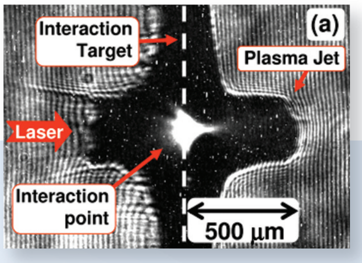
Plasma Physics



Plasma jets and narrow bandwidth ion spectra from thin foils irradiated at high laser intensity

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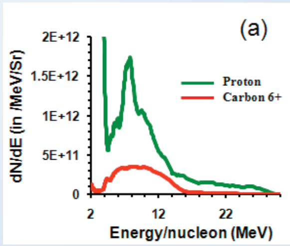
Plasma jet evolution and ion acceleration from micron to sub-micron thickness foils following the interaction of ultra intense (up to 3 $\times 10^{20}$ W/cm^2) laser pulses has been investigated using the Vulcan Petawatt laser. With the maximum achievable intensity on target, jets with Mach number up to 10 have been observed from few microns thick Cu foils expanding longitudinally with a velocity of 2×10^6 m/s. Using circularly polarized pulses, the uniformity of the jet density profile is improved significantly as compared to the jets observed from the interaction of a linearly polarized laser. While moderate energy (KeV) overdense plasma jets are formed efficiently for micron thickness target irradiated at 10^{20} W/cm^2 intensity, decreasing the target areal density or increasing irradiance on target leads to an acceleration regime in which Carbon ions and protons are accelerated, in narrow band peaks, to tens of MeV/nucleon energies.

Experimental data showing emergence of a dense plasma jet at the rear side of the interaction target, probed transversely at 600 ps after the interaction with the high power laser (above).



Proton and carbon spectra obtained from the interaction of high power laser with 100 nm thick target.

Influence of overlapping high-intensity laser beams on electron and ion generation and transport

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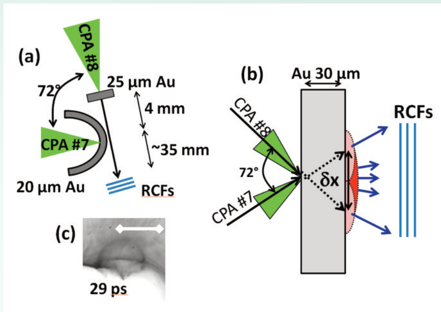
We studied the influence of overlapping high-intensity Vulcan TAW CPA laser beams when interacting with solid metal targets. We performed an experiment using two different setups as shown in figure (a) and (b). A number of measurement techniques were used to diagnose the electron transport and proton generation, including proton radiography (see figure (c)), stacked charged particle detectors, and shadowgraphy. We clearly observed striking differences in phenomena when using, for the configurations shown in (a), two beams separated by < 3 ps, compared to having them synchronized. When they were slightly delayed, we indeed observed longitudinal parallel jet-like proton deflection patterns, likely due to transverse strong field gradients at the target rear (non-irradiated side). In the case of dual overlapping synchronized beams, as shown in (b), we observed a strongly collimated accelerated proton beam, likely to be attributed to the overlapping of bell-shaped electrostatic sheaths at the target rear surface.



Two different setups of our experiment, using either (a) two temporally separated collinear laser beams, or (b) two spatially separated, synchronised, quasi-orthogonal beams. (c) Typical proton probing data obtained in setup (a), recorded ~29 ps after the laser interaction. The bar corresponds to 500 µm in the target plane.

Characterization of a line focus back-lighter

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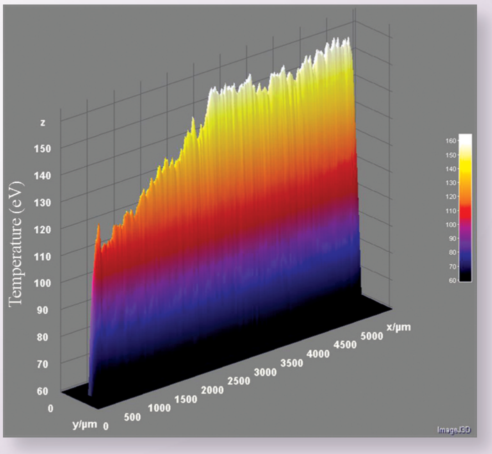
Laser produced plasmas are often used as back-lighters to other plasmas. In order to make high quality measurements of transmission, the EUV/x-ray back-lighter source must be well characterized. Accurate information regarding the emission from the back-lighter and its transmission through the opaque plasma allows for the opacity to be effectively determined. This work demonstrates how a time and spectrally integrated image of plasma emission from a crossed-slit camera has been used to infer a spatially dependant profile of electron temperature in a line-focus EUV back-lighter.

Spatially dependant profile of electron temperature in a line-focus EUV back-lighter, inferred from a time and spectrally integrated emission profile of a crossed-slit image.



Creation of persistent, straight, 2mm long laser-driven channels in underdense plasmas for fast ignition applications

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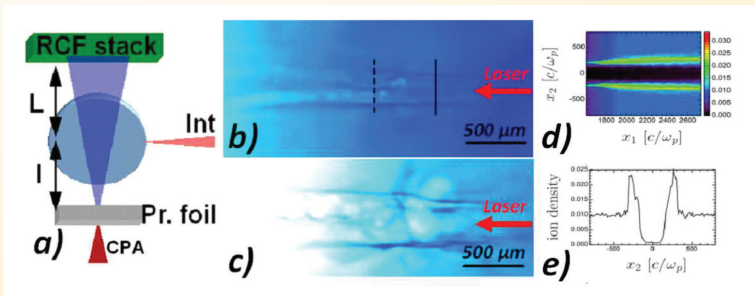
There are a number of applications of intense laser pulses that require the formation of a long-lived, long-scale, density-depleted channel in an underdense plasma. These include quality control of 100s MeV electron bunches generated in laser wakefield accelerators, high brightness X-ray generation in these channels by betatron oscillations and Fast Ignition.

Here we report the experimental detection of a smooth, persistent density depleted channel in a Deuterium plasma of initial electron density $n_e \approx 2 \times 10^{18} cm^{-3}$. The channel has been detected to extend for the entire plasma length (of the order of 2mm) and to persist, almost unperturbed, for at least 100ps after the laser has started to propagate through the plasma. Data analysis indicate that the channel preserve sharp walls with a density accumulation of the order of 2-3 n_e and an inner density of 0.2-0.3 n_e. The experimental results have been confirmed by matching 2-dimensional Particle-In-Cell simulations.

These characteristics of the channel have been made possible by the particular set of laser parameters employed (P_L = 6TW, τ_L = 30ps); the laser lays in fact below the threshold for relativistic self-focussing, thus hampering the onset of detrimental relativistic instabilities, and it is long enough to provide sustained ponderomotive push of the channel walls.



a) Top view of the experimental arrangement. b), c) Proton radiographs of the channel 100ps and 150ps after the beginning of the interaction. d) Channel creation as simulated by the 2D PIC code. e) Simulated ion density profile across the channel.

Observation of post-soliton expansion following laser propagation through an underdense plasma

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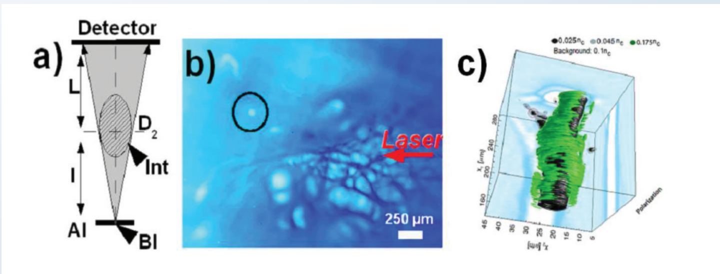
The late-time stage of the interaction between a relativistically intense laser pulse (E_L = 200J, τ_L = 30ps, $I_L \approx 3 \times 10^{18}$Wcm^{-2}, Int laser in Figure) and a deuterium plasma with initial electron density of the order of a fraction of the critical density has been experimentally studied via the proton radiography technique. The data indicate the presence of several density depletions, located around the main laser-driven channel and at the end of the laser filaments, that are interpreted to be the late-time remnants of electromagnetic solitons (namely post-solitons). Electromagnetic solitons arise from the trapping of the laser radiation inside the plasma and, on a time scale long enough to allow ion motion, are predicted to expand as a consequence of Coulomb explosion of the positively charged soliton core. These entities are of central relevance to this class of laser-plasma interactions, being one of the main vectors of laser energy dissipation during its propagation through the plasma.

For the frst time, the temporal evolution of these structures has been experimentally measured. The data indicate deviations from a pure spherical expansion, unveiling laser polarisation effects on the post soliton dynamics. Experimental data have been found to be in good agreement with ad-hoc 3-dimensional Particle-In-Cell simulations and published analytical models.



a) Top view of the experimental arrangement. b) Typical proton radiograph of the interaction: the dark circle outlines a density bubble interpreted to be a post-soliton. c) 3D PIC simulated ion density of the interaction.

Perspectives on radiative blast waves in laser-heated clustered gases

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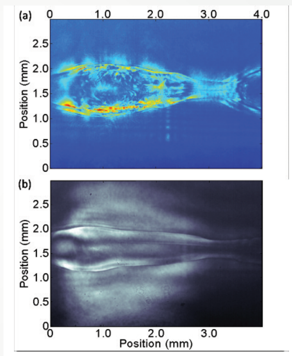
Gases composed of clusters absorb intense laser light extremely efficiently (>90%) to form a high energy density environment (up to 10^9 Jg^{-1}). The subsequent explosion of the heated gas launches fast cylindrical blast waves (up to Mach 50). In high Z materials, energy losses through ionization and radiation are highly significant to the blast wave behavior. These can be categorized as optically thin radiative shocks, a regime of particular interest for laboratory astrophysics experiments. We compare the properties of radiative shocks launched in clusters to those created by other techniques which employ kJ-class laser systems. The morphology and evolution of the blast waves are sensitive to gas density because of the change in optical depth of the medium. We explore this by applying the RAPCAL code to calculate ionization levels and radiative loss rates. We discuss the necessary conditions for radiative instabilities in the shocks and directions for future experiments.



Blast waves launched in clustered gases with a table-top laser system. These shocks exhibit turbulent structure in hydrogen (a) and large ionization precursors indicating strong radiative energy losses in xenon (b).

Femtosecond Pulse Physics

Radiation pressure effects on ion acceleration on the Gemini laser

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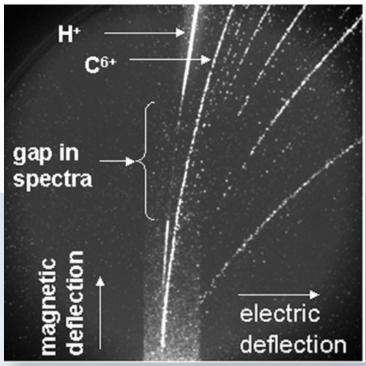
In most laser-driven ion acceleration studies carried out to date, ions are accelerated by sheath fields established by relativistic electrons at target surfaces, via the so-called Target Normal Sheath Acceleration (TNSA). A separate mechanism, Radiation Pressure Acceleration (RPA), has attracted extensive theoretical attention in recent years. Radiation pressure is exerted at the laser reflection point on a foil surface, resulting in local electron-ion displacement, and ion acceleration via the ensuing space-charge field. Cyclical reacceleration of the target ions in the Light Sail RPA mode accessible with ultrathin foils is predicted to lead to high acceleration efficiencies, and produce energetic, narrow band ion beams. In an experiment carried out on the Astra-Gemini laser we detected features consistent with the onset of this new acceleration mechanism. Spectral peaks as shown in figure were observed for very thin foils and for circularly polarized pulses, and simulations indicate their origin from RPA.



Spectrum of C^{6+} and H^{+} ions, showing a proton peak at the high energy end.

Ion acceleration from foil targets in the ultraintense ultrahigh contrast regime

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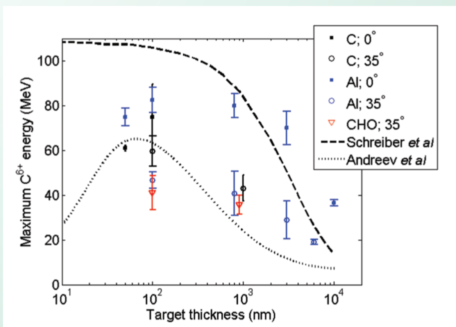
An experiment was conducted on the Astra-Gemini laser with one of the main objectives being to investigate the acceleration of carbon ions at the highest laser intensity achievable today. The Astra-Gemini laser delivers pulses of duration ~50fs with energies up to 12J at a wavelength of 800nm, reaching intensities ~10^{21} Wcm^{-2}. We explore the TNSA acceleration mechanism using a range of target materials and thicknesses as well as investigating the effect of the laser incidence angle. We found that the TNSA mechanism gives maximum ion energy for a target thickness around 100nm independent of its composition. The highest carbon ion energies were produced from pure carbon targets. Our most interesting result is the first observation of an increase in ion energy when the incidence angle of the laser is changed from 0° to 35°, in contrast to previous work.



Average of the maximum C^{6+} ion energy over multiple shots as a function of target thickness for different materials. The errors bars represent the standard deviation of the maximum energy.

Characterisation of debris emission from thick targets on Astra-Gemini

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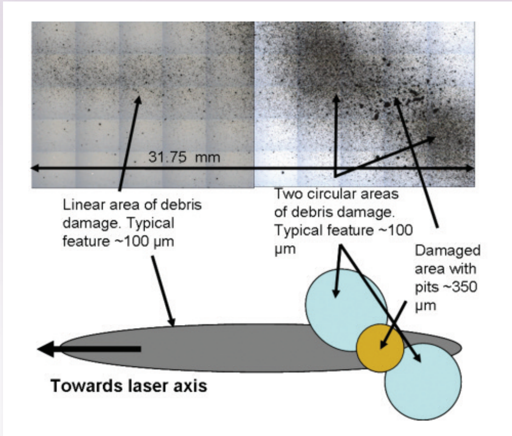
Debris characterisation measurements were made during radiation commissioning of Astra-Gemini. During the commissioning the distribution of debris from thick targets was studied. The targets used were 0.5 mm Cu, CH and Ta and 50 μm Au. The diagnostics used to measure the debris distribution were glass witness plates positioned around the target. For the 0.5 mm thick targets it was found that the debris was mainly distributed along the rear surface target normal and laser directions with particulates typically of around 400 μm. For the 50 μm thick target the distribution was mainly along the front and rear target normal directions with particulate sizes of less than 100 μm. Damage to the witness plate surface was also observed for 50 μm thick targets along the rear target normal direction. This indicates that target thickness has a significant effect on debris production and distribution.



Debris damage to glass witness plate at the target normal rear surface position. The images at the top are scans of the damage to the plate surface and the bottom diagram is a schematic of features found in the damage distribution.

High rep rate Thomson parabola-MCP assembly for multi-MeV ion spectroscopy

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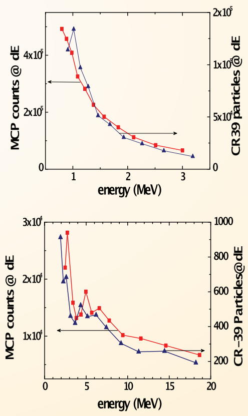
The absolute calibration of a micro channel plate (MCP) detector, installed as detector in a Thomson parabola spectrometer has been carried out. The calibration delivers the relation between a registered count numbers in the CCD camera (on which the MCP phosphor screen is imaged) as a result of the impact of an ion beam onto the MCP. The particle response of the whole detection system was evaluated by using laser accelerated ions with proton energies up to 3 MeV and carbon ion energies up to 16 MeV. In order to obtain an absolute measurement of the number of ions incident on the MCP detector, slotted CR-39 track detector was installed in front of the MCP. The signal registered on the MCP due to ions propagating through the CR-39 slots is compared to the number of particles counted on the adjacent CR-39 stripes after the etching. Careful consideration is required in evaluating the response of the MCP, since in the arrangement employed different energy ions are incident on the MCP at different angles (unlike , for example, ions accelerated by linear accelerators) , and this may affect the gain and secondary electron yield. For this reason, an in-situ calibration is important for a correct data analysis.



Correlation of integrated counts in dE energy interval due to MCP signal with number of particles on CR-39 in dE energy interval plotted with respect to energy for Protons and C^{6+}.

Proton/ion energy scaling and laser conversion efficiency using 50fs, 10^{20}-10^{21} W/cm² Astra-Gemini pulses

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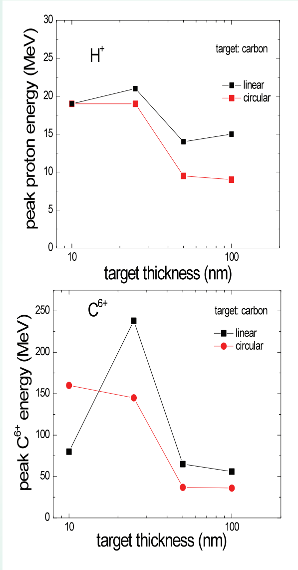
Experimental investigations of ion acceleration from thin foil targets irradiated with ultra-short (~ 50 fs), high contrast (~10^{10}) and ultra-intense (up to 10^{21} W/cm²) laser pulses on Astra-Gemini laser has been performed. These measurements provided for the first time the opportunity to extend the scaling laws for the acceleration process in the ultra-short (tens of fs) regime beyond the 10^{20} W/cm² threshold. The scaling of accelerated ion energies was investigated by varying a number of parameters such as target thickness (down to 10 nm), laser light polarization (circular and linear), angle of laser incidence (oblique-35^0, normal) and laser energy. Maximum proton energy>20 MeV and C^{6+} energy~235 MeV has been observed. The effect of target thickness on the ion flux produced was also investigated at 35^0 and normal laser incidence on target.



Maximum proton/ion energy dependence on target thickness at normal incidence on aluminium target for linear and circular polarisations

Investigation of contrast of Astra-Gemini

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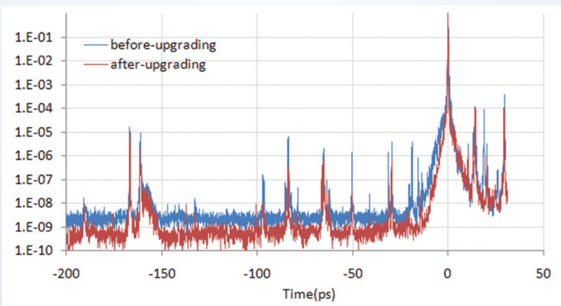
The temporal contrast of the laser pulse of extreme power up to 10^{22}W/cm² plays a crucial role in the high-field laser-matter interaction experiments as the excessive prepulse intensity can significantly affect experiment conditions due to preplasma formation. To meet an increasing demand for higher temporal quality of laser pulse, the temporal profile of Astra-Gemini was extensively investigated under various conditions, using a 3rd-order auto-correlator. The effect of various techniques has been investigated, including the spatial filter, aperture and minimising the scattering and loss etc. To minimise the overall ASE noise level, the front-end was upgraded and optimized to suppress the intracavity ASE noise, providing a cleaner seed pulse by a factor of ~10. As a result, the overall incoherent ASE and coherent contrast was improved by one order of magnitude as seen below. Some of the replica pre-pulses was reduced by a factor of ~100 or eliminated by using components with higher quality antireflection coatings.



Overall contrast before and after front-end upgrading.

Theory and Computation

Electron transport during shock ignition 13

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In the 'shock ignition' approach to Inertial Fusion Energy (IFE), the fusion target is compressed at a relatively low temperature and then ignited by a high-pressure shock driven into the target by a short high-intensity laser pulse. Because of steep temperature gradients, electrons which transport energy into the target to drive the shock must be modeled kinetically by the Vlasov-Fokker-Planck equation. The laser-target interaction also does not have time to relax hydrodynamically to the steady ablation profiles characteristic of the compression phase. Instead, shock ignition lies at the boundary between the 'ablation' regime and a 'supersonic heat front' regime in which high energy electrons stream freely into the target. High energy electrons transport energy deep into the compressed target where they beneficially generate high pressure at high density.

New perspectives on the electrodynamics of intense laser-plasmas 14

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A summary is given of work undertaken over the past twelve months by the Lancaster Mathematical Physics Group and Cockcroft Institute that focusses on new avenues for theoretical exploration of the behaviour of intense laser-plasmas. Items covered include an examination of Born-Infeld electrodynamics using plasmas, new geometrical analyses of relativistic collisional and collisionless plasmas including a new method for analysing Landau damping in non-stationary and inhomogeneous relativistic plasmas, and a new investigation of the interaction of electromagnetic fields with accelerating matter.

Cavitation and shock wave formation in dense plasmas by relativistic electron beams

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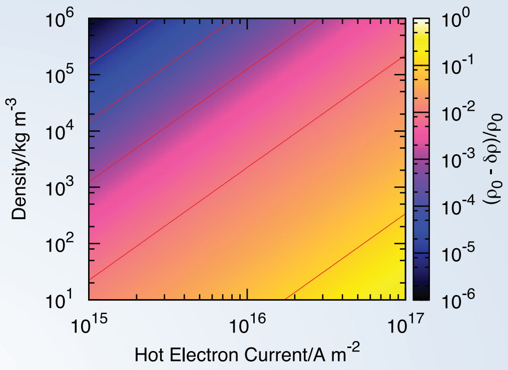
The propagation of a high current relativistic electron beam through dense plasmas, for example in fast-ignition inertial confinement fusion, produces strong heating and magnetic field generation. The j × B force and thermal pressure gradient that the return current creates may in fact cavitate and cause shock waves in the plasma around the electron beam.

Work has been undertaken to investigate this effect in different regimes of plasma density and hot electron current. An analytic model has been developed that gives good estimates of the density, pressure, magnetic field and velocity obtained in the plasma. This model is compared against the results from an MHD code that includes the effects of resistive field growth, Ohmic heating and the j × B force. The strength of the cavitation is found to be dependent upon the ratio between j^2 and the initial mass density. It was found that cavitation is indeed relevant to fast-ignition, and is strong enough to launch shocks in certain circumstances.



A parameter scan across a range of hot electron current density and initial plasma mass density. The colour scale shows the fractional amount of cavitation expected from the analytic model.

Alpha-particle stopping power for dense hydrogen plasmas

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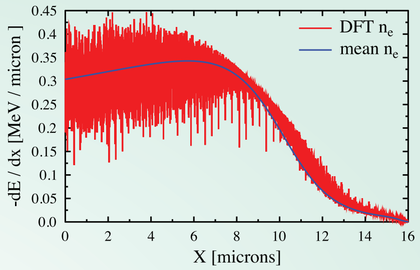
For beam energies from 0–20 MeV, a good agreement is obtained between calculated ion ranges for α-particles stopping in dense hydrogen for both highly fluctuating electron densities from DFT-MD and uniform averaged density profiles. In addition, the range calculations demonstrate good agreement with analytical range calculations using stopping power approximations in the limit of both the high and low kinetic energy as well. This agreement implies that for calculations of large-scale effects, such as ion range or averaged energy deposition, the increased accuracy provided by applying a DFT-MD density profile has little effect on the final result. It is also observed that the general functional form of the Bragg curves calculated for the variable and uniform density cases is similar. However, in variable density DFT-MD cases, fluctuations in density cause dramatic changes in the calculated stopping power over small spatial scales. This huge straggling must be considered in situations with small fluxes where heating cannot be averaged over many particles.



Comparison of α-particle stopping in hydrogen using a density profile obtained by DFT-MD and a constant mean density. The beam energy is E = 3.5MeV. The plasma has a temperature of T=20000K and a mean electron density of ne = 1.661x10^{24} cm^{-3}.

An object-oriented 3D view-factor code for hohlraum modelling

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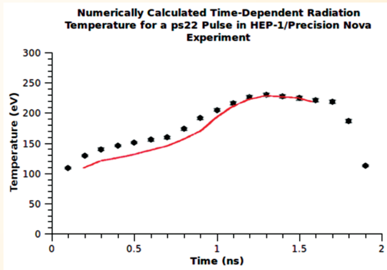
An easy to use 3D view-factor code has been developed for use in high power laser experiment design. View-factor codes use simple arguments to determine the quantities of radiation that can flow through a hohlraum geometry, and then solve a power balance equation to calculate the spatial distribution of radiation throughout a target. Because of the relative speed involved in setting up and running simulations, 3D view-factor codes are especially suited to prototyping experimental target designs.

The code allows the user to build up a wide range of hohlraum designs by combining a number of geometric primitives. Drive laser configurations can be specified in terms of individual beams or in rings; the beams themselves are implemented via a self-adjusting ray-tracing algorithm.

The code has been tested against results previously published and obtained by other experimental groups, and has been shown to reproduce experimental results with reasonable accuracy.

A cut-away rendering of a Nova hohlraum geometry created by the code.



Time-dependent temperature measurements from HEP-1/Precision Nova shots (continuous line) compare well with numerical calculations produced by the code.

Calculation of Siegert states in electric field: from atoms to molecules

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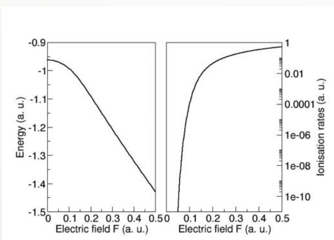
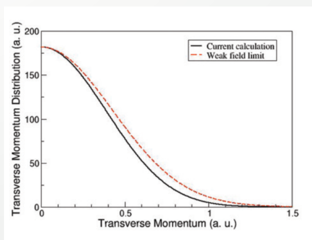
We propose a numerical method to calculate the Siegert states of molecules in a static electric field which are solutions of the stationary Schrödinger equation satisfying the regularity and outgoing-wave Siegert boundary conditions. This work follows the one for atomic Siegert states in the reference, where they calculate complex eigenenergies and eigenfunctions for one-electron atomic potential. Here we describe the modifications necessary to obtain such quantities in complex molecular cases. We discuss the reduced number of symmetries in the molecular problem and the inclusion of m-coupling. The two figures below present the result obtained for the lowest sigma state of H_2^+ with the soft Coulomb approximation for the electric field of 0.5 a.u.. The molecule axis is parallel to the laser field.

P. A. Batishchev, O.I. Tolstikhin and T. Morishita, submitted.





Finite size effects in high-intensity QED

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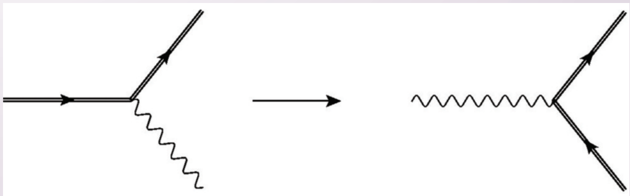
With laser fields approaching magnitudes close to the Sauter-Schwinger limit the use of strong-field quantum electrodynamics becomes mandatory. The latter is based on electrons 'dressed' by plane wave fields, solely dependent on an invariant phase. The theory developed in the sixties assumed infinite spatio-temporal extent which at that time seemed a good approximation as the number of cycles per pulse was large compared to unity. Nowadays, however, at ultra-high intensities, pulses are ultra-short, and effects of finite pulse duration must be taken into account.

We find that for both nonlinear Compton scattering and stimulated pair production finite size effects tend to 'wash out' the clear spectral signals caused by long-time averaging which is no longer possible for short pulses. Hence, observation of intensity effects on emission and production spectra clearly will require experimental fine-tuning.



Nonlinear Compton scattering or photon emission (left) and stimulated pair production (right). The processes are related by crossing symmetry. Both the photon emission spectrum and pair production rate are rather sensitive to the details of the laser beam, in particular its pulse duration.

Multi-electron dynamics on the femtosecond time-scale

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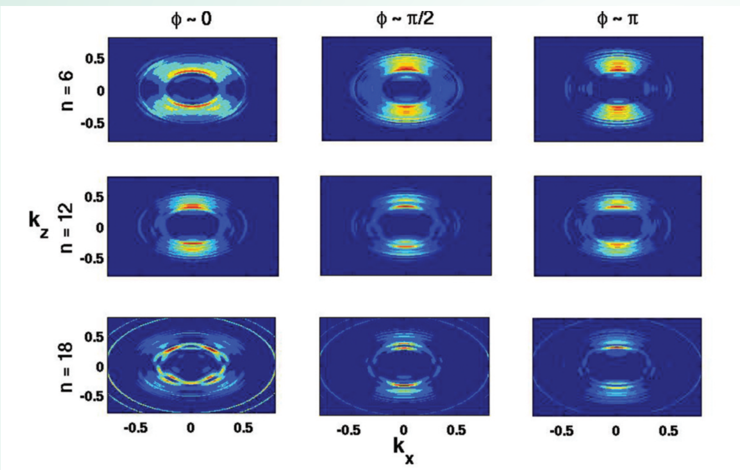
The recent emergence of attosecond light sources promises to provide deeper insight into ultrafast correlated dynamics between electrons in complex matter. Using time-dependent R-matrix theory we have been able to investigate such dynamics within an atomic system.

We consider C^+ in its ground state with magnetic quantum number M=0. The ion is excited by a linearly polarized XUV pulse into a superposition of the $2s2p^2\ ^2S$ and ^2D states. The repulsion between the two 2p electrons results in interference between the two states which occurs on a time-scale of 1-2 femtoseconds. By subsequently ionizing C^+ with a delayed ultrashort pulse and analyzing the properties of the ejected electron we are able to probe the interference and investigate the role of electron-electron interactions in the transition from ultrashort pulse excitation to long-pulse excitation.



2-dimensional momentum distributions of an electron ejected from C^+ obtained for three different excitation pulse durations: n = 6, 12 and 18 cycles. The plot shows a breathing motion for both 2p electrons for excitation pulse lengths of 6 and 18 cycles. ϕ corresponds to the phase of the breathing motion.

Hydrodynamics of the Yukawa one component plasma

21

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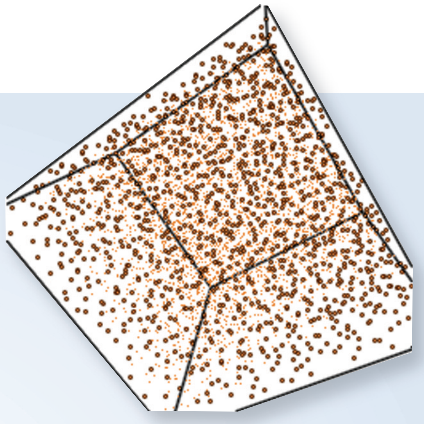
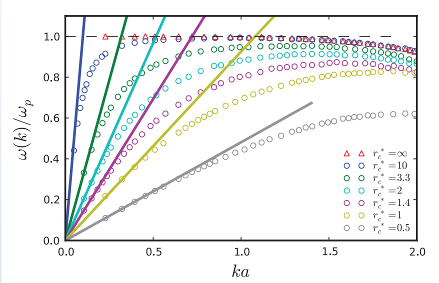
The hydrodynamic description is a very common starting point for investigating a wide range of basic and complex physical phenomena in fluids. We investigate using Molecular Dynamics simulations when this macroscopic description (rather than a more detailed microscopic description) is applicable for a physical system.
To achieve this we consider the microscopic dynamics of the so-called Yukawa One Component Plasma model. In particular, we determine how the domain of validity of the hydrodynamic description varies as the level of many body correlations (i.e. non-ideality) is varied.



Our results elucidate the nature of the hydrodynamic limit when many body correlations are present, particularly for systems with long ranged interactions. They can be used to model ion dynamics in dense plamas (e.g. 'Warm Dense Matter').



Brillouin peak dispersion relation for interaction potentials of various ranges against the hydrodynamic (linear) predictions.

The accuracy of rear-surface measurements of the angular-divergence of a laser-generated fast-electron beam

22

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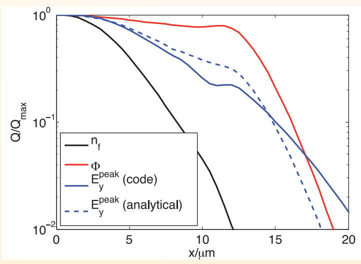
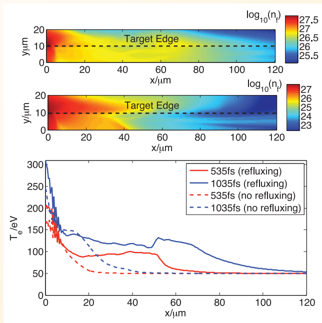
The interaction between high-intensity lasers and solid targets is of key importance in fast-ignition inertial confinement fusion, which may allow fusion ignition with less laser driver energy; and ion-acceleration, which has potential applications to cancer therapy. Understanding the properties of the relativisitic electron beam generated in these interactions is crucial. In particular, its angular divergence has ramifications for the aforementioned practical applications. This is often diagnosed using the temperature profile or the size of the region over which ion are emitted on the target's rear-surface.



Fast-electron number density, peak sheath field and sheath potential along the target's rear-surface after 100fs, and E_y^{peak} (analytical) ∝ $n_f^{1/2}$.

Simulations performed with the hybrid Vlasov code FIDO demonstrate that re-circulating currents inside the target lead to a broadening of the temperature hot-spot on the rear, thus over-estimating the inferred angular divergence of the fast-electron beam. The sheath potential was observed to be weakly dependent on the beam density and so the ion-spot size is a poor measure of the angular divergence.



Fast-electron number density with refluxing (top) and without refluxing (middle) after 1035fs. Background temperature at the rear-surface (bottom).

High absorption of ultra-intense laser pulses in near critical plasmas

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Of all the problems that ultra-intense laser-plasma physics is concerned with, the coupling of energy from the laser pulse into the kinetic energy of the plasma particles is perhaps the most important. Attaining efficient coupling is highly important and even critical to a number of prospective applications. Fast Igntion ICF and laser-driven ion acceleration are examples of such applications where coupling efficiency is either a very important or critical issue.

In the work reported here, we analyzed the absorption of 30-100fs, $\lambda \sim 1\mu m$, $a_0 >> 1$ laser pulses in near-critical plasmas. By this we mean plasmas are relativistically transparent and span the density range $0.1n_c < n_e < a_0 n_c$, where n_c is the non-relativistic critical density.

From energy considerations we have derived new analytic formulae for the two mechanisms of absorption in near-critical plasmas : Leading Edge Depletion (LED) and Transverse Ponderomotive Acceleration (TPA). For LED, for example, we obtained the following new formulae for the leading-edge propagation velocity:

$$u = \frac{v_g}{\frac{n_e}{2n_c} + 1}$$

Our new formulae have been rigorously compared to a large number of 1D and 2D fully electromagnetic Particle-in-Cell simulations.

This study has thus shown that the two absorption mechanisms that have been suggested for interactions with near-critical plasmas can both occur separately in different regions of parameter space, and, where they do, their gross properties are well described by the new analytic formulae derived here. Since LED is a significantly faster absorption mechanism than TPA this is an important step towards optimizing absorption in the near-critical regime.

Modelling Spitzer transport in laser produced plasmas by direct Vlasov methods with a BGK collision operator

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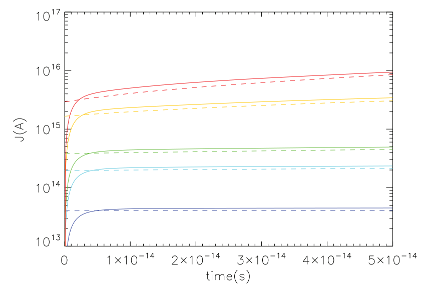
In short-pulse laser matter interaction, the absorption of incident laser energy is dominated by collisionless mechanisms but the onward transport of these fast moving electrons, and the resultant heating of the target, is dependent on the response of the cold, resistive, background plasma.

Here we briefly outline a simple approach to including collisional physics in the direct Vlasov solver VALIS, based on the BGK (Bhatnagar, Gross and Krook) collision operator. We are able to demonstrate the efficacy of this approach in two key transport problems in laser plasma interaction: thermal conduction and electrical resistivity.



Comparison of Spitzer currents (dashed lines) with those calculated using VALIS with a BGK collision operator (solid lines) for external fields of: $10^7 Vm^{-1}$ (blue); $5x10^7 Vm^{-1}$ (cyan); $10^8 Vm^{-1}$ (green); $5x10^8 Vm^{-1}$ (yellow); and $10^9 Vm^{-1}$ (red), for the case of both electron-electron and electron-ion collisions.

Effect of channel profile evolution on laser-driven electron acceleration in plasma channels

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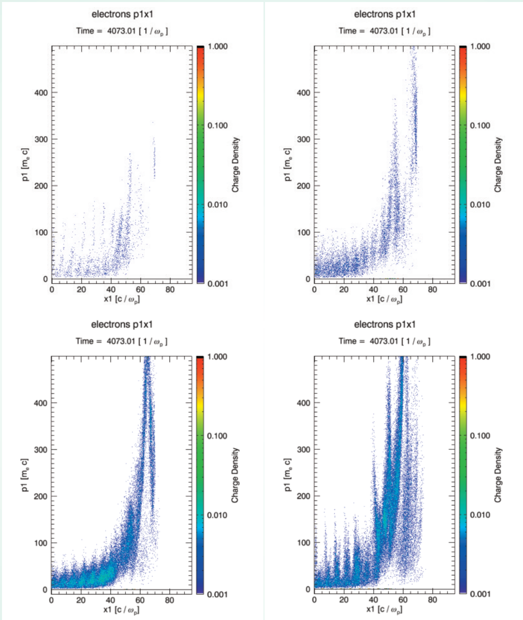

Electron trapping in a laser-driven wakefield, versus laser intensity. Laser amplitude a_0 is 1.19 (top left), 1.68 (top right), 2.0 (bottom left), 2.5 (bottom right), all other parameters equal. Laser spot diameter is 10 micron, wave length is 800 nm, ω_0/ω_p = 13.2, pulse duration is 50 fs. An increased laser intensity leads to enhanced electron trapping and acceleration.

The trapping and acceleration of electrons by a laser pulse propagating through a plasma channel has been investigated numerically. The influence of the laser intensity, background plasma density, channel transverse profile and degree of ionisation of the plasma was studied. It was found that the laser intensity and background density have the most significant impact on electron trapping, while the degree of ionisation has hardly any influence at all.

A Vlasov-Fokker-Planck code for shock ignition

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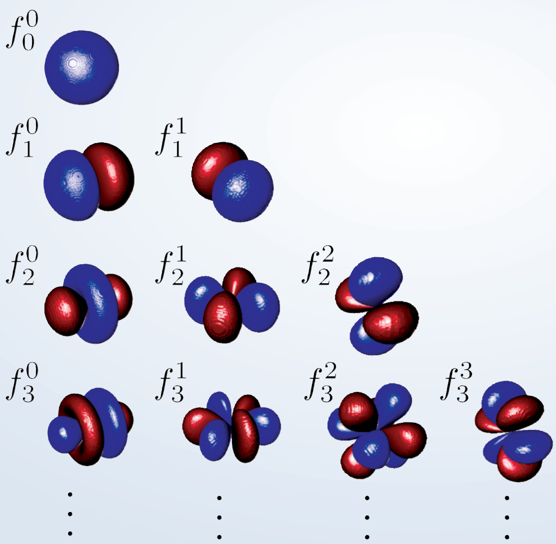
A 2D3P parallel object-oriented Vlasov-Fokker-Planck code that relies on the expansion of the electron distribution function to spherical harmonics has been developed, in order to study non-local electron transport for Shock Ignition.



The first ten spherical harmonics.

The code makes use of a rigorous formalism for the collisions between electrons, which derives from the Rosenbluth potentials and conserves energy and number. This code makes it possible to accurately model the kinetic as well as the hydrodynamic behaviour of the plasma and is particularly efficient for collisional plasmas. For Shock Ignition the electron temperatures range from more than 100keV to 10eV while densities range from less than critical to greater than solid. Shock Ignition is therefore an excellent candidate for this VFP code, because the target is sufficiently collisional to allow for extremely efficient modelling.

Multi-component effects on the x-ray scattering signal from warm dense matter

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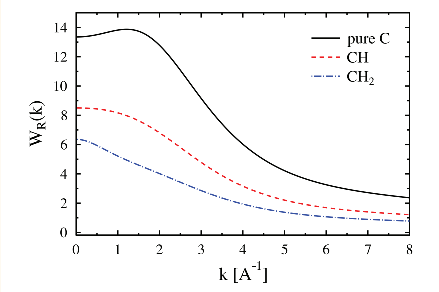
In this contribution, we investigate the effects of multiple ion species on the x-ray scattering process from warm dense matter. In particular, we discuss elastic scattering, that is, the weight of the Rayleigh peak. Based on partial structure factors from hypernetted chain solutions, a generalised approach of the theoretical model is applied to account for multi-component effects. We demonstrate that mutual correlations significantly influence the partial structure factors due to the fact that the ions with the highest charge imprint their structure on the other components. The weight of the Rayleigh peak that is directly related to the static structure factors is thus also sensitive to the interplay between the different correlated ions in the systems. These effects are especially pronounced in the case of forward scattering, i.e. for small k values. Furthermore, we demonstrate that the full multi-component description is also necessary for cases where x-ray scattering is dominated by one species. This effect is related to the differences in the statistical weight of the different contributions to the Rayleigh peak.



Comparison of the weight of the Rayleigh peak for warm dense carbon, CH and CH_2. The carbon density of $nC = 5{\cdot}10^{22}$ cm^{-3}, the temperature of $T = 8eV$ and a charge state of $ZC = 2$ are fixed for all systems. For the calculation of CH and CH_2, fully ionised hydrogen, i.e. ZH=1, with densities of $nH = 5{\cdot}10^{22}$ cm^{-3} and $nH = 10^{23}$ cm^{-3} is applied, respectively.

Ultrafast and XUV Science

Quasi-classical model of non-destructive wavepacket manipulation by intense few-cycle nonresonant laser pulses

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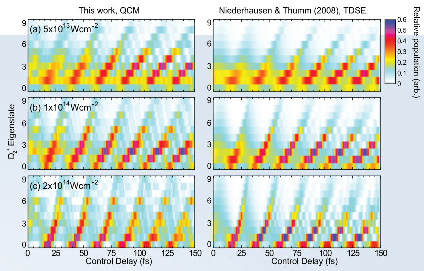
Matter exposed to strong-field few-cycle laser pulses is violently distorted on a timescale comparable to vibrational and electronic motions. In molecules, the resulting electric field polarizes electron orbitals to the extent that ionization and Coulomb explosion are likely, without the requirement of photon energy resonance. By pumping D_2 with an intense few-cycle (~10 fs) pulse, ionization launches a vibrational wavepacket in D_2^+ which may be imaged some time later by a similar probe pulse; such wavepackets have been experimentally observed.

A few-cycle "control" pulse arriving between the pump and probe applies a dipole force while the wavepacket is propagating, transferring energy into or out of the system, causing a redistribution of vibrational population. This quasi-classical model (QCM) describes the modification of the wavepacket by simulating an ensemble of classical trajectories evolving on the dynamically-distorted potential energy of the system. Manipulating the internal states of molecules has implications for quantum computation, attosecond electronic state observation and the formation of a molecular quantum gas.



Final vibrational state population distributions for three different control pulse intensities as the temporal separation between the pump and control pulse is varied. The results of Niederhausen and Thumm, Phys. Rev. A 77 013407 (2008) are reproduced for comparison with the QCM, which reproduces the periodicity and relative shift of vibrational population as the delay between the pump (6 fs, 10^{14} Wcm^{-2}) and the control is varied.

Monochromatic XUV-photon + strong-field NIR cross-correlation by atomic excitation and ionization

29

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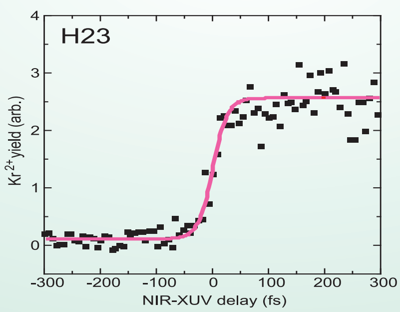
State-of-the-art x-ray free electron lasers and attosecond high harmonic generation (HHG) sources are being used to probe electronic dynamics under on ultrashort time-scales and high intensities. In a novel cross-correlation experiment, we demonstrate the capabilities of the recently commissioned Artemis facility which neatly combines the advantageous characteristics of XFELs and attosecond sources – energy tunability, sub-cycle synchronization to an optical laser and ultrashort pulse duration.



Measured and predicted Kr^{2+} yield as a function of NIR-XUV delay for harmonic 23 (photon energy 35.9 eV, wavelength 34.6 nm). The best least-squares fit reveals the rise of the yield is the result of H23 having a duration of 24 ± 2 fs.

An intense 30 femtosecond near-infrared (NIR) laser pulse is split 3:1. The low energy pulse produces a broad spectrum of XUV photons through HHG in a gas jet, which are monochromated allowing a single 35.9 eV harmonic to be focused into a krypton target, generating highly excited Kr^+ ions through single-photon absorption. The high energy NIR pulse is also focused into the krypton to a high intensity, and the delay between NIR and XUV can be controlled with sub-cycle resolution. Depending on the arrival times of the XUV and NIR, enhancement of the Kr_2^+ ion yield is used to measure the XUV pulse duration, performing an atomic cross-correlation.

Multi-pulse scheme for controlling electron localisation upon molecular dissociation

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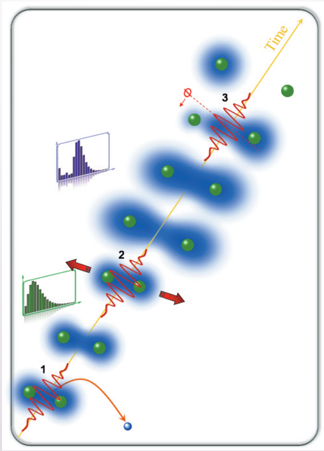
Quantum control of chemical reactions in molecules requires the precise manipulation of electronic wavepackets, which typically evolve on attosecond timescales. A powerful technique for controlling the electronic dynamics during molecular dissociation is to use few-cycle femtosecond laser pulses of infra-red radiation.



Proposed multi-pulse scheme: Pulse 1 ionises a D_2 target launching a coherent D_2^+ vibrational wavepacket. Pulse 2 non-destructively manipulates the bound wavepacket into a new vibrational distribution. Pulse 3 then dissociates the molecular ion, where careful choice of delay time allows the dissociation to be maximised and tuning of ϕ leads to strong localization of the electron to a particular nucleus.

Through controlling the relative phase relationship, ϕ, between the carrier field and pulse envelope, and using a sequence of such pulses, a new scheme has been identified for directing the localisation of the electron upon molecular break-up, i.e. whether the electron goes to the 'left' or 'right 'nucleus.

This ultrafast scheme has been identified using quantum simulations of the deuterium molecular ion (D_2^+) exposed to a sequence of 7 fs pulses. With carefully chosen pulse parameters it is possible to optimally control the vibrational wavepacket dynamics and the final dissociation event, resulting in a final 'left:right' ratio of the electron localization which exceeds 10:1.

Intensity-resolved ionization processes in few-cycle strong-field laser pulses

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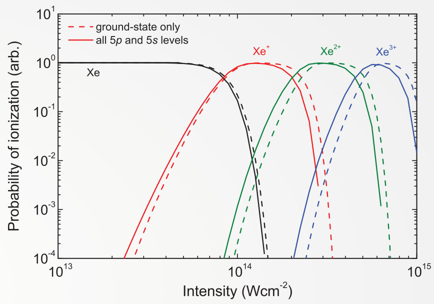
Few-cycle strong-field laser pulses cause tunnel ionization of atoms and molecules by violently distorting the electron orbitals. It is commonly assumed that tunnelling leaves the ion in the ground-state. However, enhanced ionization yields indicate excitation processes which populate lower-lying energy levels. Alternatively, these levels could be populated directly by tunnelling. Removal of electrons from lower-lying orbitals by tunnelling is also possible; there is recent experimental evidence of this in molecules.

Tunnelling from multiple atomic energy levels is modelled and a subtle shift in ionization probability is expected as a function of intensity. We have measured focal-volume-dependent ionization of xenon using NIR ultrashort pulses generated at Artemis. As the experiment is able to resolve ionization as a function of intensity, the ionization probabilities can be extracted and compared directly to theory.



Predicted ionization probabilities of xenon exposed to a few-cycle laser pulse. Ground-state only ionization (dashed line) and ionization from all 5p and 5s states (solid line) are compared; we anticipate the intensity offset will be experimentally observable.

Ultrafast dynamics of electronic structure in complex materials

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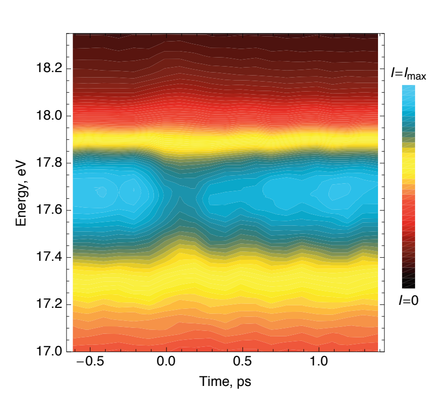
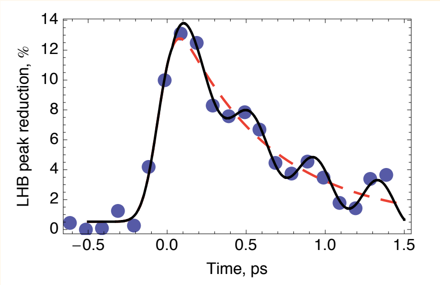
We have used the new materials-science beamline at Artemis to carry out time-resolved photoemission studies of the layered Charge-Density-Wave and Mott-insulating compound 1T-TaS_2. We drove the system into a transient metallic phase using ultrashort pulses of laser light, and used high-harmonic UV pulses to generate photoelectrons, revealing the changes in electronic structure. After photoexcitation there is a collapse in intensity of the Lower Hubbard Band, transfer of spectral weight towards the Fermi level, and subsequent oscillation of the position of the band edge at the CDW amplitude mode frequency. These features agree with those seen at k=0 by Perfetti et al. [PRL **97** 067402 (2006)]. Our angle-integrated measurements additionally show an oscillation in the LHB peak intensity, a new effect likely due to the influence of the CDW amplitude mode on the band structure near k=π/a. Further experiments will study the detailed dispersion of the dynamical response.



Photoelectron intensity map of response to photoexcitation.



Reduction in LHB intensity. Solid line: Full fit. Dashed line: Exponential component only.

Ultrafast time-resolved photoelectron imaging of excited state molecular dynamics: S_2-S_1 internal conversion in the DABCO molecule

33

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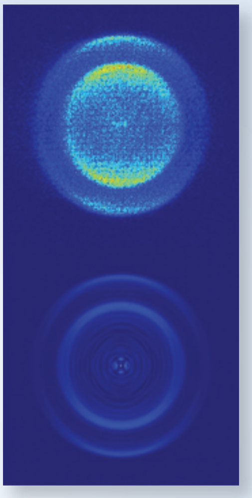
Femtosecond time-resolved photoelectron imaging was applied to the ultrafast internal conversion dynamics in photoexcited 1,4 diazabicyclo[2.2.2]octane. A systematic investigation of the electronic relaxation dynamics upon the vibrational energy of the molecule was undertaken by scanning the pump wavelength between 236.1-251.1 nm. The temporal evolution of the photoelectron spectrum and angular distribution was measured. Analysis of the data is ongoing.



Pump pulse at 236.1 nm and probe pulse at 390 nm. The raw experimental data is shown at the top, and the Abel inverted data is shown below. The outer ring corresponds to photoelectrons from ionization of the S_2 electronic state, and the inner ring corresponds to ionization of the S_1 electronic state.