High Energy Density & High Intensity Physics

A spectrometer for ultrashort gamma-ray pulses with photon energies greater than 10 MeV

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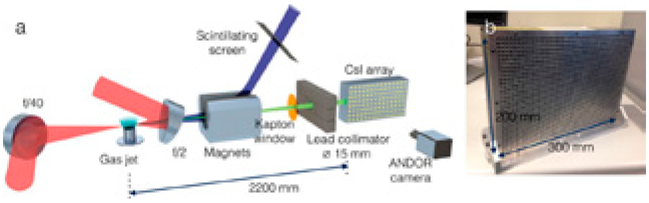
We present a design for a pixelated scintillator based gamma-ray spectrometer for non-linear inverse Compton scattering experiments. By colliding a laser wakefield accelerated electron beam with a tightly focused, intense laser pulse, gamma-ray photons up to 100 MeV energies and with few femtosecond duration may be produced. To measure the energy spectrum and angular distribution, a 33 × 47 array of caesium-iodide crystals was oriented such that the 47 crystal length axis was parallel to the gamma-ray beam and the 33 crystal length axis was oriented in the vertical direction. Using an iterative deconvolution method similar to the YOGI code, modelling of the scintillator response using GEANT4 and fitting to a quantum Monte Carlo calculated photon spectrum, we are able to extract the gamma ray spectra generated by the inverse Compton interaction



(a) Experimental setup of the Compton scattering experiment, including the γ-ray spectrometer. (b) Photograph of the CsI scintillator array used as the detector.

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Debris studies for high-repetition rate and high-power laser experiments at the Central Laser Facility

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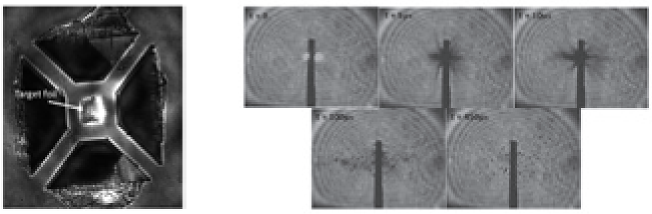
Many of the new large European facilities that are in the process of coming online will be operating at high power and high repetition rates. The ability to operate at high repetition rates is important for studies including secondary source generation and inertial confinement fusion research. In these interaction conditions, with solid targets, debris mitigation for the protection of beamline and diagnostic equipment becomes of the utmost importance. These facilities have the potential to take hundreds, if not thousands, of shots every day, creating massive volumes of debris and shot materials.

In recent testing of the Central Laser Facility's High Accuracy Microtargetry Supply (HAMS) system on the mid-repetition rate Gemini facility (15 J, 40 fs, 1 shot every 20 seconds), diagnostics were deployed to specifically look at the debris emitted from targets designed for high repetition rate experiments. By using a high frame rate camera, it has been possible to observe and characterize some of the debris production, whilst also looking at target fratricide.

Alongside these results from Gemini, we also present results of static debris measurements undertaken on the Vulcan Petawatt high energy, high power facility, where the cumulative effects of debris produced by high power laser experiments have been observed.



Left: On shot rear surface probe data showing the laser clipping the target frame of a 100 nm-thick silicon nitride target suspended on a silicon frame of 300 x 300 μm^2.

Right: High frame rate camera images (210k fps) at t=0, 5, 10, 100 and 450 μs from the arrival of the laser pulse on a silicon nitride target with a 300 μm diameter aperture. At t=0 the initial plasma flash at the interaction point can be seen.

Reprinted from N. Booth, S. Astbury, E. Bryce, R. J. Clarke, C. D. Gregory, J. S. Green, D. Haddock, R. I. Heathcote, and C. Spindloe "Debris studies for high-repetition rate and high-power laser experiments at the Central Laser Facility", Proc. SPIE 10763, Radiation Detectors in Medicine, Industry, and National Security XIX, 107630S (11 September 2018); https://doi.org/10.1117/12.2318946.
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High-resolution µCT of a mouse embryo using a compact laser-driven X-ray betatron source

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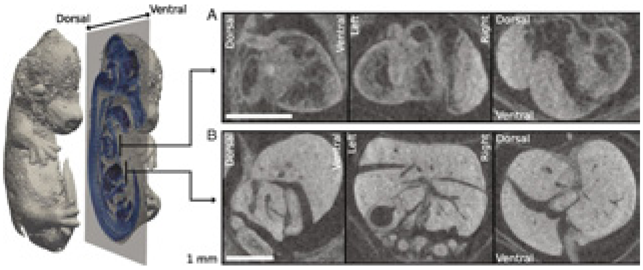
In the field of X-ray microcomputed tomography (µCT) there is a growing need to reduce acquisition times at high spatial resolution (approximate micrometres) to facilitate in vivo and high-throughput operations. The state of the art represented by synchrotron light sources is not practical for certain applications, and therefore the development of high-brightness laboratory-scale sources is crucial. We present here imaging of a fixed embryonic mouse sample using a compact laser–plasma-based X-ray light source and compare the results to images obtained using a commercial X-ray µCT scanner. The radiation is generated by the betatron motion of electrons inside a dilute and transient plasma, which circumvents the flux limitations imposed by the solid or liquid anodes used in conventional electron-impact X-ray tubes. This X-ray source is pulsed (duration <30 fs), bright (>10^{10} photons per pulse), small (diameter <1 µm), and has a critical energy >15 keV. Stable X-ray performance enabled tomographic imaging of equivalent quality to that of the µCT scanner, an important confirmation of the suitability of the laser-driven source for applications. The X-ray flux achievable with this approach scales with the laser repetition rate without compromising the source size, which will allow the recording of high-resolution µCT scans in minutes.



An isosurface rendering of the reconstruction from the laser source is depicted in gray. A sagittal slice of the reconstruction is overlaid in blue. Enlarged sections of sagittal, coronal, and transverse slices around the heart and liver are plotted in A and B, respectively. (Scale bars, 1 mm.)

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Observation of ultrafast proton interactions in water using the Gemini Laser Facility

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The solvated electron has been extensively studied in many areas of radiation chemistry. A large focus of this research has been in radiation biology, as solvated electrons are a product of ionising radiation reacting with water molecules that can cause damage to DNA. Many of these studies employ chemical scavenging techniques, where a chemical is added to the water that reacts in some measurable way to the ionising radiation.

Using an optical streaking technique with a high degree of synchronicity, and measuring changes in transmission of the pristine water sample, we use laser-driven protons to generate solvated electrons in water, whilst simultaneously probing their evolution on a sub-nanosecond (10^{-9} s) timescale.

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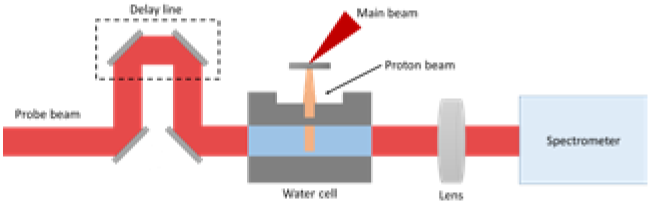
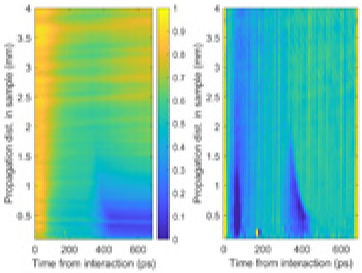


Above: Sketch of the experimental setup



Left: Experimentally obtained optical streak showing the response of H_2O to protons produced by Target Normal Sheath Acceleration. The x-axis represents the temporal evolution of the opacity from time of the laser-foil interaction. The y-axis shows the spatial evolution along the central axis of the proton burst. Right: Differentiated image showing the rate of change of transmission with respect to time, highlighting the region of the streak where the ion pulse is depositing energy the subsequent electron solvation process.

DNA DSB Repair Dynamics following Irradiation with Laser-Driven Protons at Ultra-High Dose Rates

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Proton therapy has emerged as more effective in the treatment of certain tumours than photon-based therapies. However, significant capital and operational costs make proton therapy less accessible. This has stimulated interest in alternative proton delivery approaches, and, in this context, the use of laser-based technologies for the generation of ultra-high dose rate ion beams has been proposed as a prospective route. A better understanding of the radiobiological effects at ultra-high dose-rates is important for any future clinical adoption of this technology. In this study, we irradiated human skin fibroblasts-AG01522B cells with laser-accelerated protons at a dose rate of 10^9 Gy/s, generated using the Gemini laser system at the Rutherford Appleton Laboratory, UK. We studied DNA double strand break (DSB) repair kinetics using the p53 binding protein-1(53BP1) foci formation assay and observed a close similarity in the 53BP1 foci repair kinetics in the cells irradiated with 225 kVp X-rays and ultra- high dose rate protons for the initial time points. At the microdosimetric scale, foci per cell per track values showed a good correlation between the laser and cyclotron-accelerated protons indicating similarity in the DNA DSB induction and repair, independent of the time duration over which the dose was delivered.

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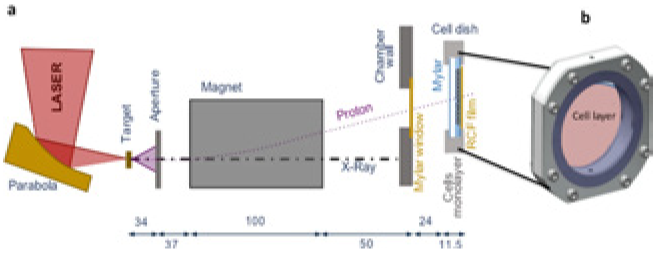
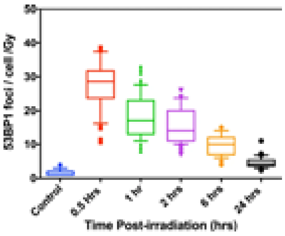


Above: (a) Schematic of the experimental set up for irradiation of AG01522 cells with 10MeV laser accelerated protons (b) Design of the dish where cells were grown as monolayers on 3 μm thin Mylar.



Left: Quantitative analysis of the variations in 53BP1 foci per cell per Gy in AG01522B cells after exposure to 10 MeV (LET-4.6 keV/μm) laser-accelerated protons shown as whisker box plots generated using Prism 6 software.

Reprinted from Hanton, F., Chaudhary, P., Doria, D. et al. DNA DSB Repair Dynamics following Irradiation with Laser-Driven Protons at Ultra-High Dose Rates. Sci Rep 9, 4471 (2019) doi:10.1038/s41598-019-40339-6 published by Springer Nature, under the Creative Commons Attribution 4.0 International License.

Measurement of the decay rate of laser-driven linear wakefields

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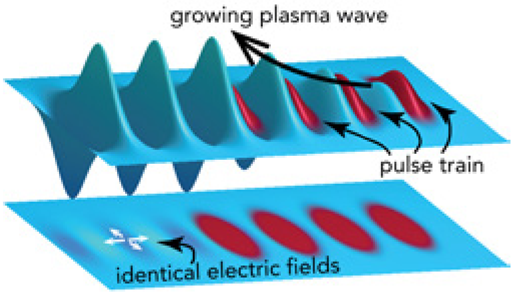
In the multi-pulse laser wakefield acceleration scheme (MP-LWFA), a train of laser pulses propagating through a plasma excites a plasma wakefield, which could be used to accelerate charged particles to GeV energies at a rate of several kHz. If the distance between the laser pulses is equal to the plasma wavelength, the wake amplitude is amplified by each subsequent laser pulse. We have performed an experiment to measure the lifetime, T_{wf} of the plasma wakes, in order to determine the maximum number of laser pulses that can be used to amplify these wakes.

In this report, we describe the method for determining T_{wf} using Temporally Encoded Spectral Shifting (TESS). Preliminary analysis confirms that measured values agree with theory. Further results will be reported in future publications. These advances in MP-LWFA could pave the way towards high-repetition rate laser-plasma accelerators.



A simulation of four laser pulses, separated by the plasma wavelength, driving a plasma wakefield through resonance.

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Investigations of Optical Guiding through Hydrodynamic Optical-Field Ionised Plasma Channels

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Long, low-density plasma channels can be generated by Hydrodynamic Optical-Field-Ionisation (HOFI) and are capable of operating at kilohertz repetition rates, making them ideal waveguides for multi-GeV laser-plasma accelerators. In this report, the effects of spatial offset at the entrance of the channel are investigated.

Stability of the *f*/40 beam far-field was characterised by a leak inside the South compressor in LA3, and by a focus camera inside TA3. These measurements indicated that pointing jitter of the Gemini South F/40 beam was dominated by contributions from LA3. As the spatial offset at the channel entrance increased, an increase in guided spot size and reduction of energy transmission of the *f*/40 pulse was observed. The plasma channel acceptance angle was found to be approximately 3.7 µrad, which can inform future experiments of the same type.

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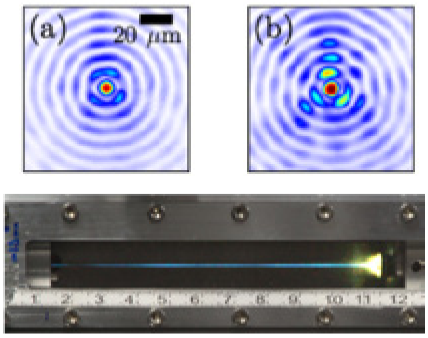

Figure 1: Transverse intensity profile of the channel-forming beam at the start of the line focus (a) and 100 mm downstream (b). (c) SLR image of a hydrogen plasma column ionised by the channel-forming beam.

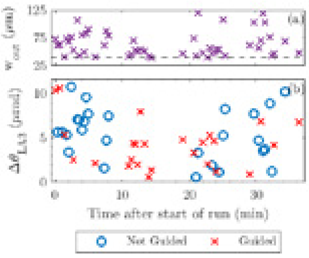

Figure 2: (a) Variation in the guided spot size w_{out}. (b) Graph showing how guiding quality is correlated with time and the LA3 leakage position for 50 consecutive shots.

Experimental Signatures of the Quantum Nature of Radiation Reaction in the Field of an Ultraintense Laser

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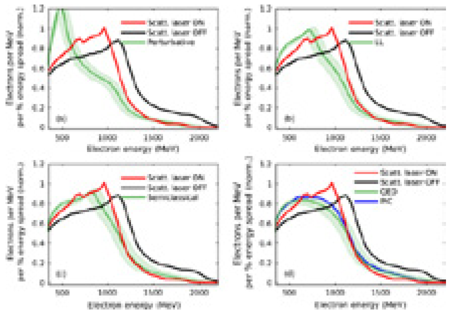
The description of the dynamics of an electron in an external electromagnetic field of arbitrary intensity is one of the most fundamental outstanding problems in electrodynamics. Remarkably, to date, there is no unanimously accepted theoretical solution for ultrahigh intensities, and little or no experimental data. The basic challenge is the inclusion of the self-interaction of the electron with the field emitted by the electron itself – the so-called radiation reaction force. We report here on the experimental evidence of strong radiation reaction, in an all-optical experiment, during the propagation of highly relativistic electrons (maximum energy exceeding 2 GeV) through the field of an ultraintense laser (peak intensity of 4×10^{20} W/cm^2). In their own rest frame, the highest-energy electrons experience an electric field as high as one quarter of the critical field of quantum electrodynamics and are seen to lose up to 30% of their kinetic energy during the propagation through the laser field. The experimental data show signatures of quantum effects in the electron dynamics in the external laser field, potentially showing departures from the constant cross field approximation.



Experimentally measured electron spectrum without the scattering laser (black line) and the spectrum of scattered electrons (red line) compared to (a) the theoretical prediction assuming a model only based on the Lorentz force, (b) the Landau-Lifshitz equation, (c) a semiclassical model of radiation reaction, and (d) the quantum model of radiation reaction.

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Making pions with laser light

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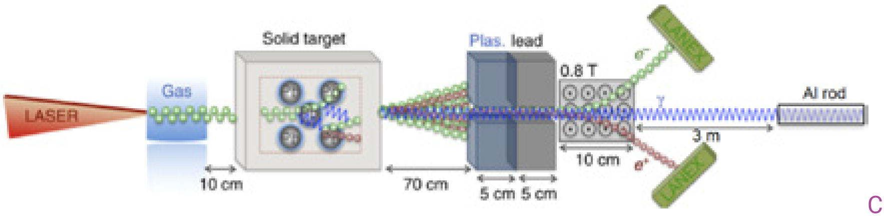
The interaction of high intensity, short pulse laser beams with plasmas can accelerate electrons to energies in excess of a GeV. These electron beams can subsequently be used to generate short-lived particles, such as positrons, muons, and pions. In recent experiments, we have made the first measurements of pion production using 'all optical' methods. In particular, we have demonstrated that the interaction of bremsstrahlung generated by laser-driven electron beams with aluminium atoms can produce the long-lived isotope of magnesium (^{27}Mg) which is a signature for pion (π^+) production and subsequent muon decay. Using a 300 TW laser pulse, we have measured the generation of 150 ± 50 pions per shot. We also show that the energetic electron beam is a source of an intense, highly directional neutron beam resulting from (γ, n) reactions which contributes to the ^{27}Mg measurement as background via the (n, p) process.



Experimental geometry for measuring pion/neutron production.

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Experimental Testing of Targets for a High Accuracy Microtarget Supply (HAMS) System on the Gemini Laser System

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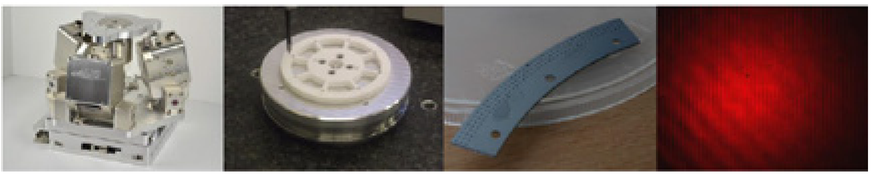
It is widely understood within the high-power laser community that recent developments in diode-pumped and high repetition rate laser systems will give unprecedented access to laser shots. This will provide a challenge for target fabrication in making enough experimental samples. While in the past access to facilities and shot rates during access periods have been the limiting factor for high power laser experiments, this will soon not be the case. There has already been a shift in development of the user base from fundamental science experiments to industrial applications, using the laser experiment as a reliable source for secondary aims. The Gemini laser system has been operating at a high repetition rate for high intensity (0.5 PW) experiments for a number of years, and the Central Laser Facility has developed a target methodology to deliver to the user community the maximum number of solid targets and to fully utilise the available time on the laser. Targets for the High Accuracy Microtarget Supply (HAMS) system have been tested and have been proven to survive in a manner to allow shot rates comparable with the available laser repetition rate (0.1 Hz). Investigations into target geometry have been carried out and debris production has been studied by high frame rate camera imaging. The study of the relationship between target geometry and debris production has allowed the design of optimal target support infrastructure, such as aperture size and structure, for high repetition rate experiments on the Gemini system.



The four physical integrated parts of the HAMS system, which will allow for automated target alignment after integration of feedback programming.

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Observation of Laser Power Amplification in a Self-Injecting Laser Wakefield Accelerator

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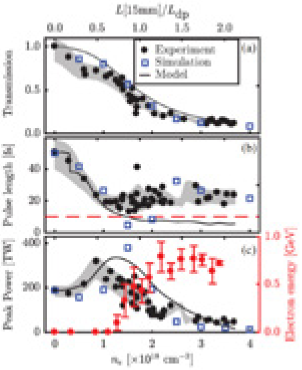
We report on the depletion and power amplification of the driving laser pulse in a strongly driven laser wakefield accelerator. Simultaneous measurement of the transmitted pulse energy and temporal shape indicate an increase in peak power from 187±11 TW to a maximum of 318±12 TW after 13 mm of propagation in a plasma density of 0.9×10^{18} cm^{-3}. The power amplification is correlated with the injection and acceleration of electrons in the non-linear wakefield. This process is modelled by including a localized redshift and subsequent group delay dispersion at the laser pulse front.



Experimental and simulated (a) transmitted laser energy fraction, (b) pulse duration (FWHM), and (c) peak pulse power and maximum observed electron beam energy (red circles) versus plasma density for a 15 mm nozzle diameter. The grey shaded regions indicate rms error (statistical and measurement errors) of a moving average of the data points. The red dashed line in (b) is the instrument limit of the FROG for time-bandwidth limited pulses. The solid black lines are calculated from our pulse evolution model.

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Temporal feedback control of high-intensity laser pulses to optimize ultrafast heating of atomic clusters

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We describe how active feedback routines can be applied at a limited repetition rate (5 Hz) to optimize high-power (>10 TW) laser interactions with clustered gases. Optimization of x-ray production from an argon cluster jet, using a genetic algorithm, approximately doubled the measured energy through temporal modification of the 150 mJ driving laser pulse. This approach achieved an increased radiation yield through exploration of a multi-dimensional parameter space, without requiring detailed a priori knowledge of the complex cluster dynamics. The optimized laser pulses exhibited a slow rising edge to the intensity profile, which enhanced the laser energy coupling into the cluster medium, compared to the optimally compressed FWHM pulse (40 fs). Our work suggests that this technique can be more widely utilized for control of intense pulsed secondary radiation from petawatt-class laser systems.

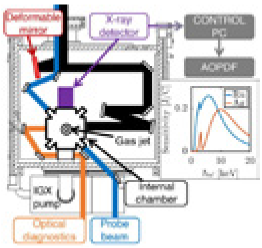

Figure 1: The gas jet target is housed in an internal differentially pumped chamber. Diagnostic output is fed into the control PC that applies settings to the acousto-optic programmable dispersive filter in an optimization feedback loop. Sensitivity for the 0.1 μm Ru and 2 μm Ag filtered PIN diodes is shown.

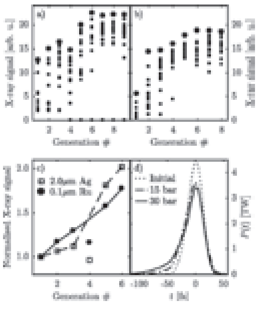

Figure 2: Optimization of Ru-filtered PIN diode X-ray flux with backing pressures of (a) 30 bar and (b) 15 bar. Each point is the average of 50 shots, with the best individual of each generation shown as a larger point. Error bars are omitted for visual clarity. (c) Improvement of the X-ray signal through the 0.1 μm Ru and 2 μm Ag filters, normalized to their starting values with the unmodified laser pulse (Generation 1) for a backing pressure of 30 bar. (d) Power profiles of the initial and optimized pulses from the 15 bar and 30 bar runs.

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Processing of Gemini betatron images for biological tomography

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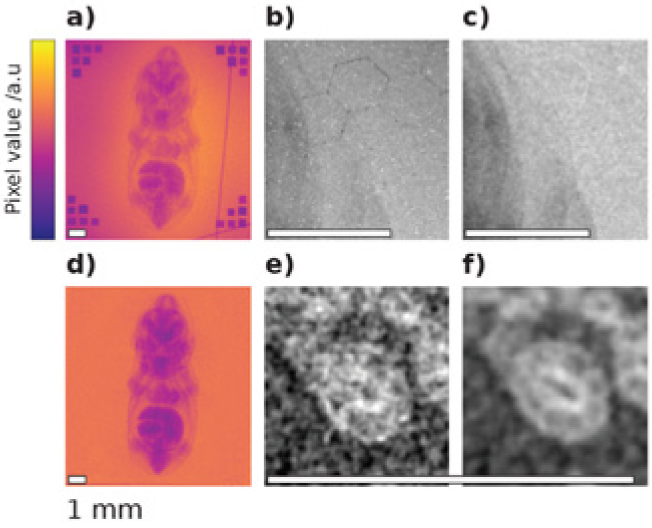
X-rays generated through betatron oscillations of electrons in laser wakefield accelerators have ideal properties for biological imaging. In recent years, experiments on Gemini have increased the flux and critical energy of betatron x-rays into the 10s keV regime that is needed to penetrate cm-scale objects, such as bone samples, mouse embryos, and soft tissue biopsies. Data analysis is complicated by fluctuations in x-ray profile, spectrum and brightness. In this report, we discuss the image quality and processing steps taken to perform tomographic reconstruction on a dataset obtained using Gemini.



(a) Raw image of mouse embryo detected by the x-ray CCD, wires are placed as fiducials for tomographic reconstruction. (b) Region of image showing hot and cold pixels and (c) the result of applying a selective median filter. (d) Processed version of the image in (a). (e) Zoomed region showing remaining noise and (f) the result of applying a non-local-denoising technique.

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Comparison of the properties of bright compact x-ray sources

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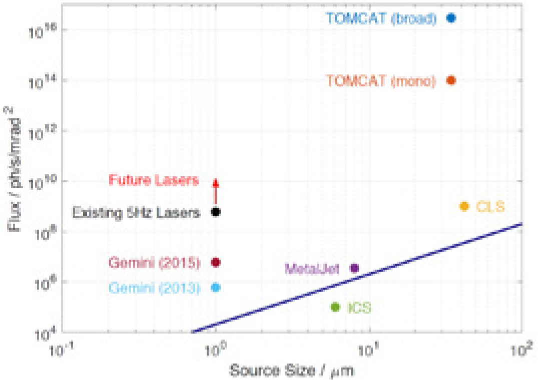
Compact x-ray sources with much higher brightness than conventional electron-impact x-ray tubes are being developed to translate the advanced techniques achievable at synchrotron beamlines to laboratory settings. The benefits for biological research will be faster scanning at very high resolution for rapid microtomography and in vivo studies. X-ray sources based on relativistic electron beams produced in miniature plasma accelerators driven by high power lasers have ideal properties for these applications of micron-scale source size, extreme brightness and ultrashort image exposure time. The lateral coherence of the beam enables phase contrast imaging, providing superior contrast between soft tissues compared to traditional absorption-based radiography. The purpose of this report is to compare the performance of plasma accelerator based x-ray technology to other options available to researchers, and to discuss future capabilities.



Flux of compact x-ray sources plotted against the x-ray source size. Values for the MetalJet (purple circle) and the Compact Light Source (yellow circle); parameters of the TOMCAT beamline (broad bandwidth: blue circle, 2% bandwidth: brown circle); simulated limit to solid anode tungsten sources (blue line); laser-based ICS source (green circle) and laser-betatron source. Existing lasers operating at 5 Hz could increase betatron flux to 6 x 10^8 ph s^{-1} $mrad^{-2}$ and developments in the near future could reach >10^{10} ph s^{-1} $mrad^{-2}$.

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Ultrafast Imaging of Laser Driven Shock Waves using Betatron X-rays from a Laser Wakefield Accelerator

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Betatron radiation from laser wakefield accelerators is an ultrashort pulsed source of hard, synchrotron-like x-ray radiation. It emanates from a centimetre-scale plasma accelerator producing GeV level electron beams. In recent years, betatron radiation has been developed as a unique source capable of producing high resolution x-ray images in compact geometries. However, until now, the short pulse nature of this radiation has not been exploited. This report details the first experiment to utilize betatron radiation to image a rapidly evolving phenomenon, by using it to radiograph a laser-driven shock wave in a silicon target. The spatial resolution of the image is comparable to what has been achieved in similar experiments at conventional synchrotron light sources. The intrinsic temporal resolution of betatron radiation is below 100 fs, indicating that significantly faster processes could be probed in future without compromising spatial resolution. Quantitative measurements of the shock velocity and material density were made from the radiographs recorded during shock compression, and were consistent with the established shock response of silicon, as determined with traditional velocimetry approaches. This suggests that future compact betatron imaging beamlines could be useful in the imaging and diagnosis of high-energy-density physics experiments.

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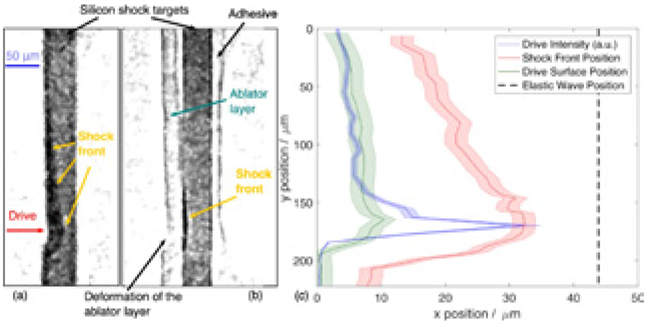

X-ray images of shocked silicon targets taken with betatron radiation. (a) Radiograph of a laser driven shock in silicon at 5.2ns after the start of the interaction. The shock driving laser travelled from left to right. The geometric magnification of the images was 30. (b) Radiograph of a shock wave in silicon with a 25μm CH ablator layer on the drive surface taken at Δt=6.5ns. Also visible is adhesive at the rear of the target, which did not participate in the interaction. (c) Drive laser intensity (blue), shock front position (red) and drive surface position (green) as a function of y found from the image of the untamped silicon sample, where the shaded area indicates the error. The black dashed line shows the position that the elastic wave, which was not observed in this experiment, would have reached after 5.2ns (travelling at 8.43 kms^{-1}).

Reprinted from Wood, J.C., Chapman, D.J., Poder, K. et al. Ultrafast Imaging of Laser Driven Shock Waves using Betatron X-rays from a Laser Wakefield Accelerator. Sci Rep 8, 11010 (2018) doi:10.1038/s41598-018-29347-0, published by Springer Nature, under the Creative Commons Attribution 4.0 International License.

Bremsstrahlung emission from high power laser interactions with constrained targets for industrial radiography

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Laser–solid interactions are highly suited as a potential source of high energy X-rays for non-destructive imaging. A bright, energetic X-ray pulse can be driven from a small source, making it ideal for high resolution X-ray radiography. By limiting the lateral dimensions of the target we are able to confine the region over which X-rays are produced, enabling imaging with enhanced resolution and contrast. Using constrained targets we demonstrate experimentally a (20 ± 3) μm X-ray source, improving the image quality compared to unconstrained foil targets. Modelling demonstrates that a larger sheath field envelope around the perimeter of the constrained targets increases the proportion of electron current that recirculates through the target, driving a brighter source of X-rays.

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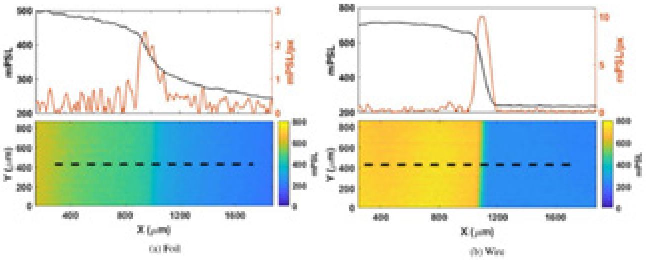

Penumbral radiograph, scale in mPSL (unit of flux for IP), and lineout for (a) foil and (b) wire targets. The dashed line in each radiograph is where the lineout is determined.

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Bremsstrahlung emission profile from intense laser-solid interactions as a function of laser focal spot size

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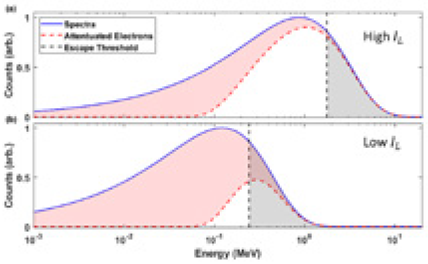
The bremsstrahlung X-ray emission profile from high intensity laser-solid interactions provides valuable insight into the internal fast electron transport. Using penumbral imaging, we characterise the spatial profile of this bremsstrahlung source as a function of laser intensity by incrementally increasing the laser focal spot size on target. The experimental data shows a dual-source structure; one from the central channel of electrons, the second a larger substrate source from there circulating electron current. The results demonstrate than an order of magnitude improvement in the intensity contrast between the two X-ray sources is achieved with a large focal spot, indicatir preferable conditions for applications in radiography. An analytical model is derived to describe the transport of supra-thermal electron populations that contribute to substrate and central channel sources through a target. The model is in good agreement with the experimental results presented here and furthermore is applied to predict laser intensities for achieving optimum spatial contrast for a variety of target materials and thicknesses.



Schematic of electron circulation throughout the target, demonstrating how the two source structure emerges in the X-ray emission.

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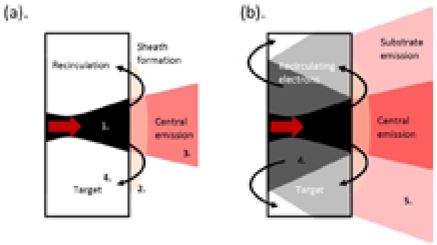

Maxwellian distribution for electrons with temperature at two different laser intensities, top for 10^{20} Wcm^{-2} and bottom for 4 x 10^{18} Wcm^{-2}, this correlates to the laser at best focus and 150 μm defocus. The red dashed line indicates electron transmission through the target, black dashed line is the escape energy cut-off. The population of electrons between these two lines contributes to the substrate source (unshaded), the other two (red—collisional, grey—escaping) can only contribute to the central source.

Reprinted from C D Armstrong et al. (2019) Bremsstrahlung emission profile from intense laser-solid interactions as a function of laser focal spot size, Plasma Phys. Control. Fusion 61 034001, doi: 10.1088/1361-6587/aaf596, under the under the terms of the Creative Commons Attribution 3.0 Licence

EMP control and characterization on high-power laser systems

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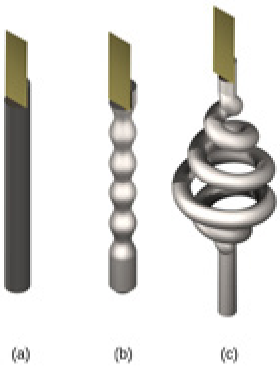
Electromagnetic pulses (EMP) generated during the interaction of high-power lasers with solid targets can seriously degrade electrical measurements and equipment. EMP emission is caused by the acceleration of hot electrons inside the target, which produce radiation across a wide band from DC to terahertz frequencies. Improved understanding and control of EMP is vital as we enter a new era of high repetition rate, high intensity lasers (e.g. the Extreme Light Infrastructure). We present recent data from the Vulcan laser facility that demonstrates how EMP emission can be significantly reduced. We show that target holder (stalk) geometry, material composition, geodesic path length and foil surface area can all play a significant role in the reduction of EMP. A combination of electromagnetic wave and 3D particle-in-cell simulations is used to inform our conclusions about the effects of stalk geometry on EMP, providing an opportunity for comparison with existing models of laser-target charging.



Three different stalk designs used to support the laser target: (a) cylinder (b) sinusoidally modulated stalk (c) spiral stalk. A significant reduction in EMP amplitude was observed for plastic stalks of all stalk designs compared with a metallic stalk of type (a). The biggest overall reduction was seen for a plastic spiral stalk design

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An optically multiplexed single-shot time-resolved probe of laser–plasma dynamics

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We introduce a new approach to temporally resolve ultrafast micron-scale processes via the use of a multi-channel optical probe. We demonstrate that this technique enables highly precise time-resolved, two-dimensional spatial imaging of intense laser pulse propagation dynamics, plasma formation and laser beam filamentation within a single pulse over four distinct time frames. The design, development and optimization of the optical probe system is presented, as are representative experimental results from the first implementation of the multi-channel probe with a high-power laser pulse interaction with a helium gas jet target. The probe has also uncovered interesting, evolving front surface dynamics on solid targets. The novel concept presented here has the potential to be extended and adapted for cross-disciplinary research interests that could benefit from temporally resolving ultrafast processes, particularly in cases where the underlying dynamics appear stochastic.

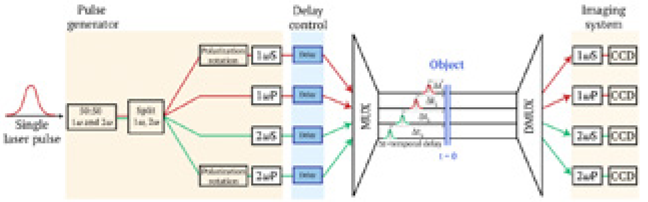

Figure 1: Process flow diagram of multiplexed optical probe concept. A single ultrashort laser pulse is divided into four separate laser pulses which are uniquely encoded by frequency and polarization. The four pulses are independently delayed in time and then spatially multiplexed (MUX) to propagate co-linearly in order to optically probe a given point in space and time. The inverse process (DMUX) is then applied to spatially separate and form an image for each of the channels. This enable 2D spatial and picosecond temporal resolution over multiple frames with a single laser pulse.

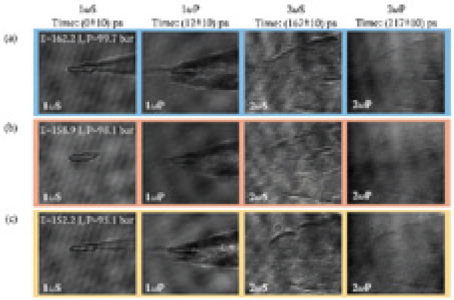

Figure 2: Shadowgraphy measurements of each probe output channel from the experiment for (a) E = 162.2 J, P = 99.7 bar (b) E = 158.9 J, P = 98.1 bar and (c) E = 152.2 J, P = 95.1 bar.

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Dual Ion Species Plasma Expansion from Isotopically Layered Cryogenic Targets

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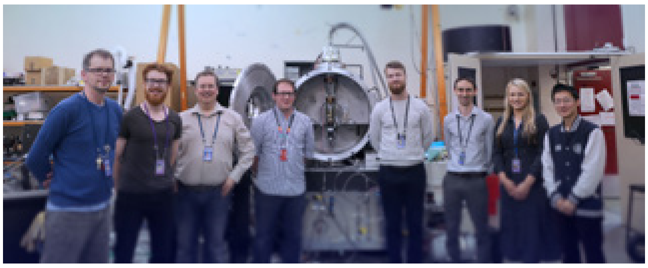
In this study we utilise the state-of-the-art cryogenic targetry capability, jointly developed by the Central Laser Facility and A-SAIL consortium, to freeze nanometre-thick layers of solid density deuterium onto the rear surface of a target substrate, on which hydrogen rich monolayers are present.

In this unique target configuration, a heavier (deuteron) ion species exists as a separate layer between the target vacuum interface and a lighter (proton) ion species, and we show that this results in the ability to control the acceleration of the heavier ion population expansion dynamics, resulting in a spectrally peaked, directional beam.

In the full article[1], we present the first theoretical consideration and experimental demonstration of a plasma expansion scheme of this nature.

This article was featured as a CLF highlight.



Part of the experimental team alongside the CLF/A-SAIL cryogenic targetry apparatus

[1] G.G. Scott et al., Phys. Rev. Lett. 120, 20480, 2018

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Supersonic Turbulence in the Laboratory

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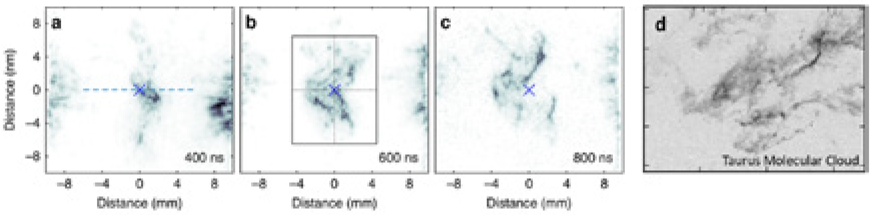
The properties of supersonic, compressible plasma turbulence determine the behaviour of many terrestrial and astrophysical systems. In the interstellar medium and molecular clouds, compressible turbulence plays a vital role in star formation and the evolution of our galaxy. Observations of the density and velocity power spectra in the Orion B and Perseus molecular clouds show large deviations from those predicted for incompressible turbulence. Hydrodynamic simulations attribute this to the high Mach number in the interstellar medium (ISM), although the exact details of this dependence are not well understood. Here we investigate experimentally the statistical behaviour of boundary-free supersonic turbulence created by the collision of two laser-driven high-velocity turbulent plasma jets. The Mach number dependence of the slopes of the density and velocity power spectra agree with astrophysical observations and support the notion that the turbulence transitions from being Kolmogorov-like at low Mach number to being more Burgers-like at higher Mach numbers.



Schlieren images showing the region between two colliding supersonic jets taken at (a) 400 ns, (b) 600 ns, and (c) 800 ns after the peak of the drive laser. The development of filament-like structures is characteristic of supersonic turbulence and consistent to those found in the Taurus molecular cloud (d) G.V. Panopoulou et al. MNRAS, 444, 2507 (2014).

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