Central Laser Facility
Highlights

Council for the Central Laboratory of the Research Councils

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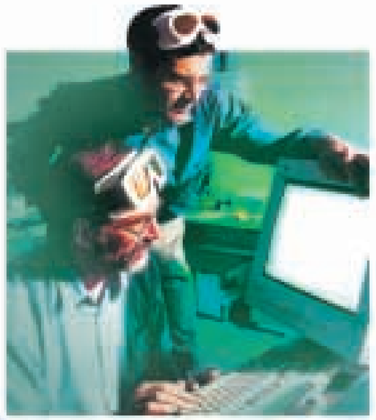
MESSAGE
FROM OUR DIRECTOR

Research at the Central Laser Facility (CLF) is a partnership between its staff and members of the UK and overseas scientific communities, who use the specialised laser equipment provided to carry out a wide range of experiments in physics, chemistry and biology.

This brochure of highlights appears at a very exciting time for the CLF with the development of advanced, world-leading facilities generating petawatt powers, ultrafast time-resolved infrared spectroscopy and high repetition rate ultra-high intensity laser irradiation. The facilities enable a broad base of rapidly expanding areas of research to be investigated with applications in Inertial Confinement Fusion, astrophysics simulations, bioscience, accelerator science and molecular physics.

We hope that the following pages convey just a little of the excitement that comes from being partners in our users' achievements.

Professor Henry Hutchinson
Director, Central Laser Facility

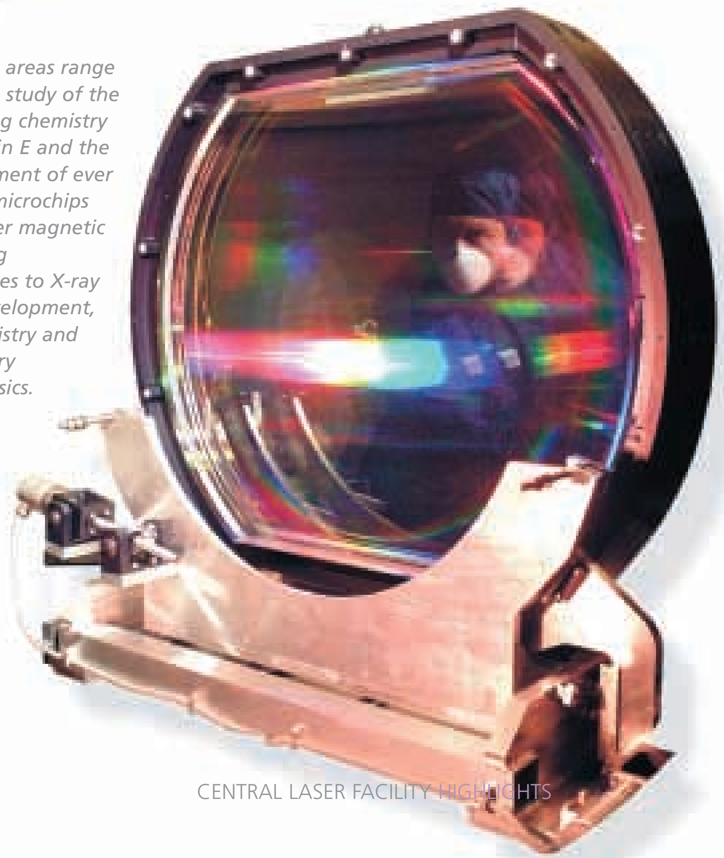


THE

CENTRAL LASER FACILITY

The Central Laser Facility (CLF) at the CCLRC Rutherford Appleton Laboratory (an institution of the Council for the Central Laboratory of the Research Councils, near Oxford, UK), is one of the world's leading laser facilities providing scientists from universities in the UK and Europe with an unparalleled range of state-of-the-art laser technology. The research is funded predominantly by the Office of Science and Technology (OST).

Research areas range from the study of the life saving chemistry of vitamin E and the development of ever smaller microchips and faster magnetic recording techniques to X-ray laser development, biochemistry and laboratory astrophysics.



The CCLRC Rutherford Appleton Laboratory employs around 1200 full-time scientific, technical and administrative staff and offers some of the most advanced facilities and expertise in the world for the support of scientific research, including

- ISIS, the world's most powerful pulsed neutron and muon source, used to study the atomic structure of materials
- Europe's biggest space science and technology department, which provides satellite- and ground-based instrumentation, testing and data analysis for earth observation, astronomy and planetary science
- Coordination and support of the UK particle physics research programme at CERN and elsewhere
- Leading high-capability computing, e-science and research in theoretical and computational science
- The Diamond synchrotron light source which is the largest science facility to be built in the UK for more than 25 years and is due to start operation in 2007
- The Central Laser Facility which includes the Vulcan and Astra ultra-high power interaction facilities and the Lasers for Science Facility.

A laser is one of the most versatile and useful tools available to scientists.

It is a device which amplifies light – by shining a light beam in at one end of a laser, a more intense beam emerges at the other. There are many hundreds of different kinds of laser which amplify visible, infrared or ultraviolet light. Laser light is very different from the light produced by, for example, a torch. It spreads out less, it contains light of only one colour (or wavelength) and it can be produced in intense pulses.

LASERS AND THEIR

APPLICATIONS

To produce laser light, it is necessary to pump energy into a suitable type of atom or molecule so that the electrons of the atom become excited and jump from one energy level to a higher energy level. If the excited electron returns to its original energy level it emits energy as a photon, or packet of light. However, if another photon of similar energy to that which is about to be released strikes the excited atom, the photon emitted is exactly in step, or in phase, with it. This is called stimulated emission of radiation. These two identical photons can each produce more, and so on, leading to a cascade of identical photons.

This **l**ight **a**mplification by **s**timulated **e**mission of **r**adiation – '**laser**' – leads to a beam of light where all the photons are in phase and are travelling in the same direction. In order to amplify the light, energy needs to be pumped into the laser. The process is rather like pumping up a balloon: the power we use to pump up the balloon is small, but the balloon stores the total energy (power x time) as air under pressure. When the balloon is burst, this energy is released in a short time, giving a high output of power. The same principle applies to pulsed lasers: in a neodymium-glass laser, for example, the pumping time is typically one millisecond. The energy is then released in a nanosecond giving a million times increase in power. So, for a pulsed laser, the shorter the duration of the pulse of light, the greater its power.

Lasers have a wide range of applications, from recreating the extreme conditions found in the centre of planets, to tracking the movement of drug molecules in living cells. For example, extremely high intensity laser energy can be focused to a tiny spot where the temperature reaches millions of degrees and the pressure rises to millions of atmospheres. Under these conditions, atoms and molecules are blasted into a gaseous soup of charged particles called a plasma. By analysing the content of such plasmas and observing their behaviour, scientists can learn about the fundamental properties of matter, whereas by studying the physics of a plasma, scientists can begin to learn more about how we can harness nuclear fusion as a potential source of energy.

The three main laser systems at the CLF – Vulcan, Astra and the Lasers for Science Facility – each consist of three principal components: an oscillator, where the initial pulse of light is produced; an amplifier, where energy is pumped into the system; and the experimental area, where the laser energy emerges and is focused on to the target. This brochure describes the technology as well as some of the cutting-edge science which it has enabled.

FACILITIES

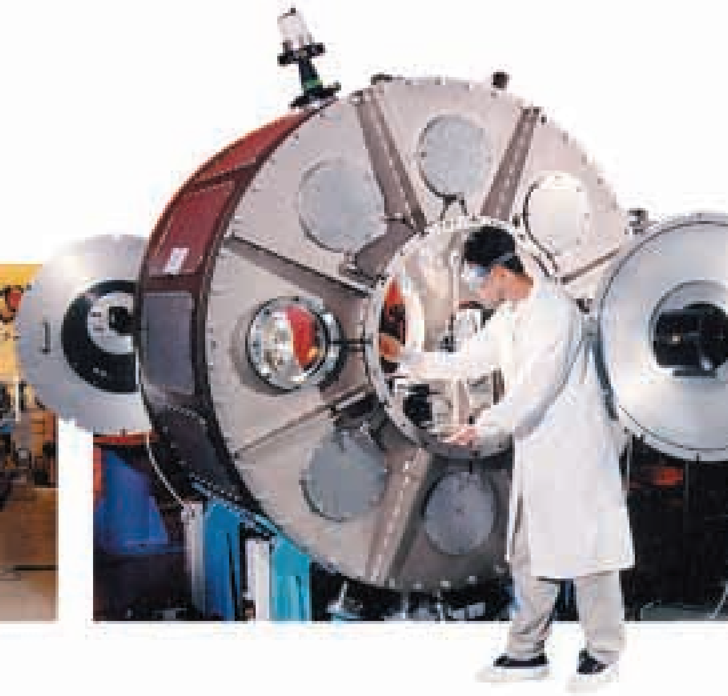
LASER SYSTEMS AT THE CENTRAL LASER FACILITY

High power lasers at the Central Laser Facility offer UK and European researchers unique facilities for studies in ultra-high intensity laser interactions with solids, gases and plasmas. The CLF has two complementary laser facilities for this work: Vulcan, a high energy neodymium-glass laser, and Astra, a high-repetition rate titanium-sapphire laser. In addition, the Lasers for Science Facility (LSF) laboratories enable a wide variety of research themes to be undertaken across the physical, biological and medical sciences for a diversity of UK research councils, for Laserlab-Europe (see 'Activities' towards the end of this brochure) and commercial contractors.

Steve Hawkes, CLF, carrying out adjustment to the diagnostic station on Vulcan.

Vulcan Petawatt Target Area.

Vulcan Target Area East.



Dr Jiunn-Yuan Lin (National Taiwan University, Taipei), preparing an experiment in Vulcan Target Area West.

VULCAN

Vulcan is a powerful and versatile system capable of delivering up to 2.6kJ of laser energy in ns pulses and over PW power in sub-picosecond pulses at 1054nm. Frequency conversion to the second harmonic gives 1kJ at 527nm. Pulse durations between 700fs and 5ns are routinely available.

Lasers such as Vulcan have been modified to operate in the ultra-high intensity regime using the technique of **chirped pulse amplification (CPA)**. In this mode, a low intensity pulse is stretched in time from a few hundred fs to a few hundred ps. This is then amplified, overcoming nonlinear effects in the laser chain, before being recompressed and focused onto the target. This pulse can be synchronised to the long pulses, enabling sophisticated interaction and probing experiments.

Target Area West (TAW) is equipped for 100TW ultra-high intensity interactions using the CPA technique. The beam can be focused to spots as small as 10μm in diameter giving a focused intensity up to 10^{20} Wcm^{-2}. A broad range of experimental configurations are available in TAW as the short pulse beam can be supplied synchronised with 1.8kJ nanosecond pulses in combination with a low power, frequency doubled or tripled sub-ps optical probe.

Target Area East (TAE) is a versatile interaction area with access to the full energy output of Vulcan. A line focus of between 7 and 40mm length can be produced for X-ray laser pumping. Cluster geometry can be provided to deliver the full Vulcan output to a single spot. Opposed beam geometry is available for driving plasma shocks and radiative heating experiments. Frequency doubling is provided for all beams as required.

The Petawatt interaction area gives users access to one of the world's leading ultra-high intensity facilities. Vulcan Petawatt delivers 500J onto target in a 500fs pulse and focused using an f/3.1 off-axis parabola resulting in an intensity on target of 10^{21}Wcm^{-2}.

Prof. Ken Ledingham, University of Strathclyde, setting up his experiment in the Astra target chamber.

Dr Karoly Osvay, University of Szeged, Hungary.

Peta Foster, CLF, optimising a parabola used in ultra high intensity experiments.

ASTRA

Astra is a high power, ultra-short pulse titanium-sapphire laser facility. It provides pulses of 800nm light with 40fs duration at energies up to 500mJ. With two experimental areas, and focused intensities up to 10^{19}Wcm^{-2}, it offers new and exciting opportunities to researchers investigating the interaction of high intensity laser light with matter.

The Astra system, in common with other high-power lasers, has a MOPA (Master Oscillator – Power Amplifier) architecture. In addition, because the source pulses are so short, it uses the technique of chirped pulse amplification to avoid distortion of the pulses and damage to the laser during amplification.

Single pulses from the oscillator, of 20fs duration and energy 5nJ, are stretched to 530ps, then amplified in the pre-amplifier to an energy of 1mJ. After spatial filtering to clean up the beam profile, the energy is increased to 200mJ in the first power amplifier. At this point half of the pulse is split off and sent to the Terawatt target area, TA1, for use in experiments which require intensities of between 10^{14} and 10^{17}Wcm^{-2} when the beam is focused. These are strong enough to break chemical bonds and ionise molecules and typical experiments in this area involve the study of photodynamics of atoms and molecules and non-linear optics.

The other half of the pulse is amplified further in the second power amplifier, where it reaches pulse energies up to 1.5J. The output from this amplifier is used for plasma physics experiments in the multi-terawatt target area TA2. This Target Area provides focused intensities up to 10^{19}Wcm^{-2} on target in a custom-made vacuum interaction chamber. The pulse compressor is in a separate chamber, also under vacuum, as the intensity of the beam after compression is too great for it to propagate through air without severe non-linear optical distortion. This area is normally used for plasma physics experiments. The experimental programme includes studies in high harmonic generation, pulse propagation in plasma capillary waveguides, proton generation with high intensity pulses and laser acceleration.

In each target area, the pulses are recompressed to a duration of about 40fs before use. Pulses are available at 10Hz in TA1 and up to 2Hz in TA2.

Spectral phase control

The different frequencies in the broad-band pulses from Astra experience slightly different delays while propagating down the laser chain. The resulting variation in times across the spectrum means the pulses cannot be fully compressed in the target area. The Dazzler is an acousto-optic modulator that adjusts the relative phases of the frequencies in the pulse in a precisely controlled way. It is positioned early in the laser chain, to pre-compensate for the phase errors that will accumulate as the pulse propagates to the target area. When the phase errors in Astra are fully corrected, the pulse length can be as short as 35fs, half the length obtained with no phase correction. The SPIDER (**S**pectral **P**hase **I**nterferometry for **D**irect **E**lectric-field **R**econstruction) instrument in the target area measures the variation in phase as a function of frequency. The phase errors it measures are used by the Dazzler controller to perform the exact phase correction required.

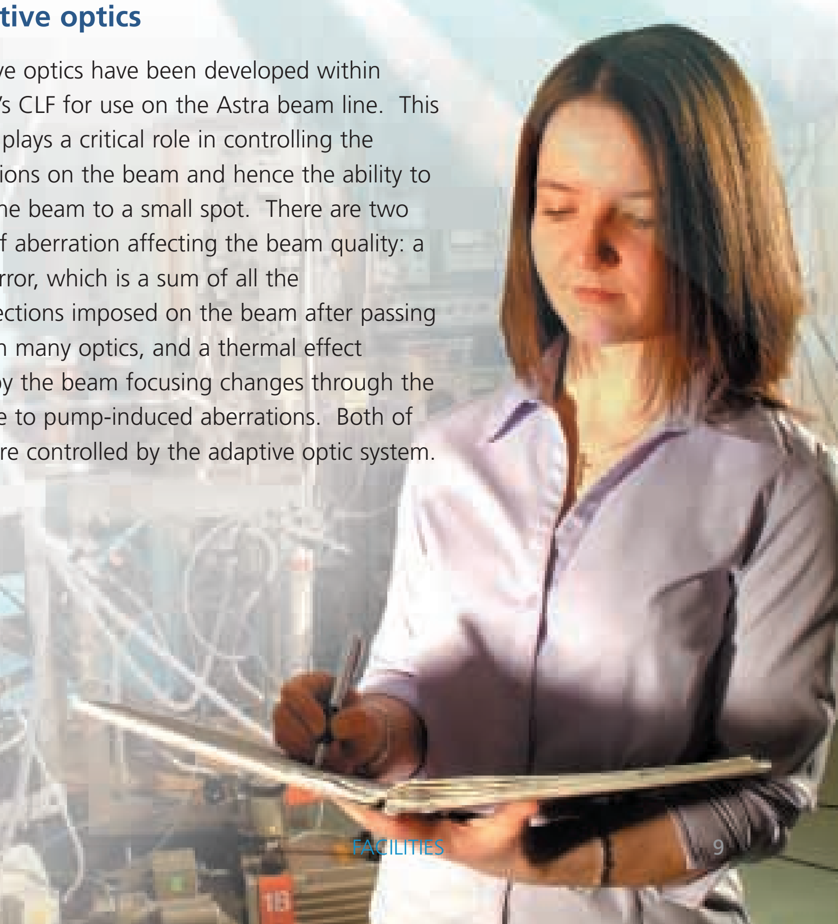
Radio Frequency (RF) plasma cleaning of Astra compression gratings

Compressor gratings are vulnerable to damage caused by carbon deposition on the grating surface. This is due to photo-dissociation of contaminant hydrocarbons, e.g. from vacuum pump oil, by the intense laser light. This layer of contamination reduces the grating efficiency from 90% to below 60% and could act as a site of further, more serious damage. A method of cleaning the gratings has been implemented which uses an RF plasma discharge inside the compressor. This technique involves striking a glow discharge in a mixture of argon and oxygen at a pressure of ~10^{-2}mbar. The process is a combination of ion etching and chemical cleaning of the gratings and has proved very successful.

Adaptive optics

Adaptive optics have been developed within CCLRC's CLF for use on the Astra beam line. This system plays a critical role in controlling the aberrations on the beam and hence the ability to focus the beam to a small spot. There are two types of aberration affecting the beam quality: a static error, which is a sum of all the imperfections imposed on the beam after passing through many optics, and a thermal effect whereby the beam focusing changes through the day due to pump-induced aberrations. Both of these are controlled by the adaptive optic system.

Dr Gail Johnston, Queen's University Belfast pictured on an experiment in Astra target area 1.



Dr Michel Salamone, University of Rome, conducting an experiment in the LSF.

Dr Fred Jamme from the University of Nottingham attaching a blanking flange to the new ultra-high vacuum facility.

LASERS FOR SCIENCE FACILITY

The **Lasers for Science Facility (LSF)** provides a broad range of lasers, laser-based techniques and expertise for scientists and industry available to users from both UK and European communities. It is divided into five areas – four laser laboratories within the Central Laser Facility and a Laser Loan Pool facility.

The Confocal Microscopy Laboratory has established a versatile time resolved fluorescence microscope with a time resolution of around 100ps duration with a wavelength coverage from the UV to near infrared.The spatial resolution of the set-up is less than 500nm. Applications include multi-photon imaging and time resolved fluorescence spectroscopy as well as time-correlated single photon counting for both solution and solid samples.

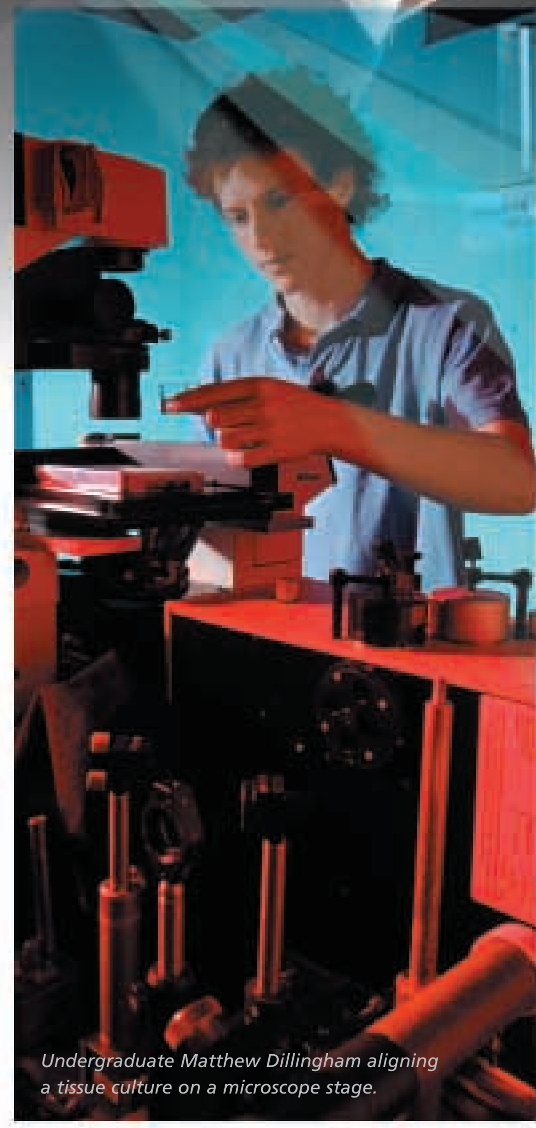
The Optical and Raman Tweezers facility provides the unique ability to manipulate microscopic particles dispersed in a liquid medium and to measure small forces on those particles in a non-intrusive and non-destructive manner. (In the Science section of this brochure, the technology is described in greater detail.) Such techniques have enabled fundamental experiments in the study of aerosol trapping as well as colloidal samples. The technique can be used to capture microscopic objects of size range 0.5-10µm, and it is able to analyse both force and Raman scattering signals from the trapped samples.

The Nanosecond Science Laboratory offers a diverse range of techniques for investigating the dynamics of chemical reactions and enables the structure and reactivity of intermediates to be characterised in the ns timescale. Two independently tuneable lasers produce wavelengths from 205 to 900nm and the main techniques employed are time-resolved resonance Raman spectroscopy, laser flash photolysis and singlet oxygen detection. In collaboration with Dr Martin McCoustra, University of Nottingham, an ultra-high vacuum chamber set-up within the facility allows laser-based surface science experiments in the ultra-fast to steady-state timescales to be carried out. This facility enables the study of gas-solid interactions, growth of semiconductor devices and interactions of interstellar grain mimics.

The Ultrafast Spectroscopy Laboratory specialises in femtosecond transient-absorption and picosecond time-resolved vibrational Raman and infrared spectroscopies to characterise chemical and biological intermediates. CLF developed the world's first double tuneable picosecond laser system which generates two synchronised and independently tuneable beams, covering the spectral region between 220nm (UV) to 10,000nm (mid IR).

The Picosecond Infrared Absorption and Transient Excitation, PIRATE, is a new facility that brings together the experienced Time-Resolved Infrared (TRIR) spectroscopy group at Nottingham University led by Professor Mike George and the CLF laser expertise at RAL. The laser system uses developments in solid state lasers to generate, pump and probe both narrow and broadband wavelengths into the mid infrared, the so-called 'fingerprint' region of molecules. This enables the structure of molecules to be studied during a chemical reaction icluding the chemistry of DNA and proteins. The laboratory also has a unique Raman Kerr gate that has revolutionised the application of Raman spectroscopy.

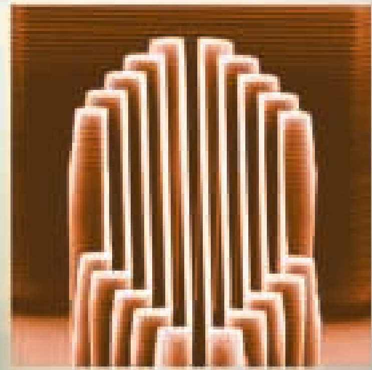
The Laser Loan Pool provides scientific lasers for researchers to use in their own laboratories.The lasers can be borrowed for feasibility experiments, used in extended research programmes or to enhance users' existing research facilities. The loan period normally lasts between three and six months. The range of lasers available includes nanosecond pulsed Neodymium-YAG-pumped dye lasers which cover most of the ultra-violet and visible spectrum. Recent acquisitions have enabled the near infra-red region to be accessed (1.6 to 3.5µm) using difference frequency generation techniques. Also available are a fluoride excimer laser, a 5W argon-ion laser with frequency-doubling and an all solid-state femtosecond titanium-sapphire laser system including a regenerative amplifier.



Undergraduate Matthew Dillingham aligning a tissue culture on a microscope stage.

Drs Caitriona Creely, Trinity College Dublin, Ireland, and Benjamin Elias, Universite Libre de Bruxelles, Belgium, conducting ultra-fast transient absorption spectroscopy experiments.

Microballoon being drilled by PDF prior to assembly in an advanced fast ignition target. The drill diameter is approximately the same size as a human hair (100μm).



Microtarget made in CMF consisting of ten 2μm thick silicon vanes with 2μm separation.

Donna Wyatt at the sputtering plant during copper coating.

TARGET
PREPARATION

The **Target Preparation Laboratory** produces most of the solid targets shot on Vulcan and Astra experiments. Target design plays a central role in many experiments and target modifications are often the quickest and most efficient way to significantly change experimental parameters or conditions. Operationally, Target Preparation has been set up to work closely with facility users throughout an experiment. With access to Vulcan and Astra being necessarily limited due to the high level of demand from the user community, significant scientific benefit can be derived by continuing to minimise the time between data interpretation and target modifications in an experimental run. Target Preparation activities fall into three main areas: microassembly, thin film coatings and expertise in microfabrication techniques.

Martin Tolley using a custom built six-axis microassembly jig to construct a high specification microtarget.

Microassembly

Many microtargets are assembled manually by highly experienced fabricators using ultra-fine hand tools and high quality microscopes. A wide range of components are used, for example 20μm diameter wire, 100nm thick foils, chemically etched copper supports and hand-machined 1mm long cones. Microtargets which have particularly precise specifications (tolerances of better than a few μm) are assembled using either generalised sliding-stage alignment rigs or, increasingly, custom-made assembly rigs. Such assembly rigs are constructed in collaboration with the Precision Development Facility (PDF) in the Space Science and Technology Department (SSTD).

Thin film coatings

Target Preparation has significant capabilities in thin film production. In-house there is a sputter coater equipped with multiple magnetron sputter heads and both RF and DC power supplies; two thermal evaporation plants and a four pocket e-beam coater. All plants are equipped with real-time film thickness monitors. A wide variety of coatings are produced of metals and non-metals whether as pure deposits, co-deposits or multi-layers. Thicknesses from a few nanometers up to several μm are made. Plastic coatings of parylene are produced in a dedicated plant with thicknesses in the range of tens of nm up to tens of μm. There is also a dedicated caesium iodide deposition plant. As well as microtarget components, thin film coatings are used to make a wide variety of filters and photocathodes. Responding to the user community, programmes have recently been developed producing textured (low density) coatings which have enhanced laser absorbance and consequently modified X-ray production characteristics.

Microfabrication

From the earliest planning stages of a proposed experiment, Target Preparation works closely with facility users to offer advice on target feasibility and design. More than 25 years of microtarget production have generated an extensive repository of techniques. A large number of external specialist contractors are also used when required – for example in high precision metal etching and specialised glass microcomponent manufacture. There is a continual programme to examine and, where appropriate, take up new production techniques.

There is a particularly strong collaboration between Target Preparation and PDF in SSTD, whose technicians perform precision micromachining. An example is the ongoing supply of gold microcones used in advanced fast ignitor experiments. Collaborative development programmes are also undertaken, particularly in innovative medium volume production techniques.

With the move to much higher repetition rates, it is anticipated that there will be a huge increase in the number of shots taken in solid target experiments. This is, amongst other reasons, leading to an increasing amount of collaboration with other departments within the CCLRC, such as the Central Microstructure Facility (CMF). The first microtargets produced for CLF by CMF used a combination of lithographic and dry etching techniques.

SCIENCE

ENABLING SCIENTIFIC BREAKTHROUGH EVERY DAY

The Central Laser Facility invites proposals from the research community for experimenters who hope to use its facilities. The planned work normally has a research theme which is already funded by a grant from one of the Research Councils, but a small proportion of beam-time is scheduled for proof-of-principle fundamental experiments which ultimately support the preparation of a grant application.

A small but significant proportion of annual beam-time is also allocated to commercial users on a full costs basis.

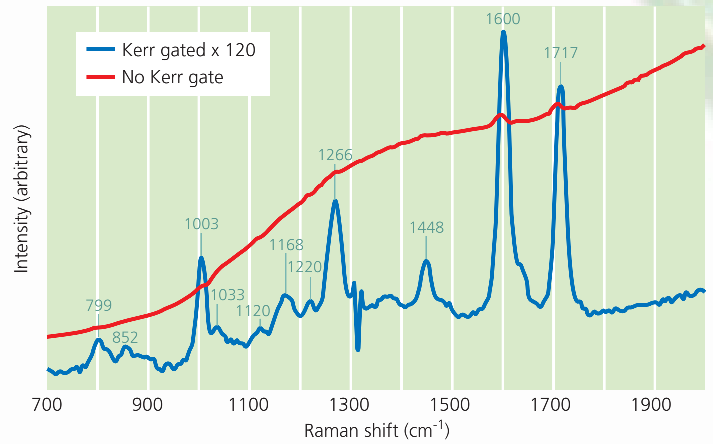
The following pages give some examples of recent cutting-edge science carried out at the CLF. From medicine to the environment, astrophysics to industry, the CLF is making a major contribution to many aspects of the understanding and wellbeing of our planet.

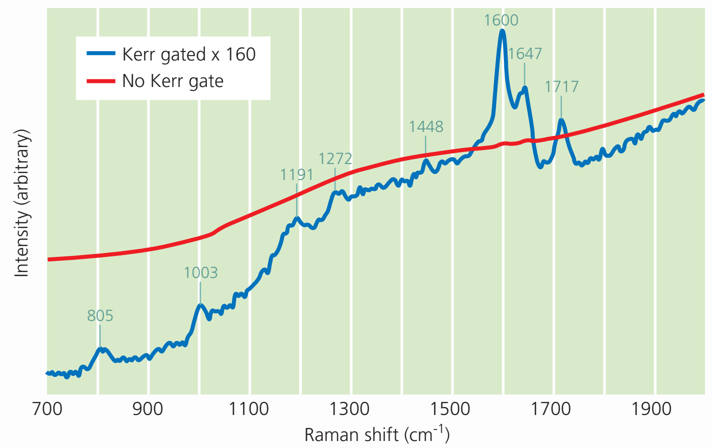
A NEW WEAPON IN THE WAR AGAINST DRUGS

Raman spectroscopy is an effective 'white powder' detector for the in situ identification of drugs. In this procedure, a laser photon is scattered by a sample molecule, the molecule loses (or gains) energy during the process and the amount of energy lost is recorded as a change in energy (wavelength) of the irradiating photon. This energy loss is characteristic for a particular chemical structure in the molecule. Together with other signals, it can provide a molecular signature or fingerprint of the molecule.

The advantages of Raman spectroscopy are that it is non-contact, can often be carried out with the sample inside something transparent, such as a glass vessel, and the results give rise to sharp molecule-specific spectra which enable immediate identification of the substance. However these detectors are ineffective for the determination of drugs in many street samples due to the presence of fluorescent additives which obscure the signal. The additives, such as brick dust, talc or paracetamol, play a key role in the mixture, boosting up its apparent market value by enhancing its volume and weight, with obvious potential harm to the user. If the fluorescence problem could be overcome, the chemical identity and the relative ratios of these additives could conveniently be used by forensic scientists to trace the origin of drugs, even in highly impure samples.

A group from the University of Strathclyde used a new Kerr gating concept pioneered at the facilities of the CLF to do just that. The approach uses a fast Kerr gate to separate the instantaneous Raman signal from the unwanted fluorescence in time. In a feasibility run, the group succeeded in detecting the Raman signal from highly impure street samples of cocaine. Raman spectra of impure amphetamine and heroin were also obtained.





Raman spectra before (red) and after (blue) Kerr gating for two street samples of cocaine. Some additional peaks such as the one at 1600cm^{-1} are due to the agents used to 'spike' the samples.

Prof. Ewen Smith
University of Strathclyde in collaboration with CLF, CCLRC

ASTROPHYSICS
AND LASERS

Astrophysicists and plasma physicists are using different approaches to understanding some of the mysterious behaviour of the Universe. Astronomers use Earth- and space-bound observatories to study such spectacular phenomena as supernovae, supernova remnants, molecular clouds, radiative jets, and gamma-ray bursts, whilst theorists use computers to make sense of the observations. But who tests the theories? Modern lasers might.

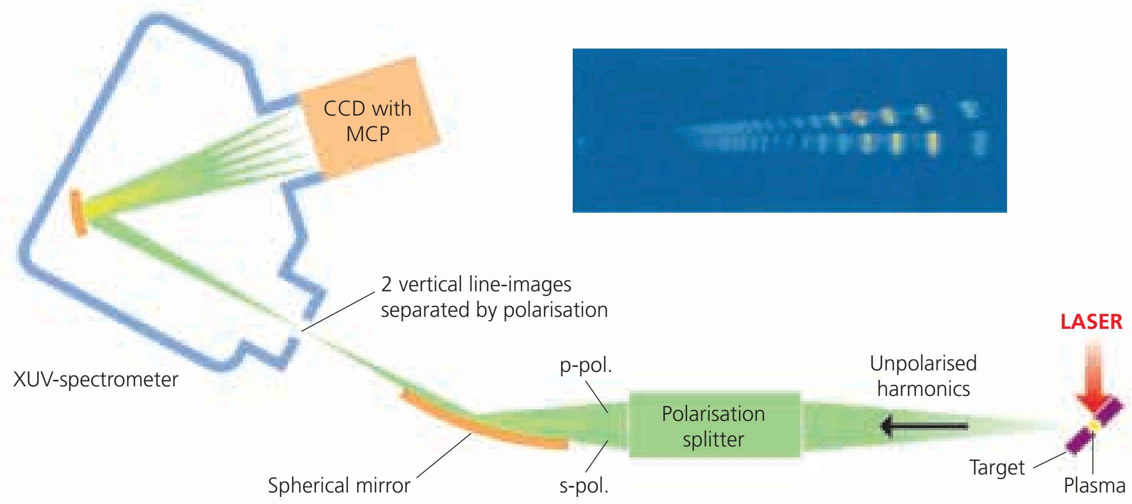
Courtesy of ESA

High power lasers deposit intense pulses of energy in small volumes producing energetic matter that otherwise only occurs in space. Rigorous design scales these picosecond or nanosecond duration, sub-millimetre experiments to the vast time and space scales of astrophysics.

For example, concepts used to understand laser-plasmas such as hydrodynamics, relativistic plasmas, radiation flow, atomic physics, opacity, and equation of state can greatly enhance the understanding of stars and nebulae. This also works the other way round: laser-plasmas can drive strong and collisionless shocks, which are designed to provide insight into the acceleration of cosmic rays and formation of high Mach-number jets; strongly coupled plasmas occur in the core of large planets such as Jupiter, and can be studied in the laboratory by lasers compressing matter; perhaps neutron star physics will be possible in the future with Petawatt lasers creating matter in extreme magnetic fields.

The advantage of an experiment is that it can be repeated and the plasma probed until the reactions and interreactions are fully understood. Will laser-plasma astrophysics open up a new way to explore our galaxy in the laboratory on Earth? Current experiments will help us find out.

Dr Nigel Woolsey,
University of York



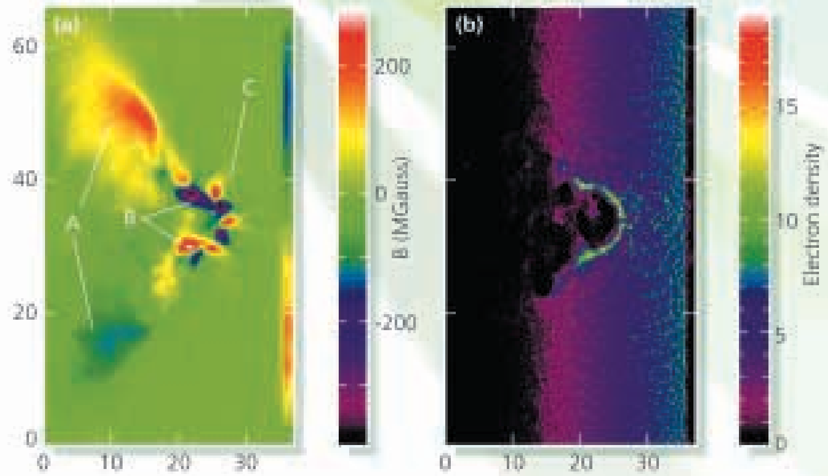
Experimental arrangement to measure the s and p – polarisation properties of VUV harmonics used to infer 700MG magnetic fields.

SUPER-STRONG
MAGNETIC FIELDS

Huge magnetic fields are predicted to exist in the high-density region of plasmas produced during intense laser–matter interactions, but until now these fields have never been measured.

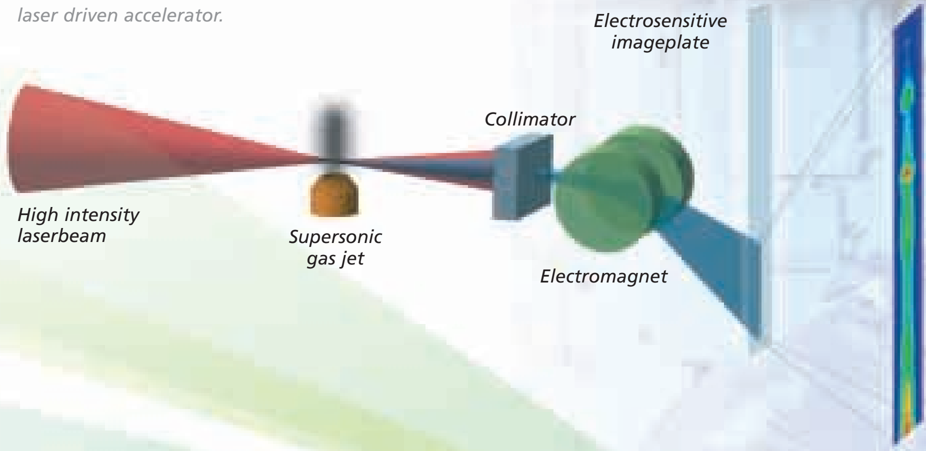
Pulses focused to extreme intensities to investigate laser–plasma interactions by a team from Imperial College London, CCLRC Rutherford Appleton Laboratory, the Atomic Weapons Establishment (AWE) and Queen's University Belfast, (using CLF's Vulcan Petawatt laser), have recorded the highest magnetic fields ever produced in a laboratory – 700 Megagauss (MG) – that is, 1 billion times stronger than the earth's magnetic field!

The magnetic fields were measured by observing light emitted from the target. Harmonics to the laser frequency are created in the ultra-high intensity interactions.The researchers made the first measurements of the polarisation properties of the higher-order 8th–25th harmonics of the laser frequency. They showed that polarisation components of the eleventh and higher-order harmonics become elliptical at high intensity. A significant change in the magnetic field strength can be inferred from these measurements, showing that the field strength approaches 700MG.



Simulation of high intensity interaction using 2D particle in cell code, OSIRIS, showing hole-boring effects and regions of magnetic field. Region (A) non-parallel temperature and density gradients; region (B) ponderomotive source; region (C) magnetic fields due to Weibel-like instability from laser generated electron beams.

The experimental set-up of the laser driven accelerator.



Dr Stuart Mangles, Imperial College London, in the Astra interaction area.

MONO-ENERGETIC ELECTRONS

Scientists from Imperial College London and their collaborators used an extremely short pulse laser to accelerate high-energy electrons in an incredibly short distance. Current accelerators are many metres long, whereas this is just approximately 1mm.

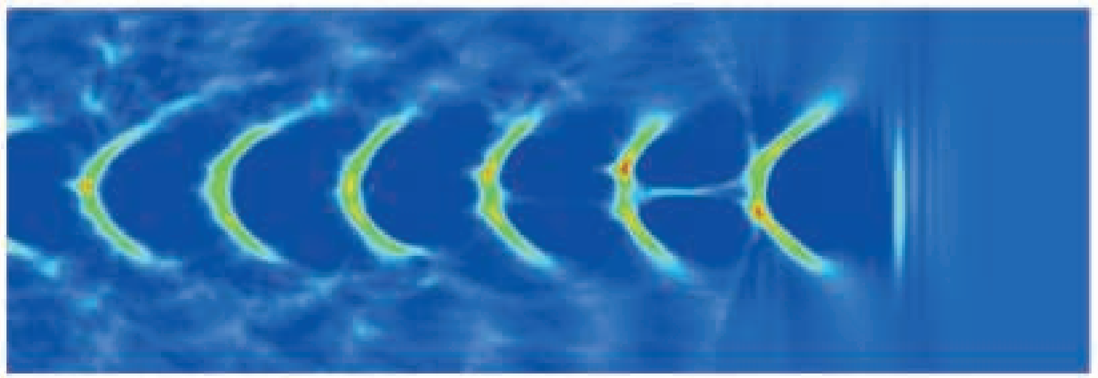
Earlier laser-driven accelerators were inefficient, accelerating the electrons to a wide range of energies. Scientists who use electron beams to research materials science – such as the structure of viruses and moon rock – need the electrons to have the same energy. The experiments using the Astra laser system at the CLF showed for the first time that a laser-driven accelerator can produce a beam of electrons with a narrow range of energies. This is a major breakthrough, representing a step towards a new technology which is much cheaper and more compact than the conventional approach and which could allow individual universities to afford these accelerators instead of relying on large national laboratories.

When an intense laser pulse is focused into a region of gas (helium in these experiments) it ionises the gas, turning it into a plasma, and can set up a wave travelling behind the pulse at very nearly the speed of light. This plasma wave generates a very large electric field, more than 100 times greater than the electric field of conventional accelerators, which can accelerate electrons. In turn this electric field can be used to accelerate electrons.

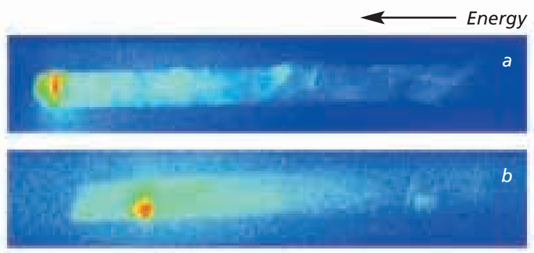
Previous experiments have relied on these plasma waves breaking (similar to a wave breaking on a beach) to produce large numbers of energetic electrons. However, this wavebreaking process has always produced an unwanted large energy spread. By carefully controlling the laser and plasma parameters the Imperial College team has shown that it is possible to use wavebreaking to produce beams of electrons with a narrow energy spread. That is why electrons are accelerated to 70MeV in this experiment over a length of just 1mm, compared with many metres in a conventional accelerator.

The work was supported through EPSRC (Engineering and Physical Sciences Research Council) and Research Council's UK Basic Technology grants.

A simulation of the plasma wave generated in the ultra-high intensity interaction.

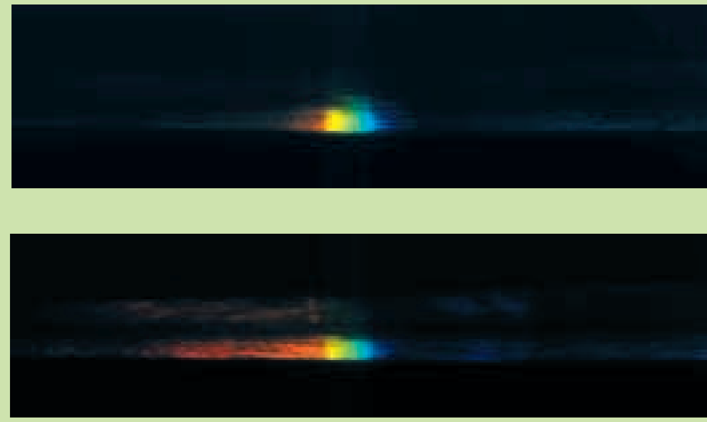


Prof. Karl Krushelnick, Imperial College London, in collaboration with CLF, University of Strathclyde and UCLA.



Data from the electron spectrometer clearly showing that a large number of the accelerated electrons are bunched at a single energy. Such energy spectra may allow the electrons to be used in other branches of physics.

The spectrum of the laser beam before and after the interaction showing the increase in bandwidth.



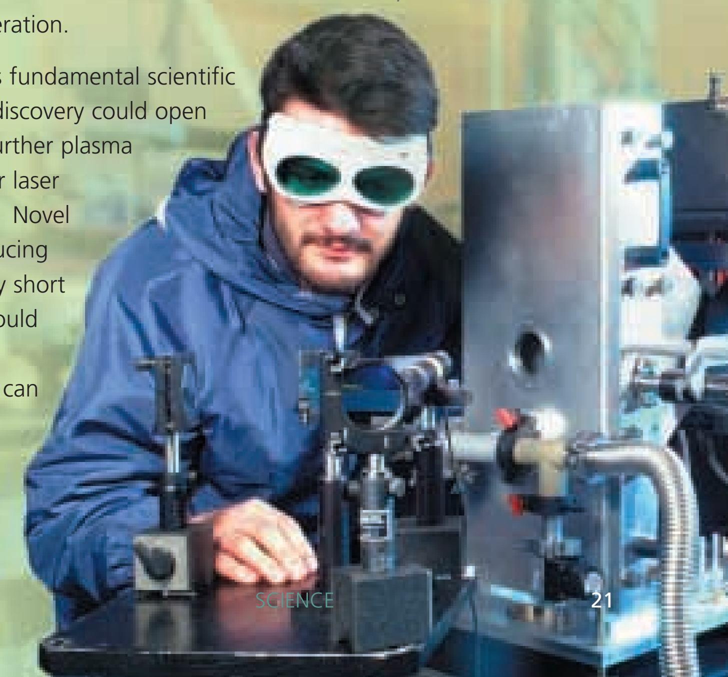
PHOTON ACCELERATION

A great deal of scientific interest has been devoted to using plasma waves produced by lasers to accelerate electrons. For the first time, a group of UK researchers have observed a similar effect on the laser light itself.

Using the Astra laser system of the CLF, the group measured the spectrum of the laser light coming from the plasma accelerator. The spectrum gives a measurement of the energy of individual light 'particles' or photons. It was noticed that the photons were gaining energy in a manner that could not be explained by conventional theories. Simulation has since confirmed that the plasma waves are indeed the source of this photon acceleration.

Along with its fundamental scientific interest, this discovery could open the door to further plasma techniques for laser development. Novel ways of producing X-ray and very short pulse lasers could result if this phenomenon can be developed further.

Alex Thomas, Imperial College London, adjusting the diagnostics in the experiment.



Sarah Watson, University College London, involved in experimental set-up for the molecular dynamics experiment.

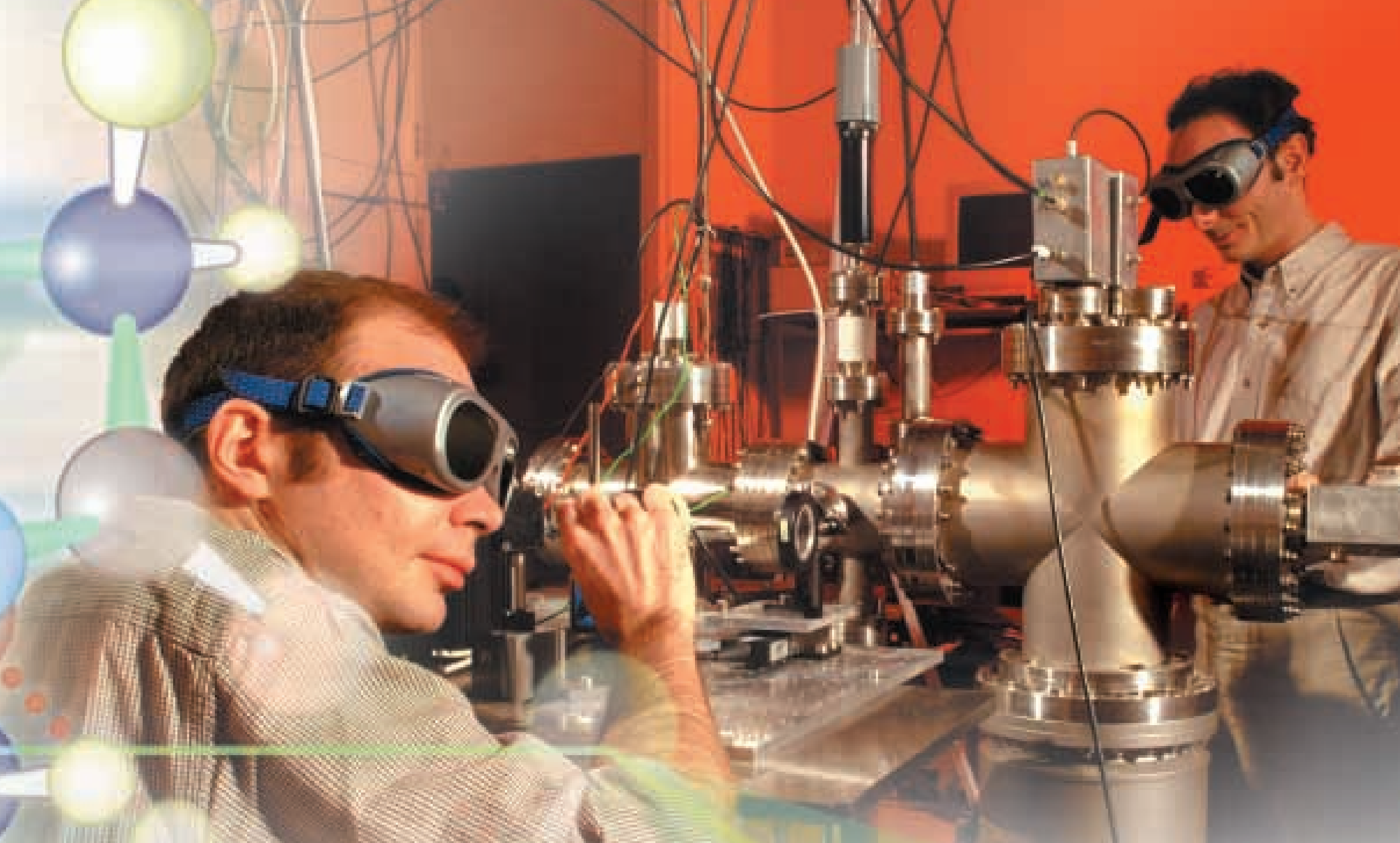
STRONG-FIELD ULTRAFAST ATOMIC AND MOLECULAR DYNAMICS

At sufficiently high laser intensities, the outer electrons in an atom may be violently ripped from the atom by ionisation. Once removed, electrons are accelerated away from the atom. If the radiation field is linearly polarised, the light field can drive the electrons back to the parent ion, and, depending on the energy of the returning electron, recollision ionisation can occur. By carefully adjusting the degree of linearity and intensity of the laser pulse, scientists using the Astra laser system of the CLF have found it is possible to optically control the trajectory of individual ionised electron wavepackets, such that the recollision process may be investigated in detail.

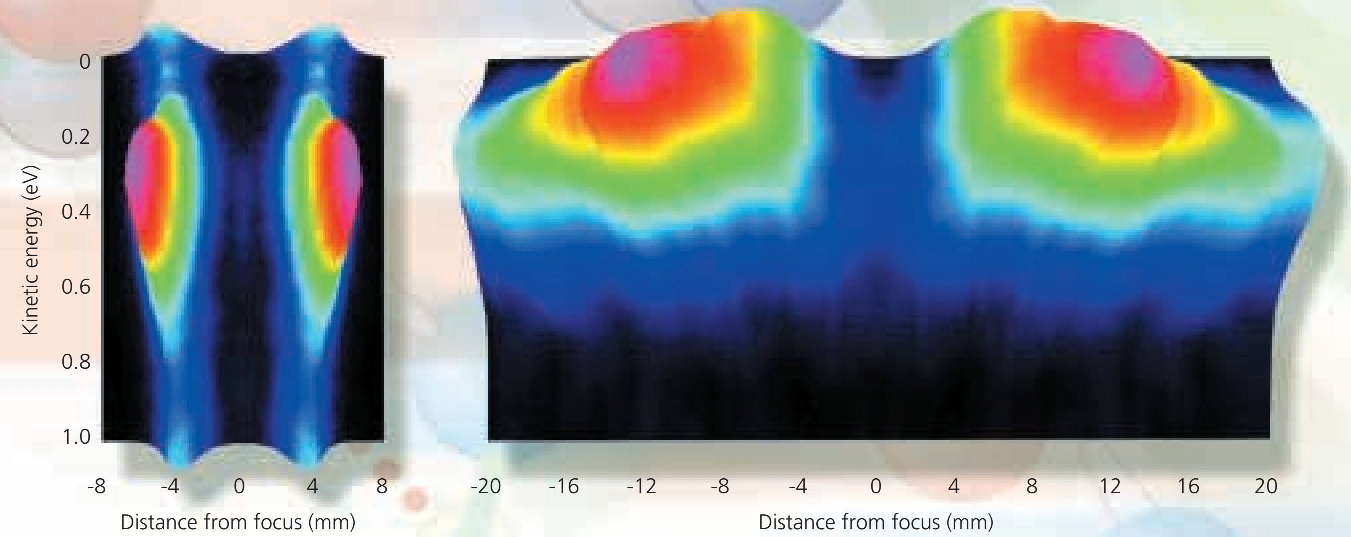
This was the first experimental observation of laser-induced recombination in Krypton + Xenon ions. An ion accelerator is used to prepare Kr^+ (Krypton) and Xe^+ (Xenon) ions – around 20% of which are naturally created in a metastable state. Ionisation is initiated by the laser pulse of either linear or circular polarisation. In the low-intensity circularly polarised case, a major enhancement in ionisation is observed over the linear case. This is the signature of an ionised electron being ejected from the atom at low energy.

The dynamic response of molecules to laser pulses is another major avenue of research for this group. The University College London – Queen's University Belfast – CCLRC Rutherford Appleton Laboratory collaboration is currently the only team worldwide able to study the break-up of the hydrogen molecular ion H_2^+ during an ultra-fast laser pulse. By comparing the results of dissociating H_2^+ ions to the dissociative ionisation of H_2, they are learning how this – the simplest of molecular systems – responds to ultra-fast strong-field light pulses. By the exact control and measurement of the focused laser intensity, the field-induced distortions to the molecule are manipulated such that the dissociation of groupings of vibrational states can be observed. The massive difference in behaviour is apparent from intensity-selective scanning of both H_2 and H_2^+.

Prof. Roy Newell, University College London, in collaboration with Queen's University Belfast and the CLF, CCLRC

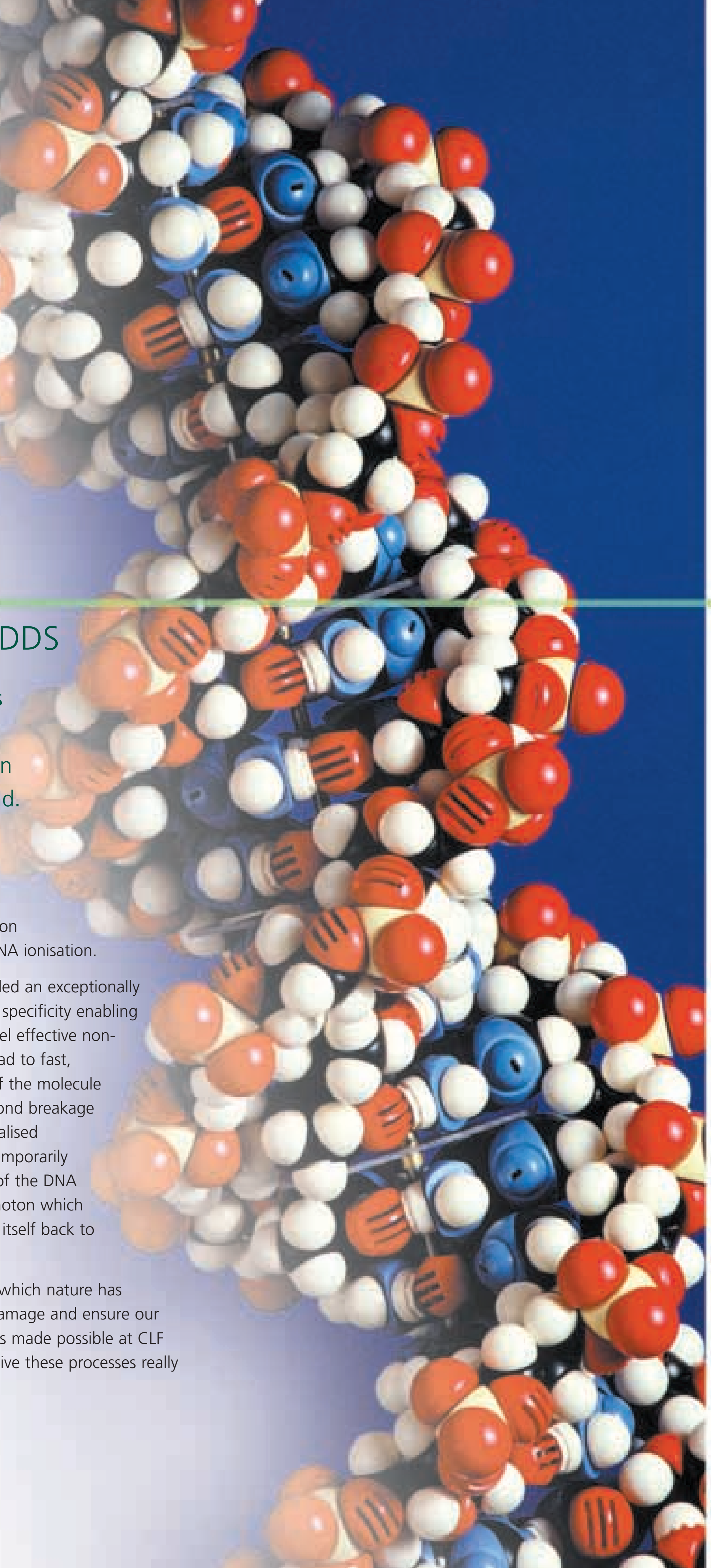


J Le Garrec and SD Le Picard, University of Rennes 1, France, on an EU-funded collaborative experiment with Prof. Newell in Astra Target Area 1.



Comparison of the kinetic energy distributions of H^+ from H_2 (left) and H from H_2^+ (right), as the laser intensity is controlled by moving the focus with respect to the molecular targets. Importantly, the geometry of the focus is identical in both cases, thus the differences observed are the consequence of dissociation dynamics in laser-generated H_2^+ being fundamentally different to that of H_2^+ delivered to the laser focus pre-ionised, contrary to assumptions made by a number of groups throughout the world.

Dr Mike Towrie, CLF, aligning the ultrafast infrared spectrometer.



DNA IONISATION:
SURVIVING AGAINST THE ODDS

The DNA contained in every living organism can be damaged by agents such as chemicals or ultraviolet (UV) radiation from the sun. One of the initial processes that follows the radiation absorption is ionisation, during which a single electron is ejected from the DNA. This initial process leads to breakage of the DNA strand. If not repaired properly, this can lead to genetic mutations and cancer.

DNA ionisation is a potentially lethal process that can lead to the death of the affected organism through genetic malfunction (eg cancer). In addition, any non-lethal DNA defects might still be passed down to successive generations, causing harm to the offspring. Widespread DNA ionisation occurs daily throughout our bodies and can be initiated simply by absorbing a UV photon of sufficiently high energy to induce the process. (Background natural ionising radiation could be another cause.) The fact that we are still here is mainly thanks to complex protective and repair mechanisms evolved throughout the existence of life over more than four billion years.

The ionisation process has been studied in great depth in the past. However, the first crucial moments over a few picoseconds (1ps = 0.000 000 000 001s or 10^{-12}) have not been fully characterised due to instrumental difficulties involved in probing such fast events. For the first time, using the facilities of the LSF, a collaborative team has succeeded in obtaining time-resolved infrared vibrational spectra of these very first moments following the absorption of a UV photon (200nm) that leads to DNA ionisation.

The measurement provided an exceptionally high degree of chemical specificity enabling the observation of parallel effective non-ionising channels that lead to fast, harmless de-excitation of the molecule followed by hydrogen bond breakage and repair, and large localised thermal effects. These temporarily alter the local structure of the DNA base impacted by the photon which subsequently rearranges itself back to its original state.

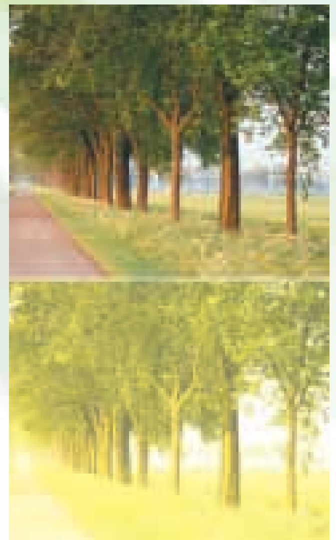
These are the processes which nature has striven to reduce DNA damage and ensure our survival. The observations made possible at CLF shed light on how effective these processes really are.

Prof. Mike George, University of Nottingham, in collaboration with Prof. Tony Parker, CLF

Hanna Iitti, Helsinki University, Finland, preparing samples for Raman experiments.

UNDERSTANDING THE CHEMISTRY OF INKJET DYES

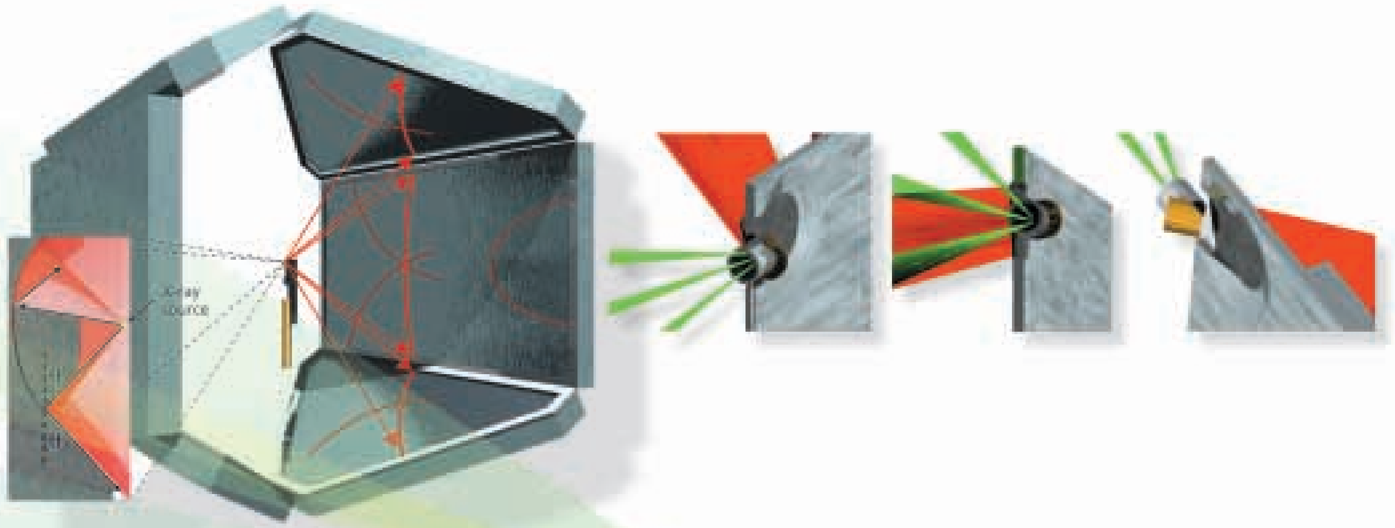
Inkjet printing is one of today's most common imaging technologies. The appearance and quality of inkjet prints depend on a multitude of factors, including the chemical compositions of the printing ink and the substrate.



Inkjet paper grades are coated with mixtures of inorganic pigments, dispersants and binders. Often optical brighteners are used to increase the whiteness of the paper. Understanding the chemistry of inkjet dyes leads to a better quality finish and greater longevity for the printed item.

Researchers from the Helsinki University of Technology applied Kerr gated resonance Raman spectroscopy to study the light fastness of inkjet prints for the first time. The excitation wavelength was chosen to selectively enhance the Raman signals from the dye molecules of the printing colours. The fluorescence of the dyes, inorganic pigments and the strongly fluorescent optical brighteners was rejected by the Kerr gate. Interactions of the dyes with the coating polymers were observed from shifts in the Raman signals of the dyes. The light-induced changes in the chemical structure of the dyes were detected as changes in the intensity of the Raman bands corresponding to specific chromophores in the dyes.

Prof. Tapani Vuorinen, Helsinki University of Technology, Finland, in collaboration with CLF, CCLRC



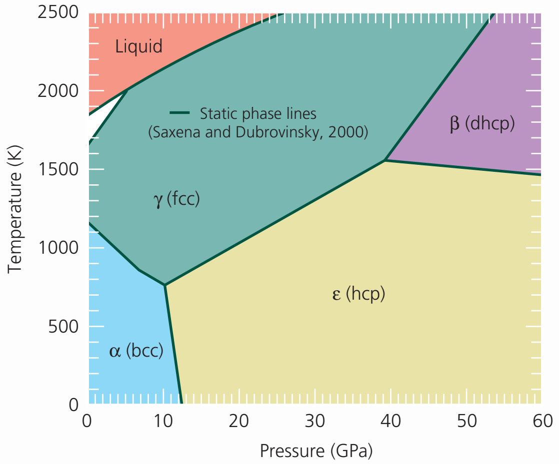
MATERIALS SCIENCE

ON THE ULTRA-FAST TIME SCALE

Materials science is the study of the underlying structure of materials and the way this structure affects their properties. This definition covers a wide spectrum of research and study, in particular the study of how materials change under conditions of changing pressure and temperature.

Generally, these results are presented as a phase diagram. An example for iron is shown below which describes a material's underlying structure as a function of temperature and pressure. This describes the properties of the material under static conditions. But what about dynamic conditions, when the material has not been given a chance to reach equilibrium or is still undergoing a phase change? Using wide-angle in-situ X-ray diffraction, (see above), and large laser facilities such as the Vulcan laser system, it is possible to study the dynamic properties of a material under shock loading conditions.

Prof. Justin Wark,
University of Oxford



Wide-angle in-situ X-ray diffraction is a diagnostic tool that collects diffracted radiation from a target as the material is being stressed. In these high power laser experiments, a foil target is hit with a short pulse high intensity laser. This will generate X-rays that last the same length of time as the laser pulse and whose wavelength depends on the foil material. By placing this X-ray source close to the material under study, diffraction will occur from many atomic planes, which are arrangements of atoms that reflect X-rays in the material. The angle of diffraction from a single plane provides a measurement of the average atomic spacing in one direction and the orientation of that atomic arrangement. Using multiple planes, it is possible to work out the crystal structure of the material. The change in pressure and temperature in the material is generated by another beam of the laser. When a high intensity laser produces an expanding plasma from a solid target, the conservation of momentum dictates a force will be applied to the remaining target. This travels as a shockwave through the samples, increasing the pressure and temperature of the material on an ultra-fast time scale as it propagates. With wide angle X-ray diffraction, the atomic structure of the material can be studied in these ultra fast conditions and how a material moves on the phase diagram between different states can be determined.

Peta Foster, Central Laser Facility, and Dr Paul McKenna, University of Strathclyde, aligning the beam on to target.

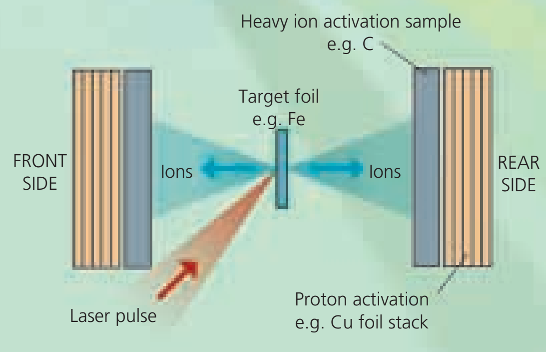
LASER-PLASMA-BASED

NUCLEAR SCIENCE

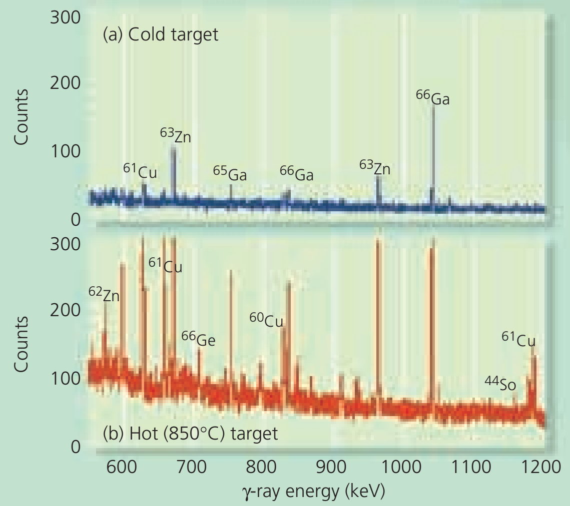
Intense laser radiation makes it possible to study fundamental properties of matter in extreme states and, through interactions with plasma, provides a unique point source of high energy particles (ions and neutrons) and electromagnetic radiation which can initiate a variety of nuclear processes in matter.

Using the world-leading Vulcan laser, a team of researchers from the University of Strathclyde, in collaboration with groups from the University of Paisley, Glasgow University, Imperial College London and the CCLRC Rutherford Appleton Laboratory, have pioneered the application of intense laser radiation to nuclear science. Highlights from this research include the demonstration of laser-driven photo-fission; the production of short-lived isotopes in significant quantities for medical imaging techniques; demonstration of laser-driven photo-transmutation reactions and heavy ion fusion reactions; and the application of laser-generated protons for spallation studies.

Developments in 'tabletop' high intensity lasers may ensure the extension of this science to produce a fundamentally new compact laser-plasma-based nuclear radiation source. This will potentially lead to applications in areas of science that have up until now been solely within the remit of the accelerator or nuclear reactor communities. This may also facilitate wider access of nuclear science to university departments, hospitals, government research laboratories and small-scale industry.



Typical experimental arrangement for investigation of laser-based ion-induced nuclear activation.



Gamma-ray spectra from a carbon sample after irradiation with iron ions accelerated by laser interactions with a heated iron foil.

Prof. Ken Ledingham,
University of Strathclyde

Sample preparation by Dr Stan Botchway and Matthew Dillingham, CLF.

Rebecca Hopkins and Dr Laura Mitchem, University of Bristol, capturing aerosol droplets using the optical tweezers apparatus.

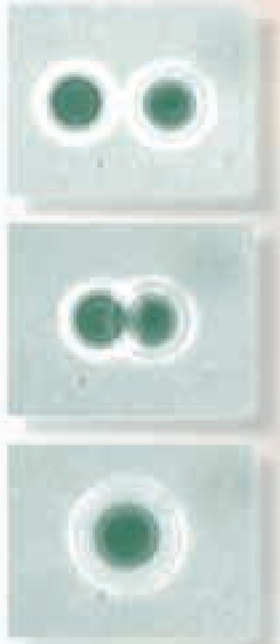
MANIPULATING PARTICLES WITH OPTICAL TWEEZERS

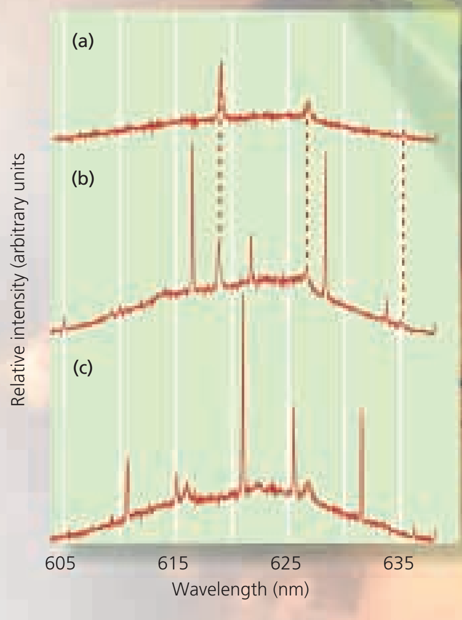
Tiny microscopic objects too small to see can be held using laser light photons instead of mechanical tweezers. The object simply becomes trapped within a focused laser light beam. Since the light does not interfere with the object, the optical tweezers provide a clean and non-invasive way of holding and manipulating these tiny particles.

The optical tweezers apparatus in the Lasers for Science Facility has been used to demonstrate that a single-beam gradient force optical trap can be used to capture single water droplets in air for periods of hours. This enables the prospect of characterising the mechanisms of chemical and physical transformations within a single droplet. The chemistry of atmospheric aerosols is an experimentally challenging area of research where measurements are often made on large collections of particles, which have a wide range of particle sizes and compositions. Under these conditions, the fundamental factors that govern the heterogeneous chemistry are frequently obscured, or at best averaged, by variations in key parameters such as the surface-to-volume ratio and the interfacial composition of the droplets. However, measurements made on a single droplet are providing more detailed information on the mechanisms of heterogeneous chemistry, the factors governing droplet mixing, and the processes that lead to the physical transformation of the particle through phase transformation and growth.

In these exciting new studies, the optical tweezers are used to capture and control water droplets from aerosols, at trapping powers of less than 10mW, using an Argon-Ion laser focussed through a microscope. When coupled with the spectroscopic technique of **cavity enhanced Raman scattering** (CERS), the change in size of an individual droplet can be determined with nm precision. This has allowed the changes in droplet size by factors such as relative humidity, localised heating by the laser and adsorption of chemical species to be monitored with unprecedented accuracy. By creating two optical traps, it is also possible to capture and manipulate two droplets – this has permitted preliminary studies into droplet coagulation.

Dr Jonathan Reid, University of Bristol in collaboration with CLF, CCLRC





The manipulation of two trapped droplets to the point of coagulation.

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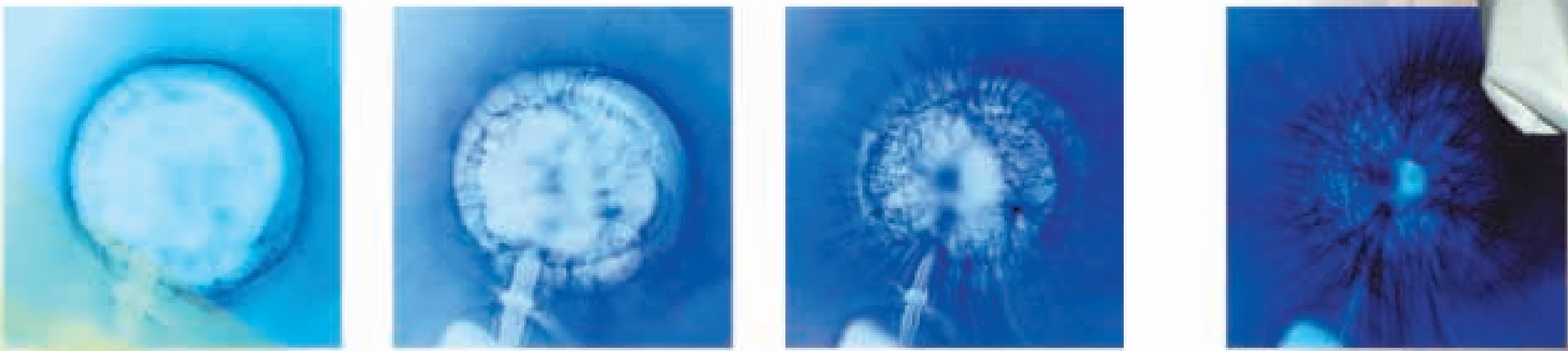
Proton projection images of a 150µm glass microballoon following irradiation by a 20TW, 1ps laser pulse (focused on the taget from the right side of the image). The four frames, obtained in a single exposure, provide time-resolved information on the electric and magnetic field distribution surrounding the laser-irradiated target at 4 different delays (up to 30ps) relative to the peak of the laser irradiation.



PROTON RADIOGRAPHY

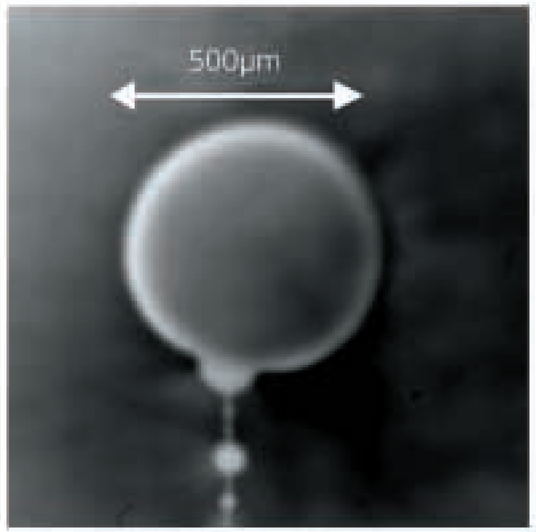
PROVIDING A WINDOW ON HIGH DENSITY MATTER

High-intensity laser pulses interacting with thin foils can transfer a significant fraction of their energy to beams of highly energetic ions (MeV) with exceptional and unique emission properties. An application of particular interest is the use of laser-accelerated protons as a particle probe for dense matter and plasmas. In other words, by propagating a proton beam through a sample and observing how the beam's characteristics are modified, it is possible to obtain information on the properties of the sample under consideration.

Dr Marco Borghesi,
Queen's University Belfast

This application is now possible thanks to the unprecedented spatial and temporal emission properties of these proton sources which allow resolution of details as small as 1µm and as short as 1ps. In addition, by choosing a proper detector and exploiting the fact that the proton beam contains many different energy components (a 'broad energy spectrum'), it is possible to obtain a 'movie' of the evolution of the target in a single laser shot.

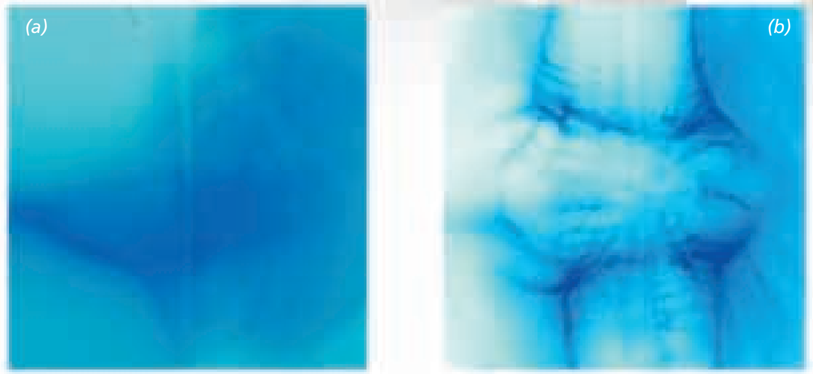
Observing how the protons are stopped or scattered via collisions with the nuclei and electrons in the sample can provide information on the distribution of material density inside it. Due to the high penetration depth of multi-MeV protons, this has application in the study of dense matter, for example in the context of Inertial Confinement Fusion (ICF). On the other hand, if electric and magnetic fields are present in the sample, they deflect the positively-charged protons via the Lorentz Force, and by mapping their deflections it is possible to reconstruct the distribution of the fields (and the associated charge/current densities). Application to the study of the ultra-fast charge and field dynamics following ultra-intense interaction has yielded exciting and novel information on the physical processes of this regime.



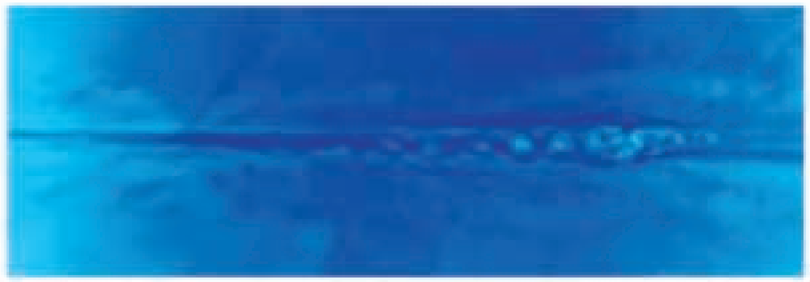
A radiograph of a plastic shell with 500µm diameter and 7µm thickness, of the kind used in ICF. This data was taken in a collaborative LLNL-QUB-RAL experiment, where radiographs of shells compressed by powerful laser pulses were also obtained.

Satyabrata Kar, Queen's University Belfast preparing the radiographic set-up.

Courtesy Ralph Jing

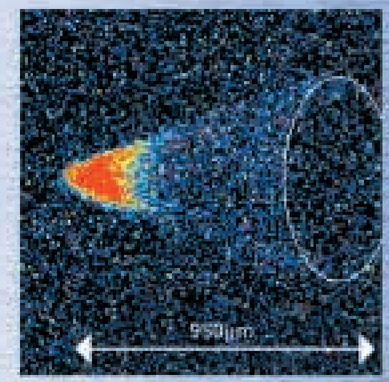


The evolution of the fields surrounding a laser-irradiated 50µm aluminium wire, irradiated at an intensity of 5 x10^{19}W/cm^2. The two frames show proton projection images of the wire: (a) before the interaction; (b) 5ps after the interaction. While (a) shows the shadow of the unperturbed wire, in (b) a dramatic deflection pattern highlights the electric fields present around the wire following the interaction. Information on the wire charge-up due to expulsion of relativistic electrons, the discharge due to an ultra-fast current flowing through the wire and the acceleration of ions from the wire can be obtained from this data.



A proton projection image of the interaction of a high-intensity laser pulse with a jet of helium gas at 50bar pressure. The laser pulse propagates through the low-density plasma created by ionising the gas and undergoes a number of highly non-linear processes, including the excitation of large-amplitude electron plasma waves, the onset of relativistic channelling and filamentation, the generation of electromagnetic solitons. As an effect of these processes, complex plasma structures are formed in the wake of the pulse, which for the first time have been detected via the associated electrostatic fields using proton projection imaging techniques.

A hollow gold cone inserted into a copper-doped deuterated plastic shell for the integrated fast ignition experiments on Vulcan with an X-ray emission pattern of the cone irradiated by the Vulcan 100TW laser pulse.



A POTENTIAL FUTURE FUEL SOURCE

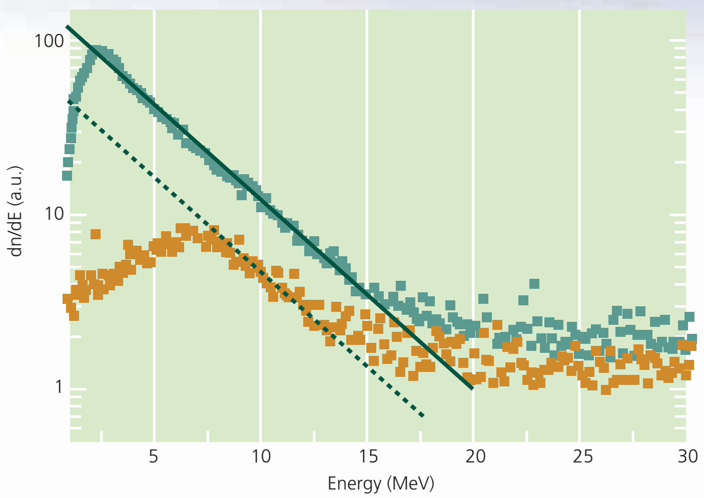
As reserves of coal and gas run out, a new technique, Inertial Confinement Fusion (ICF) – is exciting interest as a possible future fuel source. In this technique, hydrogen-like atoms, deuterium and tritium, are compressed by laser beams in a fuel pellet until, at a critical point, it self-ignites creating energy. This situation is comparable to a diesel engine in a car.

Fast Ignition is a technique designed to reduce the amount of energy required to 'ignite' the fuel. The fuel pellet is compressed, but not to a point where it self-ignites, and then a second high intensity pulse is fired in to the fuel to trigger the fusion process. This is different to traditional ICF and is more like a petrol engine where a spark plug is used to ignite the petrol under compression.

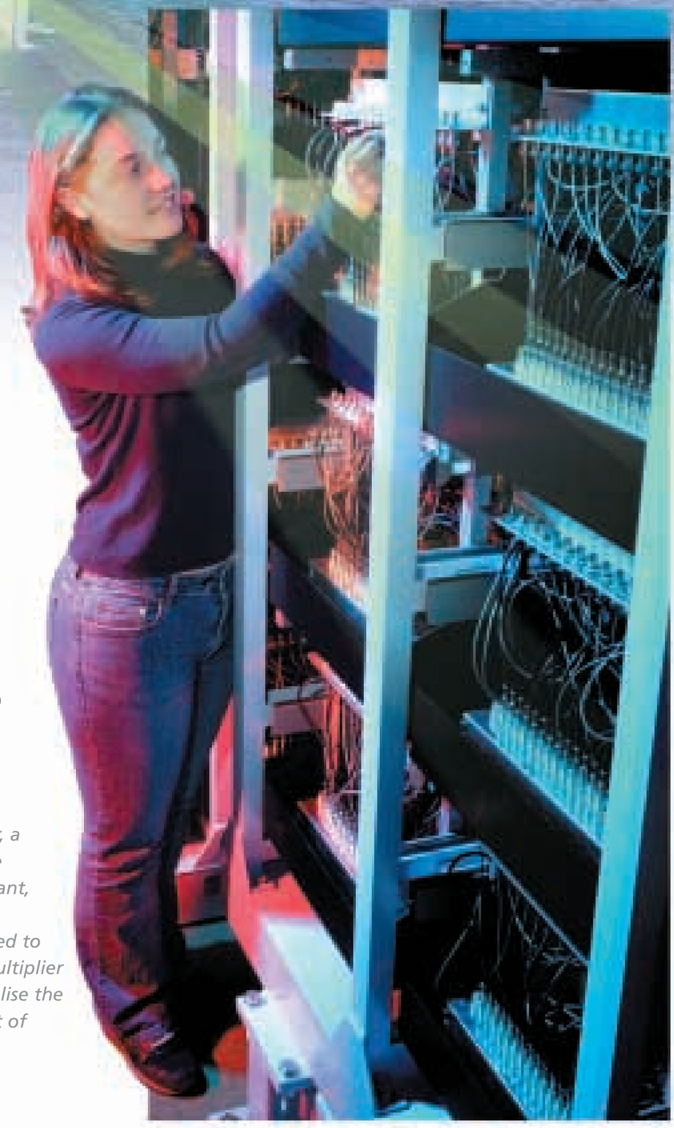
One of the most attractive paths to fusion energy is now being explored in laser fusion research: the advanced fast ignition concept. The first demonstrations of this new concept were reported by a consortium of researchers from British universities and Japanese scientists from the Institute of Laser Engineering (ILE) using the Vulcan and the GEKKO XII laser facilities. A short-duration laser pulse was coupled to a novel target that allowed simultaneous compression and heating.

More recent results (with US physicists in the consortium) show highly efficient heating of the compressed plasma by the short pulse and indicates that the there are no plasma instabilities preventing electrons penetrating to the compressed matter when the pulse duration of the heating pulse is increased to 10ps. Work at the CCLRC has concentrated on understanding physics issues associated with the interactions; namely how electrons and ions are transported under these conditions.

A Large Area Neutron Scintillator Array has been commissioned to study electron and ion energy transport in the Vulcan Petawatt laser facility. Here, each array has 256 photo-multiplier tubes coupled to a liquid scintillator that looks for the ionisation track emitted when thermonuclear neutrons knock-on protons inside the scintillator material.



An electron spectrum taken in an electron spectrometer. The green line shows the electron spectrum of a plane 25μm thick copper foil irradiated with the Vulcan 100TW laser pulse. The orange line shows an electron spectrum taken at peak compression in a cone-shell implosion. Notice the large number of MeV electrons missing in the latter case. This is an indication of an anomalous stopping process of the fast electrons inside the dense plasma.

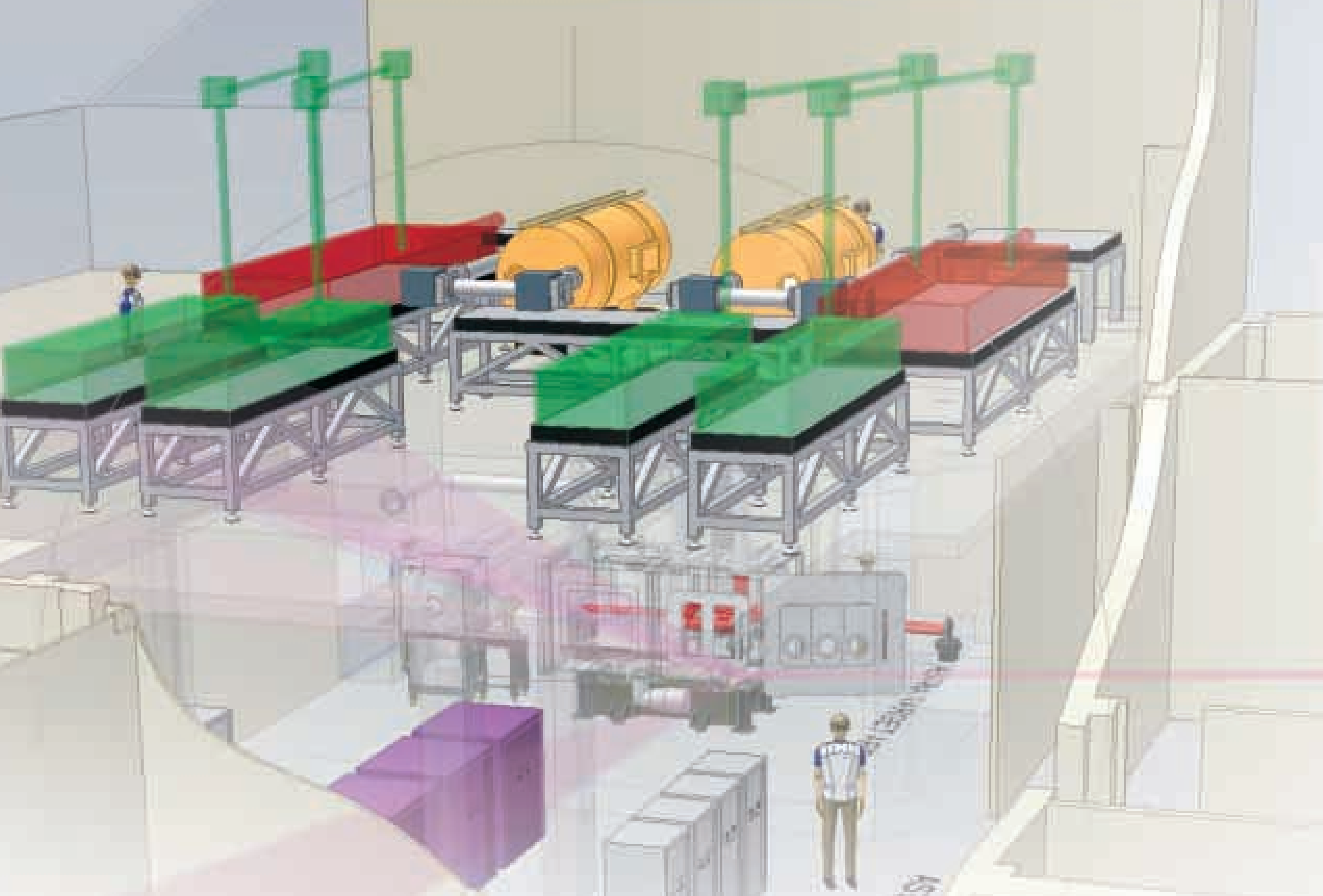


Kate Lancaster, a post- graduate research assistant, adjusting the voltages applied to each photo-multiplier tube to normalise the output current of each event.

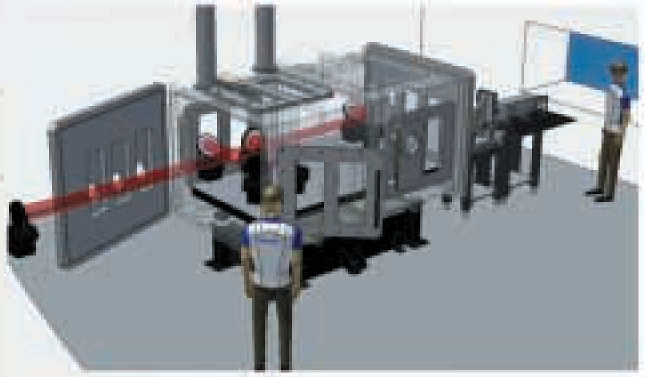
Dr Peter Norreys, CLF, in collaboration with Prof. Kodama, University of Osaka, Japan

RESEARCH
AND DEVELOPMENT

The Central Laser Facility is an enthusiastic research partner in pushing the boundaries of laser science, discovering new capabilities for our lasers and is able to make a significant contribution to the UK and European scientific community because of its investment in ongoing research into laser science. The physics of current techniques and procedures are constantly assessed in the drive for higher power and new applications, as the examples on the following pages illustrate.



Chris Hooker, CLF, inspecting optics for Astra Gemini.



The Astra Gemini interaction chamber.

Cleaning of compressor gratings using an r.f. discharge.

Dr Oleg Cheklov analysing Gemini performance.

ASTRA GEMINI

A NEW DUAL-BEAM PETAWATT LASER FACILITY

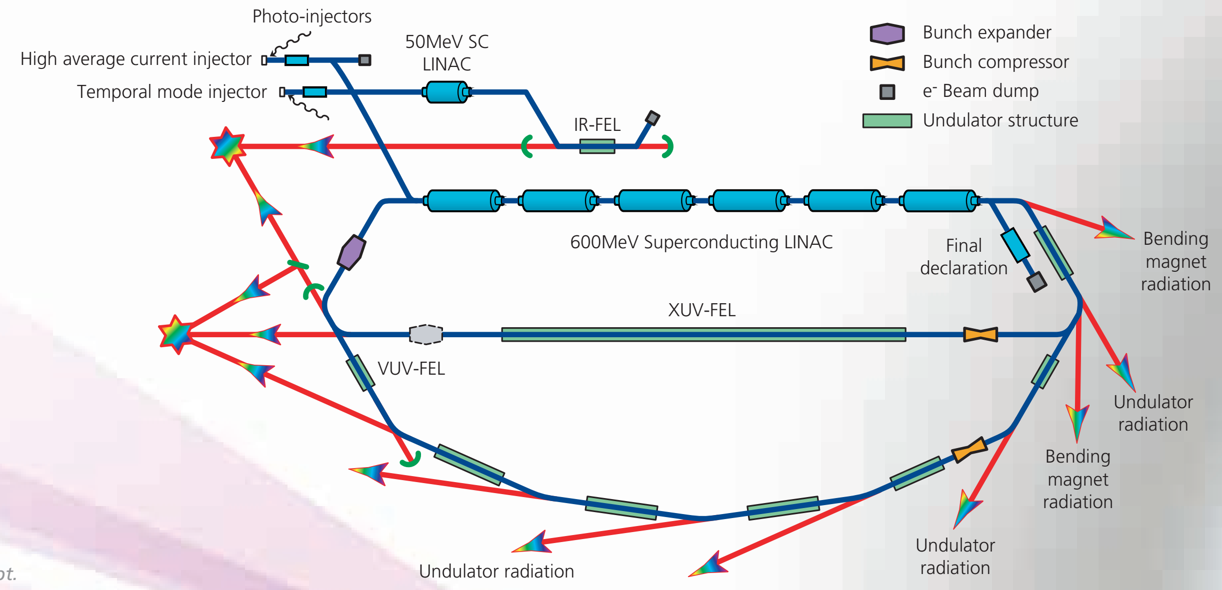
The Astra Gemini project is an exciting new development which has been funded through the CCLRC Facility Development Board to explore novel fundamental and applied science.

The Astra Gemini project is a major upgrade of the Astra high power laser system and will transform Astra from a single beam 20TW system into a dual-beam Petawatt level facility. It will be internationally unique, and will enable access to a wide range of new and novel science. Each of the synchronised 0.5PW beams will be independently configurable and focusable to 10^{22}Wcm^{-2}. Potential advanced options for 10^{23}Wcm^{-2} focusing are currently under development and evaluation. This is some three to four orders of magnitude above the current operating point of Astra. A crucial aspect of the new facility is that it will be capable of firing at one shot per minute, offering a completely new experimental approach to ultra-high intensity physics research.

Four 45mm diameter pump lasers will be constructed using ‘chains’ of neodymium-glass rod amplifiers. The pump lasers have been designed to fire at one shot per minute, and will operate in pairs to provide 50J of pump laser energy per pair. Each pair will in turn pump one of two independent 60mm diameter titanium-sapphire amplifiers. A stretched pulse from the existing Astra system will be used to simultaneously seed each amplifier which will also incorporate advanced large aperture adaptive mirrors developed within the CLF to guarantee diffraction limited focusing. Each 25J output pulse from these amplifiers will propagate through a vacuum spatial filter to an optical compressor that will compress the pulse to 30fs duration with 15J of energy – in power terms 0.5PW each.

The project will see the development of a new interaction facility complete with extensive radiation shielding, a dedicated radioisotope handling, storage and measurement facility and a diagnostics area located outside the radiation shielding. The interaction facility itself will be a large concrete ‘bunker’, with 1m thick walls and a 0.6m thick concrete roof surrounding an interaction chamber. The two 0.5PW beams will be delivered under vacuum, vertically from above, to the interaction facility. The new facility will be on line in the summer 2007 and will be used for experiments in, amongst other topics

- Relativistic Laser-plasma Physics
- Laser Particle Acceleration
- Laboratory Astrophysics
- Nuclear Physics
- Time Resolved Materials Science
- Advanced Imaging.



The 4GLS concept.

4GLS

4TH GENERATION LIGHT SOURCE

As well as being sophisticated research tools in their own right, lasers can also solve some of the challenging problems faced by designers of other scientific instruments. The CCLRC role is to provide UK scientists with access to the world's best research equipment, and this involves ensuring that it is developed in time to meet the needs of the scientific community. CLF staff are working with their CCLRC colleagues and collaborators elsewhere to deliver machines which will answer some of the 21st century's most demanding scientific questions.

A particular example is the provision of lasers as component parts of electron accelerators. These are used, for example at CERN, to probe the fundamental nature of matter by accelerating short bunches of electrons and positrons to phenomenal speeds and then colliding them, head-on, to produce short-lived, exotic products. The efficiency of this process depends on the electrons being compressed into the shortest bunches and focused to the smallest spots at the collision point, and this is only possible if their paths through the huge accelerator have been very well controlled. Electron accelerators can also be used as sources of light (see box) and again the brightness and stability of the light depends on very close control of the electrons' properties.

The source of the electrons in an accelerator has traditionally been a 'thermionic cathode', where the electrons are 'boiled' off a hot surface. Such thermal electrons leave the surface in a continuous stream, however, and travel in a wide range of directions, and it is relatively difficult to form them into well-directed, short bunches. A recent alternative is to generate the electrons by illuminating a photo-sensitive material with a pulsed laser beam. The resulting electrons come ready bunched and with the minimum spread of directions. The improved quality of the electron beams from these so-called 'photo-injectors' enables experiments to be carried out which – quite simply – used to be impossible.

Photograph courtesy of CERN.

ACCELERATOR-BASED LIGHT SOURCES

When the paths of fast moving sub-atomic particles are bent in magnetic fields the particles give off a type of light called 'synchrotron radiation'. This light can cover an extremely broad spectrum, ranging from the far infrared to the ultraviolet, or even X-rays. A number of accelerators the world over are dedicated to providing synchrotron radiation for scientific users.

The Central Laser Facility is working with staff at the CCLRC Daresbury Laboratory to design and prototype a next generation accelerator-based light source, to be called 4GLS (for 4th Generation Light Source). As well as basic bending magnets, this machine will also support more sophisticated devices, including 'undulators' and 'free electron lasers'. The opportunity to use these sources in combination with one another and with conventional lasers will be unique in the world.

Further details can be found at http://www.4gls.ac.uk

The demands on photo-injector lasers are severe. They need to operate with high powers and short pulse lengths, sometimes at the difficult ultraviolet end of the spectrum and for long periods of time with very high reliability. The biggest challenge, however, is to maintain exceptional pulse-to-pulse stability. Such lasers are not available commercially and their production therefore falls to specialist teams, such as the one in the CLF, using state-of-the-art laser materials and advanced design techniques.

4GLS

Dr Oleg Chekhlov, CLF, aligning the OPCPA amplifier stage.

PROGRESS TOWARDS MULTI-PETAWATT LEVEL LASERS

Petawatt lasers can be found either already in operation or under construction at many laboratories around the world. To maintain CLF's position as a world-leading provider of ultra-high intensity lasers, a programme of work has been conducted to prove a technique which will deliver the generation of facilities beyond Petawatt.

The technique of optical parametric chirped pulse amplification (OPCPA), pioneered at the CLF, has become well known for the exploitation of extreme gain bandwidth to achieve ultra-short, and thus ultra-high power optical pulses. As large aperture crystals are readily available to handle high energies (and have very low spatial and spectral aberrations) focused intensities can be predicted which are much higher than with conventional short pulse lasers.

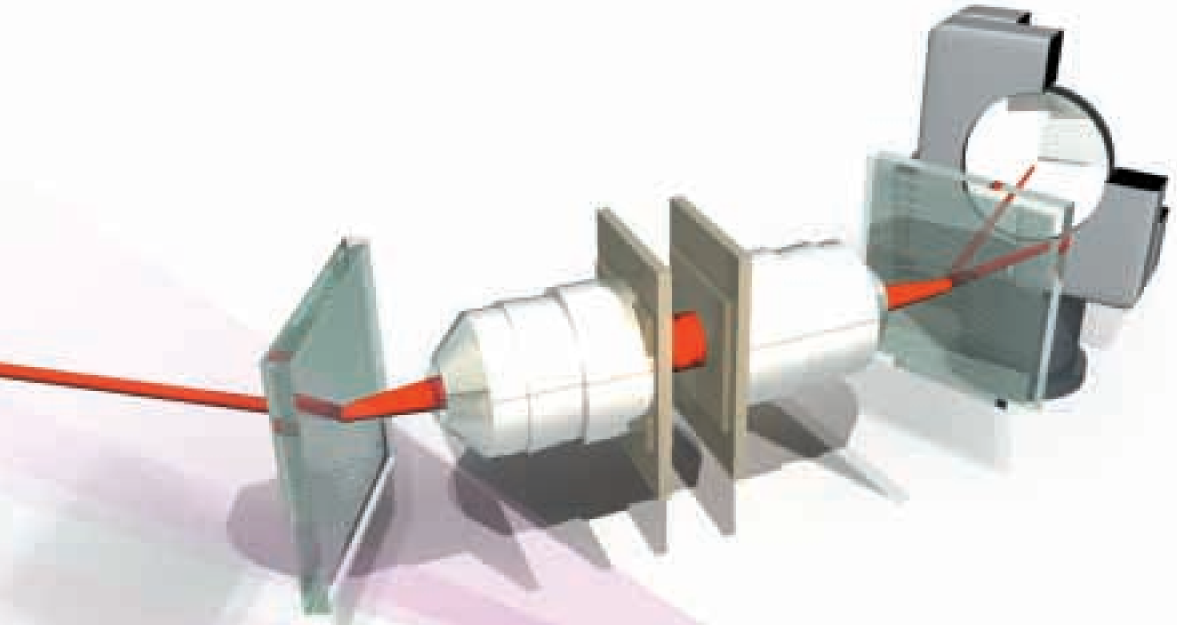
The two beams produced from the OPCPA amplification process, one of which is of high beam quality, which is subsequently compressed and sent to target, and the other which is of poorer quality and dumped

Following successful implementation of the technique at low energies, both at the CLF and elsewhere, the process has recently been scaled up to test it at the PW level. A recent programme aimed to fully assess the technique at much higher powers and consisted of a series of experiments on Vulcan.

In this test experiment a single 135mm diameter 150J 650ps pulse at 527nm was used to pump a 3-amplifier OPCPA system consisting of two LBO and one KDP crystals. With the crystals working at close to degeneracy and slightly non-collinear, a chirped and stretched 70nm bandwidth pulse of 1nJ at 1053nm was amplified to 35J and compressed to 85fs giving a potential power of 0.4PW.

Dr John Collier, CLF, CCLRC
Rutherford Appleton
Laboratory

Dr Ian Ross, CLF, who realised the potential of the OPCPA scheme to generate ultra-high powers.



The optical stretcher used in the attosecond laser system.

TECHNOLOGY PARTNERSHIPS

The Basic Technology Research Programme is a £100 million initiative managed by the Engineering and Physical Sciences Research Council (EPSRC) on behalf of all of the Research Councils working under the auspices of Research Councils UK (RCUK). The Programme is building UK capacity in technology research to underpin the next generation of tools, techniques and processes that will impact across the scientific disciplines supported by the Research Councils and potentially form the basis of the industries of the future.

Attosecond Light Source

A £3.5 million research grant from the UK Research Councils' Basic Technology Programme has been awarded to a team of scientists to develop and build the first attosecond (as) domain laser system capable of freeze-framing and controlling the motion of electrons. (1as = 10^{-18}s).

The length of the pulses in the UK attosecond system, generated using a technique known as high harmonic generation, will be about 200as.

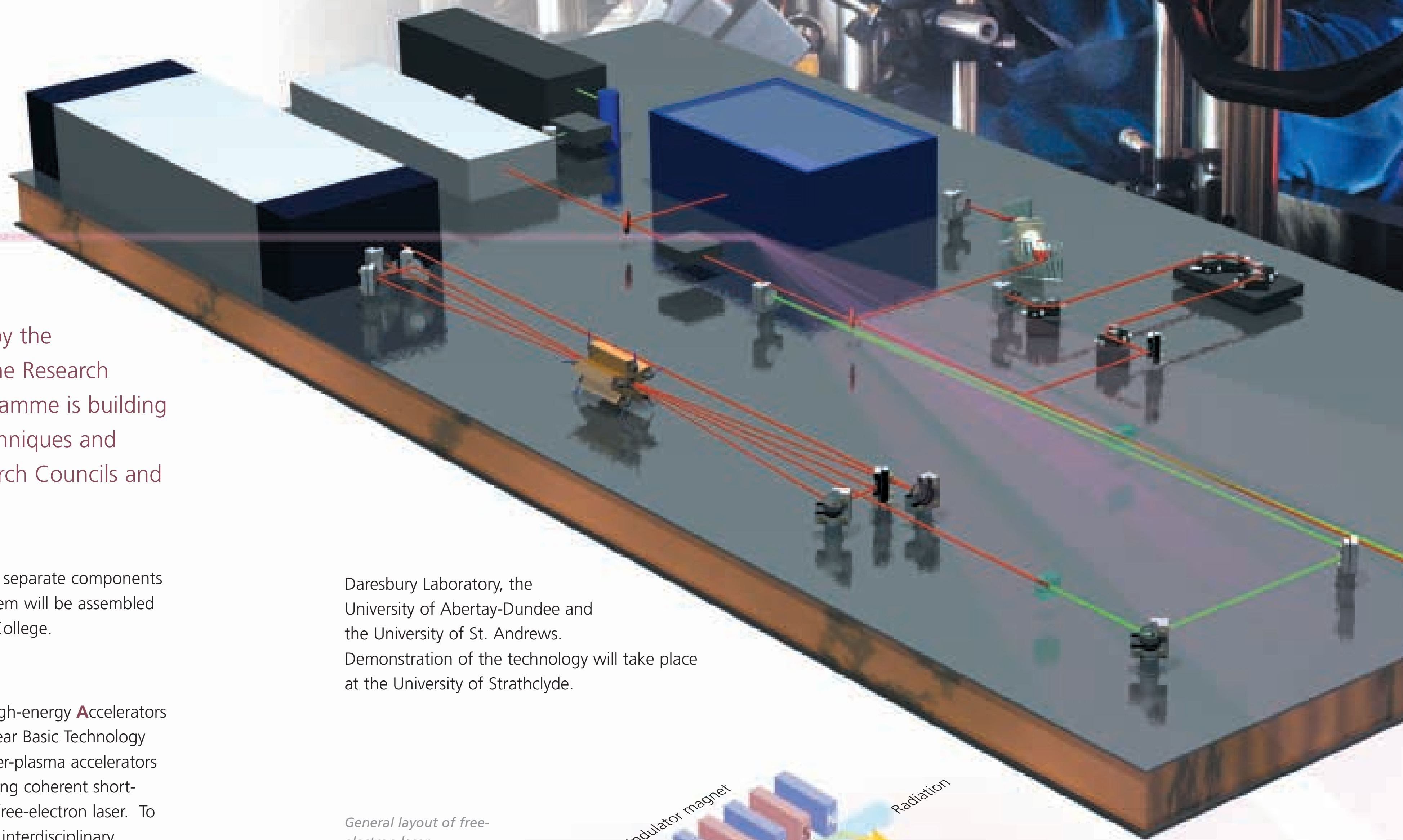
The award is made to a collaboration of groups led by Dr John Tisch and Professor Jon Marangos from the Department of Physics at Imperial College London and consists of researchers at University College London, the University of Oxford, the University of Reading, the University of Birmingham and the CCLRC Rutherford Appleton Laboratory.

The groups will each build separate components and the final working system will be assembled and operated at Imperial College.

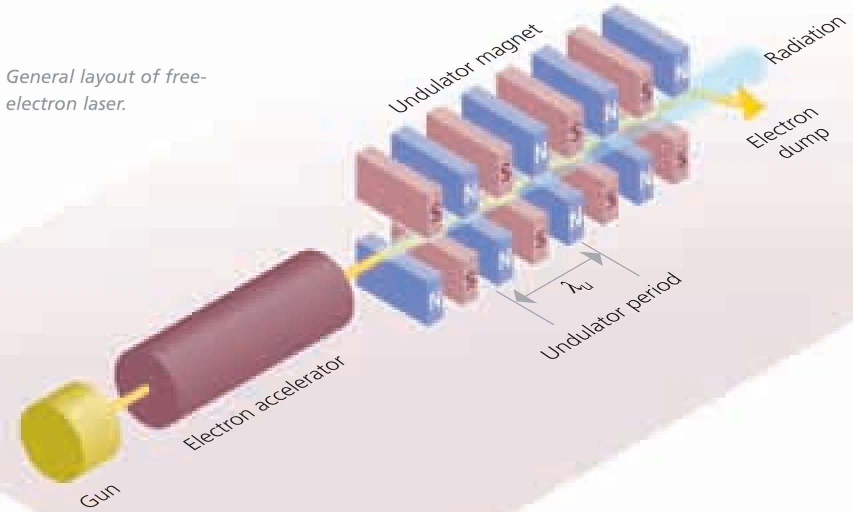
ALPHA-X

Advanced **L**aser-**P**lasma **H**igh-energy **A**ccelerators towards **X**-rays, is a four-year Basic Technology programme to develop laser-plasma accelerators and apply these to producing coherent short-wavelength radiation in a free-electron laser. To realise these objectives, an interdisciplinary programme involving advanced plasma, laser and electron beam physics has been set up. The ultra-short pulses of short wavelength radiation from these compact sources have the potential of revolutionising time-resolved studies in a wide range of applications. A consortium consisting of the major laser, plasma and accelerator research groups in the UK has been created. These include groups from the University of Strathclyde, the University of Oxford, Imperial College London, CCLRC Rutherford Appleton Laboratory, CCLRC Daresbury Laboratory, the University of Abertay-Dundee and the University of St. Andrews. Demonstration of the technology will take place at the University of Strathclyde.

Chris Murphy preparing the Astra target chamber for an ALPHA-X experiment.



Layout of the 5fs OPCPA laser system.



General layout of free-electron laser.

ACTIVITIES

MAKING OUR SCIENCE ACCESSIBLE TO ALL

Even though the lasers at the CCLRC Rutherford Appleton Laboratory are used by researchers and industrialists throughout the year, the Facility regularly opens its doors to the public. In partnership with a local secondary school, the Central Laser Facility educates and nurtures the young scientists of tomorrow either by assisting them in their National Curriculum activities or even simply by igniting a spark of interest as students see what 'science in application' really means.

Working in higher education, CLF trains PhD students in the practicalities of experimentation in order to send them back to their research groups fully conversant with the capability of the machine that they hope to use. From basic health and safety to hands-on practice in preparing targets, they are able to make significantly more productive contributions to their research area as a result.

And finally, in a series of Open Days which have become a feature of the South Oxfordshire diary, the CLF is no less proud to show off its know-how to interested neighbours from the locality of the Chilton-Harwell campus and to people further afield.

WORKING WITH YOUNG PEOPLE

The CCLRC Rutherford Appleton Laboratory runs an annual event for Year 9 schoolchildren local to its Oxfordshire base and to its sister establishment, the Chilbolton Observatory in Hampshire. Year 9s are just embarking on their first public examinations in science and so the CCLRC is keen to encourage the pupil who has shown the most enthusiasm for science or put the most effort into science activities during any given year. The CLF was pleased to field Kate Lancaster of the Physics Group as speaker for the most recent of these high-profile events (see above).

Kate has been holding workshops with the pupils of the nearby John Mason (secondary) School under the auspices of the Researchers in Residence scheme of the Research Council UK.

Working with Year 10 and Year 12 students and giving careers advice, Kate prepared one of the groups for the regional 'Express Yourself' conference at the University of Warwick which became one of five groups picked to attend the final at the prestigious Royal Institution. Kate also hosted a tour of the Vulcan facility for the John Mason pupils, including talks and demos by colleagues Rob Clarke and Steve Hawkes.

noise - bringing science to life

Meanwhile, Kate has been recruited as a national role model to inspire the next generation of scientists and engineers. NOISE (New Outlooks in Science and Engineering) is a campaign sponsored by EPRSC and designed to encourage young people to consider the range of careers available in both disciplines. NOISE means the CLF is directly involved in bringing science and engineering awareness to a wider public through science roadshows, radio, television, press and website articles.
The CLF is also closely connected to the 'Science Ambassadors' scheme which matches working scientists to science events and open days around the country.

Training for new researchers

New PhD students, representing many of the research groups which regularly use Vulcan, are invited annually to spend a period at the CLF to learn more about Vulcan's role in their research. The courses cover a mix of lectures and practical work and are funded by the CCLRC; topics covered range from basic safety issues to hands-on practice with target chambers and the use of plasma diagnostic instruments. Numbers are kept low to enable individual tuition.

The fruits of this investment in school children, both locally and nationally, are demonstrated when it comes to the annual Graduate Assessment Days run by the Human Resource Department of the CCLRC. The CLF has been able to appoint a number of high-calibre graduates since these assessments started. The picture (above) shows a recent group touring the CLF.

The CLF 'at home'

Many of the CCLRC workforce are drawn from the neighbouring area, of course, but there are plenty of local residents – and employees who work in other divisions of the CCLRC Rutherford Appleton Laboratory – who welcome the chance to see what happens at the home of the world's most intensely focused laser. Pictured (below) is one such Open Day, offering lectures and tours. Many visitors commented that they were impressed by the enthusiasm of the staff whom they met.

Sir David King addressing the 730 delegates from 49 countries who attended the 31st EPS Conference on Plasma Physics and Fusion Research.

WORKING
WITH OUR PEERS

Meetings and congresses

The CLF has a remit to organise and host international scientific meetings, such as calling users together at regular intervals, but it also offers itself as the base for technical meetings which give scientists from UK and abroad the opportunity to see the facilities at first hand, some of them for the first time. For this, the CLF is fortunate to be able to take advantage of the CCLRC guest-house and conferencing centre.

The CLF recently hosted a meeting of the UK High Power Laser Science Community and LSF users, while delegates to the 31st European Physical Society's Conference on Plasma Physics and Fusion Research, convening in London, made a visit to CLF.

The CLF is also a sought-after destination for foreign students from around the world. The picture above shows a group of aspiring physicists from the University of Stuttgart, Germany, visiting Vulcan, where they had current work explained by Waseem Shaikh (above).

The multi-disciplinary LSF users assemble to discuss all aspects of developing and applying laser technology as well as to be given the opportunity to comment on future developments at LSF.

Members of the Laserlab-Europe participants council meet at Laser Centre Vrije University, Amsterdam.

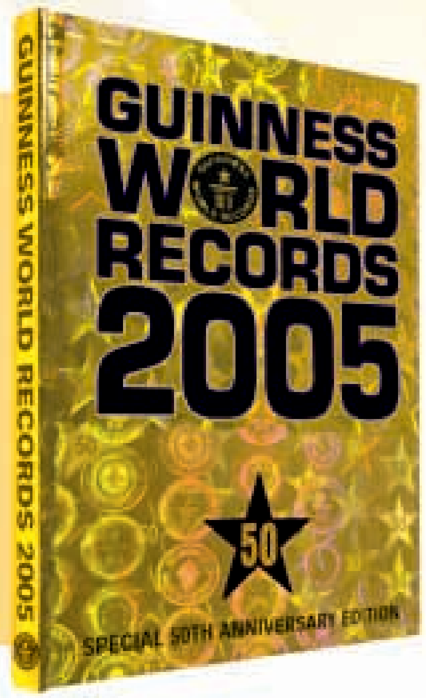
Laserlab-Europe

The CLF is part of Laserlab-Europe, a consortium of 17 laser infrastructures from nine European countries which together form an Integrated Infrastructure Initiative (I3) complemented by one infrastructure which deals only in Internet and database technologies. Laserlab strengthens the leading role of European laser researchers who, through Joint Research Activities, aim to overcome technological hurdles to produce laser light of high power and high intensity. Laserlab-Europe also enables the largest national laboratories conducting laser-based inter-disciplinary research to engage in the Transnational Access Programme for European researchers in the sciences and life sciences. As a supplementary but not insignificant benefit, collaboration within the Initiative allows laboratories to fill in the gaps in their own state-of-the-art instrumentation. Activities such as this lay the foundations for networking among the European laser research fraternity which will be sustainable for many years to come.

Guinness World Records

Two of the CCLRC facilities – the Vulcan laser and the ISIS pulsed neutron source, both based at RAL, have found fame in the Guinness World Records 2005. Vulcan earned the accolade of being the highest-intensity focused laser in the world, capable of producing a beam with an intensity of 10^{21} Watts per cm^2 (that's a thousand million million million Watts) – equivalent to all the sunshine falling on the Earth being focused onto the end of a single human hair.

Prof. Henry Hutchinson, Director CLF, David Hawksett, Science Editor GWR and Colin Danson, Vulcan Group Leader.



ENDPIECE

In his preface, Professor Henry Hutchinson promised you an exciting tour of the Central Laser Facility and the ground-breaking science with which it is almost daily associated and I hope you have found the reading of this brochure an exhilarating ride!

The CLF is a department of the CCLRC, a world-leading scientific establishment serving research communities from the academic and commercial world. Complemented by the state-of-the art support technologies made available by collaboration within the CCLRC, the CLF has a scientifically demanding and invigorating future ahead. I hope you will want to keep abreast of that future and will look out for the next edition of this report.

In the meantime, the contact details for the Central Laser Facility are to be found on the back cover of this brochure.

My thanks for their production assistance are extended to the users of the CLF and members of staff (in particular, the editorial team: Stan Botchway, Alison Brown, John Collier, Peta Foster, Peter Norreys and Gemma Round); to the CCLRC Photographic and Reprographic Services and to Ampersand Design.

Colin Danson
Editor

as	Attosecond (=10^{-18})
BBSRC	Biotechnology and Biological Sciences Research Council
CCLRC	Council for the Central Laboratory of the Research Councils (of the UK)
CERN	Centre Européen de la Recherche Nucleaire
CERS	Cavity Enhanced Raman Scattering
CLF	Central Laser Facility
CMF	Central Microstructure Facility
CPA	Chirped Pulse Amplification
DC	Direct Current
EPSRC	Engineering and Physical Sciences Research Councils

LIST OF ABBREVIATIONS

When dealing with numbers of these magnitudes, standard prefixes are used.

Small numbers:

10^{-3}	milli-
10^{-6}	micro-
10^{-9}	nano-
10^{-12}	pico-
10^{-15}	femto-
10^{-18}	atto-

Big numbers:

10^{3}	kilo-
10^{6}	mega-
10^{9}	giga-
10^{12}	tera-
10^{15}	peta-

FEL	Free Electron Laser
fs	Femtosecond (=10^{-15})
Hz	Hertz
ICF	Inertial Confinement Fusion
IR	Infrared
I3	Integrated Infrastructure Initiative
(k) or (m) or (n) J	(Kilo) or (milli) or (nano) joule
KDP	Potassium Dihydrogen Phosphate
LBO	Lithium Triborate Crystal
LSF	Lasers for Science Facility
MeV	Mega electron volts
mm	Millimetre
MOPA	Master Oscillator – Power Amplifier
MRC	Medical Research Council
µm	Micrometre
Neodymium-YAG	Neodymium Yttrium Aluminium Garnate
NERC	Natural Environment Research Council
nm	Nanometre
NOISE	New Outlooks in Science and Engineering
OPA	Optical Parametric Amplifier
OPCPA	Optical Parametric Chirped Pulse Amplification
PDF	Precision Development Facility
PW	Petawatt
ps	Picosecond (=10^{-12})
RAL	Rutherford Appleton Laboratory
RCUK	Research Council UK
RF	Radio frequency
SSTD	Space Science and Technology Department
TW	Terawatt
VUV	Vacuum Ultra-Violet
Wcm^2	Watts per square cm

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