Astra Gemini

Target alignment in Astra-Gemini

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The challenge of positioning targets at the focus of a laser with an accuracy of less than a micron is a significant one. The positioning of targets is performed in many different ways and typically involves long working distance microscopes, retro-reflection or absolute positioning. This is a particular problem in Astra-Gemini, as utilising short focal length parabolas means that, in order to reproducibly access the highest intensities available, targets must be positioned with < 8 micron accuracy. If we are to move to higher intensities through even shorter focal length optics, the issue of accurate alignment of a target must be addressed.

In Astra-Gemini we are designing two complimentary systems to enable accurate target alignment. An upgraded camera system to allow us to have high resolution imaging of the rear surface of targets and a multi-wavelength Mach-Zehnder interferometer to position the front surface of targets to sub-micron accuracy.

Interference patterns of the three colour interferometer; a. when the interferometer is perfectly aligned, b. with a vertical tilt on the target mirror showing a rotation of the fringes and c. with a horizontal twist on the target mirror, narrowing the spaces between the fringes.

Measurement of the difference in the Gemini gate valve windows thickness by its effect on timing between the North and South beams

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We overlapped the North and South beams of Astra-Gemini in time and then measured the relative difference in timing between the two beams when the vacuum gate valves between the target chamber and the compressor chambers were closed. The difference in timing was found to be 350 ± 17 fs with the South beam being delayed relative to the North beam, this is caused by a difference in the thickness of the sapphire windows in the gate valves. The change in timing can be used to estimate the difference in thickness, it was found that the South beam gate valve sapphire window is 60 ± 3 μm thicker.

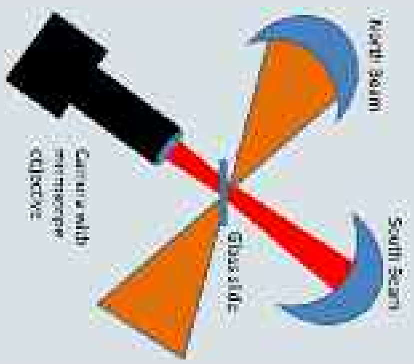

Fig 1: Schematic of the set up used. Timing of the North and South beams was done by using the North beam to form plasma on the glass slide surface and the South beam to probe for this plasma. If the South beam observes this plasma on the glass then it has arrived after the North beam, if no plasma is observed then the South beam has arrived earlier.

Analysis of thermal lens in the Gemini amplifier under high repetition pump rate

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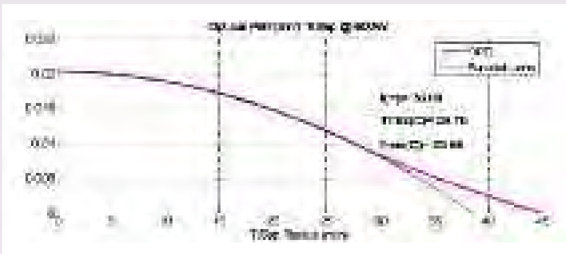
The development of thermal lens in a disc of Ti:Sapphire crystal of the Gemini laser amplifier has been theoretically studied for the case of optical pumping the crystal at 10 Hz repetition rate. Steady state temperature maps of the crystal were calculated at several pump levels and at the room temperature cooling conditions. The spatial temperature distribution was recalculated into optical path difference to estimate an effective focal length of the thermal lens. It has been shown that focal length of 36.7m is expected at 600W of the total optical pump falling onto the Ti:Sapphire crystal. Compensation of the thermal lens has been theoretically analyzed using Zemax software. Beam re-collimation using image relay telescope lenses has been shown as an effective way to compensate thermal lens in the Ti:Sapphire crystal.

Temperature distribution map along 25mm (vertical) length and 45mm (horizontal) radius of the Ti:Sapphire crystal. The map corresponds to 600W of input pump power.



Radial variation of optical path difference (OPD) due temperature distribution in the Ti:Sapphire crystal. The black line is the paraxial lens OPD dependence.

Development of dielectric-coated adaptive mirrors

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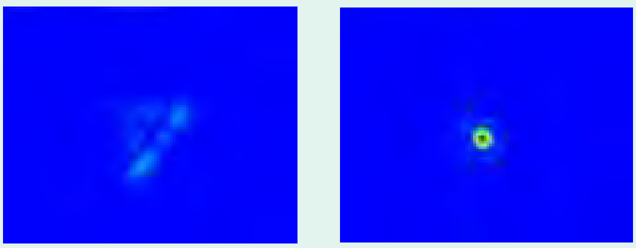
Adaptive mirrors have been used in the high-power laser facilities at the CLF for many years. Previously, such mirrors were made with metallic coatings, despite the lower damage threshold of metal mirrors, because the stresses present in dielectric coatings caused the very thin substrates to become strongly curved. This in turn restricted their ability to correct wavefront distortions. A strategy to overcome this is to coat the substrate on both sides with the same coating, so the stresses cancel out. A deformable mirror with a dielectric coating, made using this technique, was demonstrated for the first time earlier this year. The mirror performed just as well as metallic-coated mirrors made previously. One of the test mirrors made as part of this work will be installed in Astra during the next few months, in order to improve the optical quality of the beams sent to TA2 and Gemini.



Initial and corrected far-field spots of an 800 nm CW diode laser beam, demonstrating the performance of the dielectric-coated adaptive mirror described in the text.

Monitoring Astra Gemini with Penguin

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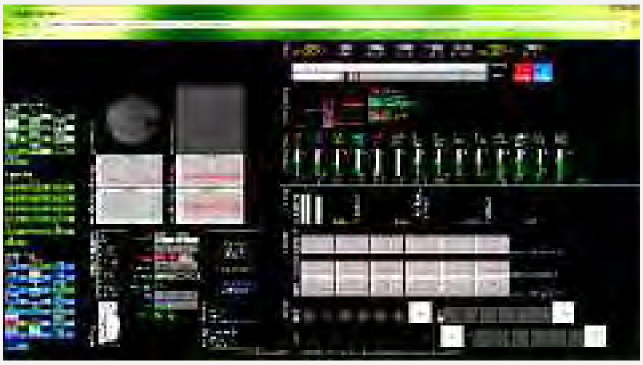
The Astra Gemini laser facility consists of a large number of lasers and optical instruments, together with a team of Laser Operators to run it on behalf of visiting experimental scientists. There are upwards of 100 PCs to control the facility and acquire diagnostic data; these too need management.

This article describes a web-based software suite named penguin which uses a variety of applications and multiple databases to enable scientists and laser operators to monitor key aspects of the system, including current pump laser energies, progress of the experiment, the health of the internal network, pressures within the newly-installed gas system, and the operation of instruments and diagnostic PCs recording the data.

Other applications within penguin are used retrospectively to analyse the performance of key laser parameters and overall use of the facility, and for the purpose of compiling operational statistics.



Penguin:Operations showing (on left) the status of diagnostic PCs, networked and other devices; (centre) various images and traces, information about current energy modes and compression chamber status; (on right) shots taken yesterday and today, pump energies over the course of today, various gauges and thermometers, and energy, pulse-length, traces and images for the last six shots.

Adaptive optic developments for the Astra Gemini target area

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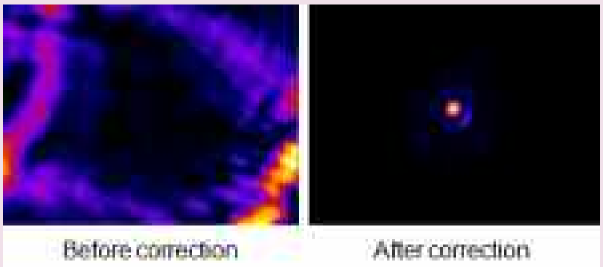
A new commercially produced deformable mirror has been tested for its wavefront correcting capabilities. One of the main aims was to see how it would cope when there is a thin mirror with an off-centred hole in the beam. The thin mirror is required if using an on-axis F/0.87 parabola, but it introduces a lot of aberrations to the wavefront. The previously used deformable mirror found it difficult to cope with these high levels of aberration and the annular beam correction due to the hole, but the new Intense Laser Adaptive Optic (ILAO) mirror from Imagine Optic dealt with these distortions well. Before correction, the focal plane from a 3.5m lens showed highly dispersed light as the beam was so aberrated, but after correction the light converged well to a focal point with a similar encircled energy as when the thin mirror was not present.



The focal planes before and after correcting the wavefront with the thin mirror in the beam.

Implementation of adaptive optics on the Astra-Gemini beamlines

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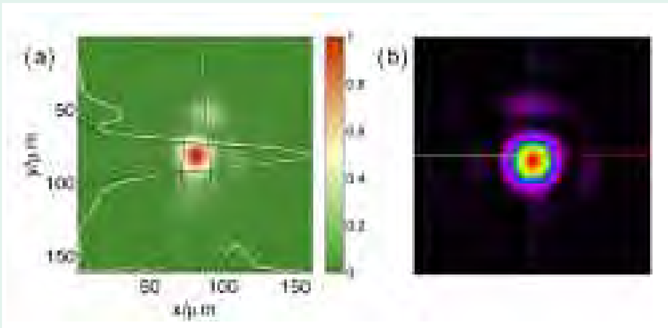
In order to achieve the highest possible intensities with high power lasers, adaptive optics must be used to correct for aberrations that are inherent in the laser system. We have trialled two deformable mirrors in the Astra-Gemini target area, one a CLF produced gold piezoelectric optic, the other a commercial mechanically driven mirror. We have obtained improved focal spot quality using both the f/20 and the f/2 parabolas. The figure displays the f/20 focus which contains 57% of the energy within a spot of radius 16.7 μm ($1/e^2$). The wavefront of the corrected beam has a variation of less than λ/20 RMS. Also shown is the expected focal spot constructed using commercial software. We expect to be able to field these adaptive optics routinely on future experiments (depending on individual beam layouts).



(a) Measurement of the focal spot from the f/20 parabola using an adaptive optic. (b) Focal spot constructed from the wavefront, measured using a HASO wavefront sensor.

Modified cross-correlator for use on beam combination experiment

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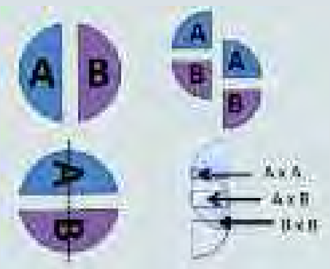
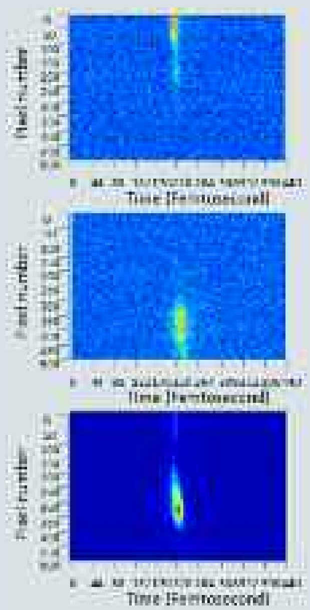
Here we report a modified near field (NF) autocorrelator (AC) for measuring the cross correlation of two recombined beams. The Astra-Gemini laser has two half petawatt beams that are seeded from the same pulse. The cross correlator was built to measure AC of both beams and a cross correlation of the combined beam to prove the recombination.



NF of the two beams to be combined (top left). Sampling the beams using the D shaped mirror, denoted by the dotted line (bottom left). Spatially offsetting the two NF in each arm of the cross correlator (top right). AC of beam A and B and cross correlation of A and B (bottom right).

AC of A (top), AC of B (middle) and both AC and a cross correlation of A and B (bottom).



DiPOLE

Multislab Yb:YAG crogenic gas cooled high average high power amplifier 7.4 J at 10 Hz

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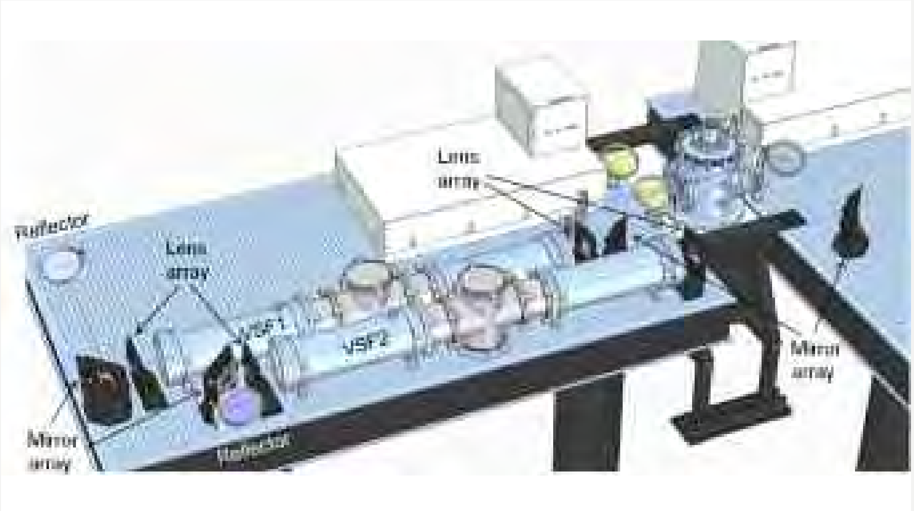
In the DiPOLE laboratory we have recently implemented a multi-pass relay-imaging extraction architecture, which includes spatial filtering, and allows up to eight passes through the amplifier head. This has enabled more efficient extraction at higher coolant temperatures, where gain is lower and the impact of ASE is reduced, as well as improving the spatial quality of the output beam. We have obtained 9.5 J at 1 Hz and 7.4 J at 10 Hz, corresponding to $\eta_{o\text{-}o}$ efficiencies of 24% and 23%, respectively, for seed energies of approximately 20 mJ.



Engineering diagram of the DiPOLE layout; detailing the Vacuum spatial filters, Mirror and lens arrays.

Engineering

Remotely controlled gas system for high repetition rate experiments

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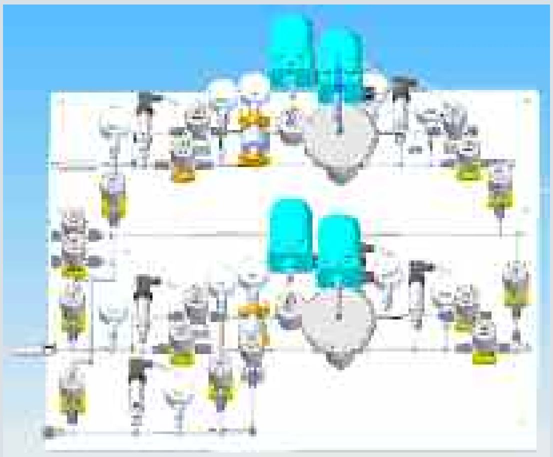
A remotely controlled gas delivery system has been developed and installed in Astra Gemini. This reduces laser time lost through adjusting gas pressures from inside the bunker and through regular hardware modifications to satisfy experimental need. It has been fielded in a number of experiments and feedback from those using the system on a day-to-day basis has been positive. Gas species selection and pressure control is available from the control room allowing targets to range in pressure from 67mbarA to 100barG. It is connected to a safety system that shuts off the gas supplies in the cupboards should there be gas alarm, or gas emergency stop. There is provision to connect the system to the fire alarm system.



The main control panel where the source gasses are switched and pressure is controlled.

TAP vacuum improvements

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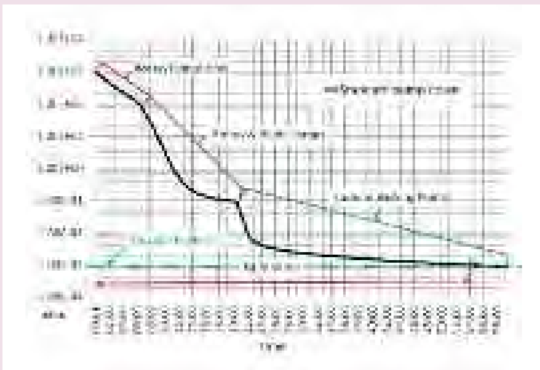
The vacuum system on TAP has been characterised over the last few years and an upgrade path identified. Much of the upgrade has now been implemented reducing the benchmarked time to shoot from 54 minutes to 15 minutes. This has been achieved by revising the roughing philosophy and adding a large cryogenic vacuum pump. Further gains will be realised when the new roughing pump is fully integrated into the control system. The 15 minute pump down will still be influenced significantly by the amount of non vacuum compatible hardware required for the experiment but the ratio of the reduction is still valid. Cryogenic vacuum pumps are known for their vibration and this was of significant concern when the project started but evidence on recent experiments and the analysis carried out detailed in the CLF Annual Report 2011/2012 article 78 suggest that the TAP infrastructure is unaffected by the vibration.



Benchmarked TAP Interaction Chamber Pump Curve.

Instrumentation

Dynamic range and sensitivity comparison of optical CCDs

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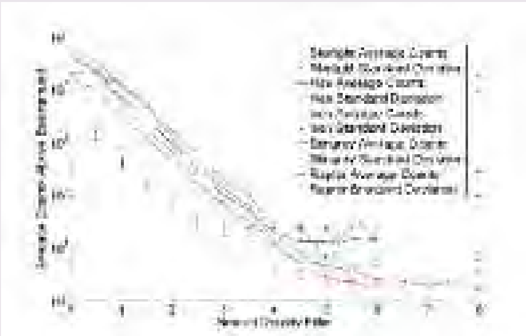
The CLF own and use a variety of high dynamic range CCD cameras that are used for a variety of measurements on many of the experiments performed at the facility. The performance and characteristics of these cameras are of utmost importance when choosing which camera to use in any particular circumstance. Therefore, a calibration to determine the dynamic range and threshold sensitivity of the cameras has been conducted.

The cameras tested were the Starlight Express 16bit CCD camera, the Andor Neo which has a 16bit CMOS sensor with the capability of dual amplification, the Andor Ixon which has a 16bit Electron Multiplying CCD (EMCCD), a 16bit EMCCD Raptor Kite and a 14bit Allied Vision Technology Stingray camera.



Average counts and standard deviation of LED incident onto the 4 CLF cameras.

Gamma-ray scintillator spectrometer

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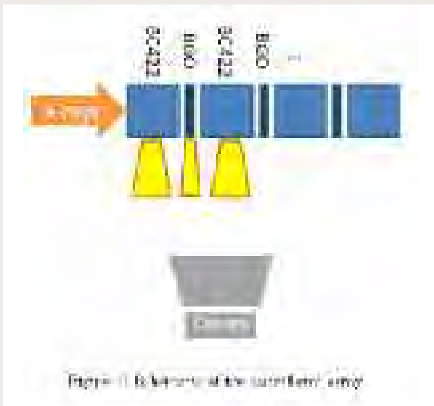
Copious amounts of hard X-rays (in the 0.1-10MeV region) are typically produced in intense laser-plasma interactions. Characterising this emission enables a greater understanding of the interaction physics, including providing insight into electron dynamics inside opaque targets.

Previous gamma/X-ray spectral measurements have been conducted using thermoluminescence dosemeters (TLDs), nuclear activation or bremsstrahlung cannons.

The downside to these diagnostics is processing time and sensitivity. With new high power laser systems being developed that promise high repetition, a spectrometer that can operate in real time would be desirable.

A spectrometer with low processing time and high sensitivity requires a novel method of detection and x-ray attenuation. Scintillators are materials that absorb a photon that has a high energy and emit a lower energy optical photon and are therefore ideal for X-ray detection. Scintillators also have short (sub ms) decay times which means they can be used on high repetition systems.

Schematic of the scintillator array.



Wavefront sensor-less adaptive optics for high powered lasers

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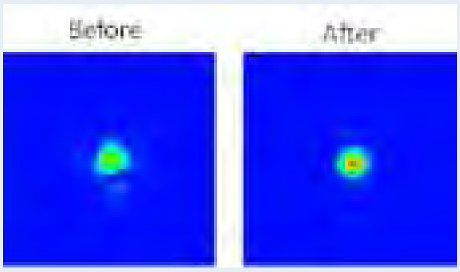
Adaptive Optics (AO) is required in lasers to correct for aberrations in the laser beam. Current methods employ wavefront sensors to detect aberrations and Deformable Mirrors (DMs) to correct the aberrations.

Wavefront Sensor-less AO is a method which could be applied that finds the optimum wavefront by monitoring the quality of a focal spot. This method eliminates the need for a wavefront sensor - a fragile and expensive piece of equipment – and so substantially reduces the price of a system.

In the Adaptive Optics Laboratory, a CCD camera was used to capture images of the focal spot of a beam. Using the result of a metric for each image, 2 algorithms were compared: "Surface Fitting" and the Nelder-Mead Method; each of these was tried with 2 variations, one of which modelled the DM.

The results showed that of the 4 algorithms, all showed an improvement to focal spot quality; 3 of these were extremely high quality and indistinguishable. The methods which did not use models of the mirror resulted in higher spot quality, but took longer: the result of being able to work at the resolution of the DM.

These results show proof that WSAO could be used within a high powered laser system, and further research is being done into the possibility of using WSAO to allow continuous improvement to a system which has a slowly varying aberration.



Focal Spot improvement using the Nelder-Mead method

LSF

Waveguide-enhanced 2D-IR spectroscopy for the gas-phase

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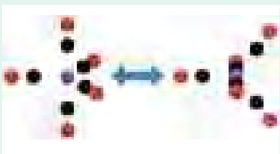
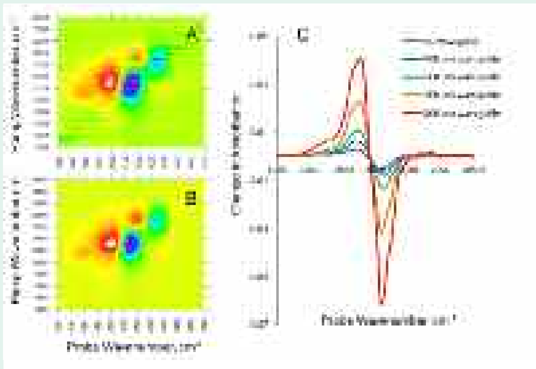
Ultrafast 2D-IR spectroscopy is a mature technique in application to the condensed phase, detailing many important structural dynamics and energy transfer processes in solution. Experiments involve ultrafast IR excitation of a sample, followed by time-resolved IR probing. The technique follows ultrafast changes in structure and/or vibrational energy transfer by monitoring the ways in which the IR (vibrational) spectrum of a sample varies with time and/or pump wavelength.

When studying the dynamics of any chemical reaction, the role of the environment cannot be ignored. For example, in many 2D-IR experiments, one must consider if observed changes in the vibrational spectrum are truly intra-molecular or solvent-mediated. Often, solution phase experiments will be performed under a variety of conditions (e.g. in different solvents) to help resolve such ambiguity. The possibility to perform experiments in the gas phase is an opportunity to remove solvent effects.



Fluxional motion of the $Fe(CO)_5$ molecule.



A and B, 2D-IR spectra of $Fe(CO)_5$ vapor without and with the waveguide, respectively. C Pump – probe difference spectra of $Fe(CO)_5$ vapor, pumping at 2013 cm^{-1}, in various waveguide conditions.

Ultrasensitive dark-field microspectroscopy with a supercontinuum source

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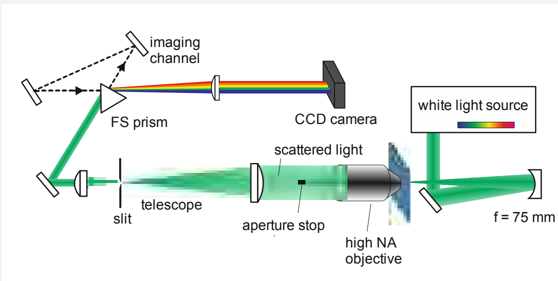
A highly sensitive dark-field microscope for visible scattering spectroscopy of nanoparticles has been developed. Front illumination with a curved mirror allows us to use 95% of the numerical aperture of the objective for detection. Subsequent losses are minimized by dispersing the scattered light with a prism.

In a first experiment, scattering spectra of single gold nanoparticles with an average diameter of 40 nm were measured. Variation in the total scattering cross section was correlated with the position of the resonance band, and was assigned to a distribution in particle size.

The efficient suppression of background light was demonstrated by the simultaneous measurement of the fluorescence of a single quantum dot and scattering from its surrounding. These results represent the first detection of the fluorescence of a single emitter without the use of a filter in the detection arm.



Setup of the developed dark-field spectromicroscope

Plasma Diagnostics

Improvements in Thomson parabola studies: a new ImageJ script for spectral energy analysis and measurements using a double image plate detector

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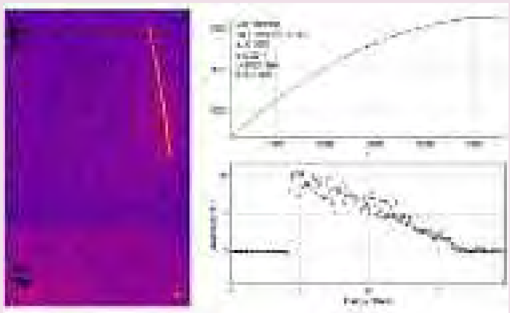
An ImageJ script has been developed for calculating Thomson parabola ion spectra. It is an easy-to-run pluging that gives a quick view of the ion spectrum which can be useful when working in the lab. Since it is integrated in ImageJ it has the advantage of allowing the use of other functions in ImageJ such as zooming, flipping and rotating images, operation between images and adjusting the contrast while running the code. It also converts the pixel intensity to PSL values and gives a parabola fit for the signal. Using this script a study of the use of two IP's has been done to extend the range of proton detection. Calculations show that the double IP detector improves the detection efficiency up to a factor of three for energies between 7.5 and 12 MeV. As a trade-off, artificial signals can be created in the first IP for those energy values.



Left - Ion signal on the IP; Right.upper - Parabola fit dialog box; Right.bottom- Spectrum dialog box.

Use of bubble detectors to generate neutron spectra from high power laser sources

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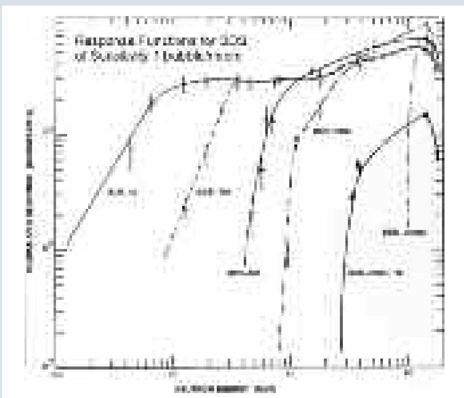
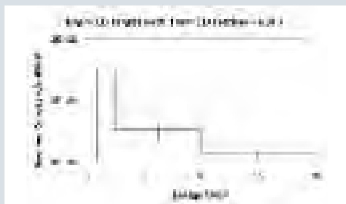
We generated a fast neutron source by using the Petawatt laser facility at Vulcan to accelerate deuterons from thin (~10μm) foils of deuterated plastic into thicker (1mm) targets also made of deuterated plastic. The resulting D-D fusion reaction produced fast neutrons with highest flux at an energy of 2.45 MeV, and also a significant flux component up to 20 MeV.

A bubble detector spectrometer was used to diagnose this flux and provide a rough spectrum of the neutron source as well as allowing calibration of neutron Time of Flight diagnostics to absolute values.



Response functions for bubble detectors as a function of neutron energy.



Histogram of Neutron Density for a typical pitcher-catcher target arrangement.

A single bubble detector tube with visible bubbles.

Temporally and spatially resolved measurements of fast electron dynamics using a chirped optical probe

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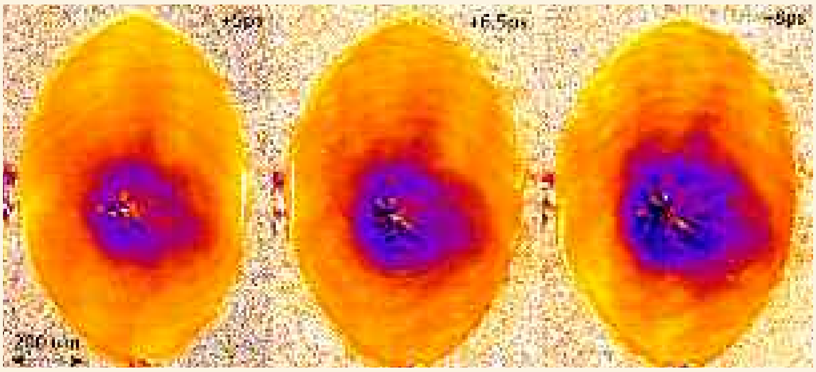
In this article we present a novel implementation of a diagnostic that temporally and spatially resolves the fast electron-sourced sheath fields that result from intense laser-plasma interactions. The diagnostic measures the time-dependent reflectivity on the rear surface of a laser-irradiated target, which can be used to infer valuable information on fast electron dynamics.

The optical diagnostic was deployed on an Astra Gemini experiment where 100 nm – 50μm thick Al foils were irradiated at 10^{21} Wcm^{-2} using a separate drive pulse. In a single shot three 2D reflectivity maps of the target rear surface were obtained, showing a rapidly expanding region of plasma formation together with filamentary structures. Such observations, when coupled with complementary ion measurements, yield crucial information on fast electron transport and the timescale for rear surface acceleration of ion beams.



2D rear surface reflectivity profile for a 50 μm Al foil 5-8 ps after the main interaction. Note: viewing angle of the target means that the horizontal dimension is contracted.

Investigations into generation of neutron spectra from high powered laser sources via the use of activation foils

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The energy spectra of neutrons generated by a laser source are evaluated through the use of activation foils.

A pack of metal foils are placed close to the target to be bombarded by the created neutrons which causes nuclear reactions to occur within the foils. Daughter nuclei may be detected via their characteristic gamma emissions. The reactions that create the products within the foils have known energy cross sections. By comparing the cross sections of multiple reactions within the foils, it is possible to create energy spectra of the neutrons incident upon the foils.

The technique was successfully demonstrated, with neutron energy spectra produced from close to the interaction, with some limitations to be resolved. It also gave absolute numbers of neutrons produced, as well as being able to differentiate between different emission types from the target.

Four of the foils activated by neutrons during the investigation.

Target Fabrication

Micro-grating structures as laser targets and diagnostic devices

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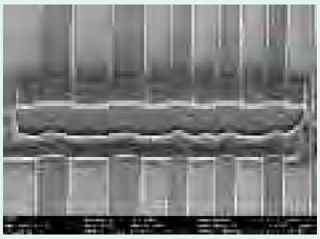
Micro-grating structures can play important roles in high power laser experiments. They may be the primary target in, for example, ion acceleration experiments or they may be used as diagnostic devices.

The grating dimensions may vary from a few microns in pitch down to line or space dimensions of less than 200nm. There are a range of different fabrication techniques to allow the production of these structures.

Various microfabrication techniques are described along with examples. The third example (a 50mm x 50mm area of CH polymer with micron-scale grating) is described in greater detail about how it was fabricated using a novel reflow technique before being coated on the reverse side with aluminium and finally being diced into individual target–sized squares pieces, mounted and shot.



Left Figure. Micron scale test structures in lithium niobate. The grating lines are visible at the top and bottom of the image. Platinum has been deposited and a trench etched by focused ion beam across the centre to reveal the cross-section of the etched grating. (photo courtesy of JA Fülöp) Right Figure. Reflowed resist film. The rounded sidewalls and top can be seen. Before reflow, the sidewalls were vertical and the top flat.

Production and characterisation of diamond-like carbon foils for experimental delivery

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Statistics and trend analysis of experiments at RAL has seen a large demand in recent years for carbon and metallic foils with no backing foil with thicknesses of 10's of nanometres and below.

A common target material requirement for recent and upcoming experiments is carbon due to its favourable Bragg peak. Previously experience shows that amorphous carbon foils are weak at low thicknesses and denature very quickly with moisture absorption. An investment was made into a capability to produce Diamond-Like Carbon by Plasma Enhanced Chemical Vapour Deposition. In house experience has shown DLC survives at low thicknesses and is less likely to be destroyed when irradiated by a pre-pulse.

Characterisation of the Diamond-Like Carbon bonding nature was achieved by Raman Spectroscopy using a Renishaw 514nm Laser excitation source. Using Origin Pro 8 a Gaussian fit was applied to various different Raman data obtained from a range of coatings.

The modified RIE80 etch system uses Plasma Enhanced Chemical Vapour Deposition (PECVD) of a mixture of methane (CH_4) and Argon plasma to create Dimond-Like Carbon.

Initial set-up of a droplet generator

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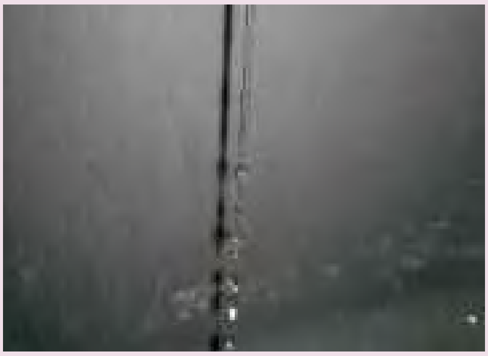
Droplet generators have applications as sources of liquid laser targets. This paper describes the droplet generator system currently being developed in CLF and reports on early progress.

An overview of the droplet generator design is given and a simple set-up is described. The importance of removing dust contamination and careful assembly is emphasised. Theoretical considerations indicate the mechanism of droplet formation of pulsed fluid through reduction of the stream surface area. Imaging the system droplets is difficult and requires a high speed camera as well as an electronic shutter and good synchronisation between illumination, camera and droplet frequency.

The project acts as a basis for follow on work to produce thin disc targets by colliding cryogenic hydrogen droplets.

Droplet generator

Macroscopic droplet image



Vulcan

Large temporal window near field autocorrelator

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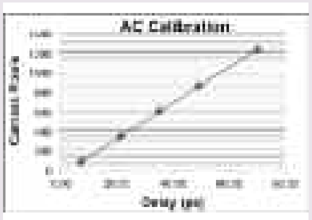
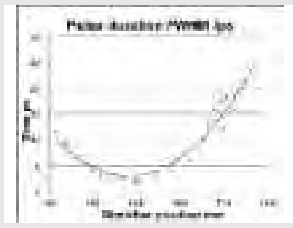
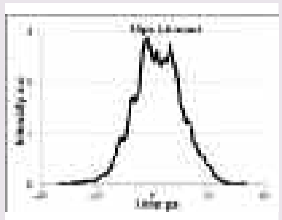
The synchronized CPA beam 8 (B8) delivered to target area west (TAW) are tunable with respect to beam 7 (B7). Both beams share a stretcher but separate compressors. The standard configuration is to operate B7 at 1ps and detune the B8 compressor to several tens of ps. In the past, a streak camera was used to perform the compressor tuning on B8, but it was not possible to operate this diagnostic on shot. We have developed a large window autocorrelator (AC) capable of measuring pulses of >30ps on shot, with a resolution of 300fs.



Calibration cure for the AC performed using a 150fs Ti:Sapphire laser.



B8 stretcher tuning curve measured using the large window AC.



NF AC in TAW beam 7.

Construction of a pump amplifier chain for the 10 J OPCPA beamline

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The Vulcan 10 PW Upgrade has been designed based on numerical modelling of several different and complex procedures. To ensure that the baseline design is more accurate a test facility has been built to test the first stage of Optical Parametric Chirped Pulse Amplification (OPCPA) gain media. This facility consists of a shaped long pulse oscillator, a rod amplifier, a frequency doubling stage and finally the OPCPA stage. Once commissioned this will be used to pump a small aperture, 40 mm, crystal seeded by the 10 PW Front End system to enable verification of the early stage pumping and amplification requirements, and ultimately lead to great assurance that the requirements for the larger aperture amplification stages are reasonable.

Alignment of the double passed 45 mm rod amplifier system with the Faraday Rotator between the first and second passes to reduce likelihood of damage

Modelling and performance of a regenerative amplifier laser cavity and the rod amplifier chain for the 10 J OPCPA pump laser and development of arbitrary waveform generator control software

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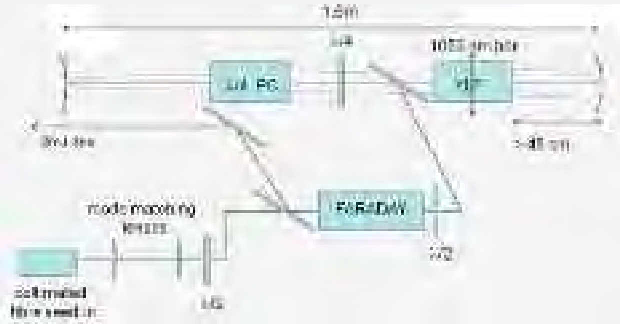
Software can be very useful when designing or operating high power laser systems. However, it is often the case that commercial software is not suitable for the task and the creation of an in-house solution is necessary. This report describes software that was developed to aid in the design of the regenerative amplifier cavity as well as a separate piece of software that was developed for control of the temporal shape of the seed pulse for the 10J OPCPA beam-line. We also describe modelling of the rod chain in MIRÓ which is able to predict the energy scaling and pulse shape change as the mJ energy is scaled up to the 30 J level.



High repetition rate diagnostics for the Vulcan laser

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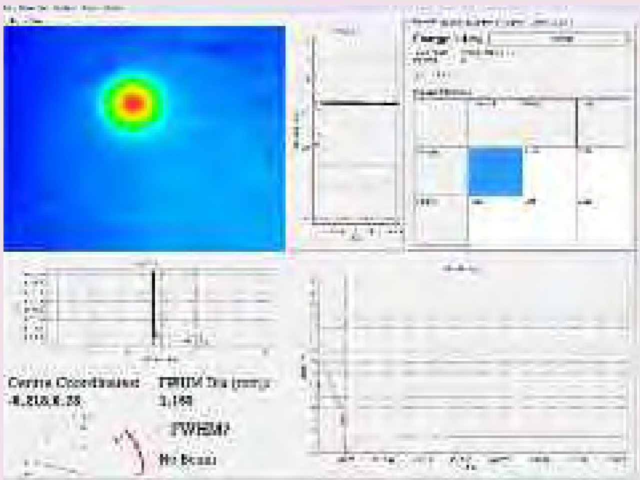
In Vulcan diagnostics capable of providing information about a laser beam in real-time are highly useful for measuring the stability of the beam. This allows operators to make better, more informed decisions based on the most up to date information.

In Vulcan a new piece of software entitled “Measure Energy and Plot” was created in order to analyse beams in real-time. The software is capable of measuring energy and beam centre position and displaying a short history of these parameters on graphs in real-time. As well as this, the software can save this information in a daily file for longer term stability analysis.

As well as the position of the beam and energy contained within the beam, MEAP is also capable of estimating beam size and displaying cross sectional plots of the beam in order to estimate beam uniformity.

These tools have enabled a better understanding of the energy stability on Vulcan, which is altering the way in which operations on Vulcan are conducted.



Measure Energy and Plot Software