its own DPSSL pump laser built in. It produces an average modelocked output power of >500mW at 85 MHz with a pulse duration of <20 femtoseconds.

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 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, two of which are new this year. The UHV end-station for time-and angle-resolved photoemission spectroscopy (ARPES) with XUV pulses is equipped with hemispherical electron analyser, five-axis cryo-manipulator, sample preparation chamber and fast load-lock. In this reporting year, a second UHV chamber for time-resolved photoemission has been commissioned. This is equipped with a low noise level electron time-of-flight analyser, magnetisation coils and MOKE. E-beam heating, ion sputtering and LEED/Auger are available for in-situ sample preparation. The atomic and molecular physics end-station contains a velocity map imaging detector and has been upgraded this year with a differentially pumped gas source. The flat-field spectrometer is used for high harmonic generation (HHG) spectroscopy and for HHG optimisation experiments. This year a coherent XUV imaging chamber with multilayer focusing mirrors and sample positioning has been installed.

In this reporting year, the Artemis laser system has been upgraded with a new second stage amplifier, increasing the pulse energy available from the system to 12 mJ at 1 kHz.

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

In the imaging area, the *Octopus* cluster offers a range of microscopy stations linked to a central core of pulsed and CW lasers offering “tailor-made” illumination for imaging. Microscopy techniques offered include total internal reflection (TIRF) and multi-wavelength single-molecule imaging, confocal microscopy (including multiphoton), fluorescence energy transfer (FRET) and fluorescence lifetime imaging (FLIM), 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.

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

Engineering Services

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

Theory and Modelling

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

Target Fabrication

A high quality target fabrication facility is operated within CLF delivering advanced microtarget production capabilities integrated with experiments. The facility deploys a wide range of complementary target production techniques such as microassembly, thin film coating (including diamond like carbon) and foam production. Many microcomponents are produced in collaboration with the STFC micromachining and MEMS facilities. Extensive characterisation capabilities underpin all microtarget production and R&D programmes. Target Fabrication is ISO9001 accredited. Commercial access to target fabrication capabilities is available to external laboratories and experimentalists via the spin-out company Scitech Precision Ltd. This year progress has been made in the introduction of cryogenic thin film hydrogen/deuterium targets. The facility has also extended its capability to produce mounted ultrathin (few nm) foils in a range of materials. Further advances have also been made on a high accuracy wheel system populated with MEMS-produced targets deployable against medium to high repetition rate drivers.

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 that is principally focussed on the industrial and commercial application of high power lasers and the by-products 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 in 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 10 Hz or above repetition rate. A conceptual design of a cryogenic Yb:YAG amplifier that can be scaled to kJ energy levels and beyond, owing to its geometry, unique laser design and cooling technique has been developed.

A lower-energy DiPOLE prototype amplifier system has been built and is currently operational, delivering routinely 7J /10 Hz with good energy stability. This year CALTA has focussed on the delivery of a £10.3M contract to supply a 100 J DiPOLE to the HiLASE project in the Czech Republic. The base line design of the 100 J DiPOLE has been completed and a new cleanroom has been commissioned to allow the building of this commercial system.

The CLF will continue to develop multi-Petawatt technologies that are crucial to a future upgrade to the Vulcan high power laser to 20 Petawatt (PW). This includes developing dielectric Adaptive Optic mirrors, ultra broadband optics such as diffraction gratings and the realisation of specialised large aperture crystals required in multi Petawatt facilities. This year a dielectric-coated deformable mirror has been developed operating at 800nm. To test large DKDP crystal's performance we have now established a components test laboratory adjacent to the 20 PW Front End. This consists of a single stage of OPA pumped by temporally shaped pulses amplified by a Nd:glass rod amplifier chain and subsequently frequency doubled. The coming year will see amplification of broad band pulses up to 7 J of energy.

Access to Facilities

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

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

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

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. Novel technologies and techniques developed in the course of our science programme are proactively assessed for their exploitation potential.

Economic impact stems from:

- Demonstrating our capability
- Engaging and partnering with Industry
- Reaching out to National and International networks
- Leveraging external funding
- Ensuring our intellectual property is recognised, protected and utilised to maximise return
- Supporting existing spin-out companies and forming new ones where appropriate
- Engaging with the public, in particular through outreach to schools and colleges
- Addressing the big challenges - Security, Energy, Environment and Healthcare

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 economic impact activities for FY13/14, which are in addition to the significant new contracts for CALTA (see separate article in this report). Over the year, income in excess of £500k has been generated. There has been a lot of work establishing new relationships with industry and in raising awareness of CLF technology, techniques and capabilities at national and international level.

Industry Engagement

Funding made available through the Business and Innovations Directorate enabled access to OCTOPUS for two companies, Evotec and Unilever. This work is expected to lead to new interactions and open new opportunities with other parts of these organisations. BAE Systems commissioned a desk study that was conducted by the CLF theoretical physics group. Again this contract has enabled additional engagement with other departments within BAE opening up the potential for future collaborations.

Winning Contracts and External Funding

A proposal to develop new methods to enhance pulse contrast using transmission gratings was submitted to ELI-ALPS in Hungary and was successful.

The novel imaging programme in collaboration with DSTL continued with a very successful campaign in Gemini. This work was performed under contract with DSTL.

Proposals into the CFI fund from Artemis and HPL developing new detector technology were successful and have received funding to proceed. These projects will enhance our capabilities and advance our commercial interaction programmes.

Spin Out Companies

Spin out companies are important not least because of the benefit they provide to UK society by enabling economic growth through wealth and job creation.

Cobalt Light Systems Ltd. now employ 40 staff. Sales of the INSIGHT100 liquid scanning machine now exceed 300 units installed in more than 65 airports across the globe, including Heathrow terminal 5.

Scitech Precision Ltd. SPL are looking to further broaden and develop their portfolio. During this year SPL amalgamated with Colsicoat Ltd. a move that has strengthened SPL and allowed new skills in coating technology to be brought into the company. New opportunities lie in high repetition rate targetry, both in the positioning and manipulation of multiple targets and in the manufacture of the targets themselves.

Demonstrating Capability

Funding has been secured through the Harwell Imaging Partnership (HIP) for an experimental campaign in Vulcan TAW in March 2015 to further demonstrate the imaging and diagnostic capabilities of Laser Driven Sources. HIP also agreed to fund a 3 year PhD studentship with Strathclyde in this area. This innovative project will bring together academics and industry from aerospace, automotive, nuclear and high value manufacturing.

A new Technology Demonstration area has been agreed as part of the R1 refurbishment and will be ready by the end of 2014. This will provide a professional environment in which to meet with industry partners and demonstrate CLF technology, processes and techniques.

International Engagement

In June a scoping mission to China resulted in new opportunities being identified for CLF expertise, particularly in laser based microscopy and single molecule imaging for health applications. These will be followed up as appropriate in the mid to long term. STFC (CLF) exhibited at Photonics West in the USA which was important in communicating our capabilities on an international stage. Significant support was provided to UKTI in the promotion of opportunities for UK business through the Extreme Light Infrastructure (ELI) programme.

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. A noticeable step-change towards high profile opportunities to communicate CLF work is apparent in this year's report, while still maintaining a high level of outreach via the usual outlets. Opportunities for communication and engagement have been diverse and reached many new audiences. From featuring alongside fellow research councils in government to coverage in major media outlets such as Radio 4's Inside Science and a front cover feature in SPIE Professional magazine, to a newly established artist research residency.

Figure 1: Marisa Martin-Fernandez and Pavel Matousek representing CLF on the Lasers for Health stand

CLF science in parliament

In June 2013, CLF science was invited to represent STFC during a 'Science of Health and Wellbeing' themed event in the Members' Dining Room of the House of Commons, hosted by the Parliamentary Office of Science and Technology. The exhibit, entitled 'Lasers for Health', featured examples of biomedical work carried out on the Octopus and Ultra systems as well as CLF spinout Cobalt Light System's work on bone disease diagnosis. CLF senior research fellows in these areas manned the stand and spoke about the science presented (see figure 1). The event featured stands from all seven research councils and was well attended by parliamentarians.

Engaging the public

As part of the Rutherford Appleton Laboratory public lecture series, CLF hosted an evening of talks that answered the question 'What can lasers do for you?'. The evening was well-attended, with an audience of almost 100 people made up of attendees from all age groups, from 'less than 11' to '65+'. Just over 70% of the audience voted that they strongly agreed the talks were 'enjoyable and interesting'.

Figure 2: Laser Extravaganza public talk proved very popular

Figure 3: Ceri Brenner speaks to the public in the RAL lecture theatre

CLF staff were on-hand at the STFC Light Fantastic public event at The Cornerstone in Didcot, running a popular laser workshop that explored the properties of laser beams and how they help us explore worlds that we cannot see with just our eyes. Ceri Brenner was invited to speak as part of the IOP London branch public lecture series held at Aldermaston and the IOP in London, entertaining enthusiastic audiences with a talk entitled "Super intense lasers: the bright approach to exotic plasma physics".

CLF science is also reaching the public via the blogosphere with Chris Tynan's piece on using lasers for illuminating cell communications, published on the Wellcome Book Prize website as part of a review of the science in Adam Rutherford's book Creation.

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 7 articles released during the reporting period. Examples of CLF stories that have been picked up include coverage of Diamond Light Source experiments implementing CLF's laser trapping capability, a major contract win for CALTA to develop DiPOLE 100 J and results from the Gemini laser showing that Einstein's flying mirror thought experiment was spot on. There was also coverage of funding received to upgrade the Octopus and Ultra systems for studying cell behavior, Prof. Peter Norreys' Institute of Physics award and CLF's contribution in helping a UK company gain a contract to deliver a target chamber to the CETAL Petawatt facility in Romania.

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.

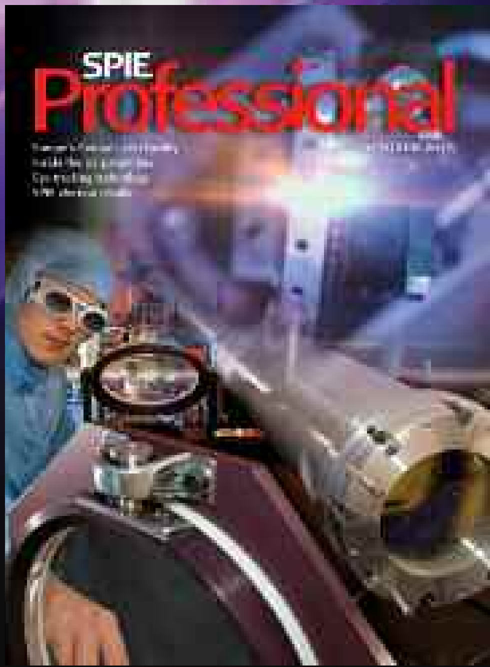

Figure 4: Front cover of SPIE Professional featuring images of the CLF

CLF workspaces have also been caught on camera during the filming of an interview with @Bristol as part of a STFC large public engagement award, as part of footage for a documentary on climate science and an intriguing timelapse of the Vulcan TAP gatevalve being replaced can now be found on the STFC youtube channel.

In the media spotlight

CLF work has been broadcast over many media platforms this year, further extending outreach of what we do to new and diverse audiences, both technical and general public. CLF science carried out on the high-power laser systems was one of five up-and-coming areas of research selected to present during the 'You Heard It Here First' event hosted by the British Science Festival in September 2013. The event is geared towards engaging the media with exciting and emerging areas of research and was well attended by both members of the science media and general public. It was voted as 'most interesting' by media attendees and 'most impact on my life' by general public attendees.

The lively sounds within the Gemini laser bay were captured during an interview for Radio 4's Inside Science programme for their 'Show us your instrument' feature. The programme aired during peak listening hours and the clip remains on the BBC iPlayer service. Following on from the British Science Festival media event, the Naked Scientist radio programme featured an interview with Ceri Brenner on research carried out on the CLF's high power laser systems.

CLF staff have twice this year been invited to contribute to features in photonics sector publications, with a special feature on the CLF written for SPIE Professional magazine and a feature on high-power laser amplifiers for Electro-optics magazine.

Visits and tours

The CLF continues to welcome visitors and host tours around the facility. Over the reporting period, 1246 people have visited the CLF, an increase of more than 20 % over last year's total. Great use has been made of the CLF visitor centre as a venue for hosting meetings, introductory talks and as a starting point for group tours, which has enabled this increase in capacity for visitors.

Artist Research Residency

An artist research residency has been initiated this year, in collaboration with and funded by two renowned orgnisations 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 3 months, to engage with both the science and the scientists in order to inspire their creative work. Ceri Brenner represented the CLF on the interview panel alongside Nick Kaplony, ArtQuest programme co-ordinator and Nicola Triscott and Sandra Ross, Director and Curator, respectively, of The Arts Catalyst. In early 2014 it was announced that Alistair McClymont was the selected artist who was to be given "*a unique opportunity to develop his practice (and potentially a new body of work), through a period of intense research and engagement with leading scientists and the frontier science that they conduct at* *the Central Laser Facility*". Coverage of the residency has so far been documented on Alistair's 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*." We anticipate many new and exciting ways to communicate CLF science will come out from this residency, as well as CLF staff and users gaining communication and outreach skills from their time spent engaging with an artist on their technical field of expertise.

Figure 5: Images from Alistair McClymont's blog of the residency, exploring light generated in beta barium borate crystal with Mike Towrie (left) and laser damage of optics with Chris Hooker (right).

Inspiring the next generation

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 6 weeks. Over the reporting period, the CLF has been able to host 11 school students in the facility through the RAL work experience placement scheme. A great demonstration of the effectiveness of these programmes was shown this year when two of the students who spent time in the plasma physics group during August 2013 were accepted onto Oxford DPhil placements to study high power laser plasma interactions.

Figure 6: Michael Hirsch speaking at Barking and Dagenham College

There still remains much participation by CLF staff in the STEM ambassador scheme, which includes visits to local schools and career events. For example, Stan Botchway spent time with Didcot Girls School to help with their use of microscopes in the classroom and well as passing on valuable advice on correct maintenance and service.

CLF science was used to inspire attendees of The Skills Show Experience at Barking and Dagenham College with a talk given by Michael Hirsch on 'How to become a Scientist'. Ceri Brenner gave a talk entitled "What would YOU do with the most powerful laser in the world?" in the famous Faraday Lecture Theatre of the Royal Institution for the IOP Physics in Perspective conference. Over 300 A-level students attended and enjoyed the interactive parts of the talk during which they used voting pads to answer questions posed by Ceri. The talk was also recorded and is available to the public on the IOP youtube channel. Ceri also assisted the IOP Stimulating Physics programme of teachers conferences by giving keynote talks during their York and Cardiff sessions on 'Super Intense Lasers: bringing research to reality'.

Figure 7: Ceri Brenner speaking at IOP teachers conference in Cardiff

CLF supported the International Youth Physics Tournament coming to the UK for the first time by hosting an Executive Committee meeting for the event at the Cosener's House and pledging sponsorship. Peter Norreys was later invited to give a keynote talk at the opening event, which will take place at the beginning of July 2014.

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

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. Individual high-level contributions to such meetings during 2013-14 total 20 conferences. The CLF has been responsible for organising and hosting a number of conferences and user meetings throughout the year, including the 5th Target Fabrication workshop series, which was initiated by the CLF in 2004 and has grown to a biennial series of international meetings.

Figure 8: HPL Community Meeting 2013

The CLF hosted The 15th European Conference on the Spectroscopy of Biological Molecules (ECSBM15) in Oxford in August 2013 and also ran a two-day workshop on Laser Diagnostics, funded by Laserlab-Europe, at the Cosener's House. The CLF continues to host the High Power Lasers (HPL) Community Meeting and the HPL and Artemis user forums and this year also hosted the UK 8th High Energy Class Diode Pumped Solid State Lasers (HEC-DPSSL) Workshop in Oxford in March 2014. CLF maintains links with the Culham Plasma Physics Summer School and has organised for lectures to be hosted at RAL as well as tours of the CLF for all of the 60 PhD students involved.

Outside of the UK, the CLF has been engaging with the African Laser Centre in South Africa and was invited to their 10th anniversary in early 2014.

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.

CALTA – The Centre for Advanced Laser Technology and Applications

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Introduction

STFC has established CALTA at the CLF to develop DiPOLE, a new kind of laser, and to encourage applications of all our technology in wider society.

Technology

Our next-generation technology development centres around a Diode-pumped solid-state laser called DiPOLE. Because diodes provide the power for the laser, such systems are much more efficient than the current competing technologies for high power (petawatt level) lasers. Improved efficiency, together with their robust and compact nature, means that this technology could ultimately be made transportable for remote site operations. Another important feature of DiPOLE is that the design is scalable to very high energy (~kJ) pulses. DiPOLE currently produces 10J pulses and a 10Hz repetition rate, and we are building the next generation which will produce 100J pulses at the same repetition rate.

In addition to DiPOLE, CALTA can access all of the technologies developed at CLF over many years in pursuit of its core scientific mission.

Collaboration with ELI

In January 2014 we made the final deliveries of a 10J DiPOLE head to our colleagues at the Extreme Light Infrastructure in Prague. Meanwhile work on the 100J DiPOLE that we are building for HiLASE, another major Czech infrastructure project, proceeds apace – the latest milestone being completion of the refurbished clean laser lab in which the laser will be built here at CLF for integration and testing. This will be a truly world-class laser system.

Application areas

With access to high-power lasers, including in due course DiPOLE, a raft of application areas opens up. The laser light can be applied directly, perhaps in areas such as laser materials processing. Or, with suitable targets and detectors, imaging techniques such as ultrafast X-ray imaging will become possible. CLF's background technology in areas such as simultaneous control of multiple motion systems, is also applicable in a range of settings.

Figure 1: The DiPOLE amplifier head (14EC1568)

Applying laser light

We expect that pulses of light at 100J with a repetition rate of 10Hz will find applications in traditional areas of laser materials processing such as shot peening, and also in new areas not currently accessible to lasers. Other possible applications include diverse fields such as communications, medical applications, and laser-driven fusion. We are working to engage potential industrial users.

Lasers as radiation sources: X-ray imaging and more

In its current form, DiPOLE produces pulses of a few nanoseconds' length. Shortening these pulses will of course increase the power level, and with 100J of energy it is feasible to reach power measured in petawatts (PW). The advent of PW class lasers brings with it the possibility to generate a variety of different types of radiation. For example, x-rays can be generated for use in imaging applications. The pulse of radiation is very short (of order of picoseconds, ps) which means that motion in the image is "frozen". The radiation source can be made very small (sub-mm), which minimises the need for collimation. Finally it is bright enough that a single ~ps pulse can form an image of a large object. This raises the possibility of being able to image, for example, the blades of a gas turbine in an X-ray image taken while it is running. And the fact that DiPOLE runs at 10Hz raises the possibility of x-Ray movies. But X-rays are only one of the types of radiation that can be generated when a laser hits a target. We are working with potential customer communities to push forward these areas, exploiting the fact that that we can trial applications using spare capacity on CLF's laser suite. This allows us to establish strategic partnerships at an early stage and so guide other activities in order to ensure that CALTA's effectiveness is as high as it can be. For example, this year we demonstrated, using Gemini, what will be possible using electron backscatter imaging – a new and potentially game-changing imaging technique.

Figure 2 – The new DiPOLE 100 lab, in which the laser for HiLASE will be built, nearing completion (top) and being formally opened (bottom). (14EC2507 & 2531)

Applying other high power laser technology

CALTA has access to a wealth of technology developed in CLF over the years.

A beam stabilization system has been developed to handle multiple interacting control demands. The most obvious application is to stabilise very large laser systems but other complex equipment with multiple controls can also benefit from this technology.

Our engineers have produced a simple, elegant safety interlock system with a unified interface which works across all our laser systems. While the most obvious application is to other major laser systems, any facility which needs controlled access with multiple points of entry can benefit from this technology.

With many motorised systems to control for beam shutters, mirrors, and so on, we faced the problem of interfacing their multiple manufacturer's drive systems to our own unified system. We have developed a "universal" motor controller card, and an intuitive user interface, to allow simple control of a large number of motorised functions across different platforms. This could readily be applied in other major facilities but also in any setting where multiple motorised systems need to be managed.

We have developed advanced adaptive optics systems to keep our various laser beams stable as thermal gradients in the optics and the air tend to distort them. In order to provide Chirped-Pulse Amplification (CPA) with high-power lasers, we have developed diffraction gratings capable of withstanding very high energy pulses. We are working to refine optical parametric amplifiers which use non-linear crystals to add pump energy to a seed laser, and we are working on beam combination to allow the beams from two lasers to be added coherently to act a single laser of double the power.

Conclusion

All of CLF's technology, and the development of DiPOLE, puts CALTA in a good position to generate real societal impact and we are now steadily following CALTA's business plan with major contract wins from the Czech Republic and developments in other areas.

References

1. The CALTA website: http://stfc.ac.uk/calta/
2. The ELI Beamlines website: http://www.eli-beams.eu/

High Intensity/Energy Science

The evolution of plasma shock waves on the sub-microsecond timescales

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This report describes the use of a fast multi-frame camera in assisting the diagnosing of laser-produce shock waves.

The experiment was conducted at TAW, Vulcan using a cluster of laser beams, with intensity 10^{15} W/cm^2, which was focused onto a 500 μm carbon rod to produce a plasma that expanded into 0.7 mbar of argon gas. The self-emission, from the plasma and the shock-wave propagating through the background gas, can be imaged using a 16 frame camera on the ns timescales. In acquiring 16 ultrafast images on a single shot, the observations of the shock dynamics aids immediate assessment during an experimental campaign and enables more accurate understanding of the complex dynamics during data analysis.

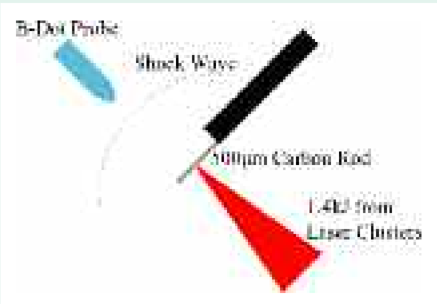

Figure 1. A schematic of the experimental setup for this experiment to measure the magnetic field across a shock wave. The 6 infrared beams were focused into a single spot on a 500 μm carbon rod. This drove a shock wave which propagated out towards a B-dot probe.

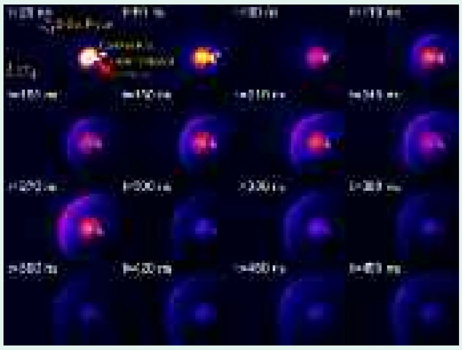

Figure 2. A set of the 16 images each with a 5 ns exposure taken by the SIM16 camera on one laser shot of the self-emission from a plasma shock wave. The shock wave expands out over time towards a B-dot probe, through an Ar background gas. The times shown are relative to when the laser cluster irradiates the carbon rod target.

Single Photon Energy Dispersive X-ray Diffraction (SPEDX)

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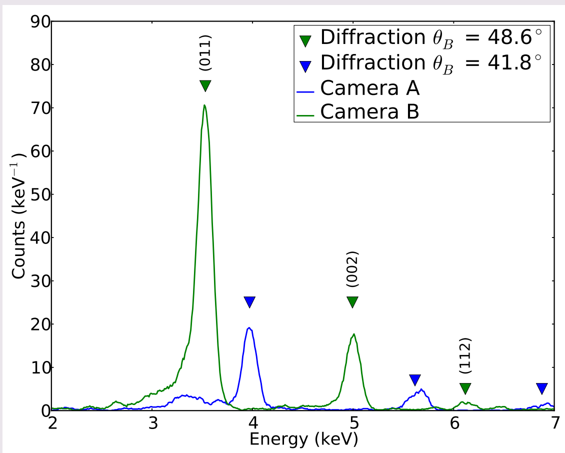
Advances in high power laser facilities have enabled the generation of solid state matter in increasingly extreme states allowing for studies of conditions found inside planetary interiors. Laser-driven experiments not only drive the target to these extreme conditions but also present a significant challenge for diagnostics where survival of the diagnostics themselves and the data on them is at risk.

Single Photon Energy Dispersive X-ray diffraction (SPEDX) is a technique being developed which will enable in-situ x-ray diffraction experiments to be performed at these large laser facilities.

In the report we present experimental results from TAW which demonstrate the first SPEDX from laser-shock compressed targets. In addition a novel mode of operation was used which allowed for a maximum shot rate of once every 10 minutes.



Spectra measured of static tantalum from two CCD cameras at indicated Bragg angles.

Laser-Driven Ion Acceleration in a Hybrid RPA-TNSA Regime

3

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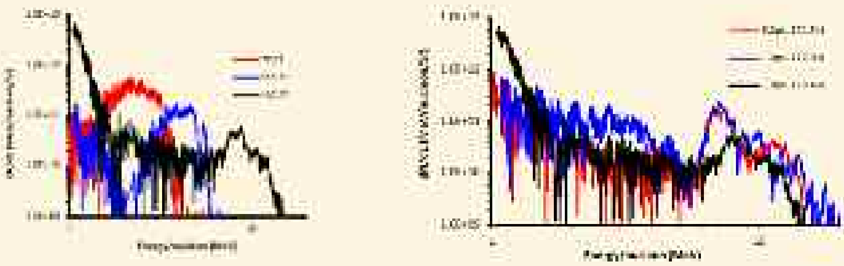
Evidence of narrow band features in the ion spectra produced by irradiating ultra-thin (10nm) high Z foils with the intense Vulcan Petawatt laser are presented. The energy of the observed peaks in the carbon spectra are a two-fold increase compared to those obtained with thicker foil targets at the same facility. A systematic scan over several laser and target parameters yielded data which extended the quadratic scaling of the ion energy with the dimensionless RPA scaling parameter previously reported. One of the key findings of the campaign was the observation of similar ion energies even after the temporal stretching of the laser pulse by a factor of 5, underpinning the role of laser fluence, rather than laser intensity, in the RPA regime.



(a) The C^{6+} ion spectra of three different shots with three different values of $a_0^2\tau_p/x$ showing an increase in the peak energy with an increase in the value of $a_0^2\tau_p/x$. (b) C^{6+} spectra obtained from three shots on 10 nm Au targets of [energy on target (J), pulse duration (ps)] [171.54, 5.2], [177.00, 1.0] and [179.46, 1.0] in red, blue and black respectively, showing no increase in peak energy with temporal stretching of the laser pulse.

Magnetic Field Dynamics during Intense Laser Channeling in Underdense Plasma

4

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Investigations of channel formation in an underdense (~0.001 n_c) deuterium plasma following intense laser pulse propagation, and of the resulting magnetic field dynamics, were carried out in Target Area West.

Two laser pulses were utilised, an interaction pulse (120 J, 15 ps, 1053 nm) and a probe pulse (60 J, 1 ps, 1053 nm) incident on a 25 μm Au foil. The probe pulse created a beam of protons via TNSA for use by a proton probing imaging (PPI) diagnostic.

A combination of 2D PIC simulation and particle tracing was used to analyse the evolution of the MG magnetic fields formed during channel formation, which were consistent with the presence of a relativistic electron current along the channel's axis. These findings may have relevance to the Fast Ignitor scheme for ICF.

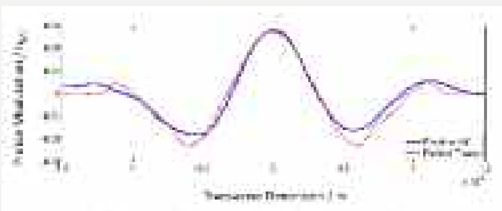

Figure 1: Comparison of the proton modulation for the experimentally observed data (solid blue) and the particle tracer data (dashed red).

Figure 2: Comparison of (a) B_0, (b) r_B and (c) L_r between the PIC simulations (blue line) and the particle Tracings (red points).

Proton spectra calculation from Radiochromic Film stacks with high-energy proton correction

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In laser plasma experiments it is important to fully characterise the ion beam that is generated. Radiochromic Film (RCF) is frequently used for characterising the beam, as a single film gives a two-dimensional proton beam profile. RCF is used in a stack diagnostic with multiple layers of RCF with alternate metal filters, this allows a coarse spectrum to be retrieved.

Typically though, when retrieving spectra from a stack diagnostic, it is assumed that protons only deposit energy in the layer of RCF that it stops in.

In this report, we first present the typical method of approximate spectrum retrieval, and secondly, we show that by using an iterative algorithm the true spectrum can be calculated.

We have shown that using the approximate method, the total number of protons can be overestimated by 2.4, and the conversion efficiency from laser energy to beam energy can be overestimated by 2.2.

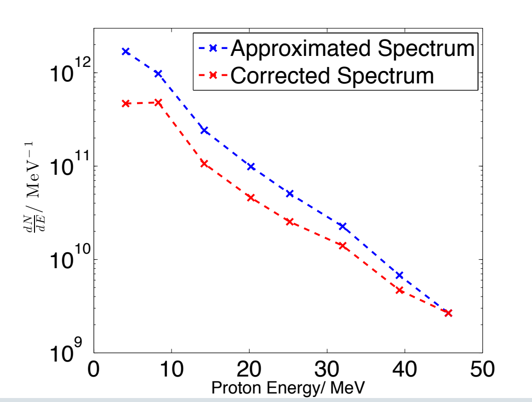

Figure 1: The original approximate spectrum, and the spectrum after being corrected using the computational process summarised in figure 5. The protons were accelerated from a 100nm thick plastic target irradiated by a 392J 1ps pulse focussed to a 9μm spot.

Diagnosis of high-energy photon emission during imaging experiments using copper activation techniques

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Optimising the photon yield and spectrum for imaging applications requires the use of multiple diagnostic techniques, all designed to look at specific spectral windows. For the high-energy components standard techniques using scintillators and image wrap-around stacks are ineffective as their sensitivities at high-energies is very poor. In this paper we present data obtained from the copper activation techniques, observing photons >10MeV, their directionality, scaling and dependence on target and laser conditions.

Detection of laser driven deuterium ions by employing differentially filtered image plate detectors in Thomson spectrometers

7

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We demonstrate a novel method for characterising the full spectrum of deuteron ions emitted by laser driven multi-species ion sources. The procedure is based on using differential filtering over the detector of a Thompson parabola ion spectrometer, which enables discrimination of deuterium ions from heavier ion species with the same charge-to-mass ratio, such as C^{6+}, O^{8+}, etc.

During the experiment, Fuji Image plates were used as detectors in the spectrometer, whose response to deuterons could be absolutely calibrated over a wide range of energies using the differential filters and slotted CR-39 nuclear track detectors.

As well as for characterisation of ions with same charge-to-mass ratio, this technique would also be well suited for other applications, including the filtering of a proton track in a magnetic spectrometers or the characterisation of highly energetic ions, where the tracks are merged and cannot be distinguished.

M-L band emission x-rays (3-3.5KeV) from palladium coated targets for isochoric radiative heating of thin foil sample

8

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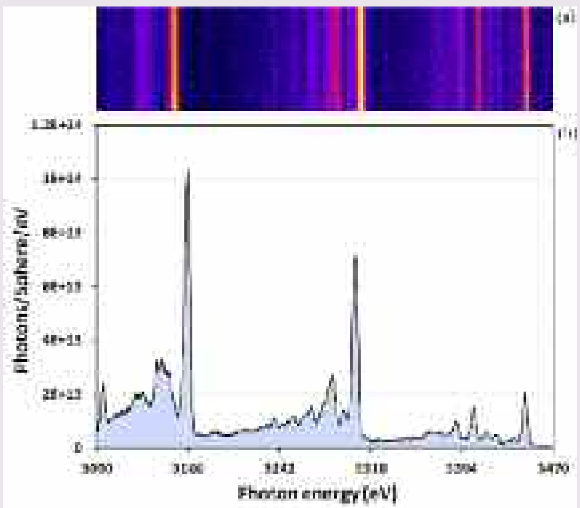
A bright L-shell band x-ray source designed for radiatively heating thin sample foils to warm dense matter conditions is described. Palladium coated targets were irradiated with 10^{15}W/cm^2 laser pulses (200ps, 2ω) in TAW, Vulcan. This led to nearly 3% conversion from laser energy into M-L band x-rays of similar pulse duration, within the 3-3.5keV range. See figure 1. This emission has been seen before but is further characterised. In particular, the front and rear emission for various thicknesses of palladium coating was investigated. Emission just below the aluminium L-edge (1475-1550eV) is also reported, and the possibility of using the source to radiatively heat a thin aluminium foil sample to warm dense matter conditions is discussed.



Sample spectrometer data. Target was 50nm Pd on 13.1µm CH. (a) Raw data from CCD; (b) processed lineout.

High efficiency proton beam generation through target thickness control in femtosecond laser-plasma interactions

9

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In this article, we report on an experimental investigation into ion acceleration on Astra Gemini which can produce a focused intensity of ~10^{21} W cm^{-2}. This is comparable to the highest intensity Nd:Glass systems but in a relatively compact area and operating at a significantly higher repetition rate.

The interaction of this laser with aluminium target foils, ranging in thickness from 100 nm to 50 µm, generated proton beams which were then characterised. The variation of the maximum proton energy as well as the total beam energy as a function of target thickness will be shown. We demonstrate that a Ti:Sapphire based laser system can not only be used to produce proton energies in excess of 30 MeV through sheath acceleration, but also produce high average doses, marking an important breakthrough for high repetition rate studies.

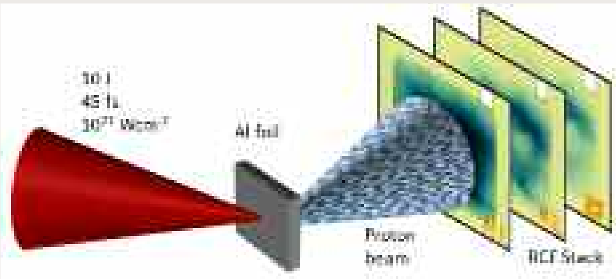

Fig1 - Overview of experimental set-up showing Astra Gemini interaction beam and radiochromic film (RCF) stack.

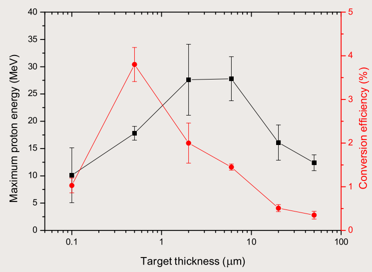

Fig 2 - Maximum detected proton energy (squares) and conversion efficiency (circles, for proton energies > 0.9 MeV) as a function of target thickness for Al foils. Data plotted are averages taken over a number of shots for each target thickness.

Investigation of collective electron dynamics in relativistically transparent laser plasma interactions

10

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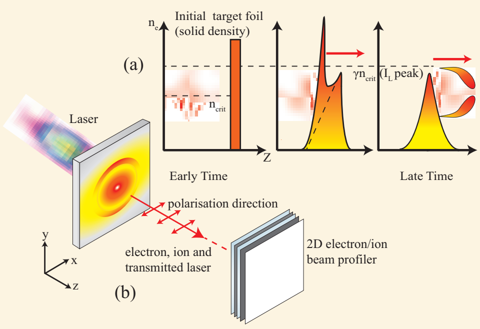
The collective behaviour of pondermotively-driven electrons in the interaction of an ultraintense laser pulse with a relativistically transparent target is investigated both numerically and experimentally. The 2D profile of the electrons is found to lengthen along the laser polarisation axis in the case of limited transparency. For higher degrees of transparency a double lobe structure forms in the electron beam in the orthorgonal plane to the polarisation direction. Numerical results demonstrate good agreement with the experimentally measured degree of transparency and elucidate the laser-electron dynamics of the transition to transparency.



(a) Schematic illustrating the target electron density evolution and induced transparency.

(b) Schematic showing the laser foil interaction and the position of the electron and proton spatial-intensity distribution detector.

Polarisation dependence of ion acceleration from ultrathin foils

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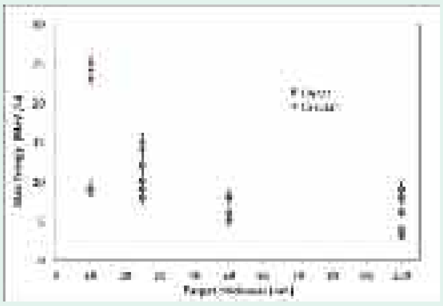

Figure 1. Maximum energy of carbon ions for linearly (blue) and circularly (red) polarised laser light as a function of target thickness.

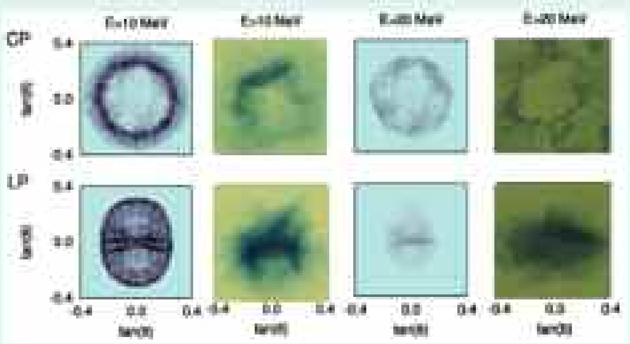

Figure 2. Simulation (blue) and experimental (green) RCF beam profiles for circular polarization (top) and linear polarisation (bottom) for proton energies greater than 10 MeV (left) and 20 MeV (right).

In this experiment the effect of the laser light polarisation on the acceleration of ions from ultrathin foils was investigated.

The experiment employed 40 fs laser pulses with controllable polarisation, focused at normal incidence onto carbon foils by an f/2 parabolic mirror up to intensities of ~ 3×10^{20} W/cm^2 . The laser light polarisation (circular or linear) was controlled by a quarter waveplate and a double plasma mirror configuration was employed.

The highest proton and carbon energies (up to 25-30 MeV/nucleon) were observed for circularly polarised pulses and 10 nm targets. A strong difference in the beam profile was observed for linearly and circularly polarised pulses. The main characteristics of the data are reproduced by 3D Particle in Cell simulations.

These results provide possible evidence of a regime in which RPA is the dominant acceleration mechanism since hot electron heating is reduced.

Cell irradiation with laser-driven proton and carbon ions

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We have demonstrated the first irradiation of in-vitro human fibroblast cells (AG01522) with laser accelerated carbon ions. The experimental set-up used allowed cell samples to be irradiated with a full spectrum of proton and carbon ions simultaneously, achieving dose rates of 10^{10} and 10^{9} Gys^{-1} respectively. This allowed insight into the radiobiological effects of employing ultra-high dose rates and comparison between low and high LET radiation. The damage on cells was quantified by using 53BP1 immunofluorescence assay which allows double strand breaks to be visualised.

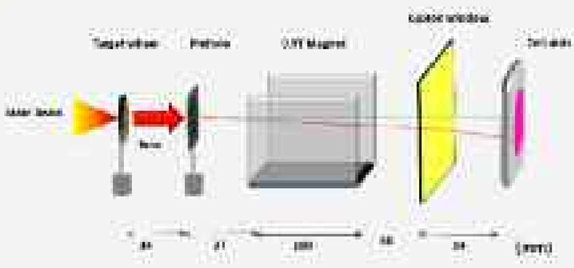

Figure 1: Schematic of the experimental layout.

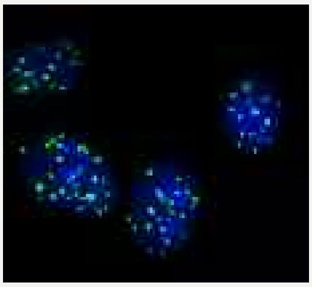

Figure 2: Cell snapshot, showing the double strand break formation after irradiation from carbon ions.

Inhibition of self-injection by ionisation injection

13

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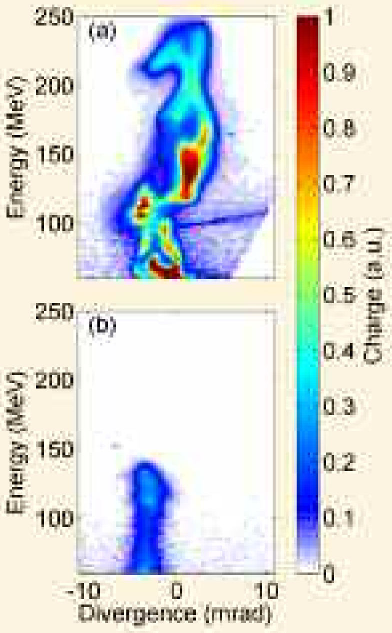

Electron beams obtained at plasma density of $1.1x10^{19}cm^{-3}$ exhibiting the clear difference between ionisation injected and self-injected beams under same laser conditions.

Experimental evidence of the suppression of self injection in a laser wakefield accelerator is found. We find that when employing an alternative injection mechanism, such as ionisation injection, the characteristic features of self-injected electron beams are greatly suppressed and electron beams with superior collimation and better emittance are observed under similar laser and plasma conditions. While previously it has been asserted that the accelerator is to be operated in a quasi-linear regime to make full use of alternative injection techniques and to avoid self-injection, our findings suggest that the accelerator can be operated in the fully nonlinear regime. The linear focusing forces present in the latter conserve emittance and thus could allow to further enhance the superior emittance of electron beams obtained with injection mechanisms other than self-injection.

Laser driven x-ray imaging of human trabecular bone

14

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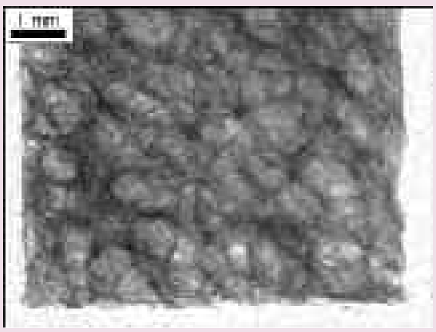
Laser wakefield accelerators (LWFAs) have developed at an exciting pace over the past decade, now capable of the production of GeV-class electron beams on a centimetre length scale. The plasma medium of a LWFA also acts as an electron beam wiggler, producing ultrafast, bright, spatially coherent hard x-rays. X-ray sources produced this way are just a few microns in size, and have previously been used to perform high-resolution phase contrast imaging of weakly absorbing samples such as insect exoskeletons. Moving towards larger and denser samples of medical interest such as bone requires a significantly harder x-ray source.



Here we use the Astra Gemini laser to produce high-brightness x-ray beams with spectra extending to many tens of keV. The beams proved sufficiently bright and energetic that we were able to, for the first time with a LWFA-driven x-ray source, record high-resolution absorption contrast images of a human femoral bone sample in a single shot.

A single-shot radiograph of a cylindrical human bone sample performed with a laser driven x-ray source.

Femtosecond-scale synchronisation of ultra-intense focused laser beams

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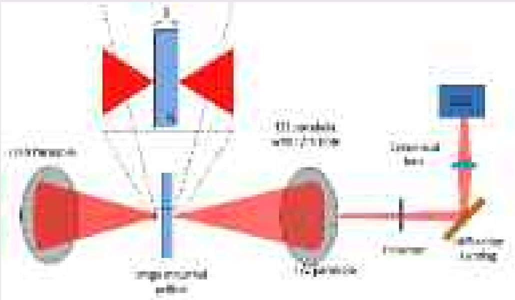
Synchronising lasers to within 10's of fs is a particularly difficult task due to the inability of mechanical and electrical to respond accurately on this timescale. Here we report on an experimental technique that ensures femtosecond-scale synchronisation of the foci of two ultra-intense laser pulses. The technique relies on spectrally-resolved optical interferometry and it is virtually applicable to any focusing geometry and relative intensity of laser pulses.



Two counter-propagating laser pulses are incident on the pellicle. A polariser is used to alter the relative intensities of the beams and allow the beams to interfere with one another as well as simultaneously providing a means for making the intensities of the pulses comparable. The diffraction grating spreads the beams in terms of frequency while the lens compresses this spread while due to the subtle path differences between the pulses, a unique interference pattern will be formed for each time delay. A CCD can be used to give real time information about the process.

A Compact Short-Pulse Bremsstrahlung Source from LWFA Electrons

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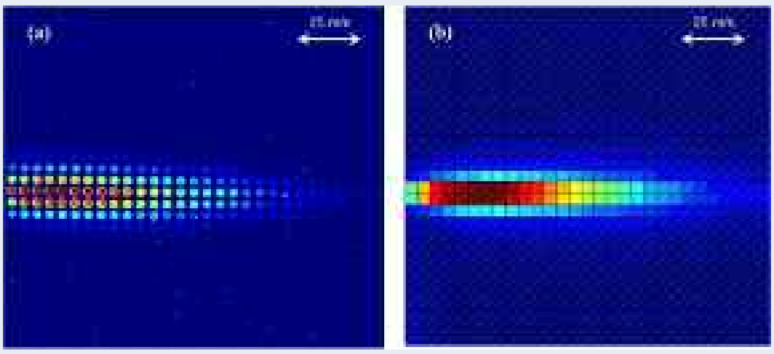
The Astra Gemini laser was used to accelerate electrons by the laser wakefield acceleration (LWFA) process. These fast electrons (300 – 600 MeV) were then passed through a thin aluminium foil in order to generate bremsstrahlung radiation. The gamma ray spectrum extended beyond 400 MeV and the use of a thin foil resulted in the emission being prompt (< 30 fs) with low divergence (< 5 mrad) from a small region (< 20 microns). The Geant4 Monte Carlo simulation package was used to model the generation of the bremsstrahlung radiation as well as its detection in a CsI scintillator stack. The simulation of the detector shows qualitatively agreement with the experimental measurement indicating that the peak power of the gamma rays was ~5 GW. The comparison of the experimental and simulation results is shown in the figure.



(a) CCD image of CsI detector recording the bremsstrahlung radiation generated in the experiment;
(b) Image of CsI detector generated by Geant4 using the experimental parameters.

Broadband measurements of transition radiation at Astra-Gemini 17

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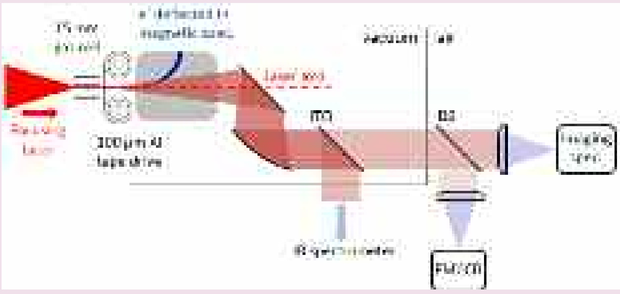
We investigated transition radiation (TR) from electron beams from laser-driven wakefield plasma acceleration (LWPA) at the Astra-Gemini facility.

Since TR carries the information of the current profile in the spectrum, spectroscopy of coherent TR is a widely recognised method to estimate an electron bunch length and longitudinal profile.

Figure 1 shows the set-up used in the experiment. Electrons accelerated in a gas cell generated TR when they passed through a 100 µm thick Aluminium foil. The TR spectrum was measured by an optical imaging spectrometer and a new double-prism mid-IR spectrometer, covering the wavelength range between (400–700) nm and (6-18) µm in a single shot. The studies on the TR spectra obtained - in combination with measurements of the bunch charge, energy spectrum and transverse profile - pursue the retrieval of the temporal profile of the electron bunch.



Schematic of the transition radiation setup.

Dynamics and Spectroscopy

Directly Observing the Ultrafast Dynamics of Massive Dirac Fermions in Bilayer Graphene

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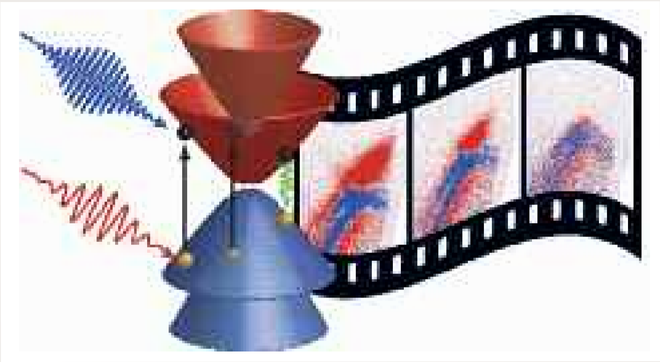
Understanding of the ultrafast carrier dynamics in mono- and bilayer graphene is essential for exploiting these materials in future electronic and optoelectronic devices.

The hallmarks of these materials are their low energy Dirac spectra consisting of massless and massive Dirac Fermions, respectively. With the advent of high harmonic laser-based time- and angle-resolved photoemission (TR-ARPES) it is now possible to record movies that directly capture the momentum-resolved out-of-equilibrium properties of these Dirac particles with femtosecond time resolution. Here, we characterize the dynamic processes in the parabolic energy bands around the band gap in bilayer graphene using TR-ARPES, addressing the timescales of hot carrier scattering processes in this system for the first time. We are able to disentangle the dynamics in the two parabolic conduction band sub-states and find that the gap in the lower sub-state plays a crucially important role, leading to a remarkably slower relaxation dynamics compared to monolayer graphene.



Left: Sketch of the massive Dirac Fermions in bilayer graphene brought out of equilibrium in a pump/probe TR-ARPES experiment. Right: Snapshots from a TR-ARPES movie of the charge carrier relaxation in bilayer graphene.

Resonant Phonon Excitation in Bilayer Graphene

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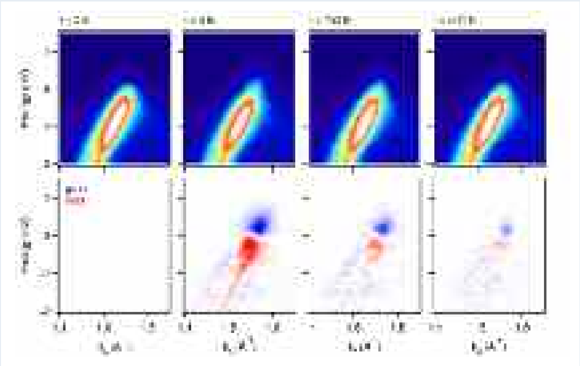
Optical excitation of Dirac carriers in graphene is known to occur through two mechanisms. For photon energies higher than twice the chemical potential ($\hbar\omega_{pump}>2|\mu_e|$), high-fluence direct interband excitation results in population inversion at early times, followed by carrier thermalization and relaxation. For doped samples and lower photon energies ($\hbar\omega_{pump}<2|\mu_e|$), the Dirac carriers are heated by metallic free carrier absorption, where the peak electronic temperature is determined by the pump fluence. Here, we demonstrate a third mechanism, active when the infrared optical field is made resonant with a vibrational mode that modulates the band structure. We investigate the response of the Dirac carrier distribution as a specific E1u phonon mode of bilayer graphene is driven to large amplitudes with a coherent mid-infrared field. The response of the electronic structure is investigated with time- and angle-resolved photoemission spectroscopy.



Snapshots of the electronic structure of bilayer graphene for different pump-probe delays (upper panel) together with the corresponding pump-probe signal (lower panel). The excitation wavelength is 6.3μm in resonance with the in-plane E1u lattice vibration.

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Photoelectron spectroscopy of methylated benzene

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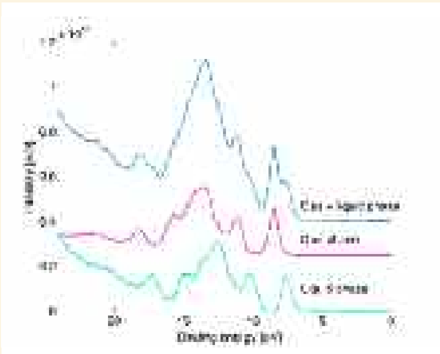
The recently developed technique of photoelectron spectroscopy of liquids was implemented in the Artemis beamline, with the vacuum ultraviolet probe generated by high harmonic generation. The photoelectron spectra (PES) of a selection of methylated benzene species in both liquid and gas phases were measured and the first eight molecular orbitals (MOs) were identified. A uniform decrease in the measured binding energy of the liquid MOs of ~0.9 eV was observed compared to the gas phase values.



While the results are still under analysis, the uniform shift in the binding energy between liquid and gas phase is intriguing and may have implications for previously report results of benzene absorbed onto metal.

The extension of the PES of liquids technique from water to other solvents at Artemis coupled with the application of PES of liquids to time resolved measurements demonstrated last year opens the door to ultrafast measurements in solvents and solutions fundamental to chemistry.

Photoelectron spectra of 1,3,5 trimethylbenzene with horizontally polarised VUV (29.6 eV).

Time-resolved spectroscopic studies of the ultrafast photoisomerisation reaction in cyanobacteriochrome Tlr0924

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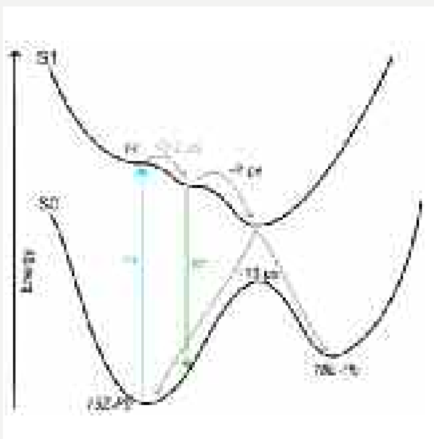
The coupling of photochemistry to protein chemical and structural change is crucial to biological light-activated signalling mechanisms. This is typified by the cyanobacteriochromes (CBCRs), which are members of the phytochrome superfamily of photoreceptors. The CBCRs exhibit a high degree of spectral diversity, collectively spanning the entire visible spectrum and mediate a variety of signalling responses in cyanobacteria by using a reversible photo-induced E/Z isomerisation of a sensory bilin chromophore. We have now used a combination of time-resolved UV-vis and IR spectroscopy to characterise the Z to E and E to Z photoisomerisation reactions of a full-length CBCR. This has allowed a detailed assignment of the ultrafast dynamics for both the forward and reverse photoisomerisation reactions.



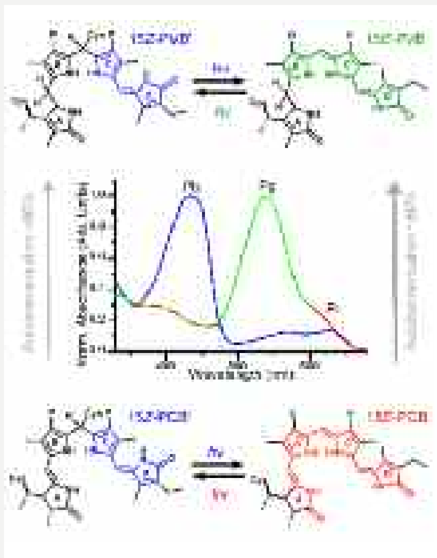


Figure 1. Structures and absorption spectra of the PCB and PVB photostates. The PCB and PVB chromophores can interconvert by autoisomerisation, the ^{15Z}Pb and ^{15E}Pg and ^{15E}Pr states can reversibly photoconvert.

Figure 2. Scheme showing suggested ground and excited state energy surfaces and the processes which occur after photoexcitation.

Ultrafast 2D-IR spectroscopy of nitrosylated haem-proteins using ULTRA

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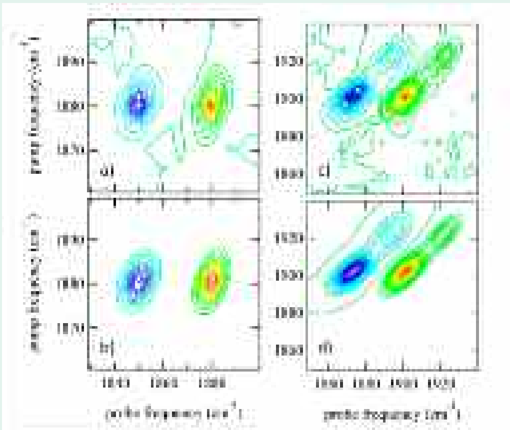
Ultrafast 2D-IR spectroscopy has shown great potential for measuring the structural dynamics of biological molecules. This report summarises recent advances in applying 2D-IR on the ULTRA laser system to study the structural and vibrational dynamics occurring in the active sites of haem proteins. By comparing the results of 2D-IR studies of the ligand transport protein myoglobin and the catalase enzyme, it is shown that the former features a more flexible structure with an interaction between a distal residue side chain and an NO ligand bound to the haem that presumably serves to aid reversible ligand binding. In contrast, the enzyme locates the NO in a more constrained geometry consistent with the need to access a particular transition state as part of the reaction mechanism. Taken together, these demonstrate the potential for 2D-IR, in concert with state-of-the-art ultrafast laser technology, to influence our view of the biological structure-function relationship.



2D-IR spectra of the NO stretching vibrational mode of nitrosylated catalase (a) and myoglobin H64Q (c). Figs (b) and (d) are fits of the data in (a) and (c) respectively to 2D Gaussian lineshape functions.

Dynamics of chemical and photochemical reactions in solution

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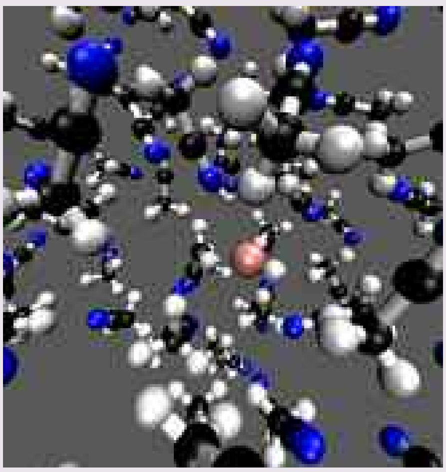
Many important synthetic, photochemical and biological reactions take place in liquid solutions, and we seek to understand better the role the solvent plays in the reaction mechanisms. Fluctuations of the liquid environment on femtosecond to picosecond timescales perturb the motions of the reacting molecules (the reaction dynamics), and the energy flow over the course of the reaction as well as equilibrating the products with the solvent bath. The dynamics of chemical reactions in liquids, observed using ultrafast transient absorption spectroscopy, can be contrasted with those exhibited by the same reactions in the gas phase. These comparisons provide us with robust evidence for the influence the solvent exerts on chemical mechanisms.



DF product of the reaction of an F atom with CD_3CN, from a simulation in d_3-acetonitrile by Dr David Glowacki (University of Bristol).

Proteins in Action: Functional Dynamics of Blue Light Sensing Proteins from Femtoseconds to Milliseconds

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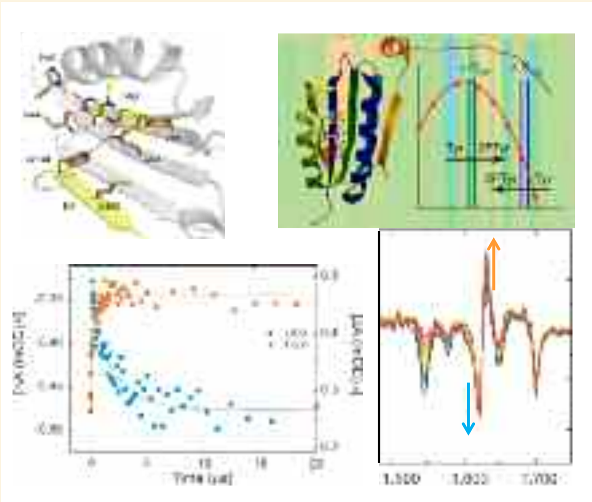
The function of proteins requires structural evolution, Such evolution occurs on an enormously wide range of time scales, from million billionths of seconds to minutes. In this work we use sensitive methods of ultrafast infrared spectroscopy to observe protein structural dynamics in real time. To achieve this we study photoactive proteins, where the function is stimulated by an ultrashort light pulse. The research described first investigates the primary mechanism of the light activation step, and then follows the change in protein structure as it adopts the signalling state. The time scale for the later process is microseconds. The pathway is probed by making mutants which modify the signalling pathway.



Clockwise from top left: Structure of the photoactive BLUF domain flavin binding site. Electron transfer analysis overlaid on transient data. Microsecond evolution of the transient IR spectrum. Microsecond protein kinetics.

Photochemical studies of astrophysically relevant molecules on a carbon surface

25

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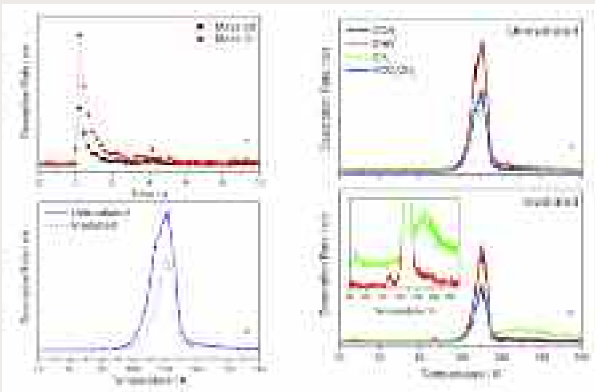
Ultraviolet (UV) processing of interstellar ices on the surface of carbonaceous and silicaceous grains gives rise to a range of molecules in the interstellar medium. Of particular relevance in this respect are larger organic species such as glycolaldehyde and methyl formate, which have astrobiological significance. To investigate this UV processing, laser irradiation of model interstellar ices adsorbed on graphite was undertaken, with the aim of studying both adsorbate and substrate mediated photochemistry. Laser induced desorption (LID) was observed for a wide range of molecules including CO_2, CH_4, CH_3OH, CH_3CH_2OH, propan-2-ol, methyl formate, glycolaldehyde, acetic acid, H_2S, SO_2 and OCS. Methyl formate (MF) was particularly photoactive, with both desorption and dissociation of the molecule being observed (see figure).



A: PID data for the irradiation of MF at 224 nm, showing the desorption of the parent molecule. B shows post-irradiation TPD spectra following that irradiation, showing the depletion of the molecule. C and D show TPD spectra for the unirradiated and irradiated MF respectively, showing the dissociation of the molecule into various molecular fragments.

Towards time-resolved electron diffraction

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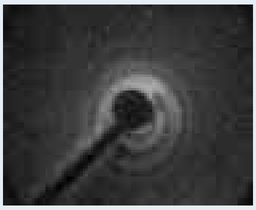
An EPSRC-funded Fellowship awarded to the PI has allowed us to build a time-resolved electron diffractometer suitable for studying dynamic structures of gas-phase and solid-state species.

Using a Ti-sapphire laser (UFL2) from the laser loan pool we created pulses of electrons from the ionisation of a thin-film gold photocathode. These electrons were accelerated across a potential of 45 kV and focussed using a newly designed solenoid lens.

To date we have calibrated a large number of properties of the new diffractometer. First, we determined how the number of electrons per pulse varied with the laser power used to ionize the photocathode. Next, we determined the transverse size of the electron pulse to be 435 μm FWHM, which is pleasing as it will allow excellent spatial resolution.

With the properties of the beam calibrated we recorded the first diffraction pattern using this apparatus. A 20 nm thick polycrystalline sample of platinum was chosen, yielding the pattern shown.

Photograph of the Wann group time-resolved electron diffractometer.



Diffraction pattern for a polycrystalline sample of Pt.

Production and manipulation of Rydberg positronium for a matter-antimatter gravitational free-fall measurement

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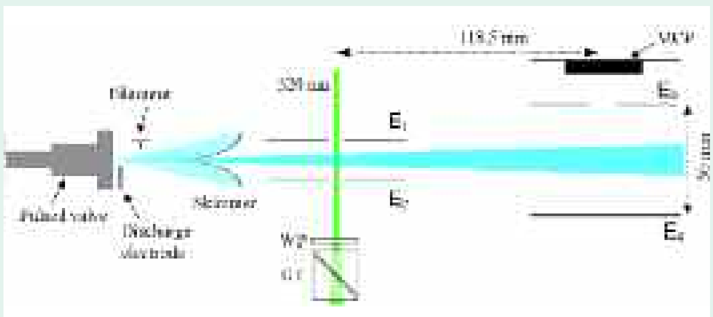
Any attempt to measure the gravitational free-fall of the metastable positron-electron system known as positronium (Ps) requires that it is excited to a Rydberg state with a long lifetime, otherwise it will simply annihilate, converting the electron and positron into gamma rays. In order to study and evaluate new ways to produce highly excited atoms, we have measured the non-resonant two-photon excitation of metastable He from a supersonic gas jet. The experimental conditions are sufficiently close to those required in the positronium apparatus that the information obtained using He will aid in developing the Ps methodology. Using the CLF NSL2 loan pool laser system Rydberg states were produced which could be resolved up to n = 70. Extraneous influences, such as ac Stark shifts and effects of black body radiation have been observed and understood, paving the way for the production of Rydberg Ps atoms in the same way.



Experimental setup. The light from the pulsed dye laser is incident upon a supersonic beam of helium atoms in the metastable 1s2s $^3S_1$ state. By scanning the wavelength between 520 nm and 524 nm two-photon transitions are driven to Rydberg states in the range from n = 20 up to the ionization limit. The Rydberg atoms are detected by pulsed field ionization in a field of strength 800 V/cm between electrodes E3 and E4.

Ultrafast carrier dynamics of AlGaInP saturable absorbers

28

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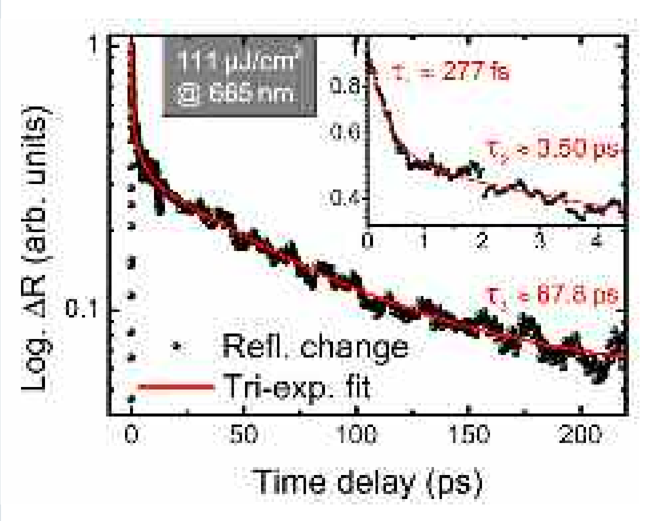
We have investigated the ultrafast characteristics of novel quantum-well semiconductor saturable absorbers based on AlGaInP, which are instrumental for the ongoing development of cutting-edge femtosecond lasers operating in the visible spectral range. With a degenerate reflective pump-probe setup, the ultrafast absorption recovery dynamics in these saturable absorbers was investigated as a function of wavelength, fluence and number of quantum wells.



Absorption recovery dynamics for an AlGaInP semiconductor saturable absorber without the fused silica layer. A tri-exponential decay is observed with a dominant fast time constant of 277 fs.

Techniques for Neutral Gas Phase Spectroscopy Exemplar: The Green Fluorescent Protein Chromophore

29

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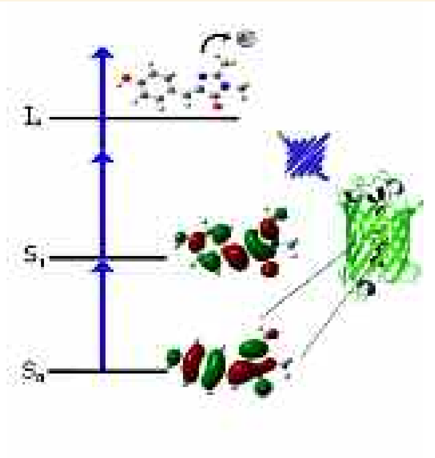
The study of biochromophores isolated from their natural environment has proved valuable for elucidating their intrinsic properties and testing state of the art theoretical methods. However, to produce these molecules in the gas phase, evaporation/desorption techniques need to be developed. We have investigated laser desorption from thin metal foils under a range of conditions and these methods have been employed to study the neutral chromophore of the green fluorescent protein, which has been widely exploited as a fluorescent tag in cell biology. Using resonantly enhanced multi-photon ionisation spectroscopy with a femtosecond laser, we have shown that removing the chromophore from the protein into vacuum results in a large shift in the absorption spectrum from the violet (395 nm) to the ultraviolet (340 nm). Understanding of this sensitive photophysics may aid the design of new fluorescent biomarkers in the future.



Life and Science Imaging

Multiphoton Imaging and Conversion of Combretastatins in 3D Tissue Models

30

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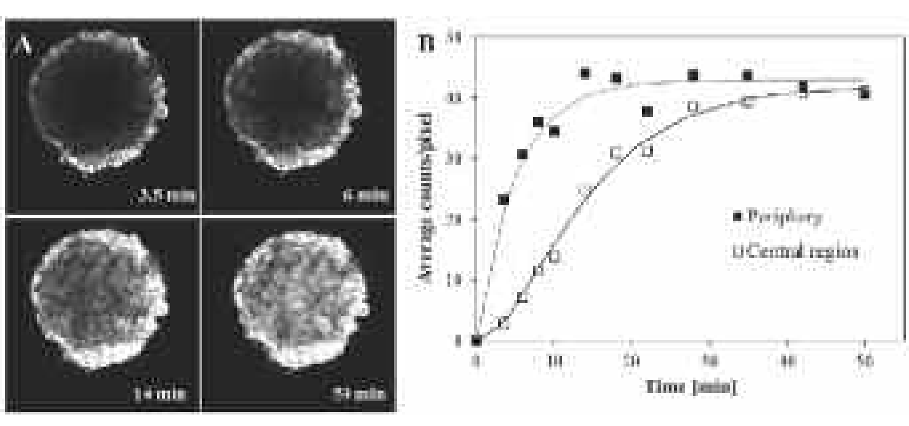
The aim of this project is to study the potential of E-combretastatins as photoactivatable anticancer pro-drugs. The activation of E-combretastatins by photoisomerization to the corresponding Z-isomer on monolayers of live cancer cells using red or near-infrared light (630 nm) has previously been demonstrated by our group. Highly specific localized cell killing using this two-photon excitation was observed within 24 h of pro-drug activation The main advantage of using longer wavelengths for the pro-drug activation is the improved transparency of tissues in this wavelength regime ("tissue window"). Therefore the current focus of the project is to demonstrate the selective, three-dimensional two-photon activation of E-combretastatins in thick, opaque specimens similar to real tissue. The model systems applied here were agarose gels (1 %) and multicellular melanoma cell spheroids.



Multiphoton FLIM images of real-time E-combretastatin (E-CA4, 25 µM) uptake into a C8161 human melanoma cell spheroid. A: A plane 75 µm above the spheroid base was imaged at different time points (each image shows a 636 µm^2 area). Panel B: displays the average intensity inside the spheroids versus time (min).

Structure-function relationships and supra-molecular organisation of the Epidermal Growth Factor Receptor (EGFR) on the cell Surface

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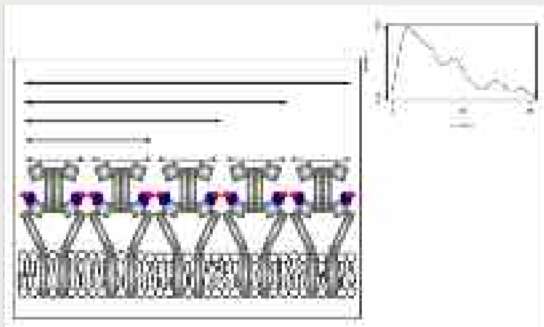
Dimerization and higher order oligomerization are believed to play an important role in the activation of the Epidermal Growth Factor Receptor. Understanding of the process has been limited by the lack of availability of suitable methods for the measurement in cells of distances in the range of 10-100 nm, too short for imaging methods and too long for spectroscopic methods such as FRET. We have developed a new a single molecule localization method (fluorophore localisation imaging with photobleaching, FLIP), on the CLF's Octopus facility and this has allowed the quantitative characterization of the distribution of EGFR-EGFR distances in cells. We show data describing the oligomerization state of the receptor, and data that suggest the involvement of cortical actin in regulating the formation of EGFR complexes.



Model of Epidermal Growth Factor homo-polymer consistent with the distances measured by FLIP (inset).

Single molecule studies of clathrin-coated vesicle disassembly

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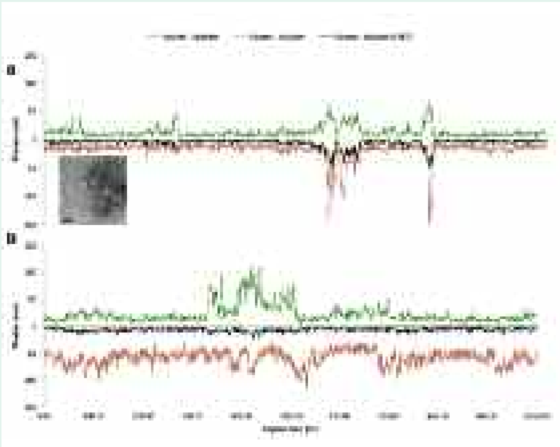
Using single molecule confocal ALEX microscopy at the Octopus facility we aimed to monitor clathrin disassembly at the single molecule level. In a previous experiment we carried out proof of principle single pair FRET analysis of clathrin cage complexes to detect intramolecular association events relevant to clathrin cage disassembly. As a result of the success of this pilot study we wished to extend our studies to address the larger questions surrounding the individual events which occur when individual clathrin triskelions dissociate, the mechanism by which Hsc70 is recruited to clathrin-auxilin cages and the events which preceed cage collapse. In light of the highlighted experimental data outlined here further work is needed to optimize the analysis. In particular we need to validate whether the burst searching operates correctly for our single molecule data and whether development is required in the analysis methods or improvements made to the quality of our data.



(a) Co-assembled donor (Alexafluor 546) and acceptor (Alexa-fluor 647) labelled triskelia giving rise to FRET positive cages,
(b) independently assembled donor and acceptor labelled cages mixed exhibiting concurrent occupation of the confocal volume but not interaction as indicated by no FRET on the DexAem channel.

Artefacts Caused by Non-Specific Binding of Fluorescent Dyes in Single Molecule Experiments

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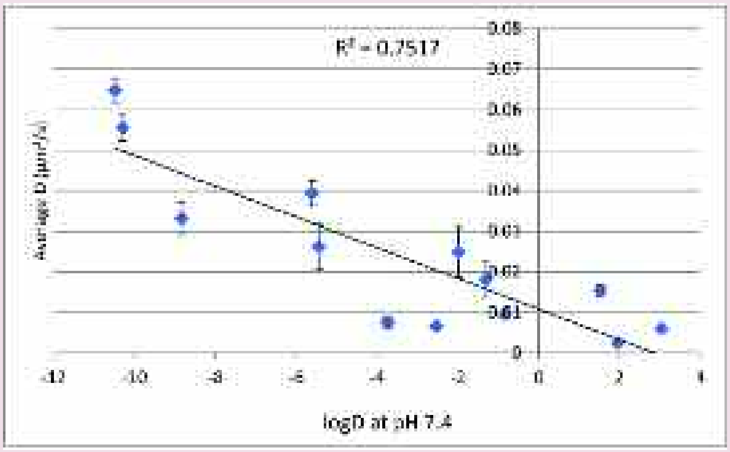
One of the major problems in the application of single molecule fluorescence microscopy techniques to cell biology is the tendency of fluorescent-labelled proteins to bind non-specifically to the cell culture substrate. We have used single molecule microscopy stations at the CLF's Octopus facility to investigate the propensity for non-specific binding of affibody labelled with a wide range of fluorescent probes frequently used for single molecule studies. We have found that there is a strong correlation between dye hydrophobicity and the tendency of affibody labelled with that dye to bind to the glass substrate used for cell culture. We therefore recommend that dye hydrophobicity is taken into account when selecting probes for single molecule work. Of the dyes we have examined, Alexa 488 appears to be the dye of choice for excitation with blue light, TMR for green, and CF640R for red.



Plot of dye hydrophobicity (logD, negative values hydrophilic, positive values hydrophobic) versus average Diffusion Coefficient (D, higher values indicate more mobile dyes and therefore less non-specific binding) for dye-conjugated affibodies added to cultured T47D cells. The plot shows a strong correlation, with hydrophilic dyes having much less tendency to bind to the substrate.

Redevelopment of the AMO end-station to incorporate a skimmed molecular beam source

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The atomic molecular and optical (AMO) end-station in Artemis is designed for the study of non-adiabatic dynamics in gas phase systems using the technique of time resolved photoelectron spectroscopy.

The redevelopment of the AMO endstation was targeted on improving the gas definition within the focus of the velocity map imaging spectrometer. To do this we used a molecular skimmer in conjunction with the gas jet to produce a differentially-pumped molecular beam.

Following a series of tests the redevelopment of the AMO end-station has been shown to have produced a sub-20 microsecond gas pulse, spatially confined to a few millimetres. The VMI has also been shown to operate with good signal to noise with the modifications. These improvements should significantly increase the energy resolution of future experiments with the AMO end-station.

A detailed cut away drawing of the gas jet and interaction chamber in the AMO end-station

XUV generation at 93 eV for coherent actinic imaging of EUVL mask defects

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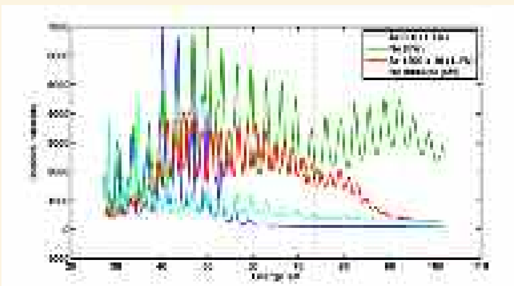
Effective imaging of optical defects in masks for EUV lithography requires the use of the same wavelength as the target design wavelength – so-called 'actinic' imaging. For next-generation lithography at 13.5 nm, microscopy options are limited by the difficulty of obtaining both optics and sources, and scanning microscopy using a synchrotron source is the norm. In this work, we describe development of an alternative 13.5nm imaging system using a source based on high harmonic generation at the Artemis laser facility, and coherent diffractive imaging (CDI) techniques.

Imaging using CDI in the XUV requires a high flux, focused XUV beam. In this paper we show initial optimisations of HHG at Artemis for 93 eV photons, suitable for use in investigating defects in lithography phase masks. The flux is measured, and the filtering properties of Mo thin films for separation of the laser and the XUV are characterized. The focusing properties of the EUV mirrors has been evaluated, and spot sizes measured. For imaging purposes, the measured flux is adequate, but higher flux would improve things considerably.



Comparison of spectra from different generation experiments. The dark blue line is generation in Ar gas using 800nm; green is using Ne with 800 nm pumping. Red is pumping Ar gas at 1300nm and has been multiplied by 10 for visibility, and light blue is combined pumping at 800 & 400 nm. The dotted vertical lines indicate the cutoff of an Al filter (73 eV, used as an aid to wavelength calibration) and the target photon energy (93 eV).

Laser driven x-ray phase-contrast microscopy of soft tissue samples

36

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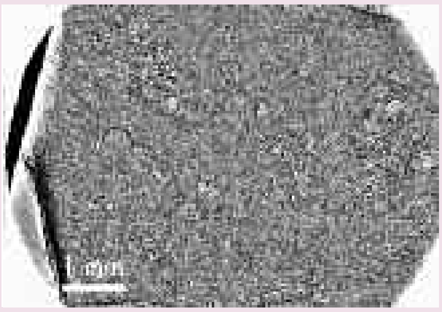
A lensless x-ray microscope was built in Astra-Gemini for soft-tissue phase-contrast imaging. The light source was a laser-plasma wakefield accelerator. A laser beam with 10 J and 45 fs, focused in a 10 mm long helium target, produces a relativistic electron beam with energies 0.5-1 GeV. The betatron motion of the electrons in the plasma structure generates a synchrotron like x-ray beam with 30 keV critical energy, 10^9 photons per shot and a source size of 1 micron. The imaging is made using a detector sensitive to 5-10 keV x-rays. The magnification is 9 and approximately 2mm x 2mm of the sample could be imaged in a single shot. A high-resolution composite image of an 8 mm diameter sample, obtained from 35 expositions, is shown in the figure. Resolution comparable to conventional histology imaging is obtained and the image can be used to understand the structure of the tissue.



High-resolution phase-contrast imaging of a soft tissue sample obtained using a laser-driven betatron source

Theory and Computation

Role of Ionization in DLA-type Fast Electron Generation

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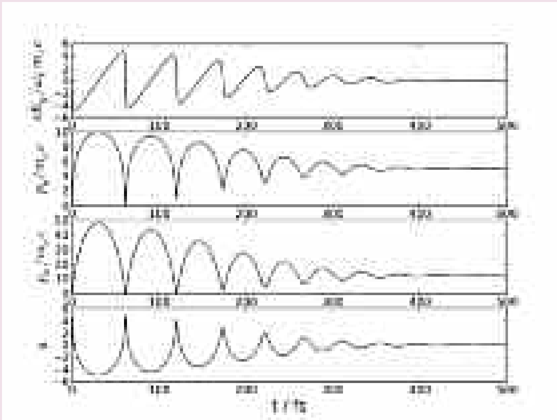
We propose that field ionization can both break adiabaticity and cause significant absorption in DLA-like interactions under certain conditions. We explain the theoretical basis for this conjecture and we present some preliminary 1D PIC calculations including field ionization supporting this.



Results of numerical integration of equations of motion for the case of an electron injected at peak vector potential (EM wave parameters: a_0=5,Gaussian pulse with 20fs duration.). Note that the electron gains net longitudinal and transverse momentum on being overtaken by the laser pulse.

Fast Electron Filamentation a broad survey of material and angular initial conditions

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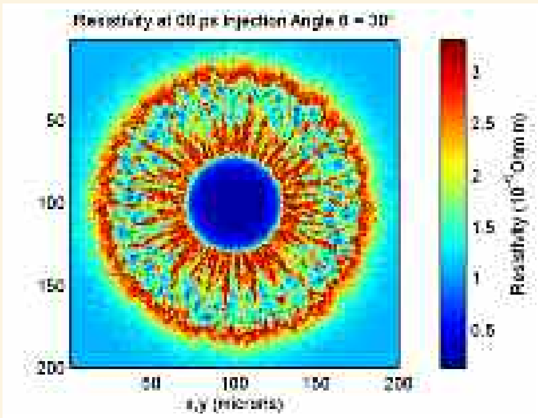
Abstract: The filamentation of laser driven fast electron currents through targets has been observed in several previous experiments. The aim of this investigation is to link some of the theory of filamentation to structures observed in magnetic field measurements in high power laser experiments. The hybrid code Zephyros is used to study the level of fast electron beam filamentation in simple targets made from a wide range of elements under differing laser intensities.

Using the Lee-More resistivity model and the Thomas-Fermi ionisation model very little difference in the level of filamentation is found.

Other simulations run to investigate the link between the transverse electron temperature and filamentation of fast electron beams revealed that, for low injection angular spread, filamentation is suppressed.



Fast particle Bremsstrahlung effects in the PIC code EPOCH: Enhanced diagnostics for laser-solid interaction modelling

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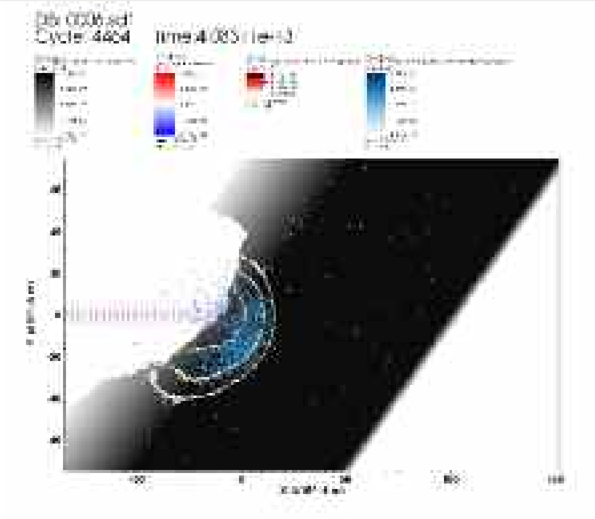
PIC codes, such as EPOCH, are key tools for understanding laser plasma interaction (LPI) but comparison of modelling with experiment is challenging - particularly for short pulse lasers, due to the spatial and temporal scales involved.

Using simulations of short-pulse irradiated Ta foils as an example we demonstrate the feasibility of adapting EPOCHís QED framework (developed for modelling exotic effects at ultra-high intensities) to generate in-line diagnostics, focussing on bremsstrahlung emission from hot electrons.

The conversion efficiency observed is low and dominated by gamma ray emission. Modifications to the laser and parameters could be adopted to soften (higher harmonic irradiation, lower intensity, thinner targets) or harden (higher intensity, thicker targets) the photon spectrum

The high energy tail of the photon distribution reflects the characteristics of the electron distribution in the LPI region which provides a potential diagnostic on the hot electrons, and a point of comparison between simulation and experiment.



EPOCH simulation of SP-LPI including bremsstrahlung emission, for a 50J incident laser. Shown is the laserís transverse magnetic field, the background electron density, the bremsstrahlung photon density and the hot electron density.

Heating in wire-like target using laser-generated fast electrons and the theory of angular rarefaction

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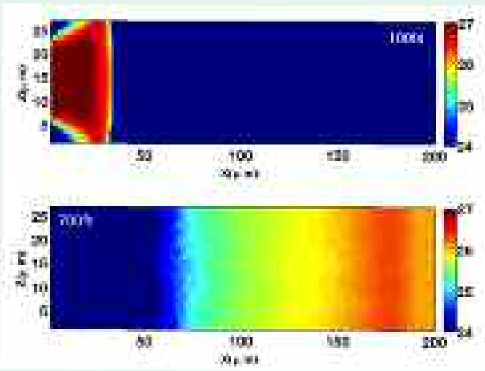
Uniform isochoric heating of solid density materials is great interest. One possible way to achieve isochoric heating is using the fast electron beam formed at the focus of an ultra-intense laser. However, uniformity is limited transverse to the beam axis by the divergent spreading of fast electron beam and by beam filamentation. Along the beam propagation direction uniform heating is limited by not only electric field inhibition but also “angular rarefaction”. Angular rarefaction results from fast electron beam divergence, which causes a longitudinal velocity space dispersion leading to a spatial dispersion along the beam axis. This occurs even when the beam is confined in the transverse direction, for example in a wire-like geometry. Results from analytical and numerical, using the 3D particle hybrid code ZEPHYROS, are presented.



Calculations of the fast electron density at 100fs (above) and 700fs (below) illustrates the spatial dispersion of an electron bunch due to angular rarefaction. A drop in the fast electron density results (electron density is shown in a log10 colour scale in units of m^{-3}).

On The Influence of Laser-Drive Parameters on Annular Fast Electron Transport in Silicon

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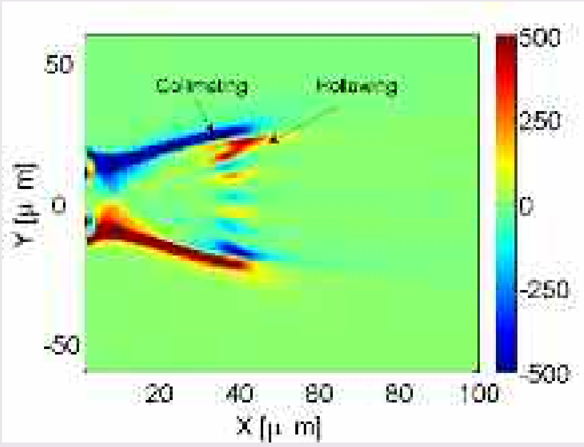
Annular fast electron transport in silicon is investigated as a function of the laser-drive pulse parameters using three-dimensional hybrid particle-in-cell (PIC) simulations. By varying the laser energy, focal spot radius and pulse duration we report that annular transport is accutely sensitive to the peak laser intensity, emphasising the key relationship between fast electron transport properties and the laser-drive parameters explored. These results may have implications for fast ignition and ion-acceleration schemes.



Study of fast electron transport with femtosecond scale laser pulses

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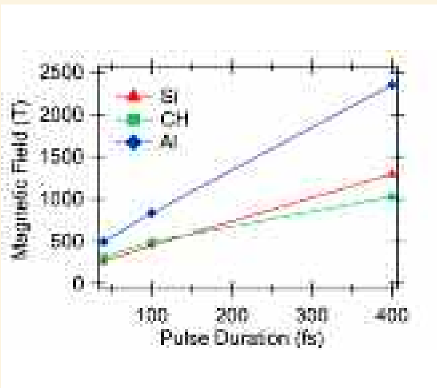
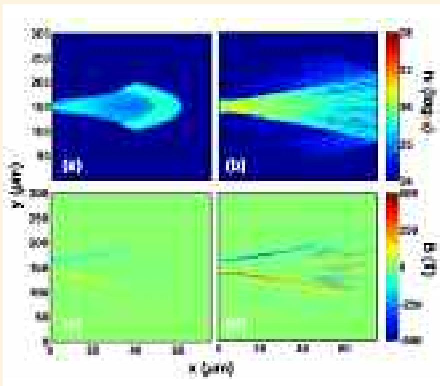
Despite the comparable intensities of the Astra-Gemini and Vulcan lasers, the transport of fast electrons through solid targets in these two facilities is very different. Using 3D hybrid-PIC simulations, fast electron transport is investigated as a function of laser pulse duration. As laser pulses are shortened to reach ultrahigh intensities, questions about the current avenues of study of fast electron transport are highlighted. For a constant input laser energy and variable pulse duration, results show that for longer pulse durations, there is a marked increase in magnetic field generation and the presence of beam filamentation for longer pulse durations.





3D simulation of hole-boring radiation pressure acceleration

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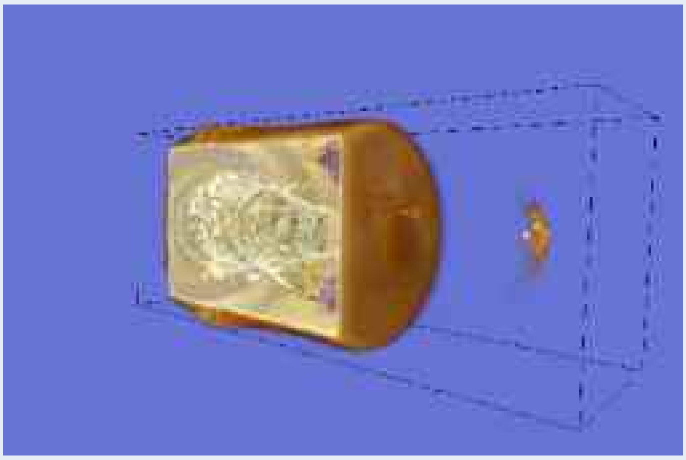
Proton acceleration from an ultra-intense laser pulse interacting with near-critical density targets has been studied by 3D-PIC simulation. A laser pulse of 4.0×10^{22} W/cm^2 intensity irradiated on a plasma of 15 n_c resulted in the generation of a high quality proton bunch of more than 1.3 GeV with energy spread less than 28%. Meanwhile, the proton bunch is high collimated with an angular spread less than 9.5 degree (HWHM). Proton bunch of such small spot size and low emittance is ideal for numerous applications such as proton beam radiography of dense materials, or potentially injection into high-energy accelerator. Hence, this work motivates experimental work designed to generate high quality energy proton bunches by the hole-boring mechanism.



Light-by-light scattering at low energies

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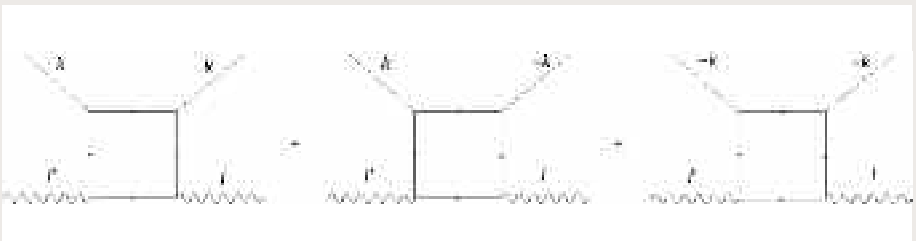
The article discusses the scattering of light by light in photon-laser collisions using the Heisenberg-Euler low energy approximation. The target is taken to be a classical background field given by an ultra-intense laser. We determine the scattering amplitude for a laser target modelled by (i) infinite and (ii) pulsed plane waves.



Feynman diagrams showing the different possibilities for the momentum transfer experienced by probe photons (wavy lines) scattering off an intense laser background (dashed lines). From left to right one has: (i) two absorptions, (ii) an absorption and an emission (forward scattering) and (iii) two emissions.

Strong fields and slow light

45

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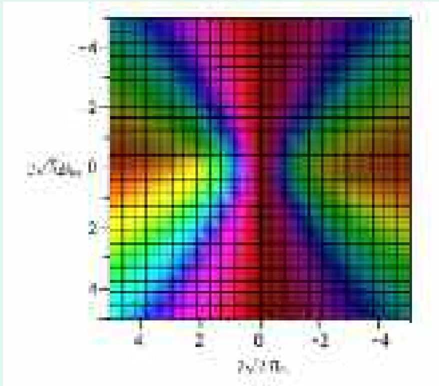
We review a recent investigation of electromagnetic wave propagation in the context of vacuum polarization. Most treatments of this topic require that the electromagnetic field can be split into a strong background component and a weaker component describing the electromagnetic wave. In our approach, we treat the background field and electromagnetic wave on an equal footing and make no assumptions about their relative magnitudes. We explore the speed of light from this perspective.



The colour indicates the square of the speed of light in a background magnetic field. Red indicates the largest phase speed, whereas orange indicates the lowest phase speed.

The effect of quantum radiation reaction on electron motion in ultra-high intensity laser-matter interactions

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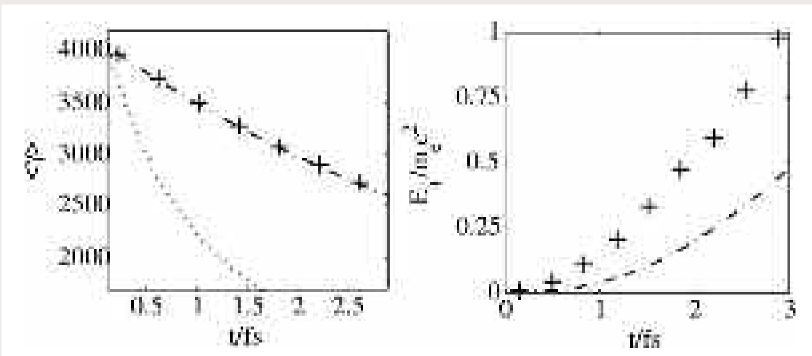
As intensities surpass 10^{22}Wcm^{-2} on a host of next-generation high-power laser facilities a new type of plasma will be generated. The electromagnetic fields in the laser focus will be so strong that non-linear quantum electrodynamics (QED) effects will play a critical role in determining the plasma dynamics, a 'QED-plasma', similar to that present in the magnetospheres of pulsars and active black holes, will be generated in the laboratory for the first time. In these QED plasmas the electrons prolifically radiate gamma-ray photons and the radiation reaction force plays a crucial role in the electron dynamics. In the QED-plasma regime the energy of the emitted photons becomes comparable to that of the emitting electron and the radiation reaction force becomes stochastic. I will show that although this is the case, a deterministic description of radiation reaction can still be used, greatly simplifying the theoretical analysis of QED-plasmas.



Left: time evolution of the average energy for an ensemble of 10^5 electrons with initial energy $4000m_ec^2$ counter-propagating relative to a circularly-polarised plane wave with a_0=20 (crosses). Comparison is made to the solution of a deterministic equation of motion including the radiation reaction force (dot-dashed line) and the solution of the classical equation, identical except for the omission of the quantum reduction to the power radiated (dotted line). Right: identical plot describing positron production.

Modelling radiative-shocks created by laser-cluster interactions

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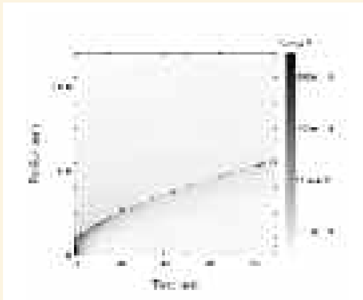
Radiative-shocks induced by laser-cluster interaction are modelled numerically using radiation-hydrodynamics. A good agreement is obtained between experiment and simulations, indicating that non-LTE effects are clearly important in the experimental regime examined, particularly at early-times due to the elevated temperatures and low densities. A range of issues associated with the successful modelling of such scenarios are identified and discussed, including the effects of the various atomic models used to generate the opacity data (LTE/steady state non-LTE/collisional-radiative non-LTE), and their effects on the shock generation and propagation. In going from LTE, to steady state non-LTE and finally to time dependent non-LTE, the simulated shocks are systematically reduced in amplitude, increased in width and reduced in propagation velocity while the amplitude of the radiative precursor is increased. This trend is broadly consistent with the the plasma being increasingly emissive with the more sophisticated and accurate non-LTE atomic models. Finally, it is found that the shock trajectory is a degenerate measure of the initial plasma conditions.



Simulated shock trajectory (blue points) overplotted on the experimental shock trajectory (red points). This simulation was performed using the time dependent non-Local Thermodynamic Equilibrium model.

Vorticity Deposition and Density Structure Generation in Colliding Blast Wave Experiments

48

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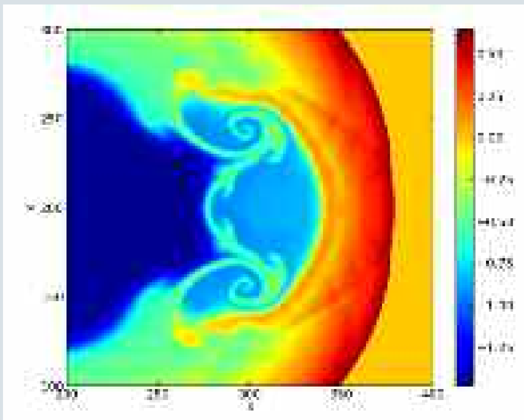
Experiments that involve colliding blast waves should involve the deposition of vorticity and the eventual generation of density structure as a result. The generation of vorticity is fundamental to hydrodynamics and is of interest for a number of reasons. Various 2D numerical simulations are presented which show the formation of density structure in simple blast wave interactions ranging from the strongly asymmetric to the symmetric case.



log_{10} plot of ρ in run A at t=3.4 showing a close up on remnant of the weaker blast wave.

Characterising the Acceleration Phase of Blast Wave Formation

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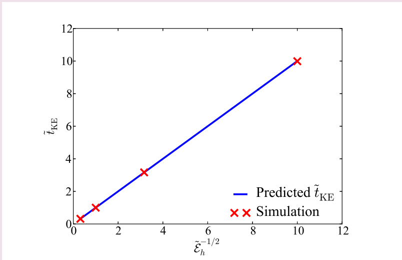
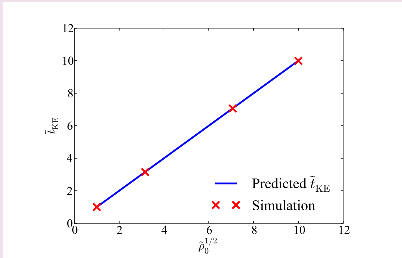
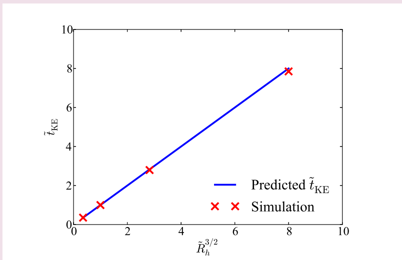
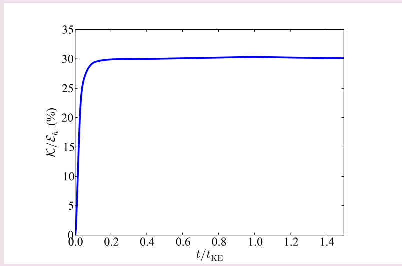
Intensely heated, localised regions in uniform fluids will rapidly expand and generate an outwardly propagating blast wave. The Sedov-Taylor self-similar solution for such blast waves has long been studied and applied to a variety of scenarios. A characteristic time for their formation has also long been identified using dimensional analysis, which by its very nature, can offer several interpretations. We propose that, rather than simply being a characteristic time, it may be interpreted as the definitive time taken for a blast wave resulting from an intense explosion in a uniform media to contain its maximum kinetic energy. A scaling relation for this measure of the acceleration phase, preceding the establishment of the blast wave, is presented and confirmed using a 1D planar hydrodynamic model.









Weak collisionless shocks in laser-plasmas

50

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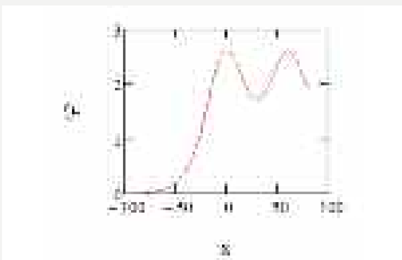
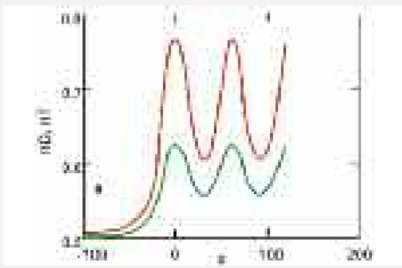
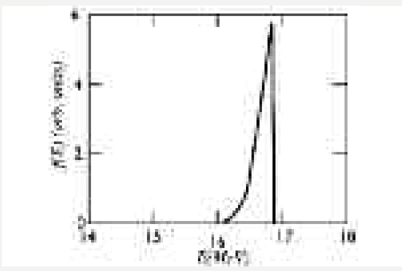
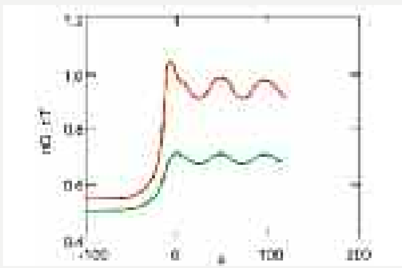
We describe an analytic theory giving the structure of weak laminar collisionless shocks in a plasma and show that it may be of relevance to observations of very strong localized electric fields in laser compressed pellets, to recent experiments on ion acceleration and to species separation in ICF targets.









Creating Astrophysically Relevant Jets with Locally Heated Targets

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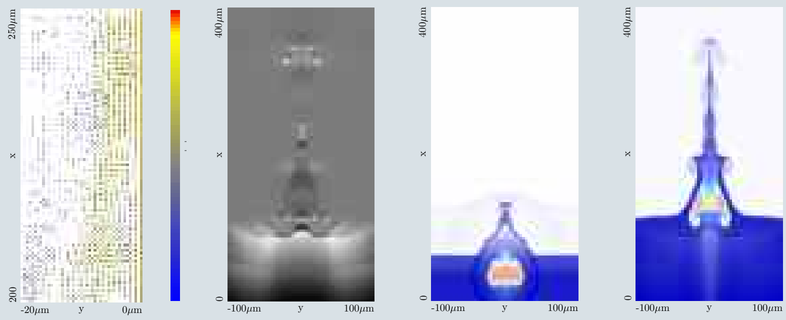
The sources of astrophysical jets are not accessible to direct observations due to the small scales on which the jet formation mechanism operates. Simulations suggest that jets emenating from young stellar objects originate from conically converging flows, generated when the stellar wind obliquely encounters the inward facing reverse shock. The use of high intensity lasers to reproduce astrophysical phenomena in the laboratory is an extremely promising approach for verifying and investigating such astrophysical models. Jets produced in laboratory experiments have, until now, usually been created by directly creating a conical flow that converges to produce a jet. This mechanism omits the first part of the mech- anism in which the stellar outflow is focused into the conical flow. In this contribution we propose a new experimental setup, with simple initial conditions, that is able to reproduce both stages of the mechanism, including the inward facing reverse shock. By selectively heating a small region inside a target, irradiated by a high-intensity laser pulse, a jet can be driven into the plasma behind the rear target surface. We present three dimensional simulations of the formation of the jet. We find jets with aspect ratios of over 15 and Mach numbers between 2.5 and 4.3. The influence of simulation parameters is investigated and the applicability of the jets totheir astrophysical counterparts is discussed.



The use of the 2D code POLLUX in modelling extreme ultra-violet laser interactions

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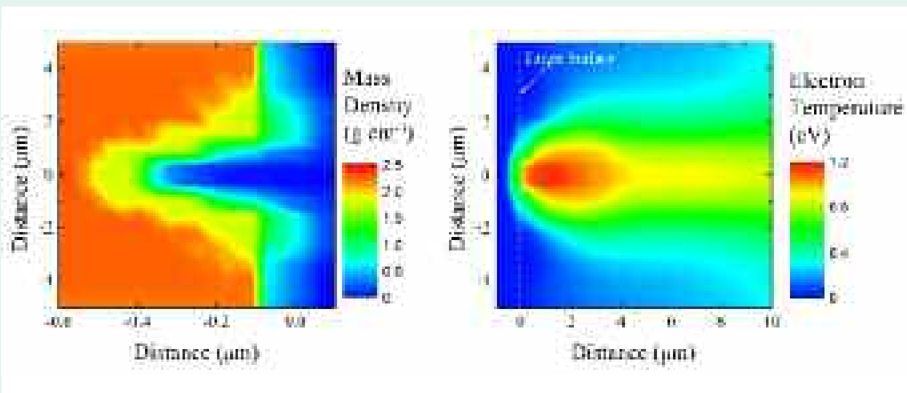
We present a simulation study which examines the interaction of moderate irradiance (> 10^9 W cm^{-2}) extreme ultra-violet (EUV) lasers with solid material. The radiative-hydrodynamic code POLLUX has been modified to include absorption via direct photoionisation and other relevant atomic physics to investigate the unique ablation properties of EUV lasers. The increased target penetration, due a typically higher than solid critical density, results in direct heating at solid density, producing warm dense matter. The simulation of an argon based capillary discharge laser (λ = 46.9 nm) interacting with a planar plastic target is reported.



Mass density (left) and electron temperature plots (right) showing the heating and subsequent ablation of a planar plastic target by an extreme ultraviolet capillary discharge laser (E_p = 26eV), with a peak irradiance of 1 × 10^{10} Wcm^{-2} and focal diameter of 650nm. The simulation time is at the end of the laser pulse at t = 800ps. The EUV laser propagates from right to left, along the y = 0 axis.

Efficiency study of harmonic generation from solid targets in the strongly relativistic regime

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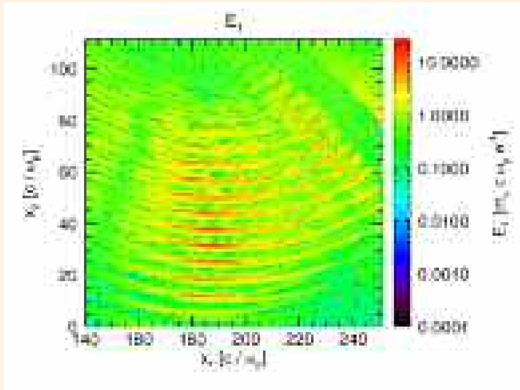
In the recent harmonic generation experiments conducted at the University of Michigan [F. Dollar et al., Phys. Rev. Lett. 110, 175002 (2013)] the harmonics' intensity was found to fall off much faster with harmonic order than in previously observed spectra which confirmed the scaling predicted by Baeva, Gordienko and Pukhov [T. Baeva, S. Gordienko, and A. Pukhov, Phys. Rev. E 74, 046404 (2006)]. In this paper a comprehensive set of two-dimensional numerical simulations is presented which demonstrate that the efficiency of the harmonic generation process is highly sensitive to very small variations in electron density scale length.



The R-matrix with time-dependence approach for ultrafast dynamics

54

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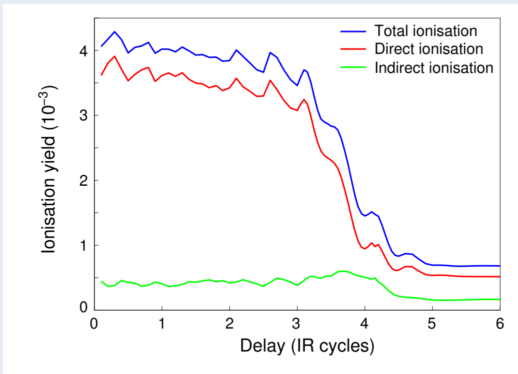
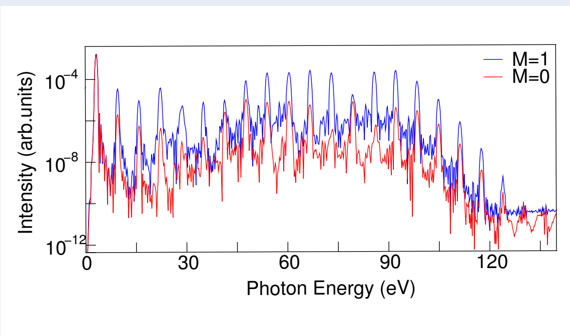
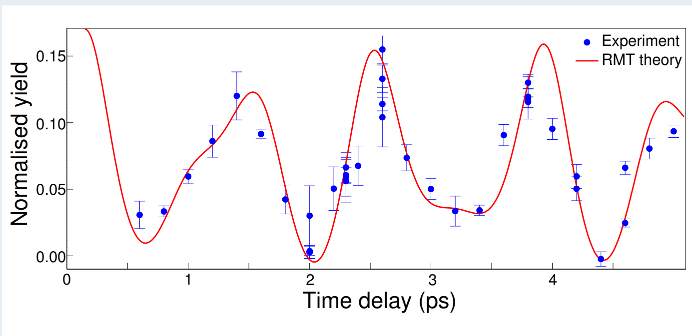
The dawn of the attosecond age, and the corresponding strides made in laser technology, have facilitated the experimental investigation of light-stimulated electron dynamics on their own characteristic time-scale. The subsequent need for theory to interpret these results has largely been met by simple, approximate methods which can reproduce the experimental results without necessarily elucidating the complex underlying physics. There are very few methods capable of modeling the laser-atom system – including the important electron correlation effects – which are both accurate and computationally feasible. Here we describe the R-matrix with time-dependence (RMT) approach, which combines state-of-the-art computational techniques with well established atomic physics codes to describe general, multielectron atoms in short, intense laser fields.







Nonequilibrium Effects on the Ionisation Energies in Dense Plasmas

55

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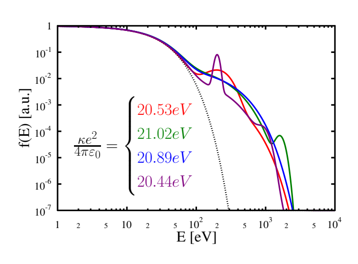

Electrostatic potentials in dense plasmas are screened by the presence of free charge carriers. Screening alters the strength and shape of the potential and therefore modifies, among other properties, the wavefunctions and binding energies of bound states in the plasma. The screening of the electron-core potential typically leads to a lowering of the ionisation energy known as continuum lowering or as ionisation potential depression (IPD) and can greatly affect the ionisation state of partially ionised plasmas. Consequently, IPD may also strongly influence a wide variety of plasma properties.

Models to describe screening by electrons and ions in local equilibrium have been developed for many years. One of the most popular model was proposed by Stewart and Pyatt and interpolates between the high-temperature, low-density Debye limit and the low-temperature, high-density limit of the ion sphere model. Of course, these easy screening models have been challenged by more elaborate theories; however only recent contradictory experimental results have posed serious questions about the applicability of these models.

The use of high-power, short-pulse laser systems and free electron lasers in the VUV and X-ray domain (XFELs) allow highly excited, solid-density materials to be created and probed on femto and picosecond timescales. Experimental results and simulations suggest the presence of a considerable nonequilibrium component to electron populations in such strongly driven systems. A well-founded theoretical approach for continuum lowering in plasmas with nonequilibrium electron distributions is therefore needed if we are to correctly analyse such materials. Such a generalised theory might also shine new light on the contradiction of recent experiments.

A robust plasma-based laser amplifier via stimulated Brillouin scattering

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E. P. Alves, F. Fiuza, R. A. Fonseca and L. O. Silva
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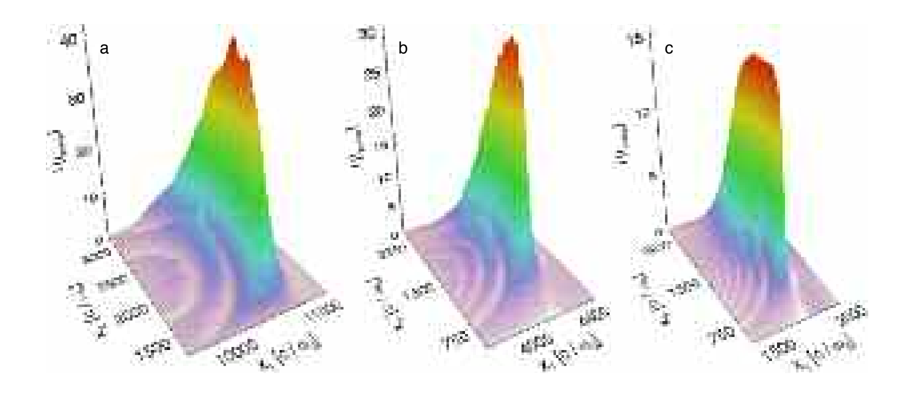
It is shown here that Brillouin amplification can be used to produce picosecond pulses of petawatt power. Brillouin amplification is far more resilient to fluctuations in the laser and plasma parameters than Raman amplification, making it an attractive alternative to Raman amplification. Through analytic theory and multi-dimensional computer simulations, a novel, well-defined parameter regime has been found, distinct from that of Raman amplification, where pump-to-probe compression ratios of up to 100 and peak laser fluences over 1 kJ/cm² with 30% efficiency have been achieved. High pulse quality has been maintained through control of parasitic instabilities.



Two-Pulse Ionization Injection into Quasi-Linear Laser Wakefields

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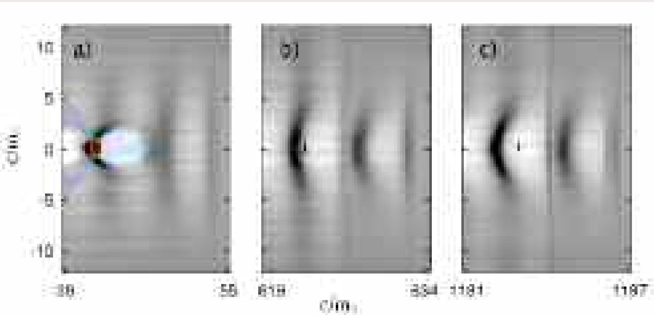
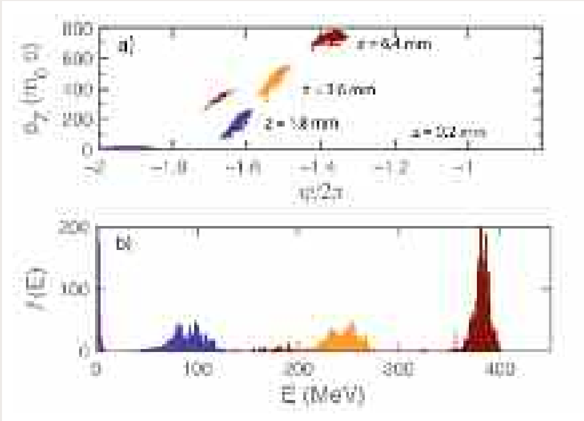
We describe a scheme for controlling electron injection into the quasi-linear wakefield driven by a guided drive pulse via ionization of a dopant species by a collinear injection laser pulse with a short Rayleigh range. The scheme is analyzed by particle in cell simulations which show controlled injection and acceleration of electrons to an energy of 370 MeV, a relative energy spread of 2%, and a normalized transverse emittance of 2.0 μm.

This is a CLF report version of the original APS paper. It should be cited as N. Bourgeois, J. Cowley, and S. M. Hooker, Phys. Rev. Lett. 111, 155004 (2013). APS link here: http://link.aps.org/doi/10.1103/PhysRevLett.111.155004



Results from Particle-in-Cell simulation showing the density of electrons along the acceleration, for (a) z 0.2mm and 2.3mm and (c) 4.5mm. Shown in grayscale are electrons ionized from hydrogen and Nitrogen $N^{<5+}$ions; the color scale shows electrons ionized from $N^{\geq 5+}$ions.



Calculated phase space distribution (a) and energy spectrum (b) of electrons ionized from $N^{\geq 5+}$ions, at distances of z = 0.2mm, 1.8mm, 3.6mm and 6.4mm of acceleration.

Simulation of photon acceleration technique for density measurement in plasma wakefields

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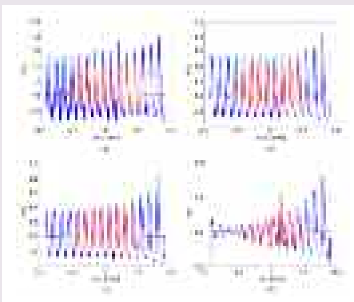
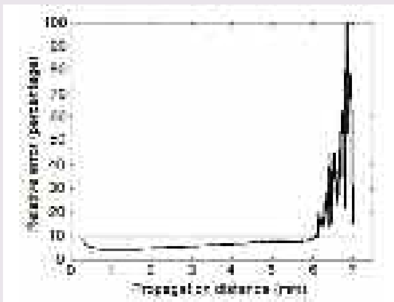
In plasma accelerators, the accelerated beams are pushed forward by the electric field produced in plasma waves (wakefields). The plasma wakefields can produce electric field up to 10-100 GV/m. It is about three orders of magnitude higher than the conventional accelerators can provide. One challenge in plasma accelerators development is the inadequacy of plasma wakefield diagnostic techniques. Several methods have been proposed to produce image of plasma density profile. Among them are Frequency Domain Interferometry (FDI), Frequency Domain Holography (FDH), and shadowgraphy. These techniques produce qualitative images of plasma wakefield. However, none of them has been used to measure the plasma wakefield amplitude quantitatively. In this report, we present a simulation result of measurement of plasma wakefield density amplitude using photon acceleration technique.





Development

LIFEtime: A New Time-Resolved Laser Spectrometer for the Life Sciences

G. M. Greetham, C. Nation, I. P. Clark, A. W. Parker, I. V. Sazanovich, P. M. Donaldson, P. Matousek and M. Towrie
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The BBSRC-funded LIFEtime instrument will probe the nature of biochemical changes using time-resolved infrared spectroscopy over > 10 orders of magnitude in timescale (femtoseconds to milliseconds). The instrument will use ultrafast IR pulses to take 100,000 "snapshots" per second of the changes in the vibrations of atoms in protein and DNA molecules. These changes provide information on how the molecules function or become damaged in nature. The new ytterbium-based laser system will be initially applied to Two-Dimensional IR and Time-Resolved Multiple Probe Spectroscopy techniques, with future development planned towards time-resolved imaging applications.

LIFEtime logo, implying the ability to record dynamic data over orders of magnitude in time.

Super resolution developments in the Octopus facility

Stephen Webb, Chris Tynan, Stan Botchway, David Clarke, Benji Coles, Sarah Needham, Dan Rolfe, and Marisa Martin-Fernandez
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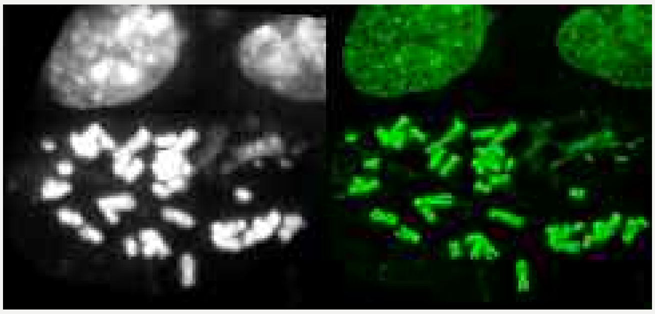
The Central Laser Facility's Octopus facility, located in the Research Complex at Harwell, consists of a set of advanced optical microscopy stations linked to multiple laser sources. Recent funding from the Medical Research Council and Biotechnology and Biological Sciences Research Council has supported upgrades to Octopus providing new techniques which can overcome the diffraction limit to achieve so-called "super-resolution". Techniques available include: Stimulated Emission Depletion Microscopy (STED), which uses a doughnut-shaped laser beam to deplete fluorescence around the excitation beam, achieving resolutions around 50 nm; Stochastic Optical Reconstruction Microscopy and Photoactivated Localization Microscopy (STORM/PALM), that use single molecule localization to reconstruct images with around 20 nm resolution, and Structured Illumination Microscopy (SIM), that uses patterned illumination to extract short distance information from the sample. Also, a new single molecule Alternating Laser Excitation FRET station allows measurement of inter- and intra-molecular distances in the 2-8 nm range.



Chromosomes imaged by conventional widefield microscopy (left) and Structured Illumination Microscopy (right) (Image courtesy of Christophe Lynch).

New front end for the Gemini facility

Chris Hooker, Nicola Booth, Oleg Chekhlov, Peta Foster, Chris Gregory, Steve Hawkes, Cristina Hernandez-Gomez, Victoria Marshall, Bryn Parry, Rajeev Pattathil, Daniel Symes and Yunxin Tang,
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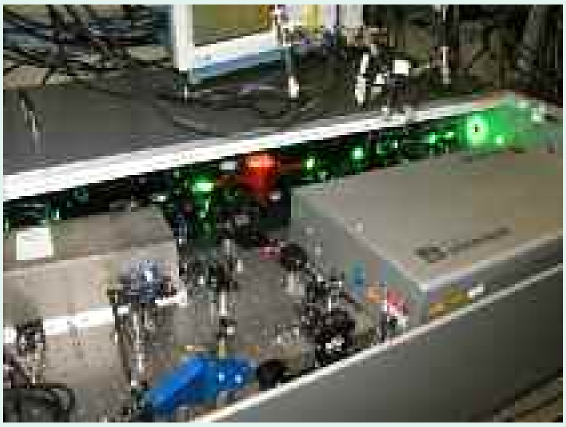
Analysis of operational statistics last year showed that the oscillator and kHz preamplifier of the Gemini system were the principal causes of lost experimental time, so it was decided to replace them. The system chosen was a turnkey oscillator from the same supplier, a Femtolasers Integral Element Pro, which is designed to fit inside the preamplifier housing. To avoid the loss of access to Gemini that would result from returning the front end to the supplier, the spare preamplifier was sent back instead, to be refurbished with a custom water-cooled breadboard. The new oscillator was installed on the same breadboard for maximum stability.

The new front-end system was installed by Femtolasers engineers at the start of April. Gemini staff were trained to operate it, and then spent two weeks integrating it into the laser: adjusting the beam size and re-setting trigger timings to restore Gemini to full operation.



A New ns OPCPA Front End for Vulcan Petawatt

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We have designed and built a new nanosecond (ns) OPCPA front-end for the Vulcan Petawatt facility. This system provides higher input energy to seed the glass amplifier chain, better stability and shaping of the spectral profile. It represents an important upgrade to the Vulcan laser as it increases the reliability and contrast, while permitting shorter pulse duration.

The Vulcan system OPCPA amplification is done in two stages. Firstly on a picosecond time scale to ~12 ∝J energy, this is then stretched to 4.5 ns before further amplification in the ns OPCPA. The new system is specifically designed to work with the pre-amplified ps seed. A custom, flash-lamp pumped Nd:YAG laser provides 500 mJ of pump light in a temporally shapeable pulse. We achieve 60 mJ output in the IR, an order of magnitude increase on the previous ns OPCPA.

In this report we present the design considerations and features implemented to improve the performance and reliability. We describe the results from initial tests through Vulcan, including high energy target shots and measurements of temporal contrast after compression in the Petawatt target area.

The three stage ns OPCPA amplifier in operation in the Vulcan front-end

TAW Long Pulse Facility Upgrades

Margaret Notley, David Carroll, Rob Clarke, Mark Dominey, Lee Hall, Mark Harman, Scott Harrison, Rob Heathcote, Jorge Suarez Merchan, Simon Spurdle, Trevor Winstone
(CLF, STFC Rutherford Appleton Laboratory)

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Target Area West (TAW) is an eight beam facility able to deliver 2 beams in CPA short pulse (1-10ps) and 6 beams in long pulse mode at 1053nm or 527nm (1ω and 2ω respectively) for a variety of high power laser interactions.

This facility has recently undergone two major beamline delivery upgrades to improve its versatility and operability. The two upgrades took place over the 2 month period August - September 2013. Firstly improvements to the cluster of 6 ø110mm beams which aimed to enable a faster and more streamlined turn around between experiments. Secondly implementation of a new capability to deliver an additional 1kJ at long pulse to target via the other two traditionally short pulse beamline paths.

These upgrades came in response to feedback from community users and facility staff about future versatility requirements and efficiency improvements for experiments.

The six beam cluster has had new extensions benches, pillar system and lens drives installed to improve its ease of use and versatility. This system is now faster and easier to set up with more optics and diagnostics systems being in permanent positions and is less prone to focusing and instability issues from pumping the interaction chamber and vibrations.

The traditionally short pulse beamlines have had extra infrastructure installed to steer the beamlines around the compressor. This enables the pulses to be used at long pulse mode at 500J per beam at 1053nm. Delivery to the interaction chamber is via any suitable port creating a versatile high energy capability.

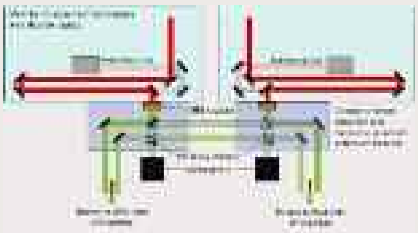

Fig. 1 Schematic of the new main 6 beam layout – everything up to extension bench is permanent set-up, with reference line. Anything after can be adjusted for direction and harmonic used.

Fig. 2 Schematic of the new compressor by-pass beam layout.

Experimental setup of the Vulcan HAPPIE Laboratory 2 for spatially and temporally coherent multibeam recombination

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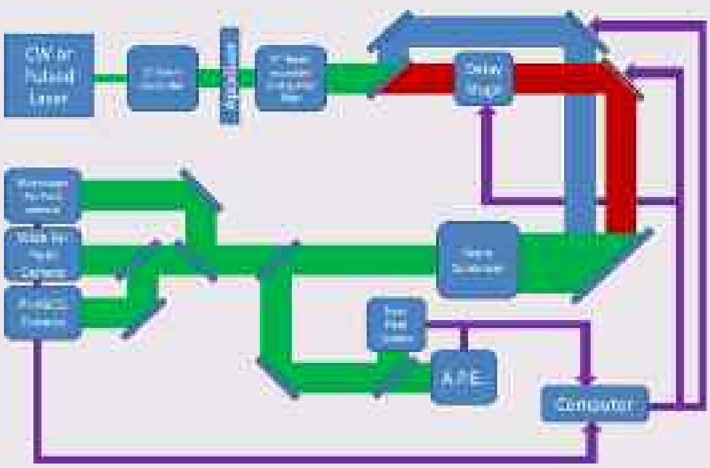
In this contribution we report on the progress made in the development of technologies to coherently combine laser beams. We discuss the establishment of a new laboratory for the progression of the work. In addition we discuss how we increase the scale of the experiment and to introduce new diagnostics into the setup.



A schematic diagram of the new layout.

48 Hour operation of DiPOLE at 7J at 10 Hz

P. J. Phillips, K. Ertel, P. D. Mason, S. Banerjee, J. Smith, T. Butcher, M. De Vido, W. Shaikh, O. Chekhlov, S. Tomlinson, A. Lintern, J. Greenhalgh, C. Hernandez-Gomez and J. L. Collier
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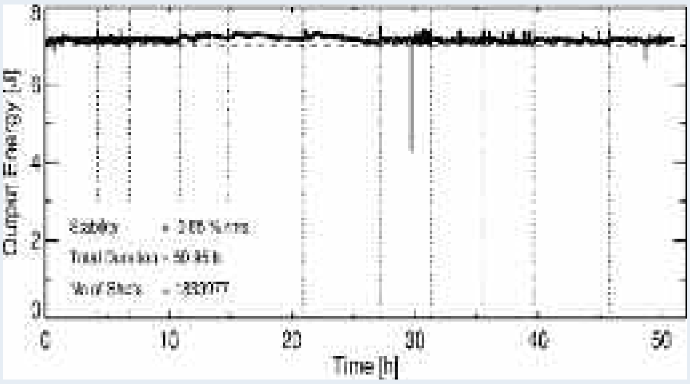
We have successfully ran DiPOLE for a total of 48 Hour operation at 7J 10 Hz. This has been achieved by running DiPOLE for a series of successive runs that have lasted for 4 hours or more. Energy stability over this time was measured to be 0.85% rms. During this run there was no damage on the gain disks and all the multi-pass relay-imaging optics. We describe the setup that allowed this extensive operation of DiPOLE. We discuss routes to engineering improvements to achieve significantly improved energy stability.



Plot of output energy during 48 hour operation of the DiPOLE amplifier.

Delivery of a 100J DiPOLE laser to the HiLASE project: Progress update

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CALTA, the Centre for Advanced Laser Technology and Applications, has been awarded a contract to supply a 100J, 10 Hz version of the successful DiPOLE concept for use as part of the HiLASE project in the Czech Republic. The project started in March 2013 and is due to complete in May 2015 – a challenging timescale for such a significant piece of work. The major elements are a front end, producing 100mJ pulses, a 10J stage based closely on the DiPOLE prototype, and the final 100J amplifier. The team is drawn from CALTA and other parts of the CLF with some agency and contract staff. The procurement phase is proceeding well, and already the front end is largely complete in the lab.

A general view of progress in the DiPOLE 100 lab, where the laser for HiLASE is being assembled. The front end is in the foreground, with elements of the 10J stage visible behind and the table for the 100J stage in the background. (August 2014)

HiPER

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The CLF is host to HiPER, an ambitious European Roadmap project that seeks to demonstrate the commercial viability of power production from laser driven fusion. Following the conclusion of the Preparatory Phase in April 2013, the project has entered the "Physics demonstration and technology development" phase.

There have been extremely positive developments of importance to HiPER over the period covered by this report.

Researchers meet at Bordeaux to discuss prospects for laser driven fusion at the launch of the IFE COST programme.

LIDT Modification Following Debris Damage

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We present a study of the degradation of optical coating when subjected to damage by laser-target debris and the subsequent effect on their Laser Induced Damage Threshold (LIDT). Tests confirm operational observations of a significant reduction in LIDT and coating lifetimes for protected silver coatings used for final optical components on high-power laser facilities.

In-situ formation of solidified hydrogen thin-membrane targets using a pulse tube cryocooler

Sam Astbury, Pete Brummitt, David Carroll, Rob Clarke, Alistair Cox, Steve Crisp, Paul Holligan, Steve Hook, David Neely, David Rathbone, Phil Rice, Chris Spindloe, Simon Spurdle, Toby Strange, Martin Tolley, Stephanie Tomlinson, Jorge Suarez Merchan
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This paper is an account of the Central Laser Facility's activities in producing a cryogenic hydrogen targetry system using a pulse tube cryocooler. Due to the increasing demand for low-Z thin laser targets CLF have been developing a system which allows the production of solid hydrogen membranes by engineering a design which can produce targets remotely allowing the gas injection, condensation and solidification of hydrogen without compromising the vacuum of the target chamber.

The design of the system is discussed along with many of the issues which arose, namely achieving temperatures lower than 13.8K (the triple point of H_2), establishing a repeatable growth procedure and producing a dynamic gas-tight seal which could be removed to expose the formed target to the laser.

Hydrogen ice growth chamber and dynamic seal mechanism.

Image of solidified hydrogen over copper target foil.

CLF's cryogenic targetry test chamber.

Automated Production of High Repetition Rate Foam Targets

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C. Spindloe, D. Haddock and M. Tolley
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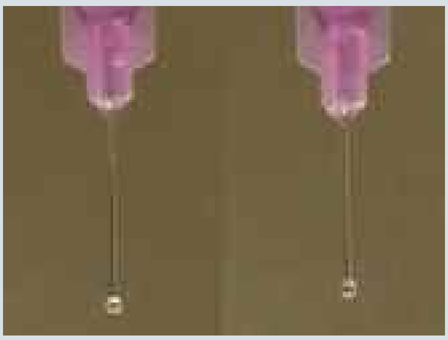
This paper reports on a production method that is using a semi-automated dispensing and curing system to maximise the output of the drying process to produce foam targets that are technically challenging and previously difficult to fabricate. The most time consuming stages of the foam production process when making a large number of targets are the filling and curing steps. Given the regular spacing and grid-like nature of arrays it was proposed that a robot might be able to complete both steps quickly and simultaneously.

A 3 axis (x,y,z) robot with dispensing capability was used to prove the principle of automated production. The interaction of the chemicals with the dispensing tips was investigated and the results of the foams produced were compared with the foams produced manually.

The robot has shown good results in improving the quality of the foams by reducing the target-to-target variation and with careful programming it is likely that the variation can be further reduced. The time taken to produce the foams has been significantly reduced.



Left: a water droplet hangs below the end of the dispensing tip. Right: a foam solution droplet climbs up the dispensing tip.

Dispensing robot with 3 axis stage.

Batch Production of Micron-scale Backlighter Targets

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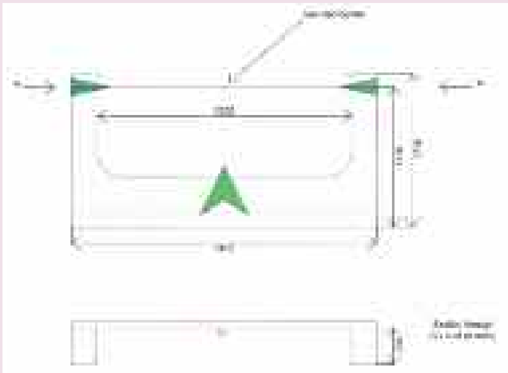
The fabrication of micro-scale backlighter targets is described. Traditionally laser targets have been fabricated using conventional machining or coarse etching processes and have been produced in quantities of 10s to low 100s. The processes described allow batch production with numbers in the 1000s. Another prime benefit of the Micro-Electro-Mechanical System (MEMS) fabrication techniques, when used here, are that they allow much smaller backlighter targets to be produced with finer tolerances, giving improved spatial resolution. Additionally, the processes provide more accurate placement of the various components relative to each other.



Schematic of a completed backlighter target (left) and a close-up of a 3µm x 3µm x 10µm target mounted at the edge of the CH supporting membrane (right).

Delivery of POLAR Targets to the First Academic Experiment on the Orion Laser Facility

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This paper describes the fabrication of a range of Polar targets made by the Target Fabrication group for the first academic access experiments on the Orion laser facility at AWE. A large number of complex fabrication technologies and associated research and development activities were required to field a total of 80 high specification targets for the academic access experiments.

Here we review the Polar geometries for an astrophysics experiment in which high power laser pulses were used to heat and compress an interaction target to a high-energy density state, mimicking that of a magnetic cataclysmic variable star, for the purpose of monitoring accretion shock formation and propagation in the extreme environment.

There were two main targets for each shot: a Polar target and a complex backlighter. The main interaction target was the Polar target which underwent a number of modifications during the experiment. The target was mounted onto the Orion target positioner.

Images of the Polar target showing the obstacle side (right) and the Au/CH pusher (left).

New Laser Safety Interlock System Design using a PSSuniversal PLC Device

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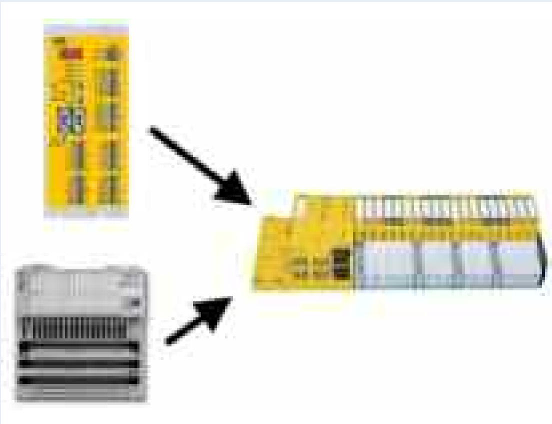
An enhanced laser safety interlocks system for the new stand-alone Research Complex G43 LIFEtime Lab has been developed. The single Pilz safety PLC for safety and standard functions replaces the Schneider Momentum PLC and Pilz 3047 safety PLCs. Improvements make the system easily scalable and expandable using the latest programming software in accordance with EN/IEC 61131-3.



Pilz PSS4000 Replaces the Pilz 3047 & Schneider Momentum PLC units

Investigation into the limitations of target positioning on Astra-Gemini

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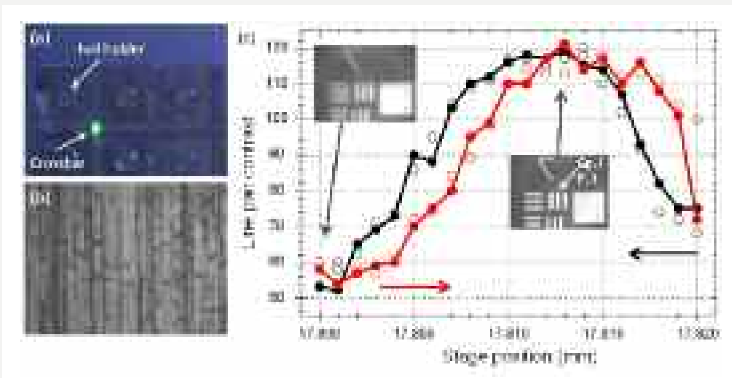
Conducting high intensity experiments using Astra-Gemini with the f/2 parabola needs the location of solid targets at focus with micron accuracy and at a relatively high repetition rate (1/minute). This presents the challenges of developing a consistent yet rapid positioning method as well as achieving the required quality of motor and control system. In this report we assess the limitations of the rear surface illumination technique with existing equipment in terms of target positioning accuracy and speed. This trial concluded that our current system is adequate for the simplest case of target material but further tests are necessary to investigate complications arising from the use of different types of target. Furthermore it highlighted that several of our standard motorized stages need to be enhanced or replaced in order to optimize output from Astra-Gemini. Following recent investment in hardware, this upgrade process is underway.



An array (a) was mapped by determining the correct focus position for each target location using illumination of the rear surface (b) and then the speed at which simulated shots could be taken was assessed. The accuracy of the current stepper motor was measured by scanning in micron steps in the focal direction (c).

The design and characterization of an improved target positioning system

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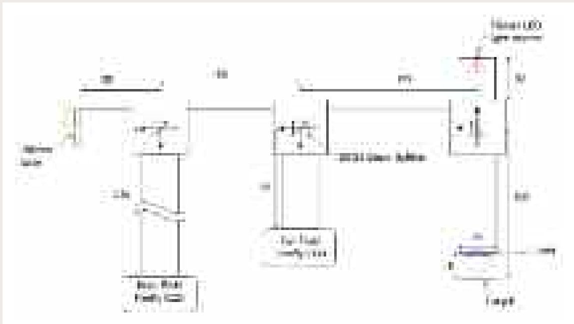
Precise target imagery for positioning and orientation in the Astra Gemini Target Area is hugely important for the experiments conducted using the laser. A novel imaging system was designed with ease of use, flexibility and running cost in mind. The designed system includes just one simple lens, rather than the high-cost Mitutoyo microscope objective that is currently fielded in the Target Area. The design introduces a method for measuring target orientation that can perform in parallel with the positioning measurements in the same compact system. The two systems use the same lens, making the whole system compact. Performance comparisons with the Mitutoyo objective lens are presented, as well as a discussion of the future work that can be performed to improve both systems.



A schematic of the Firefly system used. All beam splitters are 50:50. The LED on the top right emits at 792±30nm and is used to illuminate the target. The laser, attached using an SMA fibre optic cable, is capable of giving information about the pointing of the target. All distances are in mm.

Creating Broadband Circular Polarised Light by Reflection

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A system of reflective optics to convert linearly polarised light to circularly polarised is investigated for potential future use on the Vulcan 10PW upgrade, with broadband capabilities. A prototype system of three adjustable mirrors was created and used in parallel with a probe beam and a polarisation measurement arrangement. Tests were undertaken to understand and compare the causes and magnitudes of reflected phase change; explicitly aimed at producing a 90° phase shift for high powered lasers. Analytical solutions are derived and compared with obtained results to demonstrate a purpose-built, multi-mirror phase retarder. Experimental measurements confirmed the calculated induced phase shift of 90° for green, (λ=532nm) light with two gold mirrors at an incident angle θ_{in}=52.0±0.5° and one silver mirror with a silicon dioxide coating at θ_{in}=14.0±0.5°.

Investigating Schlieren Microscopy as a Method of Optic Inspection

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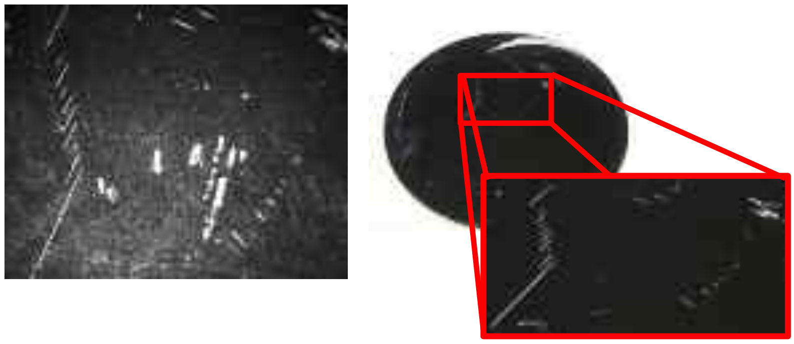
A Schlieren, or dark field, imaging system was investigated for its suitability as a method of remote optic inspection, for implementation on the Vulcan Short Pulse compressors. Images taken of various mirrors at different distances along the purpose-built beamline demonstrate precision and simplicity of the technique.



M4 dark-field image and M4 photograph. Dark field images were taken via the method described previously, photographs were taken with an SLR camera

A Study on the Effects of Aging on Radio Chromic Film

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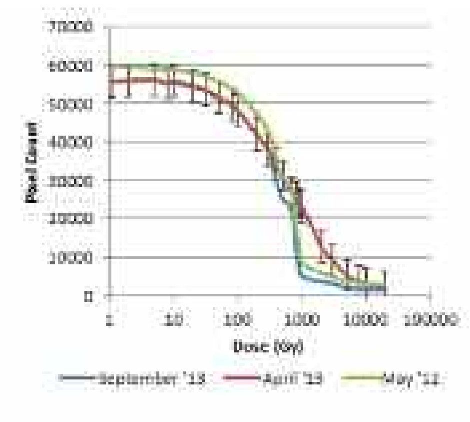
The aim of this study was to identify the effects of aging on the validity of data collected from radiochromic film. We took three scans on three types of RCF over the course of sixteen months. For the study, we chose to focus our attention on HDV2; the most commonly used RCF. From the data we collected, it was clear to see that the effects on aging caused minimal effects on the quality and the longevity of RCF as a diagnostic tool.



The average pixel count for scanned HDV2 RCF samples as a function of proton dose that samples of HDV2 RCF were exposed to. The graph shows the data from the green channel from three separate scans across 16 months.

Ray tracing to model time of flight effect in square based pyramid scintillators

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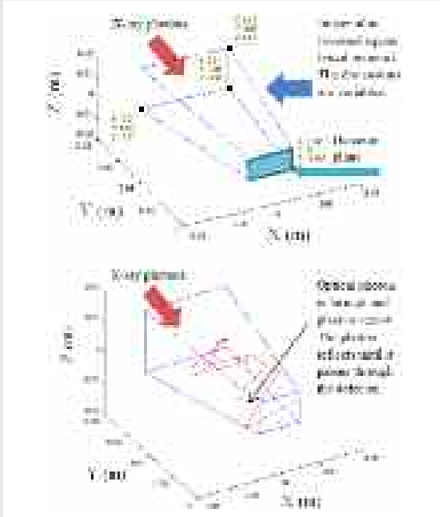
Scintillators are regularly used to convert high energy photons into optical emission, which can then be readily detected. Most scintillator based systems are designed for high collection efficiency so that the energy of the incident photon can be resolved. However, in this study we have examined time of flight aspects using a ray tracing model. As new ways of generating ever shorter x-ray pulses become available, measuring the duration of such beams is becoming a critical issue.

The aim of this project was to model the temporal signal generated at the output of an "ideal" scintillator. We assume that the scintillator has negligible lifetime so that we are only examining the effects of the detector geometry and boundary scattering/reflection/absorption on the temporal output of the system. The ideal scintillator shape would give high sensitivity and a small amount of afterglow, which allows the scintillator to produce higher time resolution outputs.



A schematic of the geometry for an inversed square based pyramid. Upper image shows how the scintillator is positioned, which direction the x-rays are incident from and the plane the optical photons are detected through. In the lower image, the red line indicates a typical path the photons travels to reach the detector.

A K-alpha Imaging Crystal diagnostic for CLF

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Laser interactions with matter are routinely diagnosed by measuring K-alpha x-rays emitted from plasma sources. Spherically curved imaging crystals combined with an x-ray detector (usually either image plate or x-ray sensitive CCD's) are one way of detecting the number and position k-alpha x-rays from within plasmas. This is an extremely useful method for collecting information on plasma conditions such as electron transport in plasma.

The CLF identified a gap in this area of x-ray diagnostics provision and has now developed an imaging K-alpha diagnostic including a crystal analyser and specific mount for deployment to high power laser experiments. This enhances the suite of available x-ray diagnostics and enables support of experiments in this area where previously this was unavailable.

The k-alpha imaging system developed consists of a spherically curved quartz crystal, 21-31 lattice structure and radius of curvature of 380mm. It has a lattice spacing of 1.541Å and at close to normal incident angle is ideal for imaging 1st order Cu K-alpha 8keV x-rays. These crystal properties were chosen to fit in with current crystals that some of our user community already have that have been successfully deployed on experiments at CLF facilities.

The system to allow alignment of the crystal consists of a crystal mount and an x,y,z drivable stage. Tip & tilt adjustment is delivered using pico motors that can be manually or electrically driven and either with or separately from target area drive systems giving flexibility for alignment purposes.

Fig. 1 3D views of the crystal mount, front and back, showing where crystal sits against a location lip (shown in yellow).

Development of a High Repetition X-ray Pinhole Camera

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The development of a high repetition, no film imaging system would be a welcome addition to the diagnostics available in the Vulcan laser target areas. It would allow multiple x-ray images to be taken without the need to gain access to the interaction chamber, increasing the shot rate.

Imaging the x-ray radiation is sufficient, in theory, to measure the spatial profile of the interaction region; that will enable identification of any unusual features or abnormalities to the spatial profile of the plasma to be analysed and diagnosed.

Overall, the test period provided some positive initial results, including a proof of principle for this imaging diagnostic, which shows it be potentially useful in future applications.

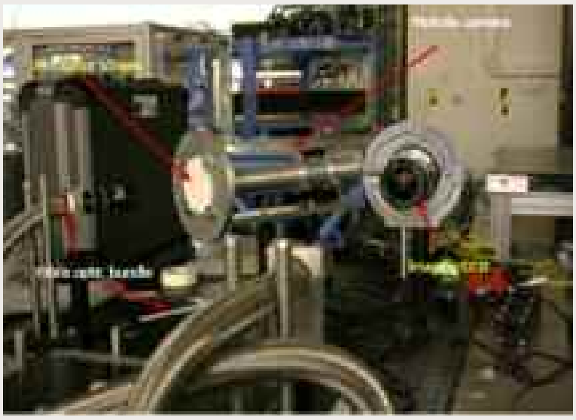

Figure 1: Photograph of the diagnostic setup showing the phosphor plate, the pinhole camera, the fibre optic bundle, and the imaging CCD.

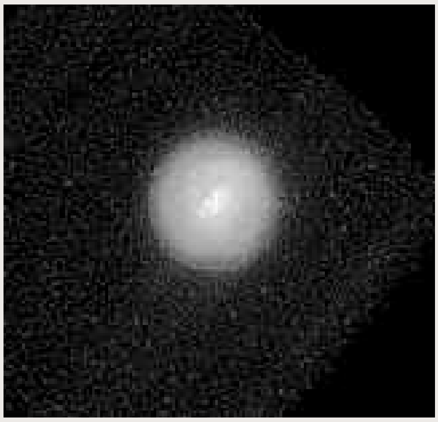

Figure 2: Image is formed on the phosphor plate. Andor Solis CCD camera recorded ~15000 counts per pixel in the image.[No filters, and 2mm pinhole]. The image has been cropped and enlarged.

Development of a plug-and-play diagnostics base for faster in-target area experiment setup

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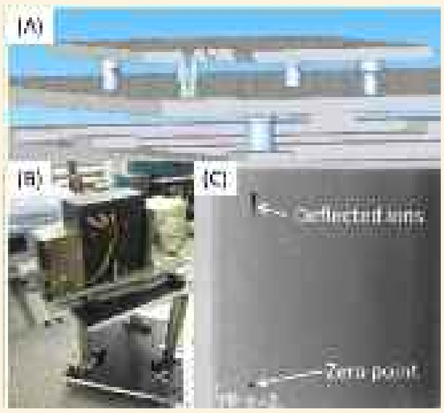
A significant amount of time during experiments is dedicated to building the setup of the experiment, typically 1 to 1.5 weeks of a 5 week experiment. During this year on Vulcan there were 9 scheduled experiments. Reducing the amount of time spent setting up experiments in the target area will improve the utilisation of the facilities so that more time can be dedicated to experimental data shots. In addition, a major bottleneck in the experimental setup is the target chamber as physical access is limited, reducing the number of internal diagnostics which can be installed / aligned at any one time. To address this, a prototype plug-and-play breadboard system has been developed. This enables diagnostics to be setup and aligned externally and then placed within the experimental setup with minimal chamber access time. This system has been recently tested during a system access period on TAW using a Thomson ion spectrometer.



(A) Schematic of plug-and-play breadboard system. (B) Thomson ion spectrometer mounted on plug-and-play breadboard. (C) Scan image of data from Thomson spectrometer pictured in (B), no electric field was applied.

Calibration of TOF Detectors Using Short Laser Pulse Generated Neutron Source

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J. Fuchs, L. Vassura
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A. Kleinschmidt, M. Roth
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In contrast to using continuous neutron sources for calibration of scintillators used for time-of flight (TOF) diagnostic, here we present absolute calibration of three scintillators (EJ232Q, BC422Q and EJ410)

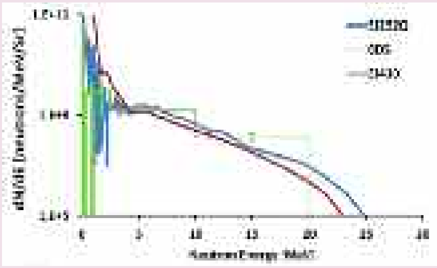
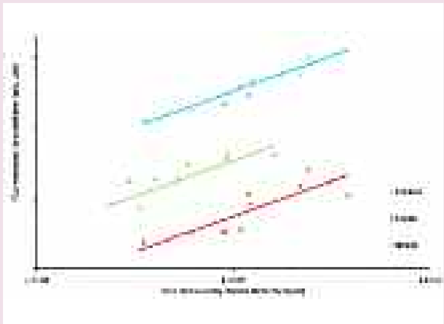


Fig.1) Calibrated neutron spectra obtained from EJ232Q and EJ410 detectors compared with spectrum obtained by BDS in the same shot.

Fig. 2) Comparison between neutron flux obtained from different scintillator detectors and the BDS for neutron energy in the range 2.5-20 MeV. The graph plots the comparison for three different scintillator detectors, EJ232Q, BC422Q and EJ410, obtained over a number of shots. The solid lines show linear fits to the data points.

using high intensity laser driven ultra-short burst neutron source. The three plastic scintillator detectors were calibrated against gamma insensitive bubble detector spectrometer, which were absolutely calibrated over a wide range of neutron energies. Over a number of shots, spanning over a wide range of neutron flux between 10^8 - 10^{10} n/Sr for 2.5-20 MeV neutrons, the comparison between the results obtained from the TOF data analysis and the BDS data follows a linear fit, which provides the final calibration factor for the scintillators.



Artemis operational statistics

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During the reporting year April 2013 – April 2014 a total of 8 experiments were delivered in the Artemis facility, as shown in Table 1. 26 operational weeks were planned, and 26.5 delivered. Eight weeks were dedicated to experiment set-up, three of which were set-up for ARPES experiments. Two weeks were dedicated to development work for optimising high harmonic generation at short wavelengths. These two weeks are considered operational as users were present throughout. Four weeks were allocated for engineering work on the laser, including some maintenance. Additionally, a four week period over Christmas was spent dealing with asbestos in the facility. Refurbishment of the laser, Topas and XUV beamline spanned eight weeks.

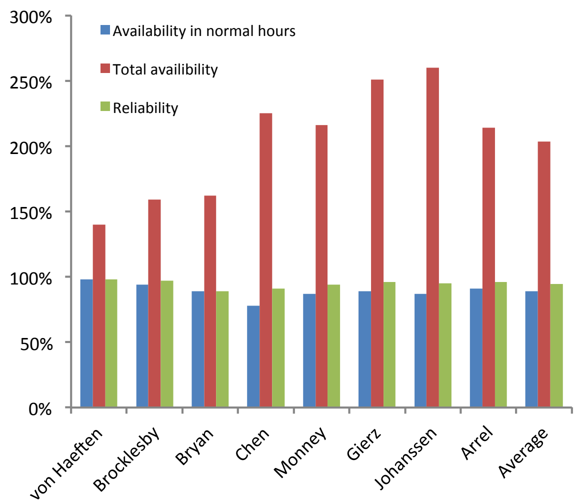
Table 1. Artemis schedule for 2013/14. Schedule includes extensions to experiments.

Week Starting	Experiment number	User and experiment
2013		
01/04		Set-up
08/04		
15/04	13120001	von Haeften - He clusters
22/04		
29/04		Laser upgrade and service
06/05		Engineering - interlocks and enclosures
13/05		Topas service
20/05		
27/05	13120001	von Haeften - He clusters (1.5 wks)
03/06		Engineering work and laser maintenance
10/06		
17/06		Set-up
24/06		Development: HHG high flux short wavelength
01/07		
08/07		
15/07	13120004	Brocklesby - XUV imaging
22/07		Set-up
29/07		
05/08	12120010	Bryan - Electron holography
12/08		
19/08		
26/08		Set-up
02/09		
09/09		
16/09	13120002	Chen - Topological phase transition
23/09		Engineering – a/c, water monitoring
30/09		Laser service
07/10		Topas service
14/10	13120000	Monney - TiSe2 ARPES (0.5 wks)
21/10		Beamline maintenance
28/10		
04/11	13120000	
11/11		Monney - TiSe2 ARPES
18/11		
25/11	13120003	Gierz - Graphene
02/12		Johannsen - Graphene
09/12	13220004	
16/12		
23/12		Engineering (Asbestos removal)
30/12		
2014		
06/01		Engineering
13/01		Johannsen – Graphene (1.5 wks)
20/01	13220004	
27/01		Beamline maintenance
03/02		Laser service
10/02		
17/02		Set-up
24/02		
03/03		
10/03		
17/03	13220008	Chergui/Arrel - Liquid jet
24/03		Development

The Artemis laser runs continuously for users from Mondays through to Fridays during experiments, and we have also been able to carry on data-taking over several weekends. Artemis runs unsupported overnight and at weekends.

The availability of the Artemis facility for the reporting year was 203%, including out of normal hours operation. This is a fall from the 238% availability from the previous year, but is considerably higher than the previous two years (172% and 157%). Laser reliability remained at a similar level to the previous year, at 94.5%. Normal operational hours are from 9am until 5pm on week days, and correspond to 100% availability (40 hours weekly).

Figure 1 shows experiment specific data for availability and reliability.



Experiments

The experiments scheduled on Artemis last year involved four of our end-stations and one user interaction chamber. We were able to schedule four condensed matter ARPES experiments consecutively on the beamline to improve efficiency. The performance of the XUV beamline deteriorated during the last half of the year, with transmitted flux and spectral resolution dropping. This was due to misalignment and damage to the monochromator input optic as well as deterioration of the coating on the toroidal mirror . We managed to compensate for the decrease in performance by improving the alignment through the monochromator and replacing the toroidal mirror used to focus into the interaction chamber. Completing these procedures delayed experiments by two weeks. The monochromator optics have now been replaced.

Laser upgrade

The second amplifier of the Artemis laser system was upgraded this year to a five-pass 'Komodo' amplifier design from KMLabs. Since the upgrade, we have been readily able to achieve pulse energies of 12-13 mJ in total at the exit of the two grating compressors. This has meant that we can readily pump the OPA with the 8 mJ necessary for optimum performance while still having enough pulse energy remaining for efficient high harmonic generation. We are also able to maintain this higher output power over longer periods between laser services. This has particularly benefited experiments using the mid-IR output of the OPA.

End-station development

There have also been significant developments to the Artemis end-stations this year. We have built and commissioned a new chamber for coherent XUV imaging experiments; adapted the spin-resolved time-of-flight chamber for use on the XUV beamline; built a chamber to house a liquid jet and electron spectrometer which will be built into a complete end-station for liquid-phase XUV photoelectron spectroscopy; and built and tested a molecular beam on the gas-phase AMO chamber. We have already had experiments and proposals using and requesting all of this new capability.

Gemini operational statistics

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S. Hawkes *Central Laser Facility, STFC Rutherford Appleton Laboratory*

During the reporting year, April 13 – April 14, a total of 9 complete experiments were delivered to the Astra-Gemini Target Area. In total 36 high power laser experimental weeks were delivered to the Gemini Target Area and 12 experimental weeks delivered to ATA2. The delivered schedule is presented in figure 2.

The availability of the Gemini laser system (delivery to the Gemini Target Area) was 83% during normal working hours, rising to 157% with time made up from running out of normal working hours. The reliability of the Gemini laser was 90%. ATA2 availability during normal working hours was 87%, rising to 143% with additional time. ATA2 laser reliability was 94%. An individual breakdown of the availability and reliability for the 9 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.

During the reporting year the Gemini South compressor grating was replaced, improving the compressor throughput to 72%, this brings the South beam in line with the North beam at having over 70% throughput. Gemini consequently delivered close to its energy design specification for all experiments during the year.

The heavy delivery schedule limited the system developments possible, however during the August access period a pulse front tilt diagnostic was installed and tested in Gemini and optimization of this aspect of the system was made.

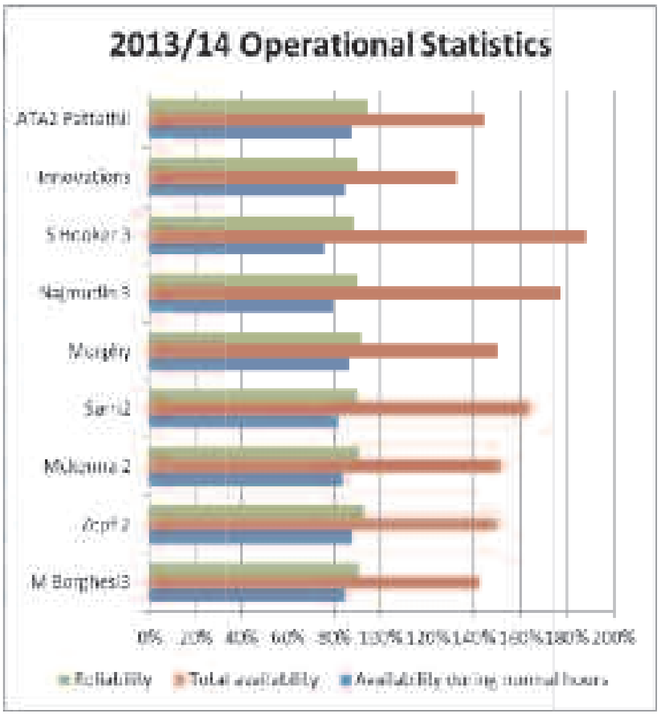

Figure 1. 2013/20014 operational statistics

01-Apr-13	07-Apr-13	Green	
08-Apr-13	14-Apr-13	12210013	
15-Apr-13	21-Apr-13		
22-Apr-13	28-Apr-13	Maintenance	
29-Apr-13	05-May-13	Set up	
06-May-13	12-May-13		
13-May-13	19-May-13	Borghesi	
20-May-13	26-May-13		
27-May-13	02-Jun-13	12210026	
03-Jun-13	09-Jun-13		
10-Jun-13	16-Jun-13		
17-Jun-13	23-Jun-13	Set up	
24-Jun-13	30-Jun-13	Zepf	
01-Jul-13	07-Jul-13	13110011	
08-Jul-13	14-Jul-13		
15-Jul-13	21-Jul-13	Quantel Service	
22-Jul-13	28-Jul-13	Set up	
29-Jul-13	04-Aug-13	McKenna (Pt2)	Pattathil
05-Aug-13	11-Aug-13	12110011	12210016
12-Aug-13	18-Aug-13		
19-Aug-13	25-Aug-13	Extension	
26-Aug-13	01-Sep-13	System access	
02-Sep-13	08-Sep-13		
09-Sep-13	15-Sep-13	Sarri	
16-Sep-13	22-Sep-13	13110016	
23-Sep-13	29-Sep-13		
30-Sep-13	06-Oct-13		
07-Oct-13	13-Oct-13	Maintenance	Pattathil
14-Oct-13	20-Oct-13	Joint set up	cont..
21-Oct-13	27-Oct-13	Murphy	
28-Oct-13	03-Nov-13	13110019	
04-Nov-13	10-Nov-13		
11-Nov-13	17-Nov-13	Set up	
18-Nov-13	24-Nov-13	Najmudin	
25-Nov-13	01-Dec-13	13110015	
02-Dec-13	08-Dec-13		
09-Dec-13	15-Dec-13		
16-Dec-13	22-Dec-13	Asbestos removal	
23-Dec-13	29-Dec-13	Christmas	
30-Dec-13	05-Jan-14		
06-Jan-14	12-Jan-14	Set up	
13-Jan-14	19-Jan-14		
20-Jan-14	26-Jan-14		
27-Jan-14	02-Feb-14	Hooker	
03-Feb-14	09-Feb-14	13110013	
10-Feb-14	16-Feb-14		
17-Feb-14	23-Feb-14	Set up	
24-Feb-14	02-Mar-14		
03-Mar-14	09-Mar-14	Innovations	
10-Mar-14	16-Mar-14	13210037	
17-Mar-14	23-Mar-14		
24-Mar-14	30-Mar-14		

Figure 2. 2013/2014 Gemini operational schedule

Lasers for Science Facility operational statistics

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RAL-based experiments

In the reporting period (April 2013 to March 2014), 28 different User groups performed a total of 37 experiments in the LSF laboratories at RAL. A total of 3946 hours laser time was delivered to the UK User community and European Users throughout the year, with 147 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 1.69:1. 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 93.5% across the categories.

There were a total of 41 formal reviewed publications produced from the year's efforts, with the LSF programme supporting 3 students completing a PhD in the reporting year.

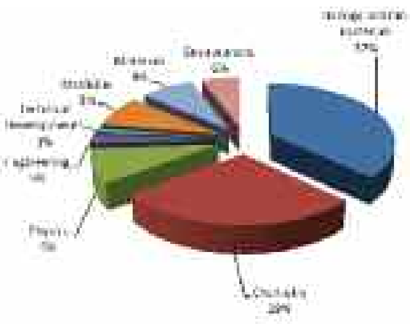

Figure 1. RAL-based bids by subject group

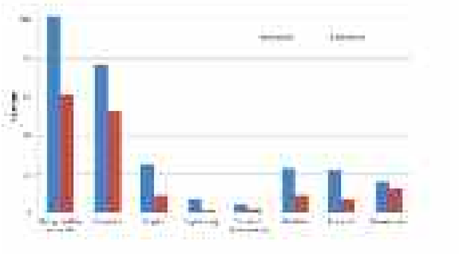

Figure 2. RAL-based experiments by subject

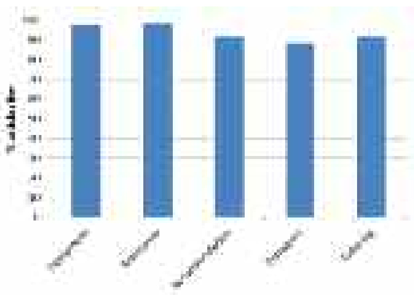

Figure 3. RAL-based average User satisfaction scores

Loan Pool

Throughout 2013/14 the Laser Loan Pool continued to provide laser loans to the UK research community. The facility delivered 366 weeks of laser time in the reporting period, supporting 16 research groups through 16 laser loans, and its work lead to the publication of 13 articles in peer reviewed journals. The ratio of weeks applied for versus weeks scheduled was 2.125:1 and the downtime was approximately 10 %.

During 2013-2014 the Laser Loan Pool was to take receipt of a high power Nd:YAG laser with 10 Joules in the fundamental for laser peening and similar applications; unfortunately the delivery of this system was delayed however it was seen during its soak test procedure and operates to specification. The first user of this new system will be Dr Pratik Shukla (University of Chester) who will be studying laser peening of ceramic materials for cutting tools.

The facility also commissioned a trial of a future purchase, a non-colinear OPA system, to obtain 30 fs pulses from the Light Conversion Pharos/Orpheus system extending the ultrafast capabilities to shorter pulses.

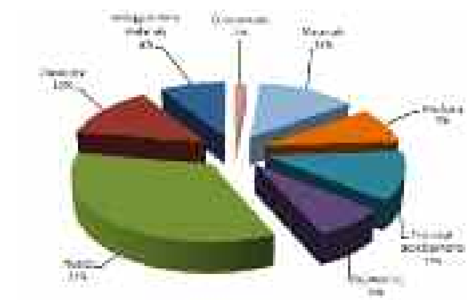

Figure 4. Loan Pool bids by subject group

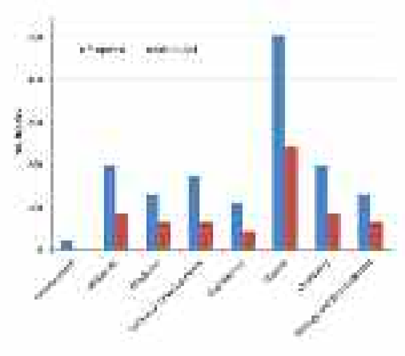

Figure 5. Loan Pool experiments by subject

Lasers For Science Facility Loan Pool Schedule 2013/14

<table>
<tr><th rowspan="2"></th><th rowspan="2">Date</th><th>NSL1</th><th>NSL2</th><th>NSL3</th><th>NSL4</th><th>UFL1</th><th>ULF2</th><th>UFL3</th><th>CWL1</th></tr>
<tr><th>Powerlite Nd:YAG + Sirah Dye + SHG + DFG</th><th>Powerlite Nd:YAG + Sirah Dye + SHG + MAD</th><th>Powerlite Nd:YAG + Panther Mid-band OPO + SHG</th><th>Powerlite Nd:YAG + Sirah Dye + SHG + DFG</th><th>Light Conversion Pharos + Orpheus + SHG</th><th>Coherent Libra OPerA Ultrafast Amp + OPA</th><th>Coherent Chameleon Ultra II + OPO Compact + SHG</th><th>NKT SuperK G2 Extreme + AOTF</th></tr>
<tr><td rowspan="27">2013</td><td>1 Apr</td><td rowspan="27">SHAH
(ICR)

Purification of gold nanorods using a tunable laser for photoacoustic imaging

1,152,007</td><td rowspan="11">BROWN
(Uni. Sussex)

UV induced chemistry of complex organic molecules in space

13,150,005</td><td rowspan="2"></td><td rowspan="27">LEVY
(Northumbria)

Preliminary studies of chemi-luminescence in Ni+RO□NiO*+R (R = O, NO, N_2, O_2)

12,250,003</td><td rowspan="2">MUSKENS
(So'ton)

12,250,002</td><td rowspan="2">BRYAN
(Swansea)

12,250,005</td><td rowspan="12">CATALUNA
(Dundee)

Ultrafast characterization of carbon-based nano-materials

12,250,008</td><td rowspan="11">KUKURA
(Uni. Oxford)

Single molecule absorption spectroscopy

12150009</td></tr>
<tr><td>8 Apr</td></tr>
<tr><td>15 Apr</td><td rowspan="25">UNALLOCATED</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>22 Apr</td></tr>
<tr><td>29 Apr</td><td rowspan="23">Greenwood (QUB)

Optimisation of Biomolecular laser desorption to study ultrafast intra-molecular charge migration

13,150,000</td><td rowspan="23">Bryan
(Swansea)

Grating-assisted photon echo (GRAPE) spectroscopy of a liquid jet in vacuum

13,150,003</td></tr>
<tr><td>6 May</td></tr>
<tr><td>13 May</td></tr>
<tr><td>20 May</td></tr>
<tr><td>27 May</td></tr>
<tr><td>3 Jun</td></tr>
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<tr><td>17 Jun</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>24 Jun</td><td rowspan="2"></td></tr>
<tr><td>1 Jul</td><td rowspan="14">BROWN
(Uni. Sussex)

UV induced chemistry of complex organic molecules in space

13,250,001</td><td rowspan="14">ARLT
(Uni. Edinburgh)

Fast fluorescence lifetime detection for high throughput screening

13,250,002</td></tr>
<tr><td>8 Jul</td><td rowspan="13">MAHAJAN
(So'ton)

Label-free CARS imaging in living organisms

13,150,002</td></tr>
<tr><td>15 Jul</td></tr>
<tr><td>22 Jul</td></tr>
<tr><td>29 Jul</td></tr>
<tr><td>5 Aug</td></tr>
<tr><td>12 Aug</td></tr>
<tr><td>19 Aug</td></tr>
<tr><td>26 Aug</td></tr>
<tr><td>2 Sep</td></tr>
<tr><td>9 Sep</td></tr>
<tr><td>16 Sep</td></tr>
<tr><td>23 Sep</td></tr>
<tr><td>30 Sep</td></tr>
</table>

Lasers For Science Facility Loan Pool Schedule 2013/14 continued

	7 Oct								
	14 Oct								
	21 Oct								
	28 Oct								
	4 Nov								
	11 Nov								
	18 Nov								
	25 Nov								
	2 Dec								**PULSE PICKER REPAIR**
	9 Dec								
	16 Dec								
	23 Dec								
	30 Dec								
2014	6 Jan	**BARKER** (UCL) Detecting trapped ultra-cold ground state argon for sympathetic cooling of complex molecules and nano-particles **13,250,009**							
	13 Jan								**ARLT** (Uni. Edinburgh) Fast fluorescence lifetime detection for high throughput screening **13,250,002**
	20 Jan								
	27 Jan					**SAPIENZA** (KCL) **13,250,003**			
	3 Feb								
	10 Feb								
	17 Feb		**CASSIDY** (UCL) Production and manipulation of Rydberg positronium for a matter-antimatter gravitational free fall measurement **13,250,005**				**WANN** (York) Towards time-resolved gas electron diffraction **13,250,016**	**MAHAJAN** (So'ton) Multimodal and flexible CARS imaging of living organisms **13,250,006**	
	24 Feb			**EWART** (Oxford) High precision temperature measure-ments for reacting flows **13,250,014**					
	3 Mar								**KUKURA** (Oxford) Development of a label-free single **protein sensor** **13,250,015**
	10 Mar								
	17 Mar								
	24 Mar								
	31 Mar								

Lasers For Science Facility RAL-Based Global Schedule 2013 Period 1

	Date	Functional Biosystems Imaging	Molecular Structure and Dynamics	Cross Department Research
2013	1 Apr	MAINTENANCE	MAINTENANCE	
	8 Apr	**FJ CURRELL** (Queen's University Belfast) **12230001**		
	15 Apr	**RH BISBY** (University of Salford) **13130000**	**DC WILLIAMS** (Trinity College Dublin) **12240002 – EU ACCESS**	**M WATSON** **SPICE**
	22 Apr		**G GREETHAM** (STFC) **13130020**	
	29 Apr		MAINTENANCE	**M WATSON** **SPICE**
	6 May	MAINTENANCE	**MW GEORGE** (University of Nottingham) **13130027**	**BF LUISI** (University of Cambridge) **13130017**
	13 May	**RH BISBY** (University of Salford) **13130000**		**A WARD** (STFC) **13130016** **HANNON** (Uni. B'ham) **SP8726-1**
	20 May	**C HAWES** (Oxford Brookes University) **13130008**	**SR MEECH** (University of East Anglia) **13130004**	**See Functional Biosystems Imaging**
	27 May	**S PASCU** (University of Bath) **13130011**		**A ALEXANDER** (Uni. Edinburgh) **13130012**
	3 Jun	**SL IRONS** (Oxford Brookes University) **13130019**		**See Functional Biosystems Imaging**
	10 Jun	**RH BISBY** (University of Salford) **13130000**	MAINTENANCE	MAINTENANCE
	17 Jun	**IK ROBINSON** (University College London) **13130025**	**AJ ORR-EWING** (University of Bristol) **13130001**	**C PFRANG** (University of Reading) **13130021**
	24 Jun	**S PASCU** (University of Bath) **13130011**		**M KING** (Royal Holloway) **12230019**
	1 Jul	**FJ CURRELL** (Queen's University Belfast) **13130010**		
	8 Jul	**C HAWES** (Oxford Brookes University) **13130008**	**MW GEORGE** (University of Nottingham) **13130027**	**See Functional Biosystems Imaging**
	15 Jul	**S PASCU** (University of Bath) **13130011**		**BF LUISI** (University of Cambridge) **13130017**
	22 Jul	**C STUBBS** (STFC) **12130002**	MAINTENANCE	
	29 Jul	**M MARTIN-FERNANDEZ** (STFC) **13130007**	**DC WILLIAMS** (Trinity College Dublin) **12240002 – EU ACCESS**	**S QUINN** (University College Dublin) **13140000 – EU ACCESS**
	5 Aug	MAINTENANCE	MAINTENANCE	
	12 Aug	**C SMITH** (University of Warwick) **13130005**	**NT HUNT** (University of Strathclyde) **13130030**	MAINTENANCE
	19 Aug	**R FREEDMAN** (University of Warwick) **13130022**		
	26 Aug	MAINTENANCE		MAINTENANCE
	2 Sep	**C SMITH** (University of Warwick) **13130005**		
	9 Sep	**C HAWES** (Oxford Brookes University) **13130008**	MAINTENANCE	**See Functional Biosystems Imaging**
	16 Sep	MAINTENANCE	**A VLCEK** (Queen Mary University of London) **13130003**	**C PFRANG** (University of Reading) **13130021**
	23 Sep	**M MARTIN-FERNANDEZ** (STFC) **13130007**		
	30 Sep	MAINTENANCE	MAINTENANCE	

Lasers for Science Facility Schedule for 2013/14 Period 1

<table>
<tr><th colspan="2">Updated:
02/12/2013</th><th colspan="2">Functional Biosystems Imaging</th><th>Molecular Structure And Dynamics</th></tr>
<tr><th colspan="2">Date</th><th colspan="2">OCTOPUS</th><th>ULTRA</th></tr>
<tr><td rowspan="13">2013</td><td>7 Oct</td><td colspan="2">K VON HAEFTEN
(University of Leicester)
13130015</td><td rowspan="2">H ANDERSON
(University of Oxford)
13230008</td></tr>
<tr><td>14 Oct</td><td colspan="2">M MARTIN-FERNANDEZ
(STFC)
13230005</td></tr>
<tr><td>21 Oct</td><td colspan="2">R BISBY
(University of Salford)
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<tr><td>28 Oct</td><td colspan="2">MAINTENANCE</td><td rowspan="3">S MEECH
(University of East Anglia)
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<tr><td>4 Nov</td><td colspan="2"></td></tr>
<tr><td>11 Nov</td><td>C SMITH
(University of Warwick)
13130005</td><td>M KING
(Royal Holloway)
13230007</td></tr>
<tr><td>18 Nov</td><td>R BISBY
(University of Salford)
13230006</td><td>C PUDNEY
(University of Bath)
13230022</td><td rowspan="2">M GEORGE
(University of Nottingham)
13230030</td></tr>
<tr><td>25 Nov</td><td></td><td>M KING
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<tr><td>2 Dec</td><td colspan="2">C HAWES
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13230019</td></tr>
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13230006</td><td>M MARTIN-FERNANDEZ
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13230005</td></tr>
<tr><td>16 Dec</td><td colspan="2"></td></tr>
<tr><td>23 Dec</td><td colspan="3" rowspan="2">CHRISTMAS HOLIDAYS</td></tr>
<tr><td>30 Dec</td></tr>
<tr><td rowspan="13">2014</td><td>6 Jan</td><td></td><td rowspan="2">M WATSON
SPICE Experiment
Cross-Department Research</td><td>M GEORGE
(University of Nottingham)
13230030</td></tr>
<tr><td>13 Jan</td><td>J WEINSTEIN
(University of Sheffield)
13230021</td><td>C CARDIN
(University of Reading)
13230023</td></tr>
<tr><td>20 Jan</td><td colspan="2">C HAWES
(Oxford Brookes)
13230013</td><td rowspan="3">A ORR EWING
(University of Bristol)
13230002</td></tr>
<tr><td>27 Jan</td><td rowspan="3">L NATRAJAN
(University of Manchester)
13230018</td><td>D HUISKONEN
(University of Oxford)
13230031</td></tr>
<tr><td>3 Feb</td><td>MAINTENANCE</td></tr>
<tr><td>10 Feb</td><td></td><td>MAINTENANCE</td></tr>
<tr><td>17 Feb</td><td>M MARTIN-FERNANDEZ
(STFC)
13230005</td><td rowspan="2">F POPE
(University of Birmingham)
13230009</td><td>N SCRUTTON
(University of Manchester)
13230010</td></tr>
<tr><td>24 Feb</td><td>C PUDNEY
(University of Bath)
13230022</td><td rowspan="4">N HUNT
(University of Strathclyde)
13230001</td></tr>
<tr><td>3 Mar</td><td>C HAWES
(Oxford Brookes)
13230013</td><td rowspan="3">FACILITY DEVELOPMENT
MRC
SUPER-RESOLUTION</td></tr>
<tr><td>10 Mar</td><td>M MARTIN-FERNANDEZ
(STFC)
13230005</td></tr>
<tr><td>17 Mar</td><td rowspan="2">F POPE
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<tr><td>24 Mar</td><td></td><td>C CARDIN
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<tr><td>31 Mar</td><td colspan="2">J WEINSTEIN
(University of Sheffield)
13230021</td><td>N SCRUTTON
(University of Manchester)
13230010</td></tr>
</table>

Target Fabrication operational statistics

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RAL Experiments

A total of six Astra Gemini and nine Vulcan experiments were supported by Target Fabrication in the reporting period April 2013 to April 2014. Of these, ten experiments (three in Gemini and seven in Vulcan) are classified as solid target experiments for which statistics on target delivery are recorded. The remaining five experiments were 'gas jet' type experiments that require target fabrication support for ancillary items such as complex filters but these items are not reported on here. The total number of experiments supported increased by three on the same reporting period in 2012-2013 and is five more than in 2011-2012. The Target Fabrication group provided a total of 45 weeks experimental support for Vulcan, of which 35 were solid target support, and 33 weeks support for Astra Gemini of which 15 weeks were solid target experiments. The total number of weeks of target support for solid targets was 50 weeks which is comparable with 2012-2013. This report does not include support for other areas of the CLF such as Artemis and the LSF.

1) Target Numbers

For the reporting year the total target numbers produced are shown in Table 1. The table is broken down into separate experiments and gives data on total target numbers produced and the subset consisting of high specification complex 3D targets that have been produced. High specification targets are defined as targets that have taken significant highly skilled micro assembly or micromachining to be produced above and beyond standard target manufacture.

The total number of targets for use at RAL produced by the group in 2013-2014 was 2507 compared to 1801 in 2011–2012 and 1080 in 2011-2012. During 2013-2014 the number of high specification targets decreased from 549 to 334 in the last reporting year; accounting for 13% compared to 30% last year. The sharp drop is due to only two experiments fielding 3D geometries as their main requirement. In contrast three experiments fielded complex multilayer targets which required significant coating capability. Specifically the 1113 TAW experiment used a large number of multilayer targets and, although not particularly complex, the delivery of 590 targets for an experiment on Vulcan is an exceptionally high number.

Experiment	Targets Produced	High Specification Targets
0513 TAP	255	
0513 GTA	120	
0713 GTA	108	
0813 TAP	43	
0813 GTA	228	
1013 TAW	321	230
1113 TAW	590	
0214 TAW	381	
0414 TAP	164	104
0414 TAW	88	
TOTAL	2507	334

Table 1: Target production summary for 2013-2014. High specification targets include 3D micro-structures, low density targets and mass limited targets.

2) Target Categories

The targets can be separated into seven main categories as shown in Figure 1 and Table 2. It is worth noting that, although single target foils were sent to Gemini, these targets were mounted onto an array of numerous single target positions. The Gemini set up takes multiple shots on each array with up to 25 shots available per single target array. In this reporting period there were 115 foils mounted target arrays equating to nearly 3000 potential shots.

Target Category	Targets Produced
Ultra-Thin Foil	679
Thick Foils	685
Multi-layered foils	653
Alignment	97
3D Micro-structures	334
Foams	33

Table 2: Target category summary. Ultra-thin foils consist of foils of 500nm thickness and below; multilayered foils are foils with materials (typically coated rather than glued) in layers.

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 ten foam targets the 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 2507 targets there were 320 target variations which averages 8 targets per variation. The flexibility provided by the Target Fabrication group is a key capability of the CLF and enables the user community to fully utilize the limited time that is available during each experiment on both the Vulcan and Gemini laser systems.

3) Experimental Response

It is seen as a significant strength of Target Fabrication to be rapidly responsive to experimental results and conditions by working collaboratively with user groups. The Target Fabrication group responds to experimental changes during a campaign and often implements a number of modifications or redesigns to the original requests. The number of modifications and variations on each experiment is variable and is dependent on the type of experiment and also on experimental conditions such as diagnostic and laser performance. For this reporting year a total of 547 targets were modified or redesigned from the agreed list. This is 22% of the total targets delivered and is a similar quantity to the previous reporting year where 594 targets were modified. It should be noted that as a percentage of total targets the modified targets fell from 33% to 22% which can be accounted for by two particular experiments; 1013TAW and 1113TAW. The two experiments required a large quantity of targets (910 total) but only requested 30 targets to be modified from the initial request. The experiments were continuations of previous campaigns leading to well-defined shot lists.

4) Adapting to Demand

The Target Fabrication Group endeavors to be adaptable to the changing demands of the user community as experiments develop. Each experiment that is carried out often has widely varying target demands and as a result the group is constantly developing its capabilities. Ultra-thin foils have continued to be widely utlilised with delivery numbers doubling from 302 to 679. The increase places considerable demands on the coating facilities available to the group. Multilayered targets increased from 132 to 653 mainly due to 1113TAW experiment in which over 500 multilayered targets were requested. 3D targets decreased from 427 to 334 and alignment requirements decreased from 147 to 97 targets.

Figure 2: Target number 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.

Figure 2 shows that foil targets have been increasing in production numbers significantly since 2011-2012. In this reporting period eight of the ten solid target experiments required either a multilayered, ultra-thin or thick foil as their main target, within which approximately 65% of the foil targets required coating capability. To deliver to the increase and in order to follow the continuing trend the group has invested in a new Thermal Evaporation coating plant to manage delivery load and expand coating capability for future years.

5) Waste Reduction

Unexpected delays or changes during an experiment often results in a number of targets that have been fabricated but that are not shot by the end of experimental campaign. Co-operating with user groups and ensuring proper recording has meant that Target Fabrication has data for all of the experiments this reporting year. Returned un-shot targets totaled 467 accounting for 18.6% of the total targets made. In 2011-2102 a 10% return of un-shot targets was recorded. In 2010-2011 23% of targets that were fabricated were either returned un-shot to Target Fabrication or were unused and the figures for 2009-2010 and 2008-2009 were 43% and 34% respectively.

The sustained relatively low return numbers can be accounted for by the continued 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, however it should be noted that this has not led to less flexibility as the percentage of re-designed and additional targets is in line with the figures for 2008-2009 and 2007-2008.

It is worth noting that any un-issued or returned targets are carefully stored and high aspect ratio targets are stored under closely controlled conditions for potential use on future experiments. Where possible all spare target components and mounts are also stored for future use. The variety of mounts and components held in stock by the Target Fabrication group contribute to their ability to adapt target designs quickly in response to experimental changes.

Only 13 targets were returned as non-conforming under the QMS in this reporting period. Target Fabrication is working to improve the recording of these by working with user groups to keep records of which targets they do not use due to non-conformities.

External Contracts

Scitech Precision Ltd, (a spinout company from CLF Target Fabrication) has supplied micro-targets, specialist coatings and consultancy to a number of external contracts. In the year 2013-2014 a total of 44 contracts were completed for coatings, characterisation and also full target design and assembly. This is an increase from 36 in the previous year. The contracts were delivered to external facilities in countries including France, Germany, Italy, India and the US. In this reporting year Scitech Precision has also added the production of phase plates and anti-reflection coatings to its product list and has supplied phase plates to LULI, GSI and other large facilities.

Summary

Target Fabrication has supported 15 experiments in the CLF and eleven other international facilities in the last year as well as providing an increasing amount of characterisation services and acting as a knowledge base for Target Fabrication activities throughout Europe. As with previous years there was an increase in the number of targets delivered to experiments.

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Vulcan operational statistics

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Introduction

Vulcan has completed an active experimental year, with 44 full experimental weeks allocated to target areas TAW and TAP between April 2013 and March 2014. This year has seen the first experiments using the new beamlines between the front end and laser areas [Ref. 1].

PERIOD	TAW	TAP
	2013	
01 Apr – 09 May	P Norreys A study of electron transport and B-field dynamics relevant to Holhraum LPI (70, 7, 90.0%) (86.5%, 125.4%)	M Borghesi Radiation pressure drive of ultrathin high Z targets with Petawatt pulses (81, 6, 92.6%) (72.1%, 108.3%)
20 May – 30 Jun	D Jaroszynski Amplification of high power laser pulses in plasma and Compton regimes : a study of the nonlinear regime (83, 7, 91.6%) (87.8%, 117.3%)	P McKenna Hole-boring radiation pressure acceleration of ions using novel layered targets (100, 7, 93.0%) (81.8%, 106.3%)
12 Aug – 19 Sep		S Kar A bright neutron beam driven by radiation pressure accelerated ions (136, 16, 88.2%) (60.5%, 90.2%)
30 Sep – 03 Nov	G Gregori Measurement of turbulent induction in laser-produced plasmas (181, 17, 90.6%) (88.1%, 109.8%)	
18 Nov – 15 Dec	**A Higginbotham** Single photon energy dispersive X-ray diffraction : A new technique to probe high pressure states (186, 36, 80.6%) (81.4%, 107.2%)	
	2014	
24 Feb – 30 Mar	M Borghesi Interacting solitary waves and rogue wave formation in plasmas (86, 16, 81.4%) (79.3%, 108.0%)	P McKenna Directed, high current, relativistic electron beams driven by controlled induced transparency in solids (92, 9, 90.2%) (71.5%, 100.6%)

Table 1. Experimental schedule for the period April 2013 – March 2014

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

Table 1 shows the operational schedule for the year, and illustrates the shot rate statistics for each experiment. Numbers in parentheses indicate the total number of full energy laser shots delivered to target, followed by the number of these that failed and the percentage of successful shots. The second set of numbers are the availability of the laser to target areas during normal operating hours and including outside hours operations.

The total number of full disc amplifier shots that have been fired to target this year is 1015. Table 2 shows that this figure compares very favourably with recent years. 121 shots failed to meet user requirements. The overall shot success rate to target for the year is 88%, compared to 85%, 89%, 92% and 89% 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
09 – 10	445	65	85%
10 – 11	764	87	89%
11 - 12	641	54	92%
12 - 13	860	93	89%
13 - 14	1015	121	88%

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

The shot reliability to TAW is down very slightly at 88%, compared with 90% in the previous two years. The shot reliability to TAP is around 91% - a slight increase from 89% in 2012-13.

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, autocorrelators) in the front end and throughout the laser area to identify and resolve specific sources of instability.

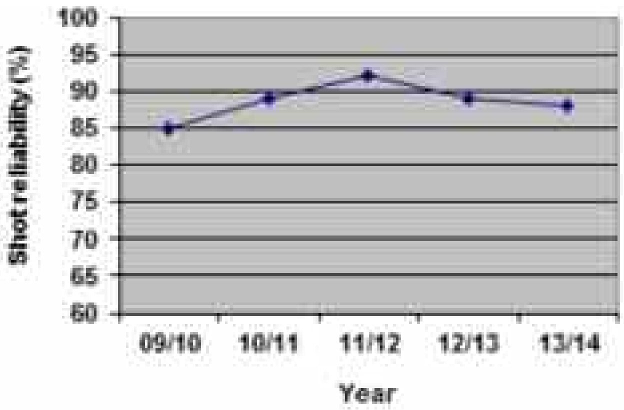

Figure 1. All areas shot reliability for each year 2009-10 to 2013-14

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 four week experimental period). The laser has not always met the startup target of 9:00 am but it has been common practice to operate the laser well beyond the standard contracted finish time on several days during the week. In addition, the introduction of early start times on some experiments continues to lead to improvements in availability.

On average, Vulcan has been available for each experiment to target areas for 78.8% of the time during contracted hours, compared with 87.5% for the previous year. Although this is disappointing, the overall availability was up from 111.8% in 2012-13 to 119.2% 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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