Femtosecond Pulse Physics

High-density, ultra-relativistic positron beams using the Astra-Gemini laser

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Sketch of the experimental setup (top-view)

We report here on recent results obtained at the Astra-Gemini laser system concerning laser-driven generation of high-quality, ultra-relativistic positron beams. Positron beams with divergence as low as a few mrad, energy as high as 600 MeV, and density as high as 10^{16} particles per centimetre cubed have been experimentally obtained. These results greatly advance previous experimental attempts in this field (30 times increase in energy and 30 times decrease in divergence). These positron beams display appealing characteristics for a wide range of practical applications such as laboratory-based studies of astrophysically relevant electron-positron-ion plasma phenomena and GeV laser-driven electron-positron colliders. Moreover, the positron density reported is only five times lower than what is produced at the Stanford Linear Accelerator (SLAC), which is, to our knowledge, the highest density of stable antimatter ever achieved in the laboratory.

X-Ray measurements of the interaction of the Astra-Gemini pulse with large atomic clusters

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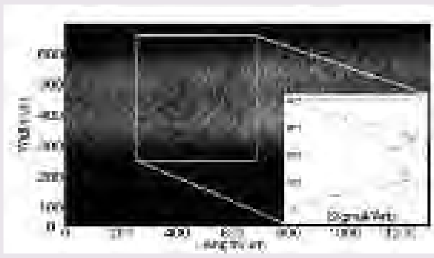
In this experiment we conducted the first laser-cluster interaction studies undertaken with the Gemini laser. To characterise hard x-ray self emission we used a beryllium filtered x-ray pinhole camera to capture the early time spatial distribution of the hot plasma filament generated in a laser cluster interaction. This initial distribution has a key role in determining the evolution of the later time shock which can be used to conduct laboratory astrophysics experiments.

Using this diagnostic we have observed the interaction of large atomic clusters, 10000 atoms, and relativistic laser intensities, ~10^{19} Wcm^{-2}. We have observed the formation of a cylindrical plasma filament at lower backing pressures which likely results from electron blow out from the laser focus. This measurement is confirmed by our streaked Schlieren diagnostic which also shows a cylindrical structure. The dependence of this behaviour on gas jet backing pressure is reported.



Plasma filament captured on the x-ray pinhole camera with ~13.6 J of energy in krypton with a backing pressure of 24.3 bar. A clear dip in density is observed at the centre of the plasma filament. The FWHM of the filament observed here is ~300 μm and the dip is ~200 μm

Relativistic electron beams with low energy spread by ionisation injection in a structured gas cell

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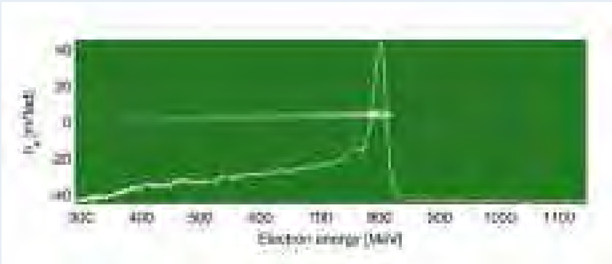
Ionisation injection of electron bunches into a laser driven wakefield was tested using a gas mix of helium and nitrogen. For the intensities on Astra-Gemini, the electrons are released from the inner shell of nitrogen in a region of the wakefield potential where trapping is possible. This configuration used one of the Astra-Gemini beams focused at f/20 into a gas cell with three compartments. The gas mix was released in the middle compartment in an attempt to improve the energy spread by spatially limiting region of ionization injection. Reproducible mono-energetic electron bunches were produced with energies in the range 600-800 MeV and energy spreads below 2%.



Spectrum of a mono-energetic electron beam on the spectrometer second scintillating screen

Extended guiding of ultra-intense laser pulses up to 4 cm in a gas cell

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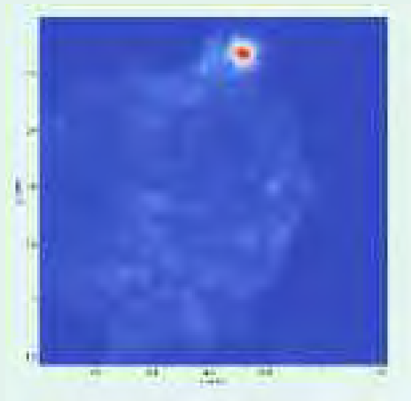
We report on the measurement of relativistic self-guiding of multi-100 TW laser pulses in an underdense plasma. The results were obtained with the use of a newly designed variable length gas cell, which greatly enhances shot-to-shot reproducibility. The spatial intensity profiles of laser pulses were imaged after propagating up to 39mm in plasma. The agreement between the size of the guided filament and relativistic plasma wavelength confirms that the laser was relativistically self-guided. Using slightly lower plasma densities than in the present case should still preserve the guiding characteristics measured in the current study, thus opening up exciting prospects of multi-GeV single stage electron energy gain with sub-petawatt lasers.



Measured spatial intensity distribution of laser pulse exiting 39mm long plasma.

Optically-stimulated side scatter in a laser wakefield accelerator

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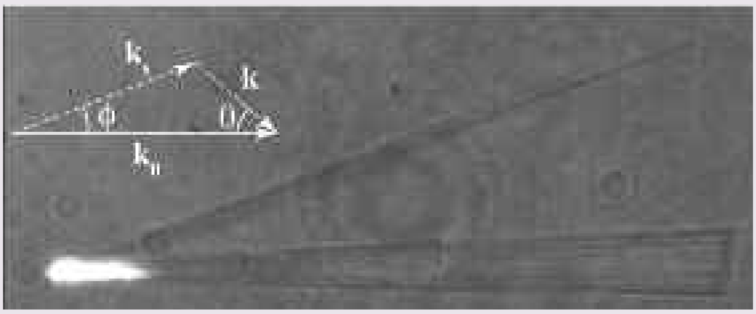
A set of laser wakefield acceleration (LWFA) experiments were performed on the Astra Gemini laser with a supersonic gas jet as the plasma target. The second Gemini beam was used to perform shadowgraphy and interferometry of the plasma, and an optical spectrometer analysed the scattered light. Filaments emerging from the plasma channel were observed at characteristic angles which increased with plasma density, indicating they were generated by Raman side scatter (RSS) of the main laser pulse. When the two Gemini beams were spatiotemporally overlapped at the beginning of the plasma channel a striking enhancement in the amount of RSS was observed. The enhancement was found to vary with the relative polarisation of the two beams, reaching a maximum when both were polarised in the same direction. This effect was attributed to an electron parametric instability where the presence of both beams could generate a plasma wave at the correct angle to stimulate the RSS process.



Shadowgraphy on a plasma channel generated with the Astra Gemini laser demonstrates the formation of a secondary channel at a large angle to the first. This is caused by strong Raman scattering of the laser pulse, where the scattered light gains transverse momentum from the plasma.

Relativistic raman side scatter measurements in a laser wakefield accelerator

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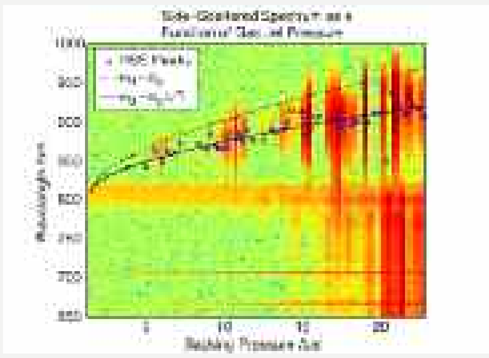
The Astra laser was used to perform Laser Wakefield Acceleration (LWFA) in a gas-jet target, with the TA2 probe beam being used for Mach-Zehnder interferometry of the plasma. An optical spectrometer recorded the spectra of light scattered at 90° from the interaction and observed light shifted from the laser wavelength by the Raman Side Scatter (RSS) instability. The expected shift as calculated from the interferometry data was found to be an overestimate, but good agreement was seen once the relativistic motion of the plasma electrons was accounted for. The required relativistic factor was constant with electron density, suggesting the RSS process occurs early in the laser-plasma interaction. The RSS bandwidth was observed to increase with electron density, qualitatively agreeing with a linear model.

A series of side-scattered spectra are plotted as a function of plasma electron density, which increased linearly with the gas jet backing pressure. Raman scatter at the plasma frequency overestimates the frequency shift, but good agreement is observed with the relativistically-lowered plasma frequency.



High energy, high charge electrons and energetic X-rays from a density tailored gas target

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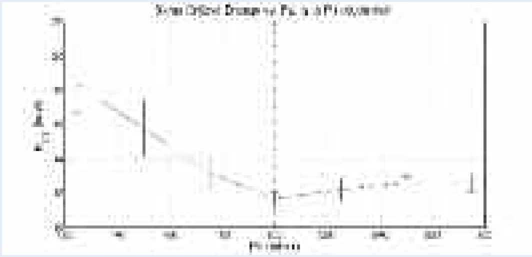
An important feature of laser wakefield accelerators (LWFA's) is the production of high brightness, temporally short x-ray beams without an insertion device. This makes LWFA's a potential source of such x-rays for university and medical laboratories.

This report focuses on data from a 3-compartment gas cell target with a density down-step/ down-ramp between the second and third compartments. Controlling the size of this step allowed the maximum electron energy and total accelerated charge to be tuned. As the pressure in the second compartment was decreased a sharp increase in the energy of the x-ray beam was observed, with maximum critical energies of approximately 18 keV.



X-ray critical energy (assuming an on-axis synchrotron spectrum) versus the backing pressure of the third gas cell compartment (P2). The backing pressure of the first and second compartments (P1) was constant at 300 mbar.

Thorough calibration of a scintillating Lanex screen as an electron bunch charge diagnostic

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An important characteristic of any particle accelerator is the total charge of the accelerated bunch that they output. In laser wakefield acceleration experiments this is often calculated from images taken of a scintillating Lanex screen with a CCD camera. Therefore it is necessary to know how many electrons are required to produce a single count on the greyscale camera image. Lanex response as a function of charge is well known. However the transmission of light through the optics to the camera, and the response of the camera, are not always well characterised. This report presents a method whereby the image of the scintillator is compared to an image plate reading of the same shot. A number of important considerations, including the modified response of Lanex and image plate at GeV electron energies, geometrical factors, natural decay of image plate signal and possible saturation effects are described.

Setup for a scintillating Lanex screen calibration. By comparing the signal levels on the lanex screens and the image plates, the lanex can be calibrated as an electron bunch charge diagnostic.

Generation of giant attosecond pulse from laser-driven relativistic electron sheets

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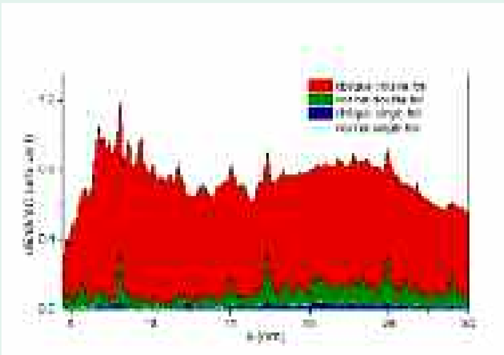
Isolated attosecond pulses are of particular interest for real-time observation of ultrafast electron behavior in atoms or solids. Apart from well-established mechanisms, instead of employing periodic nonlinear process in atoms or plasma, a flying relativistic electron sheet (FRES) could be an ideal producer of isolated attosecond pulses. It has been recently observed that the wavelength and duration of a counter-propagating probe pulse could be significantly down-shifted via coherent Thomson backscattering from a FRES. Here we report the first experimental realization of another intriguing option to generate isolated giant attosecond pulse from FRES without the need for an additional laser pulse. By irradiating a double layer target composed of ultrathin foils with S-polarized high-intensity laser under oblique incidence, a FRES is generated at first and then transversely kicked by the drive pulse reflected at second foil. Such coherent transverse motion of the FRES results in a transverse sheet current of 1.5 MA/cm^2, which produces a bright , continuum XUV radiation extending up to 280 eV, supporting a single giant attosecond pulse with peak electric field over 1TV/m.



Measured spectra from 4 nm to 30 nm for variety of targets under different incidence.

Radiation pressure of relativistically intense lasers

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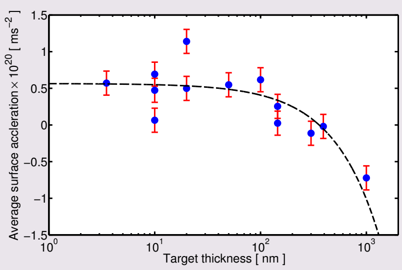
Here, we report on measurements of the motion of the laser-reflecting surface during the interaction of the Astra Gemini Laser with nm-scale targets using frequency resolved optical gating (FROG). The results show accelerations away from the laser of up to 0.5 × 10^{20} ms^{-2} during the 50 fs interactions with nm-scale targets at a peak laser intensity of 2 × 10^{20} Wcm^{-2}. Increasing the target thickness has the effect of decreasing the observed acceleration. The measured accelerations indicate that a simple light-sail model is inadequate to describe the interactions, as the target is seen to thermally expand with plasma temperatures of around 100 keV. Also, the maximum observed surface recession velocity of 0.02 c would correspond to proton energies of 1.7 MeV if accelerated by the hole-boring mechanism. This is considerably lower than seen in the experiment, demonstrating that hole-boring is accountable only for the lower energy part of accelerated ion spectra. Therefore, an electrostatic sheath acceleration mechanism is most likely dominant in these interactions.



Average surface acceleration as a function of DLC target thickness. The points show the experimental data and the dashed line is a linear fit. Positive acceleration is in the direction away from the incident laser.

Hole-boring at high intensity in near-critical density targets 11

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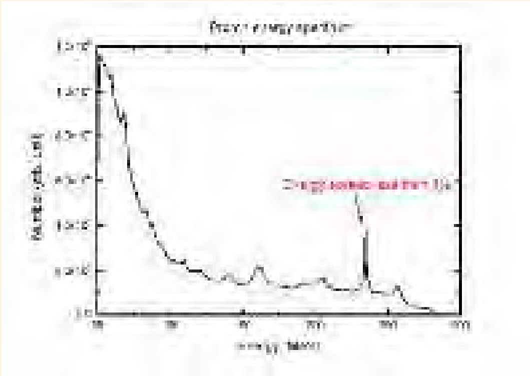
In this report we discuss the generation of high quality proton beams from HB-RPA using two-dimensional Particle-in-Cell simulation. It is found that the energy spectrum of the proton beam has a sharp spike at more than 200 MeV with an energy spread less than 1% by 4.0×10^{22} W/cm^2 laser pulse. To further elucidate the generation and control of this spectral peak, a series of simulations were carried out to consider the effect of laser pulse intensity, pulse duration and plasma density on proton peak energy and energy spread.



Proton energy spectrum at the end of the simulation for a pulse length of 35 fs and initial density 5 times critical.

High Energy Laser Interactions

Fast electron injection and transport angles in high intensity laser-solid interactions

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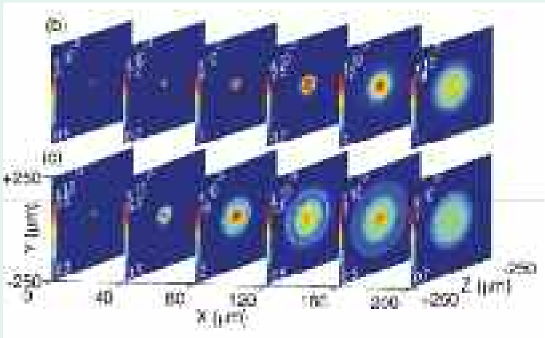
The fast electron beam divergence in solid foils irradiated by picosecond, ~4×10^{20} W/cm^2 laser pulses is characterised experimentally and via 3D simulations. The simulations are performed using Zephyros hybrid-PIC code, for a wide range of fast electron beam source conditions, with and without inclusion of self-generated resistive magnetic fields. The results are used in a plasma expansion model calculation to compare with measurements of proton acceleration, as a function of target thickness. An injection half-angle of ~50° -70° is inferred, which is larger than that derived from previous experiments under similar conditions.



False-colour 2D profiles of the fast electron density distribution at given depths for $<\theta_{1/2}>$~50° and 0.8 ps runtime, for (top) with resistive self-generated magnetic field included, and (bottom) with the B-field artificially suppressed.

Laser specular reflectivity as a function of target Z

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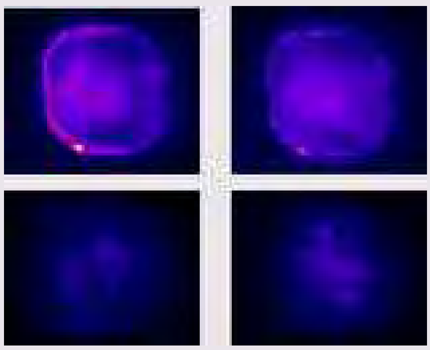
Much of the interesting physics in the interaction of a high power laser pulse with a solid occurs in the region of the critical density in the preformed plasma at the front, irradiated surface. It is at the relativistically-corrected critical density surface, beyond which the laser pulse cannot propagate, that the laser pulse is reflected and at which energy is absorbed to the production of fast electrons and high order harmonics generation.
With this experiment we show how the specular reflectivity at the fundamental wavelength and the energy fraction converted to the second harmonic vary with the target atomic number, Z (using CH, Al, Cu, Ag and Ta targets). We find a variation of ~25% between the targets. We also present measurements of specular reflectivity and the generated fraction of second harmonic radiation as a function of the peak laser intensity.



Spatial distribution of the specular reflected beam at 1ω in Cu (up-left) and Ta (up-right) and of the energy fraction converted at 2ω in Cu (down-left) and Ta (down-right)

Ion beam characterisation from ultra-thin plasticfoil targets under direct illumination with the Vulcan Petawatt

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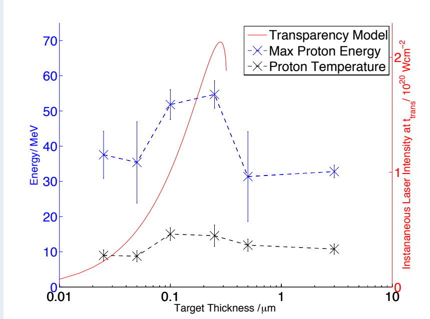
Due to improved contrast ratios on the Vulcan Petawatt laser it is of interest to directly illuminate ultrathin targets without the use of plasma mirrors. This not only greatly simplified the experimental arrangement but also increased the energy available on target.

In this report we present data showing high-energy proton production from ultrathin formvar foils with thicknesses down to 25nm irradiated with Vulcan Petawatt without the use of plasma mirrors.

Proton energies over 50 MeV were observed for targets of 250 nm down to 25 nm. Optimal foil thicknesses of 100 to 250 nm were observed.

An analytical model for predicted optimum thicknesses for proton acceleration from relativistically transparent targets was used. The observed optimum of 250 nm agrees with the model for an intensity 12% of that measured.



Blue left axis; Maximum (blue) and mean (black) measured peak proton energies as a function of target thickness. Each data point is an average value for up to 4 shots at a particular target thickness. The error bars for a) and b) are calculated from the individual shot error, number of data points and spread of points. Red right axis: instantaneous laser intensity at the time when the target becomes relativistically transparent as a function of target thickness. The laser intensity was decreased to 12% its experimental value to fit to the data. Targets thinner than 310 nm become relativistically transparent.

Probing the solid-liquid transition of carbon at ~150 GPa pressure using spectrally resolved X-ray scattering

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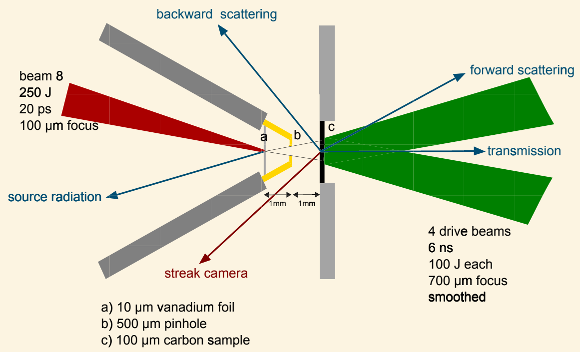
The carbon phase diagram at extreme conditions is of increasing interest for modelling planetary interiors and many high energy density laboratory applications. Despite there exist numerous theoretical models and calculations, substantial experimental data of the phase boundaries and microscopic properties are very scarce.

To overcome the lack of experimental data, we successfully applied spectrally resolved X-ray scattering from shock-compressed graphite samples. Within our experiments, this method has proven to be capable of directly determining the atomic structure of carbon close to the melting region around 150 GPa comparing the ratio of elastically and inelastically scattered radiation. Using different types of graphite targets, we were able to cross the melting line of carbon at a relatively constant pressure. This can be used to constrain models of the carbon phase diagram not only by the position of the melting line but also by resulting values of the structure factor for the liquid phase.



Sketch of the experimental setup at Vulcan, Target Area West.

Theory and Computation

Flux-limited heat-flow and magnetic-field transport in laser-plasmas

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It has long been recognised that classical theory over-estimates the thermal flux in laser-plasma interactions when the temperature gradient is steep - an effect known as flux-limited heat-flow. To account for such discrepancies, many laser plasma fluid codes employ *ad hoc* flux-limiters, typically set to some fraction s_f of the free-streaming heat-flow q_f, where $s_f < 1$ is `tuned' by comparison with kinetic calculations. Here we argue that the inclusion of flux-limited heat-flow necessitates similar limitation of the thermoelectric term in Ohm's Law; indeed, we demonstrate that without such restrictions fluid codes are liable to over-estimate magnetic field advection, sometimes by more than an order of magnitude, with further implications for thermal energy transport.

Quantum radiation reaction in laser-electron beam collisions

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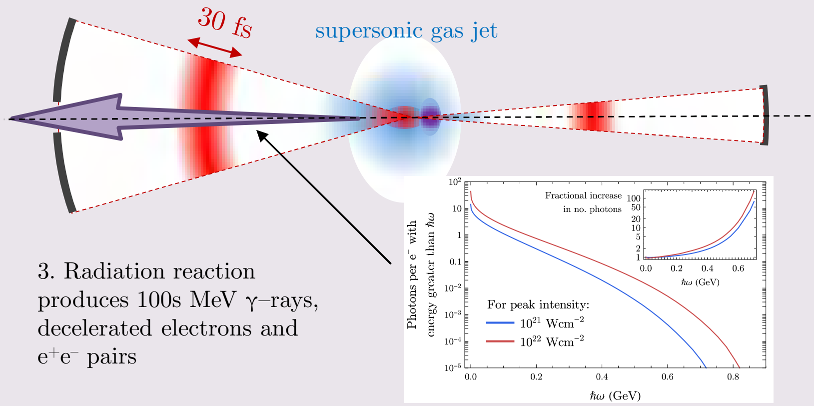
High intensity laser facilities are now capable of producing electromagnetic fields of sufficient magnitude to reach the strong-field QED regime. The dynamics of energetic electrons in these fields will be dominated by quantum radiation reaction, which will be observed in the efficient conversion of electron energy to gamma rays.

This could be demonstrated in the collision of a GeV electron beam and a laser pulse of intensity $>10^{21}$ Wcm^{-2}. As the emission process is probabilistic, it is possible for electrons to 'straggle', i.e. reach the region of highest intensity at the centre of the pulse having lost little to no energy to radiation.

Our simulations show these electrons emit much more energetic gamma rays, dramatically increasing the yield compared to that predicted by classical radiation theory.



The increase in the yield of gamma rays with energy comparable to that of the electron is increased by two orders of magnitude over that predicted classically.

Angular distribution of high harmonics generated during laser-preplasma interaction

18

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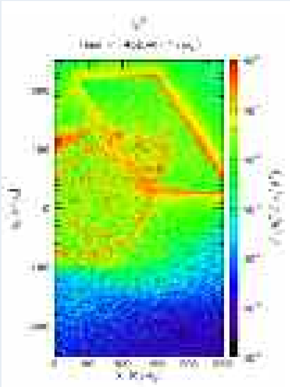
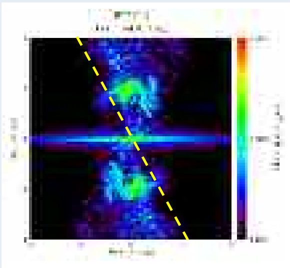
High harmonic generation in laser-solid interactions is important for the generation of sub-fs pulses having ultrahigh intensity. In order to maximise the efficiency of this process, a precise characterisation of the angular distribution of the emitted harmonic spectrum is indispensable. The results of particle-in-cell simulations indicate that the maximum intensity of the harmonics is found at angles close to the target surface, rather than close to the incident or reflected laser beam, for preformed plasma. This appears closely related to the deformation of the critical surface by the impact of the laser beam and laser-plasma instabilities in the area of impact. The effect of density gradient scale length, laser angle of impact and laser pulse intensity and duration on the angular distribution of the harmonics will be discussed.





Simulations of synchrotron radiation effects in 10PW+ laser solid interactions

19

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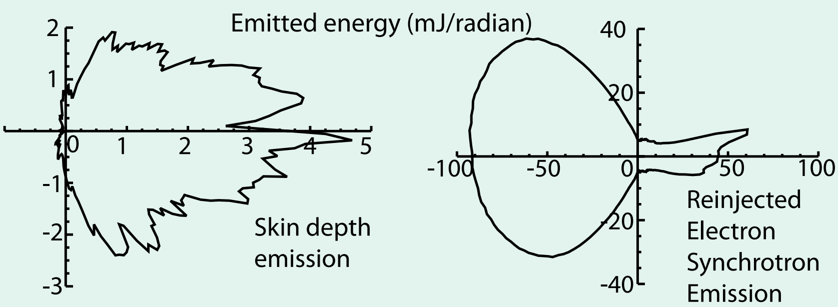
Potential applications for next generation ultra-high intensity lasers are broad, ranging from ion acceleration to fast ignition fusion. Understanding synchrotron emission from targets illuminated with next generation lasers is essential, both for developing laser driven gamma ray sources, and due to it's important effects on all other plasma physics processes in this intensity regime. In this report the current understanding of the process of synchrotron emission in laser illuminated targets is explored and the main emission mechanisms are compared.



Angular distribution of generated gamma rays for skin-depth emission (left) and Reinjected Electron Synchrotron Emission (RESE) (right).

Ultrafast processes: time dependent R-matrix methods 20

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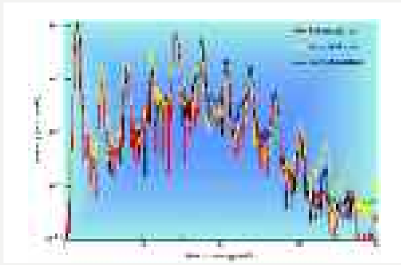
As laser pulses have become shorter it has become possible to study processes unfolding on the attosecond (1 as = 10^{-18} s) time-scale. Recent experiments have measured ionisation rates and multielectron dynamics within a single laser cycle. Such high-resolution techniques rely upon detailed theoretical models of laser-matter interactions. We have developed the time-dependent R-matrix (TDRM) method and applied the R-matrix with time (RMT) technique for the description of general multielectron atoms or ions in short, intense laser pulses. The strength of these methods is their ability to describe multielectron dynamics from first principles.

We have applied TDRM theory to investigate harmonic generation in Ar^+, finding that multichannel and multielectron interferences can substantially reduce the harmonic yield.

We have also applied the newly developed RMT method to ionisation dynamics in carbon, finding a significant proportion of the final population in channels connected with the excited, $2s2p^2$ $^4P^e$ state of C^+.



Harmonic generation from Ar^+ in a 390-nm, $4x10^{14}$ Wcm^{-2} laser pulse is strongly affected by multichannel (yellow) and multielectron (black) interferences-calculations neglecting either effect overestimate the total harmonic yield (red) by up to an order of magnitude.

Recent developments in Lorentz-Abraham-Dirac fluid theory 21

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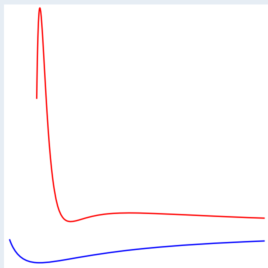
We summarize our methodology for modelling collective effects including the radiative self-force. The Lorentz-Abraham Dirac equation is used to generate a Vlasov equation, which is used to explore entropy and to induce a warm fluid theory. Our approach is a natural generalization of established methods for generating warm fluid models without radiation reaction.



The role of collisionless electrostatic shocks in laser-plasmas 22

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We propose a theory to describe laminar ion sound structures in a collisionless plasma. Reflection of a small fraction of the upstream ions converts the well known ion acoustic soliton into a structure with a steep potential gradient upstream and with downstream oscillations.

The theory provides a simple interpretation of results dating back more than forty years but, more importantly, is shown to provide an explanation for recent observations on laser produced plasmas relevant to inertial fusion and to ion acceleration.

Creating hollow atoms with a petawatt laser

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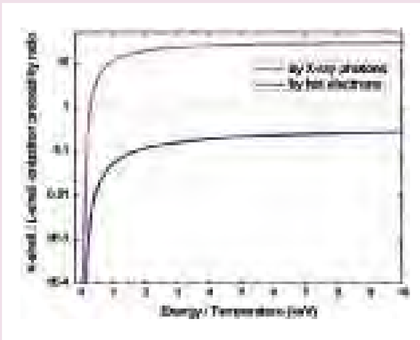
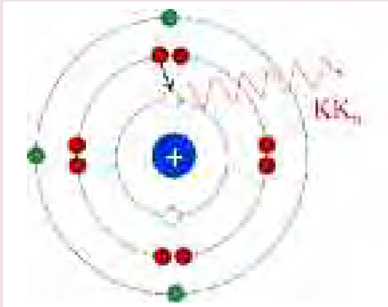
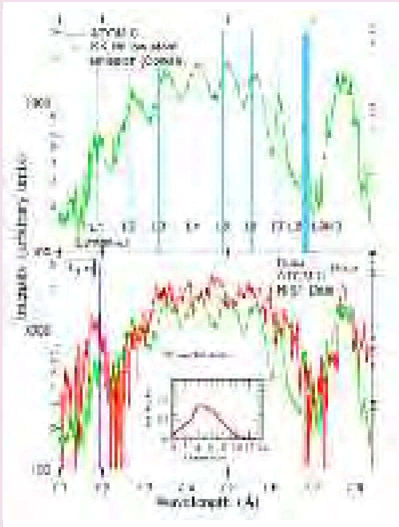
We have described hollow atoms and shown that these result in multiple features between the typical spectral lines Ly-α and He-α. These features are identified as emission of KK-α, resulting from the radiative transition between the n = 2 level to an empty n = 1 level with different degrees of ionization. Atomic kinetics calculations suggest that intense KK-α emission can occur in solid density aluminium when driven by keV Planckian radiation fields. In these extreme conditions, the high recombination rates at solid density continually repopulate bound atomic states. Strong KK-α emission has been observed in Vulcan petawatt experiments. This observation implies the existence of a keV radiation field with intensities exceeding 10^{18} Wcm^{-2}, approaching the Planckian limit. Our analysis suggests the radiation field is driven by bremsstrahlung and Thomson scattering as relativistic electrons reflux in thin targets.



– Ionisation probability ratio from the K and L shells by photo-ionisation, or by electron collisional ionisation (blue). At energies >1keV, the probability of photo-ionisation is much greater than that of ionisation by hot electrons.



Schematic of the aluminium KK hollow atom – double K-shell (n=1) vacancy and its radiative decay with the remainder of the L-shell wholly or partially intact.



-shell emission, compared to expected wavelengths of hollow atom emission by the Cowan model (b) Bottom panel: Experimental data compared with the same ATOMIC simulation as in 2(a), with accepted NIST wavelengths for the Al He-α and Ly-α transitions.

Advanced models for the effective ionisation energy in dense plasmas

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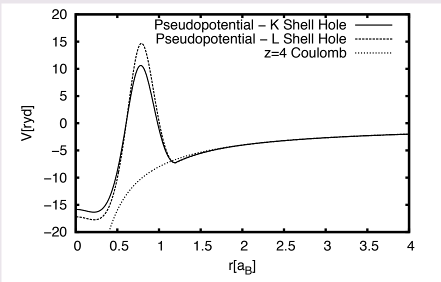
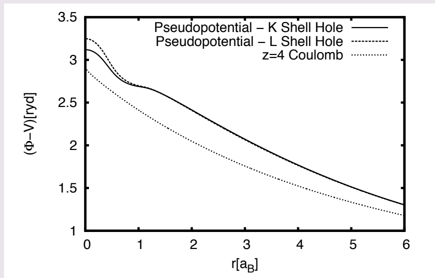
In a dense plasma, the potential of the charge carriers will be screened by the presence of other free ions and free electrons. Screening effectively limits the range of the interaction between the particles and, thus, removes the long-range divergencies of the Coulomb potential occurring in many basic calculations [Kremp et al., 2005]. As a result, screening modifies the equation of state as well as many transport and relaxation properties of a plasma.

Screening of the field of an ion also modifies the bound state structure associated with this ion. The main effect is a weakening of the bound states. Some bound states will even cease to exist if screening is strong enough [Kremp et al., 2005]. Those states remaining will have their ionisation energies altered, that is lowered [Debye and Hueckel, 1923; Zimmerman and More, 1980; Stewart and Pyatt, 1965]. This change in ionisation energy is often called continuum lowering or ionisation potential depression (IPD). The IPD should be correctly quantified if the ionisation state of a dense plasma, and thus its properties, is to be predicted in equilibrium as well as for situations driven far out of nonequilibrium [Schlanges et al., 1988].





a) The three unscreened potentials used in the calculation. The point at which the pseudopotentials converge with the Coulomb potential gives an indication of the extent of the bound states. b) The induced potential, due to the free electrons and nearby ions which is calulated as Φ - V. Note that there is significant variation of the induced potential over the extent of the bound states and beyond partially intact.

Efficient laser pulse amplification by stimulated Brillouin scattering

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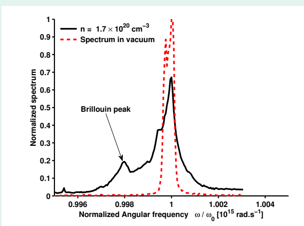
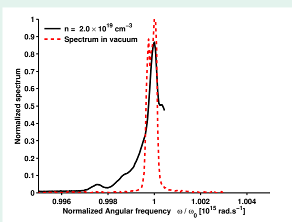
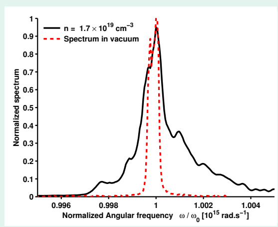
The energy transfer by stimulated Brillouin backscatter from a long pump pulse (15 ps) to a short seed pulse (1 ps) has been investigated in a proof-of-principle experiment. The two pulses were both amplified in different beamlines of a Nd:glass laser system, had a central wavelength of 1054 nm and a spectral bandwidth of 2 nm, and crossed each other in an underdense plasma in a counter-propagating geometry, off-set by 10 degrees. It is shown that the amplification factor and the wavelength of the generated Brillouin peak depends on the plasma density, the intensity of the laser pulses and the competition between two-plasmon decay and stimulated Raman scatter instabilities, by comparison with particle-in-cell simulations. The highest obtained energy transfer from pump to probe pulse was 2.5%, at a plasma density of 0.17 n_{cr}, and this energy transfer increases significantly with plasma density. Therefore, our results suggest that much higher efficiencies can be obtained when higher densities (above 0.25 n_{cr}) are used.







Vacuum birefringence revisited

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The article discusses vacuum birefringence as a change in photon polarisation resulting from light-by-light scattering. It utilises the low-energy effective Lagrangian first derived by Heisenberg and Euler in 1936 to express the scattering amplitude in terms of the vacuum polarisation tensor. Modifications due to transverse and longitudinal beam size effects are taken into account by considering Gaussian beams in the paraxial approximation.

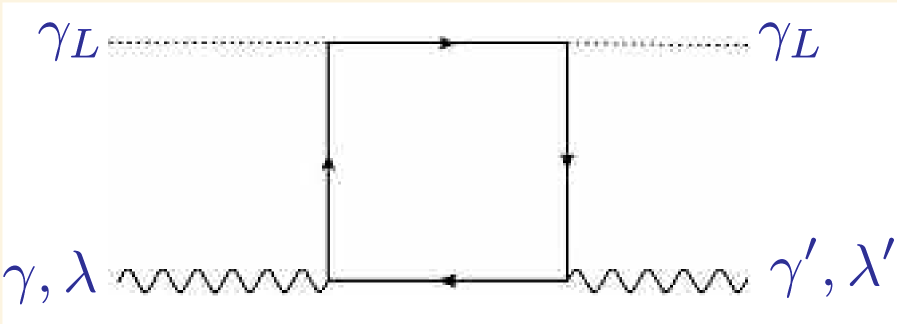

Figure: Feynman diagram describing Vacuum birefringence from light-by-light scattering. Dotted (Wavy) lines represent laser (probe) photons. The process is made possible by the presence of a virtual electron-positron loop (full lines).

Simulating driving plasma wakefield acceleration with the Diamond beam

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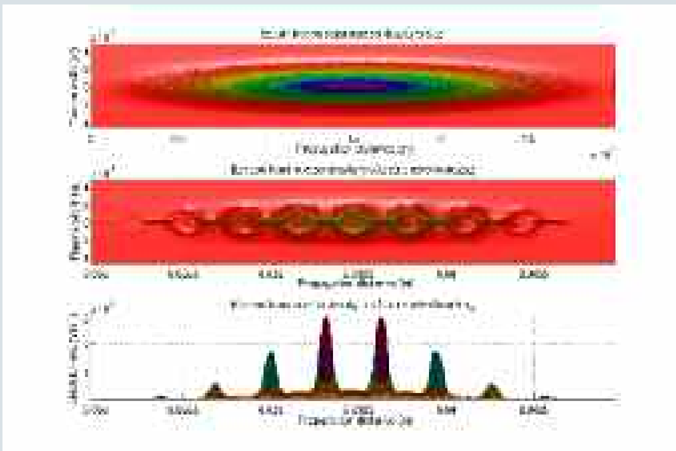
Full-scale, multi-dimensional particle-in-cell simulations to investigate the viability of using the Diamond Light Source 3 GeV electron beam to drive plasma wakefield acceleration have been performed. Micro-bunching the electron beam in the longitudinal direction using a short plasma cell was found to yield high amplitude wakefields (4 GV m^{-1}) in a second plasma cell. An ultra short high intensity laser pulse (E = 1 J, T = 50 fs) was used to heavily seed the self modulation instability to microbunch the Diamond beam. Once driven, the wake-field can be used to accelerate a witness electron beam to higher energies (up to 6 GeV in a single stage).



Short Diamond beam number density before propagating through the first plasma cell (top) and after (middle and bottom)

Effect of collisions on amplification of laser beams by Brillouin scattering in plasmas

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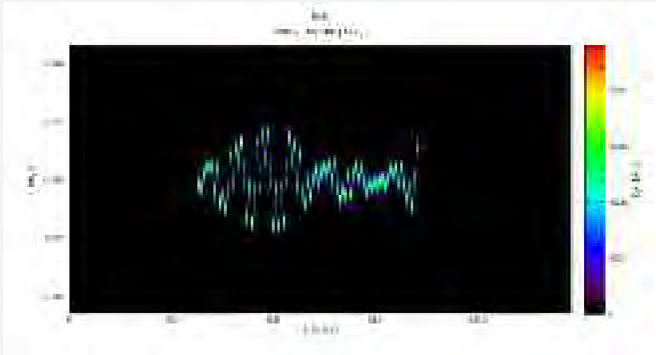
We report on particle-in-cell simulations of energy transfer between a laser pump beam and a counter-propagating seed beam using the Brillouin scattering process in uniform plasma including collisions. The results presented show that the ion acoustic waves excited through naturally occurring Brillouin scattering of the pump field are preferentially damped without affecting the driven Brillouin scattering process resulting from the beating of the pump and seed fields together. We find that collisions and the effects of Landau damping allows for a more efficient transfer of energy between the laser beams and a significant reduction in the amount of seed pre-pulse produced.



An R-matrix with pseudo-states (RMPS) approach for single photon double ionization of the He-like Li^+ ion

29

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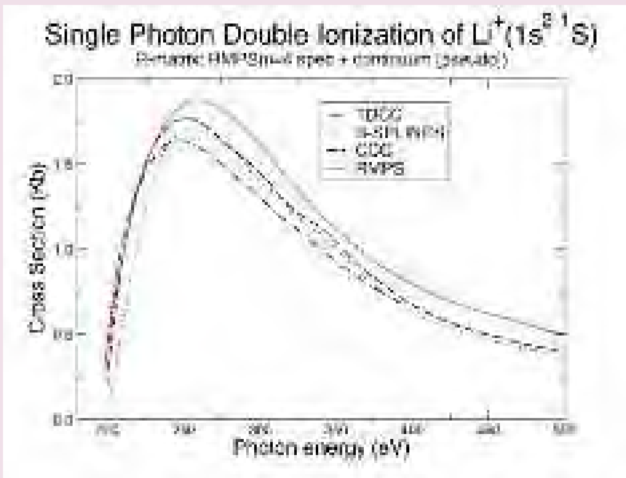
The R-matrix with pseudo-state (RMPS) method is applied to single photon double ionization cross-sections for the He-like, Li^+ ion. We investigate these processes from both the ground state and the excited 1s2s $^{1,3}S$ metastable levels of this He-like system. Comparisons of the results from the R-matrix plus pseudo-state (RMPS) method are made with other state-of-the-art theoretical approaches such as time-dependent close-coupling (TDCC), B-splines and the convergent close-coupling (CCC) methods. Excellent agreement with these theoretical approaches is achieved however some differences occur which are highlighted in the present work.



Theoretical cross sections (Kb) for the single-photon double-ionization of Li^+ ions from the ground-state for the photon energy range 200 eV to 500 eV. Results from the present R-matrix plus pseudo-states (RMPS: solid line), the time-dependent close-coupling (TDCC: dot-dashed line), convergent close-coupling (CCC: dashed line) and B-splines (dotted line) methods are included for comparison purposes.

Radiation damping of an electron in an intense laser pulse

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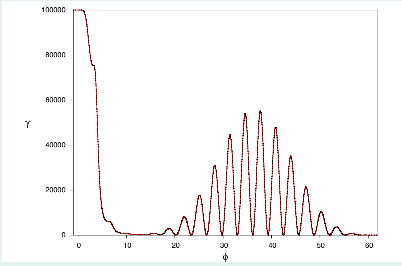
The correct theoretical description of a charged particle responding to its own radiation field remains elusive, despite more than century of investigation. We analyse a model proposed by Ford and O'Connell, and demonstrate that it can be used to test the validity of the more commonly used Landau Lifshitz (LL) equation. By comparing the two models in an intense laser field, we show that radiation reaction effects prevent an electron from accessing a regime in which the LL description breaks down.



The inclusion of gamma-ray photon emission and pair production in simulations of high power laser matter interactions

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Current high power lasers focus light to such extreme intensities (>10^{21}Wcm^{-2}) that electron dynamics in the laser fields can be strongly affected by nonlinear quantum electrodynamics (QED) effects: namely the emission of gamma-ray photons and electron-positron pairs. We will show how these processes can be included in particle in cell plasma simulation codes. The resulting QED-PIC code has been used to simulate the interaction of a 1PW laser pulse with a GeV electron beam and a 12.5PW pulse interacting with a solid aluminium target. In the case of the GeV electron beam ~50% of the electron beam energy is converted to gamma-rays. In the laser-solid interaction 10% of the laser pulse energy is converted to gamma-rays and an electron-positron plasma of density 10^{20}cm^{-3} is created.

EPOCH QED-PIC simulation of a 12.5PW laser-pulse, FWHM 30fs, striking a solid aluminium target (3D grey). 10% of the laser energy is converted to gamma-ray photons (blue) and a pure electron positron plasma of peak density 10^{20}cm^{-3} is generated.

Generation of super-ponderomotive electrons via direct laser acceleration with longitudinal electrostatic fields

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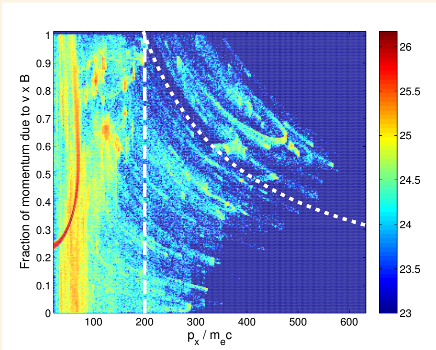
It is shown that electrons with momenta exceeding the 'vacuum' limit of $m_e ca_0^2/2$ can be produced when a laser pulse and a longitudinal electric field interact with an electron. This differs from wakefield acceleration in that both the laser and the longitudinal field are present, i.e. it is direct laser acceleration. The critical component of this mechanism is the reduction of the electron dephasing rate σ-$p_x m_e c$ by an accelerating region of electric. This mechanism can, in principle, produce electrons that have longitudinal momenta that is a significant multiple of $m_e ca_0^2/2$.



Electron phase space in 1D PIC simulation at 300 fs shown as p_x versus the fraction of each macroparticle's momentum due to ev_zB_y acceleration only. The dashed vertical line indicates the 'ponderomotive limit', i.e.$m_e ca_0^2/2$ and the dash-dot line represents the point at which the portion due to ev_zB_y is equal to $m_e ca_0^2/2$.

Control of relativistic electron beams for fast ignition using elliptical magnetic mirrors

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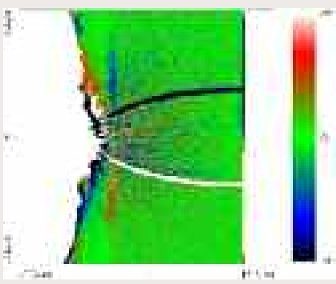
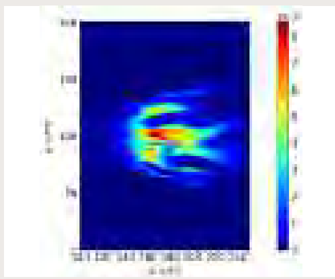
In order for Fast Ignition to be successful it is of vital importance that the energy of the fast electron is deposited inside a small region in the fuel core. In order to counteract the increasing electron spread with laser intensity, measures have to be taken in order to concentrate the electrons towards the hot spot. We present a novel elliptical mirror target geometry to collimate fast electrons based on self generated magnetic fields at resistivity gradients. Initial 2.5 dimensional collisional PIC simulations provide a proof of concept. It is shown that electrons are indeed collimated rather than just channeled inside the high-Z material. Subsequent large scale hybrid simulations with realistic length and time scales assess the performance of the magnetic mirror concept under more realistic conditions. We find an increase of the coupling efficiency into the dense core by a factor of 3 to 4. Thus the elliptical mirror scheme has considerable potential for improving the prospects of Fast Ignition.



Averaged z-component of the magnetic field at time t = 100fs. The large fields to either side of the target have been masked out.



Ion internal energy density at 20ps in Jm^{-3} in the baseline simulation for x > 100μm.

Numerical modeling of the sensitivity of X-Ray driven ICF implosions to low-mode flux asymmetries

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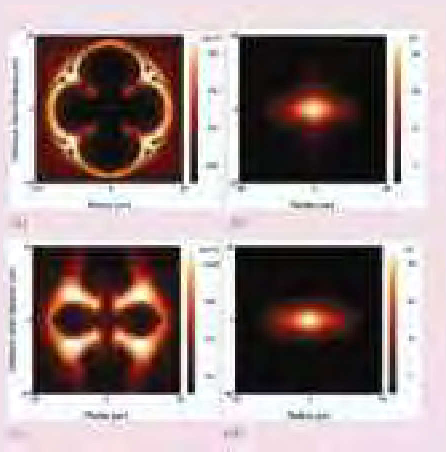
The sensitivity of inertial confinement fusion implosions, of the type performed on the National Ignition Facility (NIF), to low-mode flux asymmetries has been investigated numerically. It is shown that large-amplitude, low-order mode shapes (Legendre polynomial P_4), resulting from low order flux asymmetries, cause spatial variations in capsule and fuel momentum that prevent the DT "ice" layer from being decelerated uniformly by the hot spot pressure. This reduces the transfer of implosion kinetic energy to internal energy of the central hot spot, thus reducing neutron yield. Furthermore, synthetic gated x-ray images of the hot spot self-emission indicate that P_4 shapes may be unquantifiable for DT layered capsules. Instead the positive P_4 asymmetry "aliases" itself as an oblate P_2 in the x-ray images. Correction of this apparent P_2 distortion can further distort the implosion while creating a round x-ray image. Long wavelength asymmetries may be playing a significant role in the observed yield reduction of NIF DT implosions relative to detailed post-shot 2D simulations.



Axis of rotational symmetry is vertical at Radius = 0 μm. (a) DT layered capsule density plot at x-ray bangtime showing a positive Legendre polynomial P_4 shape. This simulation had a 10% flux asymmetry applied from 11.5-14 ns. Black arrows indicate the mass flows which occur during stagnation. After bangtime 'fingers' of fuel continue to flow inwards (red arrows). White dots depict the hot spot contour. (b) Synthetic gated x-ray image of the hot spot self emission from 1(a), white dots show the 17% contour, a_4 is greatly reduced compared to fig. 1(a). (c) The same implosion as fig. 1(a), but 100 ps later. Large a_4 brings the bangtime earlier, meaning this image is plotted at the neutron bang-time of an equivalent spherical implosion. (d) The synthetic GXD from 1(c), showing a large negative (oblate) P_2 and almost zero a_4 despite the obvious P_4 in 1(c).

Using k-alpha emission to determine fast electron spectra using the hybrid code ZEPHYROS

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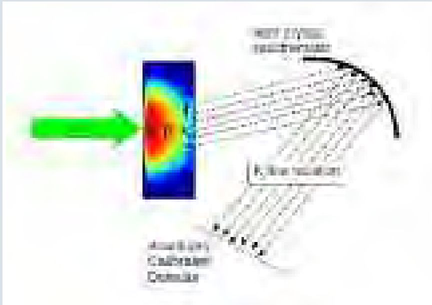
A high intensity laser-solid interaction invariably drives a non-thermal fast electron current through the target. These electrons are accelerated by the radiation field of the laser pulse and can reach energies from a few keV to several MeV. The background resistivity of the solid target or plasma means that the electron current sets up resistive electric fields, a strong return current and magnetic fields. Through a process of collisions and Ohmic heating by the return current the fast electron population loses energy to the surrounding material. On reaching the far side of the target strong sheath fields are set-up which reflect many of the electron back into the target. These processes complicate the dynamics of fast electron transport.

Understanding how fast electrons propagate through dense materials is of fundamental interest and has applications relevant to fast ignition schemes and ion acceleration. The return currents also heat solid density material to temperatures from a few to tens of eV creating high energy density states of matter relevant to the study of planetary interiors, warm dense matter and equation-of-state.

A fast electron that has been accelerated through a target produces intense x-ray and VUV emission, primarily through Bremsstrahlung radiation and K-shell ionization in the solid material. The resulting K-shell line emission can be used as an x-ray diagnostic to infer the properties of the fast electron population. Here, we show how the ZEPHYROS hybrid code can be used to infer the spectral temperature, angular divergence and absorbed laser energy of the fast electron distribution from the emitted k-.spectrum. A spectrum of this kind can be obtained experimentally though the use of an absolutely calibrated, imaging, k-alpha spectrometer.



Possible schematic showing how the k-alpha radiation can be obtained experimentally

Simulations of ring structures produced in proton acceleration from dense targets

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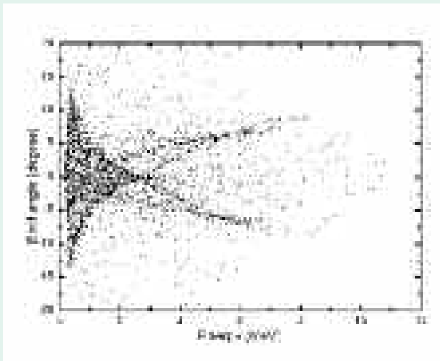
In this report we discuss the simulation of ring structures produced in proton acceleration from the interaction of a high intensity laser modeled on the short pulse laser of Vulcan Target Area West (TAW) with gold targets. An ionisation model has been included in the PIC code, and has been found to have a crucial role in the formation of the rings. The results agree well with experimental results. Using PIC codes including ionisation may open a new avenue in the understanding of laser-matter interaction.



Ultrafast and XUV Science

Hydrogen bond dynamics in water

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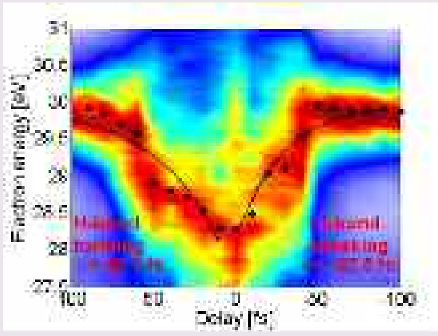
Ultrafast charge transfer dynamics in liquid water have been followed for the first time with sub 100 fs temporal resolution. Coupling the unique 30 fs monochromatic VUV source of the Artemis beamline with microliquid jet technology the researchers were able to conduct time resolved photoelectron spectroscopy from a liquid surface. This technique allowed charge transfer in water to be observed and the ultrafast rearrangement of the hydrogen bond network to be followed

Upon exciting the combination vibration mode of water with a 1.9 μm pump pulse; a monochromated 38 eV VUV pulse probed the water molecular orbitals. A motion of characteristic liquid phase energies rapidly developed gas phase energies within 40 fs, before returning to liquid phase levels within 80 fs. This energy shift points to the local breaking and reordering of the localised hydrogen bond network when a water molecule is excited by two quanta of vibrational energy.



Centre of mass motion of the $^{1}b_{1}$ liquid HOMO of water upon excitation of the combination stretch and bend mode of water. Right-hand side pump pulse arrives after probe pulse.

Snapshots of non-equilibrium Dirac carrier distributions in graphene

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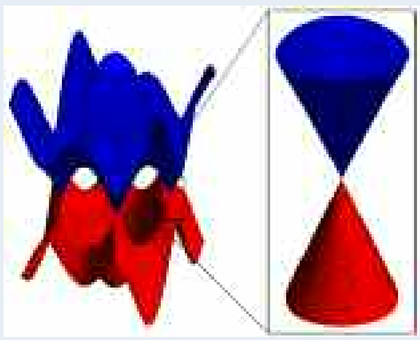
Graphene, a single layer of sp^2-bonded carbon atoms arranged in a honeycomb lattice, is one of the few ideally two-dimensional crystals available today. While the in-plane σ-bonds are responsible for graphene's extreme mechanical strength, the out-of-plane π-bonds determine graphene's peculiar electronic properties. They originate from two cosine-shaped bands that cross at the Fermi-level, where they form a Dirac cone with linear instead of the conventional parabolic dispersion. Hence, charge carriers in graphene behave like massless Dirac particles, offering the possibility to investigate the predictions of relativistic quantum electrodynamics in a simple solid state system.



Graphene's electronic structure. The valence (conduction) band is shown in red (blue). Valence and conduction band touch at the Fermi level at the K-point of the hexagonal Brillouin zone forming a Dirac cone with linearly dispersing bands.

Watching hot electrons decay on the Dirac cone in graphene

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The ultrafast dynamics of excited Dirac carriers in graphene plays a central role for many electronic and optoelectronic applications. Harvesting energy from excited electron-hole pairs, for instance, is only possible if these pairs can be separated before they lose energy to vibrations. While the hot carrier dynamics in graphene could so far only be accessed indirectly, we here present the first direct time resolved view on the Dirac cone by angle-resolved photoemission (ARPES). This allows us to show the quasi-instant thermalisation of the electron gas to a temperature higher than 2000 K; to determine the time resolved carrier density; and to disentangle the subsequent decay into excitations of optical phonons and acoustic phonons (directly and via supercollisions). Finally, we quantify the carrier multiplication and show that it agrees with theoretical predictions. This work has been made possible by the state-of-the-art time resolved high harmonics ARPES system at the Artemis facility.

Left: Schematics of the dominant decay mechanisms of photoexcited hot electrons on the Dirac cone of graphene. Right: The upper row of images shows spectra at different time delay. The lower row displays the corresponding difference spectra, i.e. the change with respect to the spectrum for the equilibrium case.

UV pump XUV probe photoelectron spectroscopy

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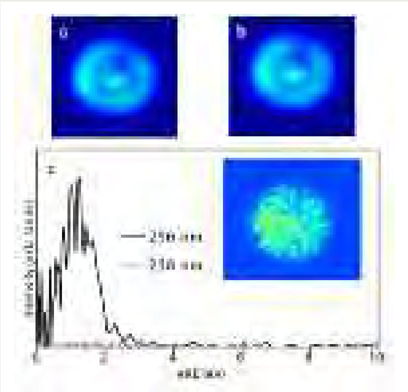
Time resolved photoelectron spectroscopy (TRPES) has proved itself as a key technique in the study of photoinduced molecular dynamics. The basic concept of TRPES is that a chemical event is triggered with an ultrashort laser pulse (pump) and the molecular system being investigated is subsequently ionised by a second, time-delayed, laser pulse (probe) at a series of different delays after excitation. The energies and angular distributions of the outgoing electrons are measured and the dynamics of the system are inferred from changes in the measured photoelectron image. One of the main reasons for its ubiquity is that all states can be ionized, in principle, meaning that it should be possible to measure the entire reaction coordinate using this method. Despite this, in most cases it has not been possible to ionise the entire reaction coordinate due some reactive intermediates and products having large ionization limits and/or poor overlap with the ionization continuum. This leads to significant "blind spots" in the reaction mechanism, where no information about the system is obtainable. The limiting factor has been the wavelength range over which conventional femtosecond lasers can work.

Recent developments in the generation of high energy femtosecond light pulses are set to revolutionize atomic, molecular and optical science.



a) VUV + UV signal with UV coming 10 ps before the VUV. b) VUV + UV signal with VUV coming 10 ps before the UV. c) inset. Difference between a) and b) showing the pump probe component of the signal. Main. Photoelectron spectrum of the pump probe signal at two different pump wavelengths.

Two-colour HHG spectroscopy and wavelength dependence of HHG in aligned molecules

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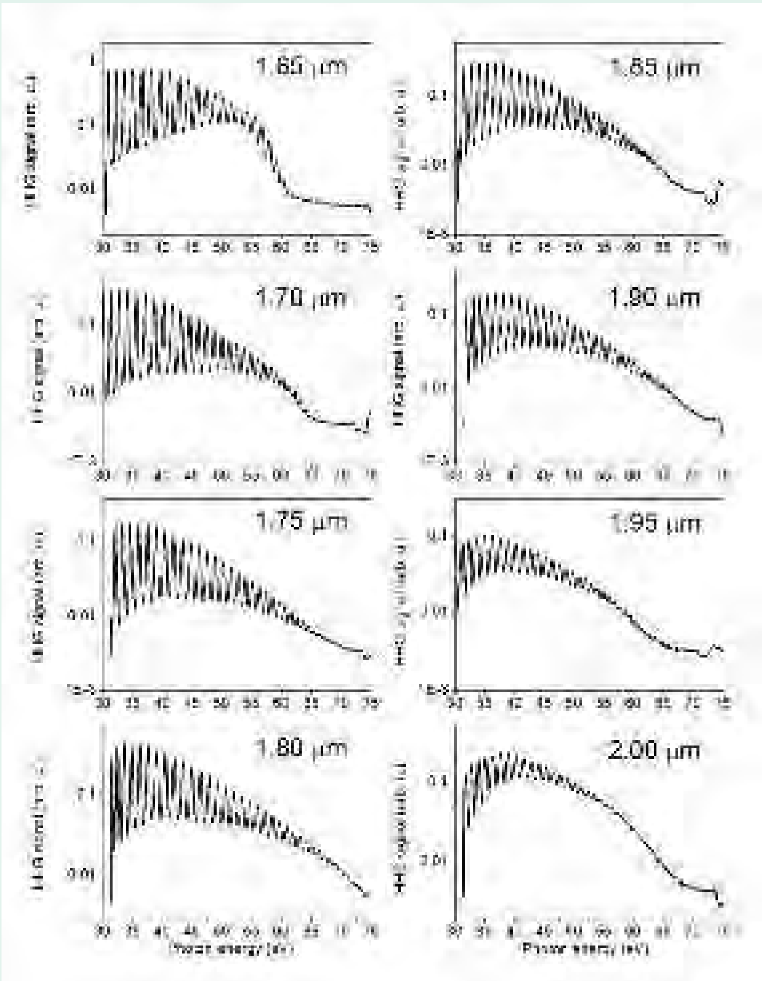
High harmonic generation (HHG) spectroscopy is a novel technique that exploits the generation of harmonics of the laser field in a molecular gas to acquire information about the molecules. HHG spectroscopy has demonstrated the capability to track the ultrafast dynamics of molecules with attosecond time resolution, however, one of the main difficulties of this technique is to produce a large enough range of harmonic orders to get sufficient information.

We have explored different ways to extend the harmonic spectrum in molecules, using a combination of two laser fields with different wavelengths and increasing the wavelength of a single laser field towards the mid-infrared. We have measured HHG spectra in ethylene with laser fields of up to 2000 nm. While this condition is in principle ideal for the generation of very high harmonic orders we have found that the low laser energy available is the most stringent limitation.



Harmonic spectra of ethylene with different single-colour fields.