

# CLF 2010 - 2011

Central Laser Facility Annual Report



Science & Technology  
Facilities Council

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The front cover shows various stages of the Raman amplification of a short laser pulse in plasma. The image was generated by Frederico Fiúza from IST Lisbon, using simulation data generated by Raoul Trines from the CLF.

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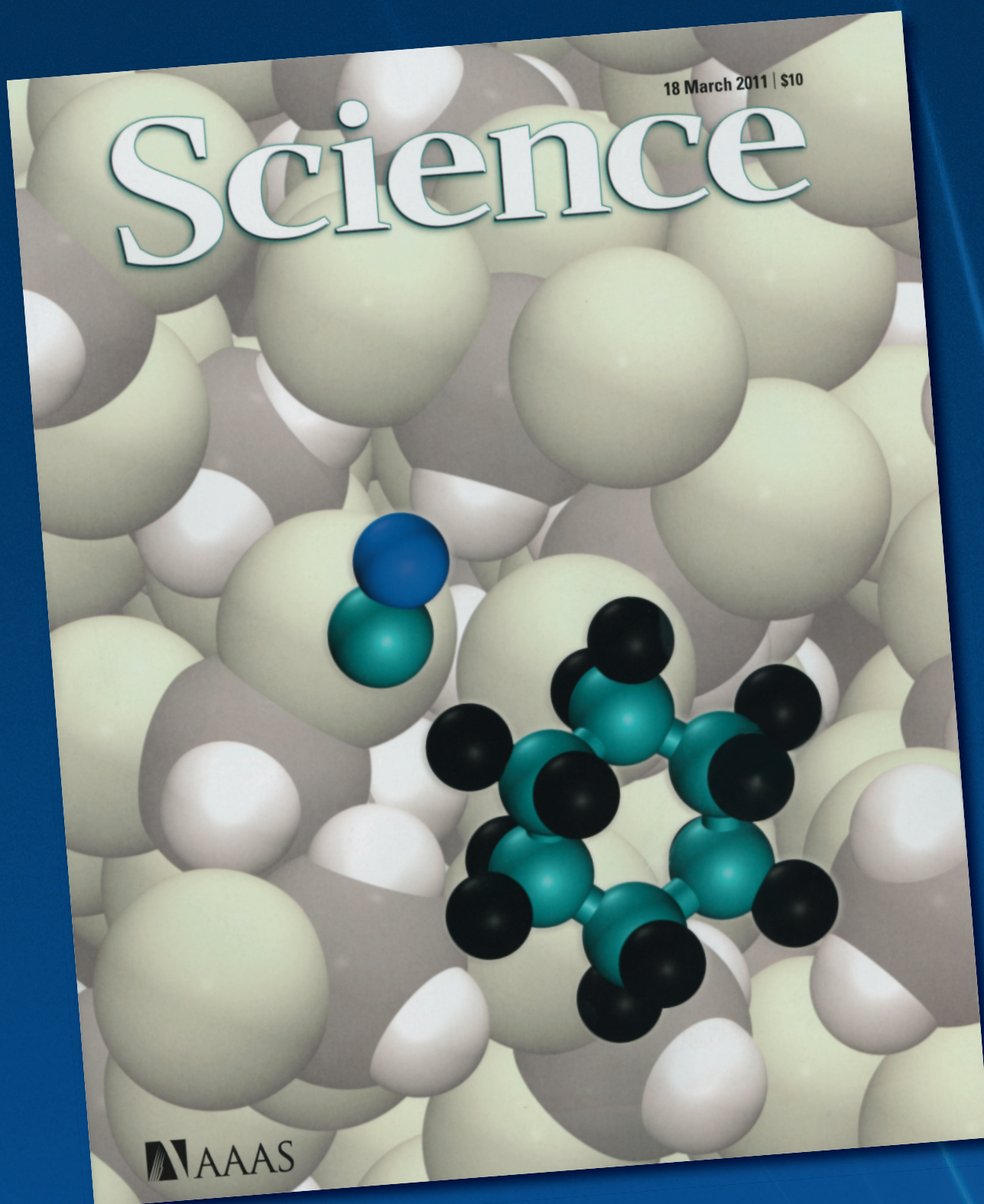
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# Foreword

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This annual report for the Central Laser Facility (CLF) at the STFC Rutherford Appleton Laboratory provides highlights of the scientific research which has been carried out by users of the Facility and its staff over the financial year 2010-11.

During this year we have celebrated the 50th anniversary of the invention of the laser – a device that has had a profound impact on our society, and without which many of the sights and sounds of modern life we have become so accustomed to would not be possible. 50 years on, the continuous development and exploitation of this invention for the scientific, economic and societal health of the UK lies at the heart of the CLF mission.

This year has been my first year as the Director of the Central Laser Facility. It has been an exciting and somewhat challenging period as we entered a Comprehensive Spending Review (CSR) against a backdrop of significant fiscal tightening. The positive news is that the CLF emerged, intact, with a comprehensive, multi-disciplinary programme across all its facilities in place, as well as a number of new directions developed. Inevitably, at such times, there is pressure on the total envelope of the programme, but within this constraint I believe we have achieved a robust and balanced outcome. During this process, much depended on the quality and impact of the science that is conducted at the CLF, and this positive outcome is testament to the strength of this work.

Consistent with their heritage, the CLF and its User community have again excelled in producing outstanding science at the highest level across a range of disciplines. For example, the High Power Laser programme has recorded its highest number of Physical Review Letters in a single year (15) and the Lasers for Science Facility has produced a number of high impact, front cover articles. A scientific highlight of the year was an article in collaboration with colleagues from the University of Bristol, that featured on the front cover of Science magazine.

In recent years, the CLF has benefited from significant levels of capital investment in the development of its facilities and this has stood us in good stead for the future, particularly in these difficult times. Over this period :

The Ultra and Octopus clusters have been fully commissioned in the newly completed Research Complex at Harwell. This first full year of operation has seen numerous multi-disciplinary experimental campaigns that have spanned Research Council programmes, as well as a healthy level of cross facility initiatives.

The second beamline of the Gemini high power laser has been fully commissioned. This milestone was the final piece of the jigsaw that has realized the Gemini vision. It now provides a globally unique capability for our national and international research community.

There have been major changes to the front end of Vulcan that have seen an improvement of the temporal contrast ratio on the Petawatt beamline of several orders of magnitude. As the science increasingly places ever tighter requirements on the spatio-temporal fidelity of the high power interaction, this is an important development that will ensure Vulcan remains competitive.

The installation of the final Atomic and Molecular Optics chamber on Artemis, fully equipped with a velocity mapped imager for both electrons and ions finally completes the originally planned complement of diagnostic instrumentation.

The availability of capital for investment in new infrastructure and facilities has been extremely constrained following the CSR. Disappointingly, it has therefore not been possible to proceed with the construction phase of the 10 PW upgrade to Vulcan on the originally envisaged timescale. STFC however remains committed to the project and will

continue with the development of the technology and planning associated with this project in preparedness should the capital situation improve.

Recognizing the economic potential that high power laser technology has, STFC have funded a new CLF Centre for Advanced Laser Technology and Applications. The focus of this new Centre is on the creation of new technology to more readily enable exploitable applications of high power laser interactions to be developed. It leverages on the CLF's proprietary DiPOLE concept and facility technology investments to date, to ultimately deliver the combination of high average power diode pumped solid state laser (DPSSL) technology with high peak power laser technology (Ti:S , Parametric). Crucially, it also strategically underpins the future development of our major facilities.

On the international scene, the profile of the HiPER Laser Energy project that the CLF leads continues to grow. The European Commission have agreed to a two year extension to the preparatory phase to cover the period of anticipated fusion ignition on the USA's National Ignition Facility (NIF), and to allow for the preparation of a business case for investment in this pioneering concept. Furthermore, the first of the "pillars" of the Extreme Light Infrastructure (ELI), in which the CLF has been a major player, has received the formal go-ahead from the European Commission. This will see the €280M ELI Beamlines facility, located in the Czech Republic, constructed over the next 4-5 years.

The success of the EU funded Laserlab-Europe consortium is once again celebrated with the award of a third incarnation of this highly effective transnational programme. Building on the strengths of Laserlab-Europe I and II, and with participation from 19 countries, Laserlab-Europe III will bring together 28 of the largest European laser research infrastructures (including CLF), a diverse user base and pioneering technology development to strengthen the

European leading role in advanced laser related research. The CLF has a long history of innovation, and it has been very pleasing to see its most recent innovation successes - Cobalt Light Systems Ltd and Scitech Precision Ltd continue to grow. Translating scientific success into innovation success, in all its forms, is playing an increasingly important role in the delivery of the CLF mission.

It has become increasingly clear to me over this last year, that in the current tough fiscal environment outstanding science is an essential, but not necessarily sufficient metric of the impact of our field. Moreover with the introduction of the Research Councils Facility Funding Model, the stakeholder and governance environment of the central facilities, including CLF, is evolving. Increasingly, we need to solicit and deploy evidence of the broader impact of what we do, that reflects both our traditional strengths whilst also speaking to a new milieu. The role that outreach plays in explaining the benefit of taxpayer investment in our areas of science to the public, industry and policymakers alike is crucial. I am delighted with the numerous high profile, high impact stories that have emerged from the CLF this year as its media and outreach profile continues to grow.

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 from that partnership and re-double our efforts in promoting 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

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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 Nd:glass laser with three independent target areas that couple long and short pulse beams in a variety of flexible geometries. A maximum of 2.5 kJ can be delivered in its eight beams. Long-pulse temporal shaping is available as well as a selection of focusing, beam smoothing, probe beam and harmonic conversion options.

TA-Petawatt is Vulcan's highest intensity area, with a ~500J/500fs beam capable of being focused to  $10^{21}$  W/cm<sup>2</sup>. A new high contrast front end seeds the rest of the Vulcan Petawatt (PW) chain delivering an ASE contrast of  $10^{10}$  at 1ns. The original large compressor gratings and final mirror have been recently replaced and the system re-commissioned to deliver its energy specification. To compliment the short pulse an additional ~100J long pulse beamline and various probe beam options can also be configured in this area.

TA-West offers dual CPA beams coupled to the long pulse beamlines. One short pulse beam operates at 80-100 J / 1 ps ( $10^{20}$  W/cm<sup>2</sup>), and the second CPA beam operates either at 80-100 J / 1 ps, or at 500 J / 10 ps configurable in flexible geometries. TA-East was decommissioned in preparation for a future upgrade for Vulcan.

A baseline design for the upgrade of Vulcan to 10 PW peak power (300J / 30fs) with focused intensities up to  $10^{23}$  W/cm<sup>2</sup> has been established and it is described in the Technical Design Report (TDR). Plans to proceed with the construction phase were put on hold.

## Astra Gemini

This high rep-rate Petawatt laser based on Ti:Sapphire technology has a unique capability to offer 2 synchronised beams, each with a power of 0.5 PW and a repetition rate of one shot every 20 seconds. The facility will enable interaction studies up to  $10^{22}$  W/cm<sup>2</sup>. 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. Both beam lines have now been commissioned. In the past few months, significant improvement in beam contrast and stability has been obtained. Improvement in the system reliability is now enabling near 24 hour operations, and thus shorter experiments.

## Artemis

Artemis is an ultrafast laser and XUV science facility, offering high repetition-rate, ultrashort pulses spanning the spectral range from the far-infrared to the XUV. The facility is configured flexibly for pump-probe experiments. Tuneable or few-cycle, carrier-envelope phase-stabilised pulses can be used to generate ultrafast, coherent XUV pulses through harmonic generation or used as pump and probe pulses. Two XUV beamlines, offering optimised time resolution or energy resolution lead to end-stations for gas-phase atomic and molecular physics or materials science.

The materials science station enables time- and angle-resolved photoemission spectroscopy with XUV pulses, and is equipped with hemispherical electron analyser, five-axis manipulator with cooling to 14K and a sample preparation chamber. The gas-phase end-station for atomic and molecular physics and chemistry contains a velocity-map imaging detector, capable of imaging ions and electrons with energies up to 200 eV, and a molecular beam source.

## Lasers for Science Facility (LSF)

The LSF, located in the Research Complex at Harwell, develops and operates facilities in two areas: molecular structural dynamics (ULTRA), and functional bio-systems imaging (OCTOPUS).

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<sup>3</sup>) capability enables highly fluorescent samples to be studied using a 4ps optical Kerr shutter. The PIRATE facility (Picosecond InfraRed Absorption and Transient Excitation) gives two independently tunable beams across the mid infrared region of the spectrum for pump / probe experiments. A new development to link the two capabilities is underway (TRMPS).

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 single-molecule imaging, confocal microscopy (including multiphoton), fluorescence energy transfer (FRET) and fluorescence lifetime imaging (FLIM). Super-resolution imaging techniques are currently under development. In addition, a "laser tweezers" laboratory is

available 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 LSF 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.

### Laser Loan Pool

Commercial laser systems are available from the EPSRC Laser Loan Pool for periods of up to 6 months at the user's home laboratory. A wide range of ancillary and diagnostic equipment is also available to support user experiments.

### Engineering Services

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

### Theory and Modelling

The CLF will offer to support scheduled experiments throughout the design, analysis and interpretation phases, if required and within the resources available. We offer hydrodynamic, particle-in-cell, hybrid and Vlasov-Fokker-Planck modelling capabilities and access to large-scale computing. Student training in computational methods and opportunities for networking with colleagues will be provided. Extended collaborative placements within the group are particularly encouraged.

### Target Fabrication

A high quality target fabrication facility is operated within the CLF offering integrated microassembly, thin film coating and characterisation areas. A dedicated chemistry laboratory has recently been commissioned. The facility is equipped with a wide range of complementary target production and characterisation equipment including evaporation and sputter coating plants, interference microscopy, SEM, AFM and surface profiling. Many microcomponents are produced in collaboration with the STFC micromachining and MEMS facilities. 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.

### 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-product interactions (e.g super bright, high energy photons, electrons, ions etc). At its heart is a campaign to develop advanced, proprietary diode pumped laser technology (DiPOLE) and associated multi-PW component technology that has been pioneered within the CLF in recent years.

The main activity within DiPOLE is the development of a scalable diode pumped solid state laser (DPSSL) concept that is capable of delivering kJ-level pulses at a 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. To test this concept in the laboratory a lower-energy 10J prototype amplifier system is currently being built.

The CLF will continue to develop technologies that are crucial to a future upgrade to the Vulcan high power laser to 10 Petawatt (PW). This includes developing a test component facility based on OPCPA, ultra broadband optics such as diffraction gratings and high damage threshold coatings, and the realisation of specialised large aperture crystals required in multi Petawatt facilities.

### 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](http://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

The delivery of high Economic Impact (EI) forms an integral component of the CLF strategic objectives and the overall delivery plan.

The CLF has a long track record in intellectual property development and technology transfer. To deliver the most effective long term EI the CLF encourages, facilitates and actively promotes:

- The further enhancement of our core expertise in photonic sciences and technology
- Encouragement of inward investment to the UK through high profile collaborations and projects
- Formation and support of new spinouts
- Securing of new intellectual property and its licensing
- Addressing societal priorities
- Training of the next generation of scientists
- Actively seeking partnerships to enhance the Harwell and Daresbury Science and Innovation Campuses (HSIC and DSIC)
- Educational programmes – internally, externally and through active involvement of industry

**Please visit [www.clf.stfc.ac.uk](http://www.clf.stfc.ac.uk) for more details on all aspects of the CLF.**

# Economic Impact and the CLF

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The CLF's world class research facility and R&D programme not only investigates the fundamental nature of science but also provides a fertile ground for Economic Impact (EI). Weaving seamlessly with our core science programme the EI agenda is represented through a number of channels such as innovation and training of the next generation of scientists. The research activities of the facility often align naturally to the key societal issues highlighted by the government such as health, security, energy and the environment but in some cases the research carried out by CLF staff is actively driven specifically to address some of these key issues. This work is often carried out in conjunction with other departments or external partners.

Some examples of these are:

## Health

During a collaborative research programme with Sheffield and Durham Universities the CLF developed a powerful method for time-resolved emission imaging microscopy based on a new class of emissive probes. These probes are very bright and have an exceptionally long lifetime; around 1000 times longer than conventional fluorescent probes. These can be used to 'tag' live cells so that biological processes can be studied under an optical microscope. The new probes, now being 'active' for microseconds rather than nanoseconds, can therefore be used to study biological processes in real time over a much longer period than had previously been possible. This has powerful potential to help our understanding of intracellular processes and biomedicine.

## Training

The CLF has a long-standing tradition in training the next generation of scientists. Our students are actively involved in not only our core research programme but also carry out their own research studies. This includes short-term A-level students working on projects or data analysis, Masters students taking a sandwich course through to PhD students who work at the facility for longer terms. During the last financial year we hosted 102 students in total resulting in 13 PhD theses.

## Energy

The insatiable demand for energy means that very soon demand for power will exceed our current ability to supply it. The CLF has been leading the HiPER project (High Power laser Energy Research) which is being carried out in partnership with ten other countries and is funded by the EU. It directly addresses our need for energy and will be developing the technology for the next generation of power stations using lasers as a means of generating power.

## Inward Investment

A good example of how the CLF is assisting with inward investment to the UK is the Extreme Light Infrastructure (ELI) laser project recently funded by the EU to a value of €280m. This is a facility being built in the Czech Republic which will require significant scientific equipment in order to become operational. The CLF, in conjunction with UK Trade and Investment, is working closely with UK industry in helping to secure contracts for this particular project for the benefit of the UK industry.

## Spin-outs

Our Target Fabrication group works closely with the user community to provide advice, delivery and characterisation of high specification micro-targets for use on laser experiments and is one of the world leaders in this field. As a result of the exceptional capability residing within this section we have recently formed Scitech Precision Ltd as a spin-out company. It supplies complex, multi-material assemblies or "targets" for high power laser experiments on large scale laser facilities in the UK and abroad. These micron scale targets act as the "sample" for investigations into the physics of extreme conditions comparable to temperatures and pressures at the centre of the sun. These targets are at the forefront of research into laser-induced fusion as a potential energy source and particle beam therapies for cancer treatment.

Another spin-out of the CLF, Cobalt Light Systems, which was established in 2008, builds on the techniques developed at the CLF and uses laser light for rapid analysis of powders, tablets, intact capsules, etc. as well as chemical analysis of deep layers within materials. At the heart of this technology is the ability to rapidly and accurately measure chemical composition without touching or changing the sample. The company has recently secured a significant contract to develop its proprietary technology, spatially offset Raman spectroscopy (SORS), for screening of liquids at airports.

# Outreach activities in the Central Laser Facility

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## Introduction

It has been an important year for outreach by the CLF. On May 16th 2010 it was the 50th anniversary of the laser and we certainly did not let this opportunity to talk about lasers go to waste. The CLF has continued to be involved in a diverse range of outreach activities from work experience to lecture tours around the country.

## Laser 50

The anniversary of the first working laser was an important event for the CLF. We decided to mark the occasion with the production and release of a special "Laser 50" glossy brochure in conjunction with the IOP and EPSRC. The brochure was compiled by Connor Curtis with Claire Dougan heading the project and Pavel Matousek overseeing the scientific content. Alongside this brochure some schools materials and shorter brochures were generated. During the week before the anniversary we staged a press conference at the Royal Institution. This involved several laser scientists from around the country talking about the past present and future of lasers. Several radio interviews (with Graeme Hirst and Kate Lancaster), a local BBC news piece, and an EPSRC produced podcast happened as a result. Mike Dunne also wrote an article for the Physics World Special issue in May.



Figure 1 - The front cover of the brochure

Later in the year we held a stand in the "Discover zone" at Cheltenham Festival of Science populated with members of the CLF and the communications team. The brave volunteers enthusiastically demonstrated their way through six days of festival goers to raise the profile of lasers. The staff who helped at the festival were Kate Lancaster, Vicky Stowell, Peta Foster, Hazel Lowe, Sonya Chapman, Ceri Brenner, Keith Markey, and from communications Mark Wells and Katy Glazer. Kate Lancaster also gave a talk on high power lasers at the festival in conjunction with David Payne, and Stephen Bown. In September a special "Laser 50" day at the British Science Festival was organised in conjunction with the Physics and Astronomy section.

## Tours

As part of our ongoing commitment to share the work of the facility we continue to run tours for the general public, schools, and VIPs. Many areas of the CLF including the research complex have opened their doors over the past year with much positive feedback.

We also continue to participate in the "other people's business" tours. These tours are designed for other STFC staff to find out what is going on in different parts of the labs and ensure a greater understanding of the organisation.

## External events

Key members of the CLF have been promoting the work of the CLF through external events. There have been talks and demonstrations at schools locally and further afield such as Hereford Cathedral School and Denbigh school in Milton Keynes. Many members of the CLF are active STEM ambassadors and continue to participate in local events through that scheme. Other external events given by CLF staff include demonstrations at Big Bang Fair 2011 (and 2010), talks and demos at Cheltenham Science Festival / British Science Festival 2010, the GCSE science live lecture tour at large venues across the country, Café scientifique lectures at Salisbury and St Edwards school (Oxford), IOP's Lab in a Lorry, Oxford Science Live frontiers season, and the SET for Britain poster competition hosted by the Houses of Parliament.



Figure 2- Keith Markey on the Laser 50 Stand at Cheltenham Science Festival 2010

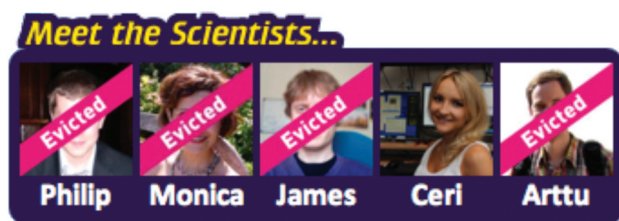


Figure 3 - Ceri Brenner wins I'm a scientist...

## Work Experience

We continue to take in school pupils for work experience in many sections of the CLF. We try to offer as broad an experience as possible to pupils taking part and get them involved in many aspects of the department. The engineering section has been extremely active in this area and has taken many students.

## I'm a scientist get me out of here

Ceri Brenner took part on the online competition "I'm a scientist get me out of here". This saw Ceri having live, online chat and question and answer sessions with schools over the two-week event. The competition is divided into zones, and in each zone several scientists battle it out for the students' votes in order to survive daily evictions. Ceri was the winner for her zone and the prize was £500 for her to carry out more outreach work. Ceri also blogged about her experience during the event for the STFC and CLF website.

## Broadcast and new media

There has been much broadcast media activity over the last year, especially radio and online videos.

The CLF featured heavily in an episode of the BBC1 show "Bang Goes the Theory" about lasers. Jem Stansfield spent a day filming in the CLF late last year for the show. Graeme Hirst and Vicky Stowell worked extensively with the team to make sure they got the footage needed. The show aired in April 2011.

Ceri Brenner appeared in a film about the CLF as part of the "Backstage science" project. Backstage science consists of a series of short films made by Brady Haran promoting the science that happens through the STFC. These videos can be found on YouTube and the STFC website.

Kate Lancaster appeared in an episode of "The Beauty of Diagrams" with Marcus Du Sautoy for BBC4. In this episode she re-enacted Newton's famous prism experiment at Woolsthorpe manor (Newton's home). This was aired in December 2010. Kate also appeared in a film made for Teachers TV on cutting edge physics, designed to help schools understand the latest developments in Physics.

We continue to use our website to promote the work of the CLF to a wider audience. Emma Springate in conjunction with Vicky Stowell have been working to keep the information up to date and to report the latest developments. We urge our users to utilise this mechanism to promote any developments as a result of the work done at the CLF.

## Rutherford Prize for the Public understanding of plasma physics 2011

This prize is run on a yearly basis and is awarded to the best communication activity carried out by a PhD student in the area of plasma physics. The prize is £500 and is awarded at the IOP plasma physics conference.

This year it was awarded to Yvonne Sutton for a video entitled "Electro-acoustic coupling in plasma". Yvonne is completing a PhD on this topic through the Open University. The video can be viewed on the CLF website.

For more information on submissions the main contact is Alex Robinson (Alex.Robinson@stfc.ac.uk).

## Acknowledgements

We would like to acknowledge all of the staff and users who take part in activities that promote the work of the CLF, and the wider plasma community.