Artemis

Monochromatised XUV beamline for ultrafast time-resolved ARPES

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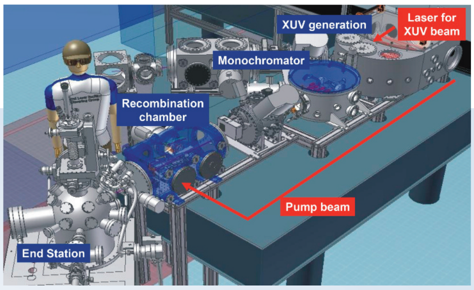
The short pulses of coherent XUV radiation produced through high harmonic generation have enabled the study of ultrafast electron dynamics in atomic systems and simple molecules. The Artemis facility now aims to exploit these XUV pulses to investigate ultrafast dynamics in experiments spanning gas-phase chemistry of polyatomic molecules and condensed-matter physics of complex materials.

We have built an XUV beamline that delivers short pulses of monochromatised XUV, produced through high harmonic generation, to an end-station optimized for photo-emission experiments on condensed matter.



Layout of the XUV beamline including the Harmonic generation chamber, the monochromator chamber to select the photon energy, the recombination chamber for pump-probe experiment and the experimental chamber for time resolved ARPES.

A specially designed monochromator allows us to select a single harmonic and preserve also the short pulse duration (10 - 30 fs). We have shown that the beamline can achieve 250 meV energy resolution and 30 fs temporal resolution, enabling us to carry out first measurements of angle- time- resolved photoemission with XUV pulses.

Spin and angle resolved photoemission with fs laser source: calibration of spin detector

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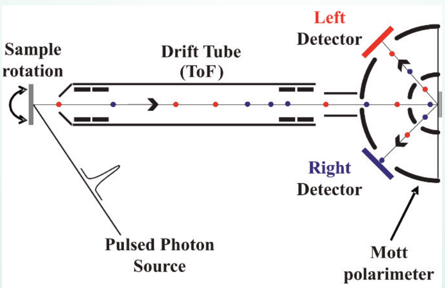
Angle resolved photoemission is a very powerful technique to explore the electronic structure of materials. Over the past three decades this spectroscopic technique has well matured partly due to the development of intense synchrotron radiation and bright fs-laser sources. Measuring the spin as well as the emission angle of the photoelectron is particularly interesting to study the magnetic properties of ferromagnetic systems or systems with large spin-orbit coupling [1-2]. The intrinsic low efficiency of the electron spin detection makes these experiments very challenging. This is why, using a laser source with a novel electron analyzer (electron time-of-flight) is a real step forward for this type of experiment particularly in terms of acquisition time and resolution. Furthermore by combining the ToF-Spin analyzer to the Artemis facility, one can study the electron spin dynamic in the sub 10-fs time domain which is of great interest to explore the switching mechanisms in ferromagnetic systems for spintronic devices.



Top view of the experimental setup in normal emission geometry. The photoelectrons travel through the drift tube up to the Mott polarimeter where they are spin resolved. The arrival time of the electrons at each detector is measured and converted to kinetic energy.

1 J.-H. Park et al., Nature, **392**, 794 (1998).
2 K. Sakamoto et al., Phys. Rev. Lett.,**102**, 096805 (2009)

Few-cycle carrier-envelope-phase controlled laser pulses for time resolved science at the Artemis facility

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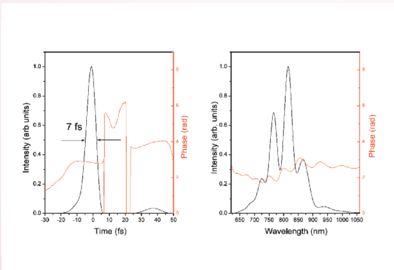
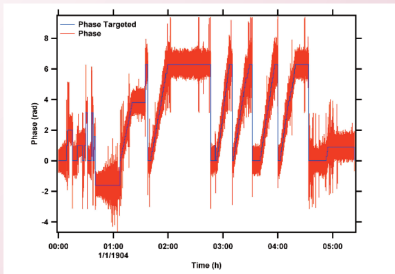
When the duration of a laser pulse reaches the few-cycle level, the phase of the laser electric field relative to the pulse envelope (the carrier-envelope phase, CEP) can have a significant effect on the physics of the interaction. Examples of this are the generation of isolated attosecond pulses [1] and the control of electron localisation during molecular dissociation [2], both of which require few-cycle pulses with stable CEP.

The Artemis facility is constructed around a CEP stabilised laser system with an output of 780 nm, 30 fs, 14 mJ pulse at 1 kHz. Part of the energy can be focused into a hollow fibre to generate few-cycle pulses. Recent improvements have reduced the pulselength to 7 fs, with 0.5 mJ per pulse. The long-term stability of the CEP stabilisation is 325 mrad rms for over five hours.

1. A. Baltuska et al, " Attosecond control of electronic processes by intense light fields", Nature 421, 611 (2003).
2. M. F. Kling et al, "Control of electron localization in molecular dissociation", Science 312 246 (2006).



FROG measurement of 7 fs, 0.5 mJ pulses produced in the hollow fibre system showing retrieved temporal intensity and phase. The FROG error was 0.006.



CEP control over five hours with 2 mJ/pulse and 325 mrad rms stability. Blue line: programmed target phase. Red line: measured phase.

Astra

Vibration in Gemini and engineering modifications (interim report)

54

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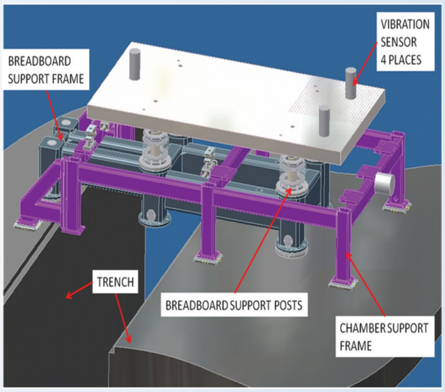
Intermittent ground borne vibration delayed and plagued early experiments in Astra Gemini. The vibration manifested itself in an elliptical or figure of eight movement of the spot at the interaction point. After analysis the source was traced back to the main magnet power supply of the neighbouring ISIS facility. The main source at 50 Hz was amplified by the support structure, multi component breadboard and key optical mounts increasing the amplitude of the vibration at each stage. Large structural changes were carried out to the main optics table and associated framework, parabola chamber and the key optical mounts. The initial testing post upgrade is positive. The image on the right shows the main optics table (breadboard), supporting structure which spans the trench leading to ISIS and the change to the key optical mounts.

The full report details the vibration scan results, changes to the hardware and initial conclusions.



The new structure and the location of the four sensors.

Temporal and spatial overlap monitoring of the dual-beam layout in Astra-Gemini TA3

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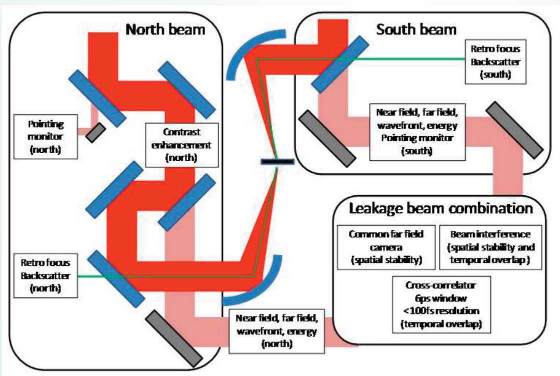
The Astra-Gemini target area is now up and running for dual beam experimental operations. It is now essential to have spatial and temporal overlap of the two beams at the target position. Two extra diagnostics have been added to the target area to monitor these overlaps on a shot-to-shot basis.

To monitor the spatial overlap, leakage from each of the beams is taken, then combined, focussed, and split to a near-field and a far-field camera. The near-field will be used to indicate the temporal overlap of the two beams and the jitter in the spatial alignment. The far-field will monitor the spatial stability of the overlap of the two beams.

A cross-correlator diagnostic has been installed in order to monitor the temporal overlap. Leakage is taken from each of the beams which are both split and overlapped with two BBO crystals to generate two cross correlation traces, one with a time window of ~ 6 ps and one with a > 6 ps window.



Schematic diagram of the beam arrangements in Astra-Gemini TA3. Red indicates the main beamlines and pink indicates leakage beams.

Upgrade of Astra amplifier 3 and the Astra interlock system

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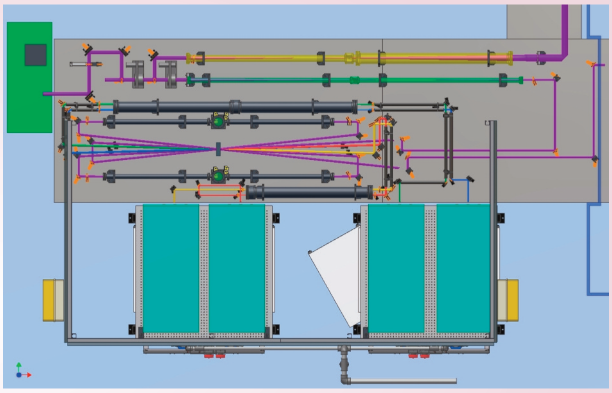
Last year a significant upgrade was carried out to the old Astra amplifier 3, which has improved its performance and removed one of the least reliable commercial lasers from the system. The old Macholite laser was replaced with four Quanta-Ray PRO-350 Nd:YAG lasers, and a new water cooling system installed. The layout of the amplifier was redesigned for better accessibility: before the changes, the beam expansion tubes were on a raised framework above the amplifier, but now everything is on the same level. The new layout is shown in the diagram. The performance of the amplifier is better than before, with a typical output of 1.2 to 1.3 Joules at 800 nm. During the same period, the old PC-based interlocks were replaced with an up-to-date system based on PLC technology, giving improved safety and full compatibility with other areas of the CLF.



Schematic of the new layout for Astra Amplifier 3.

Improved post-experiment data analysis at Astra Gemini

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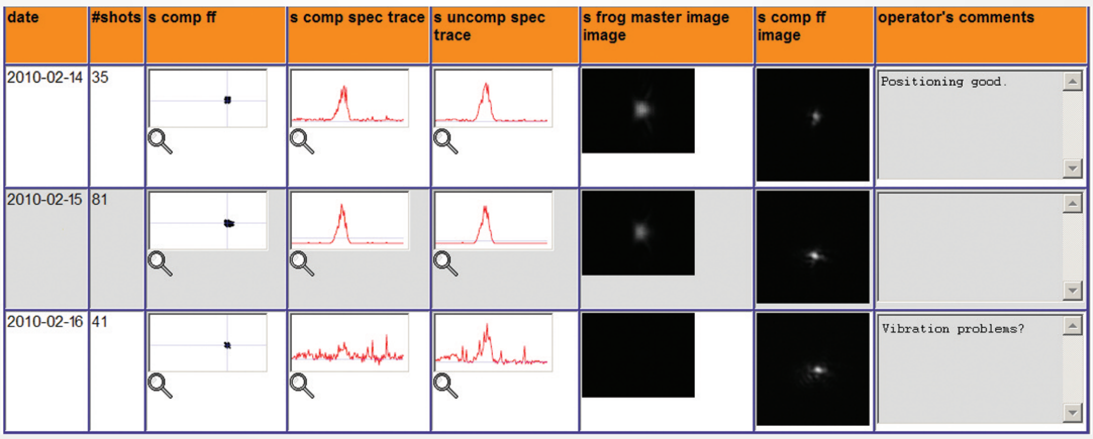
We have further improved the gathering and analysis of diagnostic data over the course of an experiment. In conjunction with the Principal Investigator, we identify the laser parameters (singular values, trace images and camera images) which are key to that experiment and make them available to users as Comma-Separated Values (CSV) files. This CSV data can be downloaded and incorporated into analysis programs written for target area diagnostics. Singular value data streams are subsequently averaged and displayed; traces are averaged and displayed as a Scalable Vector Graphics (SVG) images. The laser operator can subsequently view this data and, for image data streams such as far-field profiles and FROG traces, select the image which represents a typical image for that day. In this way we compile an overall summary table detailing the average trace plots, representative images and a scatter plot of X/Y alignment pairs on a shot-by-shot, day-by-day basis.



date	#shots	s comp ff	s comp spec trace	s uncomp spec trace	s frog master image	s comp ff image	operator's comments
2010-02-14	35						Positioning good.
2010-02-15	81						
2010-02-16	41						Vibration problems?

Three day's worth of representative images and plots.

A new phase (and amplitude) for Astra Gemini: using a spatial light modulator

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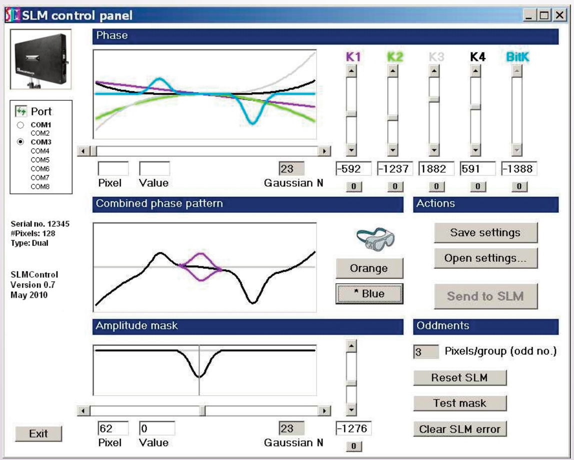
We have developed a new method for correcting the spectral phase and amplitude of the Astra Gemini laser, based on a spatial light modulator (SLM). This device uses voltages applied to a pair of liquid-crystal arrays to modify different parts of the spectrum in a spatially-dispersed laser beam.



The sum of the voltages controls the phase and the difference controls the spectral amplitude. The existing phase corrector (Dazzler) suffers from crosstalk between phase and amplitude corrections: the advantage of the SLM is that such crosstalk is minimised. The SLM is positioned at the mid plane of a 4F zero-dispersion optical setup using blazed 600 groove/mm gratings. It is controlled through a custom interface that allows the user to set the amplitudes of four polynomial phase terms and to apply localised phase and amplitude adjustments. The interface is designed for use by operators wearing laser protective eyewear.

View of the SLM control system user interface.

Ultrafast gated imaging of laser produced plasmas using the optical Kerr effect

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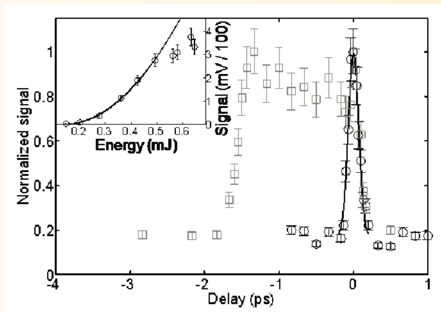
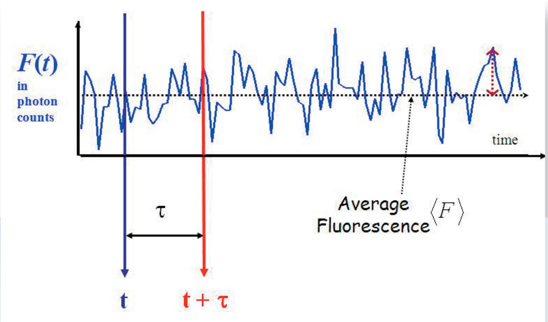
Optical imaging provides a versatile diagnostic for investigations of plasmas generated under intense laser irradiation. Electro-optic gating techniques operating on the >100ps timescale are commonly used to reduce the amount of light detected from self-emission of hot plasma or improve the temporal resolution of the detector. The use of an optical Kerr gate enables a superior dynamic range and temporal resolution compared to electronically gated devices. We have applied this method using the hollow fibre pulse compressor in Astra TA2 to demonstrate enhanced imaging of laser produced plasmas. Employing fused silica, which has an ultrafast response, as the gating material we achieved a gate time ~100fs. We also discuss alternative materials. We used the system to image plasma produced with moderate intensity irradiation and show the elimination of plasma self-emission from the image.

We conclude by exploring the possibility to produce a sub-10fs, high dynamic range "all optical" streak camera.



We use the optical Kerr effect to perform ultrafast gated plasma imaging. The opening time of the gate is ~100fs in fused silica (black) compared to slower response materials. Shown by the throughput of the device versus delay between gating and probe beams.

Lasers for Science Facility



Calculating the autocorrelation function.

Two-photon fluorescence correlation spectroscopy: FCS

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Fluorescence correlation spectroscopy (FCS) is a powerful single-molecule detection technique used to characterise the dynamics and interactions of fluorescent species by recording and correlating their fluctuations in fluorescence intensity within a microscopic detection. To demonstrate the potential of this technique using our TiSa confocal setup, the diffusion coefficient of the Rhodamine dye was measured for different concentrations and laser powers. Surface diffusion has been recorded in vivo.

The ULTRA time-resolved IR, 2D-IR and T-2D-IR station

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Developments within the EPSRC Laser Loan Pool

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The Octopus imaging cluster: A new imaging facility in the Research Complex at Harwell

63

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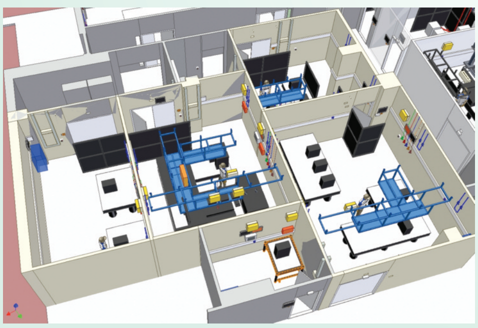
The past year has again seen major changes in the Lasers for Science Facility. The LSF's operations in the biological imaging area were relocated to the Research Complex at Harwell (RCaH) in April 2010. The Octopus cluster is a large scale imaging facility offered by the Functional Biosystems Imaging Group of the LSF which begun user operations and collaborative work in July 2010. Octopus is a new concept in multi-modal imaging. Currently in Phase I of its development, the Octopus cluster has at its core a hub of 14 lasers (3 Ti:Sa, 2 OPOs, 3 supercontinuum and 6 CW). The laser sources provide excitation light to seven microscope systems, namely a total internal reflection fluorescence (TIRF) tweezers system, 3 single molecule fluorescence microscopes, each of which is specialised in a different single molecule imaging technique, two 1-photon confocal FLIM (Fluorescence Lifetime Imaging Microscopy) systems and a 2-photon confocal FLIM system laid out as shown left.



Layout of the Octopus cluster. *The central room is the laser hub with the different microscopes lab position around it. It also houses a two-photon confocal FLIM system. Bottom right: this room houses three systems, namely a total internal reflection fluorescence (TIRF) tweezers system, a one-photon confocal FLIM system and a 5-colour single molecule tracking system. Top right: This room houses a one-photon multicolour confocal FLIM system. Top middle: The control room (see Fig. 2). Top left: Storage room. Left: This rooms houses a 3-colour single molecule tracking system (top) and an 8-channel single molecule FRET and polarisation combined system (bottom). Bottom middle: Development room.*

New data analysis software for time-resolved spectroscopy experiments in the Ultra laser facility

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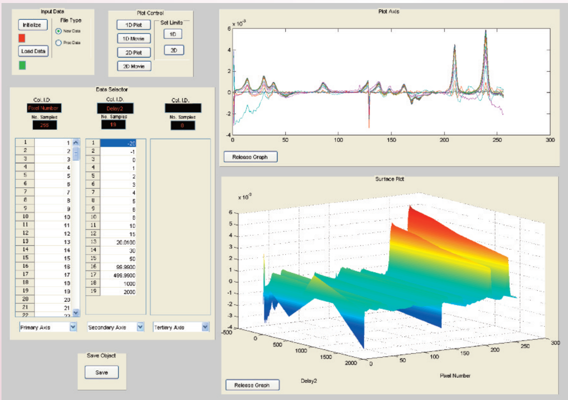
New data analysis software has been developed in response to the start of operations in the Ultra laser facility and the significant increase in experimental data that it brings. The facility generates spectral data at a typical rate of > 50 spectra per experiment with ~ 15 experiments per day, which requires visiting scientists to perform quick and efficient analysis of large data sets in order to guide their experiment. The need for expediency is reinforced because of the limited lifetime of precious biological and chemical samples that are potentially light or temperature sensitive. We describe the features of the software including correction for instrument variation (such as background intensity and detector-based electronics noise) and a flexible data display that allows visiting scientists to observe their data according to experimental parameters in two and three dimensions.



Screenshot of graphics display, showing data from sample of DMABN.

Active synchronisation of dual amplifier outputs for time-resolved spectroscopy

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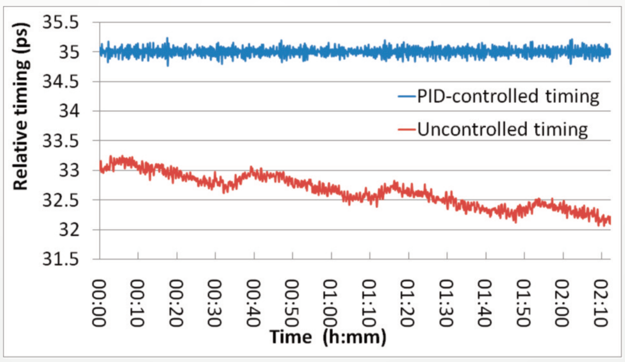
Many of the time-resolved spectroscopy experiments in the Ultra laser facility take advantage of its unique dual synchronised 2 ps and 50 fs output pulses. The relative timing between the pulses is susceptible to thermal drift of potentially several mm that occurs in the optical paths within the laser amplifiers, which significantly affects experimental measurements.

We report the development of a control system that improves synchronisation of the two outputs to 40 fs rms, achieved using a scanning optical correlator system to measure the relative timing between the pulses and a feedback loop control system to ensure that the synchronisation of the two outputs is constrained to a defined set-point.



Comparison of relative timing over 2 hours.

Optical trapping of laser targets under vacuum for ion-beam production in the LIBRA programme

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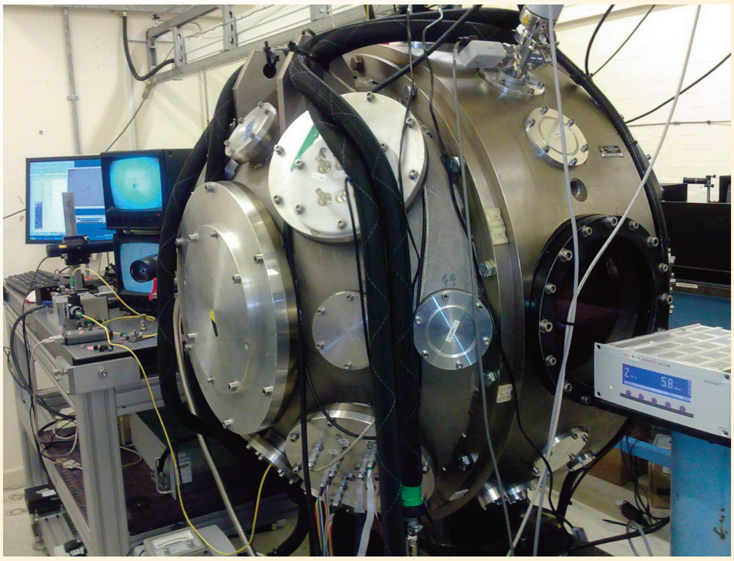
As part of the targetry package of the EPSRC funded LIBRA programme, we have successfully held a microscopic liquid droplet in the centre of a vacuum interaction chamber at a pressure of 5 mbar using laser-based optical levitation techniques. The droplet was held to a positional accuracy of 1 micron which demonstrates the concept is suitable for manipulating targets into a focused high-power laser beam. In the report we outline the underpinning methodology and optical requirements for trapping micron-sized droplets using long-working distance, high numerical aperture objective lenses. By extension of this technology, our goal in the LIBRA programme is to hold solid targets for the purpose of generating ion-beams by laser irradiation.



The vacuum chamber and diagnostics in operation. Droplet stability, laser alignment and chamber pressure are continually monitored. Trapping can be achieved from 1000 mbar to 5 mbar before efflorescence of the salt droplet occurs (i.e. a crystal is formed). The droplet is observed to be stable in position to approximately 1 micron.

Vulcan

Close-in contrast measurements of the new ps OPCPA front end

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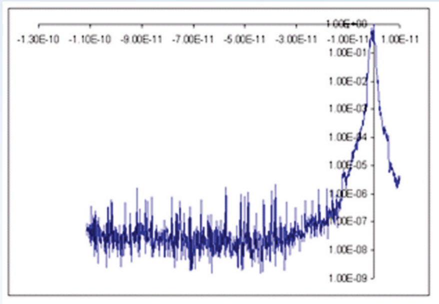
In high intensity laser matter interactions the contrast of the laser pulse can be crucial to the outcome of the physics. In this article we discuss the addition of a picoseconds optical parametric chirped pulse amplification (OPCPA) stage to the Vulcan front end improving the amplified stimulated emission.

The novel dual OPCPA pre-amplifier system is sufficiently stable to be injected into the rest of the Vulcan laser system and leads to a direct improvement of the ASE contrast by at least 2 orders of magnitude without degrading the performance of the laser system. The Vulcan Petawatt laser system now has an ASE contrast of 10^{10} at 1ns, at 100ps the contrast is better than 10^8 and the PF (Parametric Fluorescence) caused by the ps OPA starts at 30ps.



3rd order cross correlator (Sequoia) trace, which is a multi shot device that temporally scans the pulse.

Vulcan rod amplifier upgrade

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The Vulcan rod amplifier control system and power supplies have been operating and running successfully on the Vulcan laser system since the system was inaugurated in 1975. But the equipment suppliers no longer manufacture or even support the electronics for the rod amplifiers. Therefore, it was necessary for the rod amplifier capacitors and control system to be replaced, as it posed a serious risk towards the future operation of Vulcan.

The Vulcan laser was shut down for three months from 12th August until 9th November to allow the replacement of the rod amplifier racks from inside the control room and laser areas with new capacitor banks.

New Quantel racks, located on north wall of Laser Area 1, to power the 45mm rod amplifiers and control processing and power of both rod chains.

The upgrade was successfully completed three days overdue and user experiments commenced on Monday 9th November 2009.

The experience gained from this project will aid the future success of the upcoming six-year 10 Petawatt upgrade project.

Old Quantel units inside the Vulcan Main Control Room.

Vulcan computer control system upgrade

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The successful operation of the Vulcan high-power laser over the past 30 years has been heavily dependent on the use of computerized control systems. These originated with a GEC 4080 "mini" computer but in the mid 1980's were replaced with a pair of IBM 286 DOS-based PC's. The network continued to grow in size and complexity with (by the late 1990's) some peripheral PC's running Windows NT / 2000 but with the core fundamental laser control PC's remaining DOS.

A project to completely rewrite the computer control system, converting everything to windows XP compatible coding, turned out to be more complex than originally thought and became a four year project.

The bulk of the development for this took place offline with the final windows controls being tested, in parallel with the existing DOS controls, during the normal inter-experimental maintenance periods, a process which ensured minimal operational downtime.

Main control screen giving access to prime control functions and diagnostic data such as the shot firing sequence and waveform displays.

The Vulcan 10PW project – building design

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A key aspect of the Vulcan 10 PW project is the new building that will house the large amount of equipment required for the 10 PW laser facility. The building will extend the current building (R1) to maximise the available space within the limited surrounding land at RAL. In preparation for the start of phase two of the project a team consisting of STFC staff and external consultants has been working hard for the past six months to develop the Vulcan 10PW building design. This resulted in a conceptual design report presentation and review.

Following this the 10PW management team have now agreed a conceptual design for the building that has been costed to a level adequate for the project to proceed to the building detail design, ready for anticipated tender action in the Autumn of 2010.

View of new 10 PW building.

Laser R&D

The DiPOLE project: towards high energy, high repetition rate diode pumped lasers

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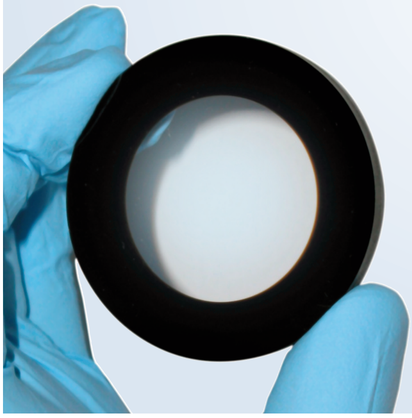
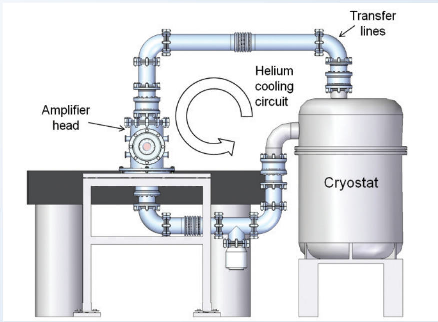


DiPOLE stands for Diode Pumped Optical Laser for Experiments. It is a new project at the CLF to develop the foundations of novel high energy, high average power laser systems based on diode pumped solid state laser (DPSSL) technology. Compared to conventional systems, this approach promises dramatically increased repetition rates (and hence average powers) at significantly higher electrical-to-optical conversion efficiency. The article presents the conceptual design of a cryogenic Yb:YAG amplifier that can be scaled to kJ energy levels and beyond, owing to its geometry and unique cooling technique. Numerical modelling predicts superior performance of the amplifier at 175K compared to room temperature.

Yb:YAG - Cr^{4+}:YAG compound disk.

A distributed cooling technique using the slab-stack architecture aids in minimising amplified spontaneous emission (ASE) losses by enabling the use of a relatively thick gain media with low doping concentration. To test the concept in the laboratory, a lower-energy, multi-J prototype amplifier system is currently under development.



Schematic diagram of the cryocooler system under development at CLF.

Timing and synchronisation system designs for the New Light Source

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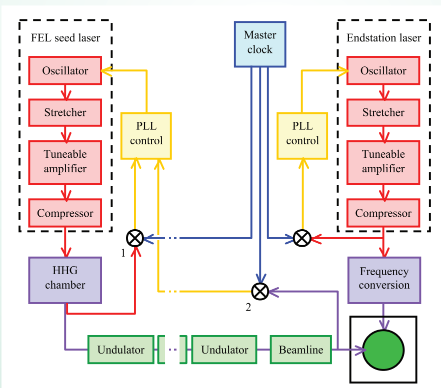
In recent years a new generation of "free electron laser" light sources has appeared, delivering beams which will revolutionise science just as conventional lasers have done since their invention 50 years ago.



A design for a system to synchronise light pulses from a free electron laser and a conventional laser at an experimental endstation.

The FELs, based on particle accelerators, are very large – many hundreds of metres long. But the light pulses they produce are very short. With a few tens of femtoseconds duration their physical length can be less than a hundredth of a millimetre. Much of the work that scientists want to do with them makes use of this very short duration, often combining beams from more than one ultrafast source in complex experimental geometries. Synchronising the pulses, which have travelled so far, so that they all arrive at exactly the right time on the target is a huge challenge. But a combination of ultra-low noise laser-based clocks, feedback-stabilised optical fibre transport and state of the art electronics promises to meet it!

Experimental setup in the Vulcan HaPPIE laboratory for multi-beam combination to achieve diffraction-limited pulses

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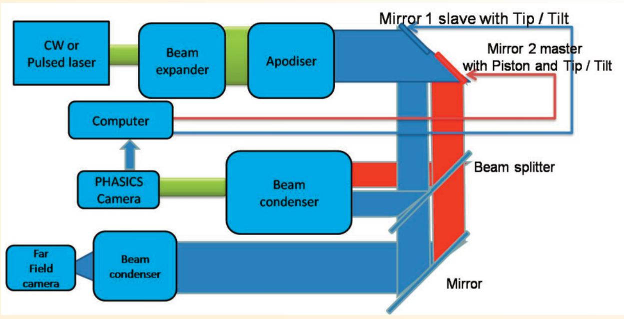
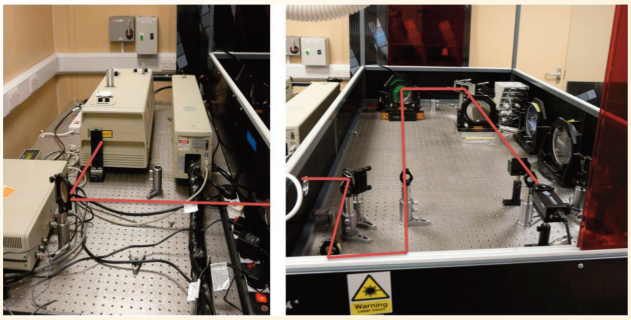
With future and current designs for high power lasers requiring several sub-beams to be combined into a single monolithic one, technology needs to be developed to allow these beams to be spatially and temporally overlapped. A CLF laboratory has been set up - the Vulcan HaPPIE Laboratory (High Average and Peak Power lasers for Interaction Experiments) to research various techniques to spatially and temporally lock two or more sub-beams.

This article explains the various methods for one-aperture wavefront measurement and then goes on to explain how a phase difference (piston measurement) between two sub-apertures can be extracted using a proprietary technology. An experimental setup to test the concept is described and future developments are discussed.



Experimental layout.



Laboratory setup, beam path is shown by the use of the red line.

Target Fabrication

Installation of the target fabrication quality management system 74

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As target complexity is increasing and also with the introduction of high repetition rate laser systems such as Astra Gemini the demands on target fabrication to improve productivity and quality increase. It is essential to be able to trace, track and record target fabrication processes both during and after an experiment to interrogate data and to understand the underlying science that is achieved. To deliver this service and to improve and streamline the processes from inception to delivery of a product the Target Fabrication Group has introduced a Quality Management System (QMS) into its experimental delivery procedures. This quality management process incorporates the full process of target fabrication from the initial conceptual design of a target, through the planning stage to manufacture and finally delivery to the experimental user group for their experimental shots.

Electroplating of gold and palladium for high power laser target fabrication 75

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Mass production of AFI cone geometries for fusion target studies 76

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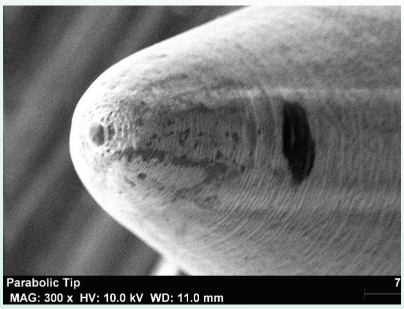
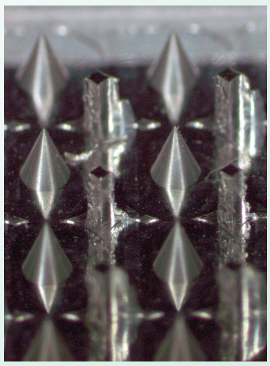
One of the baseline targets for the HiPER project uses an innovation called AFI (Advanced Fast Ignition) in which a fuel sample is compressed using multiple laser beams around the end of a gold cone. These gold cones have been fabricated and assembled at RAL since 2003 using single 'one-off' production methods. Recently mass production techniques have been developed that have dramatically reduced target costs, and therefore increase that availability of target components to the community. This initial work is summarised and more recent work to develop new target geometries and cones of different materials are discussed.



A SEM image of the parabolic shape of the tip.



An array machined in aluminium for copper plating

Instrumentation and Plasma Diagnostics

Debris analysis and mitigation for target motion systems

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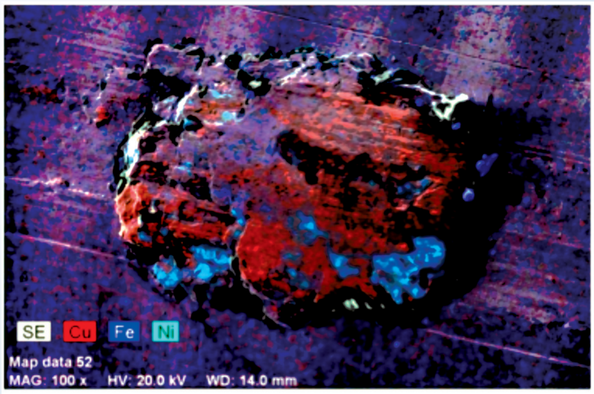
The use of motion stages within Target Area Interaction Chambers is key to the flexibility of experiments. Both targetry and diagnostics use such stages to allow in-vacuum positioning and adjustments in order to maximise the data output from shots. Failure of these systems has a high impact and usually requires the replacement of components in-situ. Over the last few years the 'sticking' encoders has dominated the failure modes for the standard motorised mounts. This report discusses the main cause of such sticking and one method for reducing the likelihood of reoccurrence.



EDX image of target debris coated onto the magnetic rod.

Calibration of image plate response to energetic carbon ions

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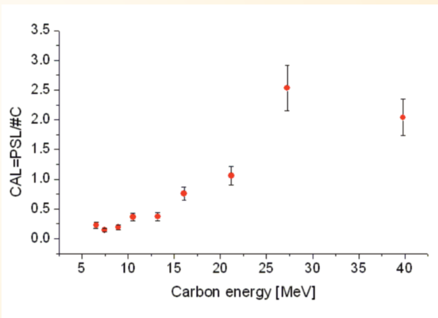
Image Plate (IP) detectors are widely used for revealing x-rays, electrons and ions in laser-plasma experiments. While IP response to protons has been reported in earlier works, we have carried out for the first time measurements in which the IP response to Carbon ions has been measured by cross-calibration with CR39. In order to obtain the IP calibration for Carbon ions of different energies a Thomson Parabola is used to disperse the ion beam. A slotted CR39 placed on the IP is used as detector so that carbon ions having reasonably close energy can be recorded at same time around the edges of the slots, both on the CR39 and IP. The PSL signal from the IP and the pits number on the CR39 were compared at a given ion energy.



Calibration curve that relates the PSL signal to the number of carbon ions as function of the ion energy.