Programme

Sunday 22 May

18:30 Welcome registration - Performance from Strath Gaelic Choir
   Amphitheatre

19:15 Dinner
   Dining Hall

Monday 23 May

08:00 Refreshments / Breakfast for delegates with onsite accommodation
   Dining room

08:40 (Invited) Radiative properties measurements for stellar interiors and accretion powered objects
   Mark Koepke, West Virginia University, USA
   Talla Dhonaidh Chaimbeul

09:20 Structure of warm dense iron using the LCLS facility
   David Riley, Queen’s University Belfast, UK

09:40 Chromatic guiding and re-acceleration of laser accelerated proton beam by helical coil target
   Hamad Ahmed, Queen’s University Belfast, UK

10:00 Interaction of intense laser and electron beams with multi-component plasma
   Andrew Beaton, University of Strathclyde, UK

10:20 Flash poster presentations

10:30 Refreshments
   Dining room

11:00 (Invited) Using X-ray free electron lasers to investigate the physics of hot dense plasmas
   Orlando Ciricosta, University of Oxford, UK

11:40 Hard X-ray radiation from laser wakefield accelerators: Increasing brightness for imaging applications
   Jonathan Wood, Imperial College London, UK

12:00 Energetic plasma and electromagnetic waves in the inner geospace: Recent advances and persistent gaps in our understanding
   Ioannis Daglis, University of Athens
12:20  EPSRC research funding opportunities
       Jaspreet Kular, EPSRC, UK

12:40  Flash poster presentations

12:50  Lunch
       Dining Hall

14:00  (Invited) Magnetic reconnection in weak and strong guide-field regimes
       Adam Stanier, Los Alamos National Laboratory, USA

14:40  Terrestrial reproduction of space radiation using intense laser-beam-plasma interaction
       Andrew Beaton, Queen’s University of Strathclyde, UK

15:00  (Invited) Supernovae plasmas
       Robert Bingham, Central Laser Facility, UK

15:40  Flash poster presentations

15:50  Refreshments

16:30  (Invited) The Orion laser at AWE: system overview and recent experiments
       Andrew Randewich, AWE, UK

17:10  Break-out and recap activity

17:50  Additional slots for meetings

18:30  Poster session and buffet meal
       Dining Hall

20:00  Close

Tuesday 24 May

08:00  Refreshments / Breakfast for delegates with onsite accommodation
       Dining room

08:40  (Invited) Measurements of resistivity in warm dense matter for astrophysical applications
       Nicola Booth, Central Laser Facility, UK
       Talla Dhonaidh Chaimbeul

09:20  Relaxation modelling of energy release avalanche in twisted solar coronal loops
       Asad Hussain, University of Manchester, UK
09:40 Measurement of magnetic pitch angle in the tokamak edge via back-scattering of microwaves from turbulence
Kai Jakob Brunner, Durham University, UK

10:00 Auger clocking femtosecond collisional plasma dynamics
Sam Vinko, University of Oxford, UK

10:20 Update from breakout and recap

10:30 Refreshments
Dining room

11:00 (Invited) Resolving ion acoustic waves in warm dense matter
Thomas White, University of Oxford, UK

11:40 Breakout and recap

12:00 Lunch

14:00 Free time/social activities and Outreach event, including short talks and demonstrations

19:00 Dinner

20:00 Comets - cosmic bringers of death, life, and new solar/stellar science open to the public
John Brown, Astronomer Royal for Scotland, UK

20:40 Close

Wednesday 25 May

08:00 Refreshments / Breakfast for delegates with onsite accommodation
Dining room

08:40 (Invited) Key plasma issues for fusion
Steve Cowley, Culham Fusion for Fusion Energy, UK
Talla Dhonaidh Chaimbeul

09:20 Modelling of plasma turbulence and detachment in the tokamak divertor with BOUT++
Jarrod Leddy, University of York, UK

09:40 Evolution of the pedestal during the ELM cycle in JET-ILW plasmas: Comparisons with the EPED model
Amelia Lunniss, University of York, UK
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<th>Time</th>
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<tr>
<td>10:00</td>
<td>Finite banana width effect on NTM threshold physics</td>
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<td>Koki Imada, University of York, UK</td>
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<td>10:20</td>
<td>Update from breakout and recap</td>
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<td>11:00</td>
<td>(Invited) Applied electrostatics and low temperature plasma process for gas cleaning</td>
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<td>Akira Mizuno, Toyohashi University of Technology, Japan</td>
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<td>11:40</td>
<td>Inhomogeneous cloud coverage via the Coulomb explosion of dust in substellar atmospheres</td>
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<td>Craig Stark, University of Abertay Dundee, UK</td>
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<td>12:00</td>
<td>In-situ characterization of the dynamics of a growing dust particle cloud in a direct-current argon glow discharge</td>
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<td>Lenaic Couedel, CNRS, France</td>
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<td>12:20</td>
<td>Freak waves in negative-ion plasmas: an experiment revisited</td>
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<td>Ioannis Kourakis, Queen's University Belfast, UK</td>
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<td>12:40</td>
<td>Plasma Physics Group AGM</td>
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<td>14:20</td>
<td>(Invited) Micro-discharges in acqueous media: the case of plasma electrolytic oxidation</td>
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<td>Alex Nominé, The Open University, UK</td>
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<td>15:00</td>
<td>Plasma-controlled solvated electron colloidal chemistry for high quality nanomaterials synthesis</td>
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<td>Paul Maguire, Ulster University, UK</td>
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<td>15:20</td>
<td>Bridging the gap between global and full fluid models: A rapid semi-analytical model for spatially resolved descriptions of electronegative plasmas</td>
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<td>Andrew Hurlbatt, University of York, UK</td>
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<td>15:40</td>
<td>Refreshments</td>
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<td>16:30</td>
<td>(Invited) Generating neutral beams for advanced plasma etching</td>
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<td>Mark Bowden, University of Liverpool, UK</td>
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<td>17:10</td>
<td>Pseudospark discharge plasma sourced electron beam for millimeter-wave generation</td>
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<td>Junping Zhao, University of Strathclyde, UK</td>
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<td>17:30</td>
<td>Breakout and recap</td>
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<td>Conference Dinner</td>
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Thursday 26 May

08:00    Refreshments / Breakfast for delegates with onsite accommodation
         *Dining room*

08:40    (Invited) Predictions of fusion alpha-particle transport due to Alfven eigenmodes in *ITER*
         Michael Fitzgerald, Culham Centre for Fusion Energy, UK
         *Talla Dhonaith Chaimbeul*

09:20    MAST upgrade opportunities
         Ian Chapman, Culham Centre for Fusion Energy, UK

09:40    Raman amplification in the coherent-wavebreaking regime
         John Farmer, University of Düsseldorf, Germany

10:00    Modelling nonlocal heat transport in fusion relevant plasmas
         Jonathan Brodrick, University of York, UK

10:20    Update and conference close

10:30    Refreshments
         *Dining room*

11:00    Coach departs for Inverness Airport
Posters

P:01 Characterising fast electron transport in laser-solid interactions via high energy x-ray emission
Chris Armstrong, STFC Central Laser Facility, UK

P:02 Investigating radiation reaction on laser wakefield accelerated electrons
Christopher Baird, University of York, UK

P:03 Laser-driven X-ray and neutron source development for industrial applications of solid-foil plasma accelerators
Ceri Brenner, STFC Central Laser Facility, UK

P:04 Fast ignition using shock accelerated ions from the target corona
Alan Cairns, University of St Andrews, UK

P:05 Stability of trapped-ion orbits around dust in the plasma boundary
Richard Cameron, Imperial College London, UK

P:06 A fast chirplet transform for analysing wave activity in time-series
John Colvin, University of Warwick, UK

P:07 Modelling nonlinear electrostatic oscillations in plasmas
Declan Diver, University of Glasgow, UK

P:08 Microwave start-up of tokamak plasmas
Erasmus du Toit, University of York, UK

P:09 Multicomponent plasma expansion into vacuum with non-Maxwellian electrons
Ibrahim Elkamash, Queen’s University Belfast, UK

P:10 Radiation pressure driven ion acceleration from shaped gas jet targets
Oliver Ettlinger, Imperial College London, UK

P:11 Quasi-stable injection channels in a wakefield accelerator
John Farmer, University of Düsseldorf, Germany

P:12 Correlating metastable-atom density, reduced electric field, and electron energy distribution in the early stages of a 1-torr argon discharge
James Franek, West Virginia University, USA

FP:13 The dusty solitary hydromagnetic wave
Joseph Gibson, Imperial College London, UK

P:14 Surface, liquid and vapour phenomena in electrical discharge formation in saline solutions
Bill Graham, Queen’s University Belfast, UK

P:15 Explosive ballooning flux tubes in tokamaks
Christopher Ham, Culham Centre for Fusion Energy, UK
P:16 Liverpool Experimental Magnetised Plasma Impurity Research Apparatus (LEMPIRA)
Brandon Harris, University of Liverpool, UK

P:17 Statistically determined dispersion relations of magnetic field fluctuations in the terrestrial foreshock
Bogdan Hnat, University of Warwick, UK

P:18 The charging of non-spherical objects in a plasma
Joshua Holgate, Imperial College London, UK

P:19 Outline of a PhD project on the investigation of the isotope effects of the pedestal on JET
Laszlo Horvath, University of York, UK

P:20 Features in the ion emission of Cu, Al and C plasmas produced by ultrafast laser ablation
Mossy Kelly, Dublin City University, Ireland

P:21 Solitary structures with ion and electron thermal anisotropy
Munchana Khusroo, Gauhati University, India

P:22 Terahertz radiation from gas ionization irradiated by intense Laguerre-Gaussian laser pulses
Feiyu Li, University of Strathclyde, UK

P:23 Measurement of the charge on an isolated probe in a non-thermal equilibrium plasma at atmospheric pressure
Paul Maguire, University of Ulster, UK

P:24 Laser plasma effects in water
Thomas Morgan, Wesleyan University, USA

P:25 Image plate and scanner characterisation
Margaret Notley, STFC Rutherford Appleton Laboratory, UK

P:26 Hydrodynamics driven by short-pulse laser plasma interactions
John Pasley, University of York, UK

P:27 Significance of negative axial wavenumbers in auroral cyclotron maser emissions
Alan Phelps, University of Strathclyde, UK

P:28 Power balance in microwave powered HID lamps
Monica Santos, Ceravision, UK

P:29 Optical generation of multi-component plasma with Gaussian optics, axicons, and axilenses
Paul Scherkl, University of Strathclyde, UK

P:30 Generation of warm dense matter by isochoric heating of a Ti-wire
Andreas Schönlein, Goethe University, Germany
P:31 Plasma optical modulators for intense lasers
Zheng-Ming Sheng, University of Strathclyde, UK

P:32 Electrostatic electron cyclotron instabilities near the upper hybrid layer
David Speirs, University of Strathclyde, UK

P:33 The role of plasma instabilities in the onset of detachment in the York Linear Plasma Device
Hannah Willett, University of York, UK

P:34 Ellipsoidal plasma mirror focusing of high power laser pulse to ultra-high intensities
Robbie Wilson, University of Strathclyde, UK

P:35 Surface and volume mode coupling experiments for high power mm-wave sources
Amy MacLachlan, University of Strathclyde, UK

P:36 Plasma dynamics at the surface interface in radio frequency discharges
Martin Blake, University of York, UK

P:37 Analysis of inductor parameters in inductive discharge of radio-frequency ion thrusters
Alexey Shiskin, Moscow State University, Russia

P:38 K-edge shift under different plasma environments
Rachael Irwin, Queen’s University Belfast, UK
Oral abstracts

Monday 23 May

(Invited) Radiative properties measurements for stellar interiors and accretion powered objects

M Koepke
West Virginia University, USA

Laboratory plasma conditions that address outstanding astrophysical puzzles are generated using x-rays from the megajoule-class Z facility at Sandia National Laboratories. Plasma conditions span $10^{16}$-$10^{23}$ e-/cm$^3$ electron densities, and 1-200eV temperatures, in local thermodynamic equilibrium (LTE) or radiation-dominated non-LTE conditions. The long-lived duration, uniformity, and large volumes (mm$^3$ to 100cm$^3$) of these plasmas allow us to perform benchmark-quality experiments. The copious x-rays can simultaneously drive separate physics experiments on each Z shot. The presentation will focus on the recent investigations of stellar interior opacities (#1) and spectral line emission from photo-ionised plasma near accretion-powered objects (#2).

1. The opacity of Cr (Z=24), Fe (Z=26), and Ni (Z=28) at $T_e \sim 190$eV and $n_e \sim 4 \times 10^{22}$ e-/cm$^3$, conditions approaching the base of the solar convection zone boundary (CZB), were measured. Models are significantly underestimating the opacity of Fe at these conditions [1]. The persistence of this difference for a range of plasmas conditions and elements would significant impact the modelling of stellar interiors and could help shed light on the solar CZB problem [2]. Future plans to probe samples having different atomic number will help our understanding of the origin of this opacity discrepancy.

2. Physical descriptions of accretion-powered objects such as black holes, x-ray binary systems, or active galactic nuclei are informed through the interpretation of emergent spectra from the photo-ionised plasma that surrounds them. Prediction of line formation in photo-ionised plasma is dependent on the details of the radiation transport treatment and the so-called Resonant Auger Destruction hypothesis typically required for interpreting the relativistically broadened Fe Kα emission from near the black-hole event horizon. Accurate and high-resolution emergent intensity was observed from a photo-ionized silicon plasma for a set of column density values that will help us evaluate understanding for radiation transport in accretion powered objects. MK is supported by DOE grant DE-SC0012515. Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.


Structure of warm dense iron using the LCLS facility

S White, B Kettle, C D Murphy, S Glenzer, E Gamboa, B Nagler, H J Lee, D O Gericke, J Vorberger and D Riley

Queen’s University Belfast, UK, University of York, UK, SLAC Natl Accelerator Lab, USA, University of Warwick, UK, Max Planck Institut für Physik komplexer Systeme, Germany

In this presentation, we will show results from an experiment on the LCLS X-ray free electron laser facility in Stanford. An optical laser was used to generate samples of warm dense Fe and Al via laser driven shocks. The warm dense matter state was probed using the free electron laser operating at 7keV and 5.2keV x-ray photon energy. The results for Fe are matched to a hyper-netted chain model and the comparison clearly shows the need for a strong repulsive term in the ion-ion potential in order to reproduce the experimental structure factors.

Chromatic guiding and re-acceleration of laser accelerated proton beam by helical coil target

H Ahmed, S Kar, R Prasad, M Cerchez, S Brauckmann, B Aurand, G Cantono, P Hadjisalomou, C L S Lewis, A Macchi, G Nersisyan, A P L Robinson, M Schroer, M Swantusch, M Zepl, O Willi and M Borghesi

Queen’s University Belfast, UK, Heinrich-Heine-Universität, Germany, Università Di Pisa, Italy, Central Laser Facility, Rutherford Appleton Laboratory, UK, Helmholtz Institut Jena, Germany

Since the first observation of laser driven ion beams, through the target normal sheath acceleration mechanism, their optimization has been a topic of interest over the last decade, in the view of potential applications in science, industry and health care [1]. Due to the high bunch charge and short duration of the pulse, achieving an efficient control of the beam properties poses significant scientific and technological challenges. Here, we present a distinctive target geometry enabling control the spectral and angular properties of the proton beams, by exploiting the transient selfcharging of the target during the interaction [2].

In this target geometry, a helical coil (HC) is attached to the rear surface of the interaction foil so that the protons generated from the rear surface of the foil propagate along the HC axis, while a charge pulse generated during the same interaction travels along the coil. The localised electric field (>109 V/m) associated to the travelling charge pulse act simultaneously as a focusing and accelerating field. Using this technique, a collimated and quasi-monoenergetic proton beam containing >108 particles at ~10 MeV was observed, in a proof of principle experiment employing the ARCTURUS laser system at Heinrich-Heine Universitat, Dusseldorf. In addition to beam collimation, the data indicates post-acceleration of laser driven protons at a rate of 0.5 MeV/mm. Particle tracing simulations elucidate focusing as well as post-acceleration of the protons within a narrow spectral band, which are synchronised with the "projected" motion of the charge pulse along the coil axis. This technique may provide a platform for producing high-energy collimated ion beams for future potential applications, including possible use in cancer therapy.

Interaction of intense laser and electron beams with multi-component plasma

A Beaton¹, O Karger², A Knetsch², G Wittig², P Scherkl¹, T Heinemann², F Habib², P Delinikolas¹, A Beaton¹, A Deng³, Y Xi³, M Litos⁴, R Zgadzaj⁵, M Hogan⁴, V Yakimenko⁴, J Cary⁶, J Smith⁷, Z-M Sheng¹, D Jaroszynski¹, J B Rosenzweig² and B Hidding¹

¹University of Strathclyde, UK, ²University of Hamburg, Germany, ³University of California, USA, ⁴SLAC National Accelerator Laboratory, USA, ⁵University of Texas at Austin, USA, ⁶RadiaSoft LLC, USA, ⁷Tech-X UK Ltd, UK

Both highly intense laser pulse and electron bunches are capable of ionising gas media through various ionisation mechanisms such as optical tunnel ionisation, single and multiphoton ionisation, impact ionisation etc. The ponderomotive and Coulomb forces of such intense pulses can drive plasma waves which support enormous electric fields (exceeding tens of GV/m) that are useful in advanced acceleration of particles such as electrons [1,2]. To extract high quality electrons, optimisation of the plasma waves is necessary such that other nonlinear processes that can spoil the acceleration process is reduced (or even eliminated). In advanced plasma wakefield acceleration setups, we use a pre-ionisation laser at the 10e14 W/cm² level to selectively ionize certain levels of a multi-component plasma or gases (such as hydrogen and helium), an electron beam to drive the plasma wave, a strongly focused laser pulse of 1e15W/cm² intensity to spike the interaction and to generate high quality electrons, and a probe beam to visualize the interaction. The dynamics of the laserbeam-gas-plasma interaction are highly multi-faceted, and depending on timing, intensity profile, laser wavelength (from UV to far-IR), focusing optics (Gaussian to diffractive optics) and delay of the individual pulses, a wide range of plasma physics such as localised “hot spots”, plasma expansion, recombination, beam refraction etc. can be explored and exploited. Supported by 3D particle-in-cell simulations [3], we have recently realised such a setup in an international flagship experiment “E210: Trojan Horse” at FACET, the Facility for Advanced Accelerator Experimental Tests at SLAC. Results of this experimental programme and the underlying plasma physics will be presented.

(Invited) Using x-ray free electron lasers to investigate the physics of hot dense plasmas

O Ciricosta
University of Oxford, UK

The last few years have seen a revolution in X-ray laser technology: when the Linac Coherent Light Source (LCLS) started operations, in 2009, the world gained the first machine capable to produce femtosecond multi-keV X-ray pulses that can be focused at intensities in excess of $10^{17}$ W/cm$^2$. These intensities are such that a hundred eV, solid density plasma can be created by volumetric heating [1], with virtually no longitudinal gradients, on similar timescales to those of the microscopic processes occurring in a dense plasma: these plasmas are thus an excellent platform to investigate such processes. The aforementioned plasma conditions are similar to those found in the external part of radiative zone of the Sun, in inertial fusion implosions, and in the transient phase of any solid-to-plasma transition. They also correspond to the strongly-coupled plasma regime, where the plasma models used in the standard diagnostic approaches are at best untested, at worst notapplicable. I will give an overview of the experiments enabled by this new generation of high-intensity lasers, particularly focusing on the isochoric heating platform for hot dense matter studies. Key results in this particular field include the first charge-resolved measurement of continuum lowering in a solid density plasma [2], and the experimental investigation of collisional rates in the same conditions [3].


Hard x-ray radiation from laser wakefield accelerators: Increasing brightness for imaging applications

J Wood1, K Poder1, N Lopes1,2, J Cole1, Z Najmudin1, S Mangles1, D Symes1, D Chapman1, D Eakins1, M Rutherford1 and T White4

1Imperial College London, UK, 2 Instituto de Plasmas e Fusão Nuclear, Portugal, 3 STFC Rutherford Appleton Laboratory, UK, 4University of Oxford, UK

Multiple experiments have now confirmed that electron beams can be accelerated to GeV energies in a plasma length of approximately 1cm via the mechanism of Laser Wakefield Acceleration (LWFA) [1][2][3][4][5], if the wakefield is driven by a short pulse laser of multihundred TW power. During the acceleration electron oscillations in the strong electric field of the accelerating structure result in a bright source of hard x-rays [6][7]. We report advances in the brightness of this source from recent experiments at the Gemini Laser Facility, and provide measurements confirming its suitability for high resolution x-ray imaging. Finally we demonstrate how this so-called betatron x-ray source can be applied in the fields of medically relevant imaging, including new results of imaging embryonic mice, and in the imaging of highly transient shock waves in solid density material. This was the first experiment using betatron radiation to image a rapidly evolving phenomenon. Such an experiment would have previously required a much larger and more expensive synchrotron or X-ray Free Electron Laser source, where there are the additional issues of precise timing with a high intensity optical driver.

Energetic plasma and electromagnetic waves in the inner geospace: Recent advances and persistent gaps in our understanding

I A Daglis
University of Athens, Greece

Geospace is characterized by energetic plasma populations with a wide dynamic range of energies, spanning more than 8 orders of magnitude -- from eV in the plasmasphere to tens of MeV in the outer Van Allen belt and hundreds of MeV in the inner Van Allen belt. A wealth of charged particle and wave measurements from spaceborne and ground-based instruments has shaped a comprehensive understanding of the interactions of the various plasma populations with electromagnetic waves during geospace magnetic storms and magnetospheric substorms. However, there are still gaps in our comprehension of dynamic wave-particle interactions in the inner geospace.

EPSRC research funding opportunities

J Kular
EPSRC, UK

(Invited) Magnetic reconnection in weak and strong guide field regimes

A Stainer
Los Alamos National Laboratory, USA

Magnetic reconnection can release magnetic energy by changing the topology of magnetic fields in highly conducting plasmas. It plays a key role in a wide range of magnetised plasma phenomena from solar flares, geomagnetic storms, and sawtooth oscillations within magnetic confinement devices. To explain many such phenomena, it is important to understand the rates of magnetic reconnection in large and weakly collisional systems. Also, since fully kinetic simulations of large systems are too computationally expensive, a key question concerns what physics must be retained within reduced models to reproduce the reconnection rates and global evolution of such systems.
Here we consider a wide range of guide field, which controls the rotation angle (shear) of the magnetic field across the reconnection layer and modifies the kinetic physics of the reconnection region. For the weak guide field (high shear) regime, with magnetospheric application, we demonstrate that the commonly used Hall-MHD model is insufficient to reproduce the rates and global evolution of an equivalent fully kinetic system, since it misses key physics related to the anisotropy and agyrotropy of the ion pressure tensor. A hybrid model with kinetic ions and uid electrons that retains this physics is sufficient to reproduce the main features of fully kinetic simulations in this regime.

For the strong guide field (low shear) regime, with solar corona and tokamak application, we compare a very simple reduced two-fluid model that includes effects of parallel compressibility and electron inertia against cold ion fully kinetic simulations. Good agreement is found in both the rate and overall length of the reconnection layer, despite visible differences in electron scale physics [2], indicating that such a model may be sufficient.


Terrestrial reproduction of space radiation using intense laser-beam-plasma interaction

A Beaton1, P Delinikolas1, G Manahan1, B Hidding1,2, O Karger2, T Königstein4, G Pretzler4, G P McKenna1, R Gray1, R Wilson1, S M Wiggins1, G H Welsh1, D A Jaroszynski1, J B Rosenzweig3, A Karmakar5, V Ferlet-Cavrois6, A Costantino6, M Muschitiello6 and E Daly6

1University of Strathclyde, UK, 2University of Hamburg, Germany, 3University of California, Los Angeles, USA, 4Heinrich-Heine-University Düsseldorf, Germany, 5Leibniz Supercomputing Centre, Germany, 6European Space Agency, The Netherlands

Space radiation poses a major hazard both for astronauts and spacecraft electronics, especially during prolonged mission periods [1,2]. High energy protons and electrons, originated from the sun or deep space, are trapped in the Earth’s magnetic field, forming radiation belts and act as main contributors regarding astronauts’ radiation dose and electronic malfunctions [3]. Recent studies [4] have shown that laser-plasma interaction is capable of producing electron bunches with properties similar to space radiation. Figure 1 shows the energy spectrum experimentally obtained from laser-driven plasmas compared with the current specification of the naturally trapped radiation near Earth (AE8/AE9 models[5]). Through this generation of Maxwellian distributed radiation the potential of plasma based accelerators for space radiation environment testing is highlighted.

An alternative is the terrestrial reproduction of the ‘killer’ electrons component via electron-beam-driven plasmas. As shown in figure 2, interaction between an initially ‘monoenergetic’ electron beam and a fully ionised plasma can lead to a broadband energy spectrum. That is due to the effect of deceleration of the electrons situated at the front of the bunch while the electrons of the tail are accelerated by the produced wakefield. Initial particle-in-cell (PIC) code simulations have shown that PWFA is also capable of delivering spectrum similar to the one produced by the AE8 and AE9 models. The energy spectrum in figure 2 is produced from propagating a 7.5MeV electron bunch in a plasma with electron density 0.41·1023 cm−3.


(Invited) Supernovae plasmas

B Bingham 1, 2

1Central Laser Facility, STFC Rutherford Appleton Laboratory, UK, 2University of Strathclyde, UK

Supernovae are spectacular and powerful events outshining the host galaxy for several months. Observations indicate that only a small fraction of the released gravitational binding energy is in the form of the electromagnetic radiation and the kinetic energy of the ejecta. Most of the gravitational binding energy is carried away by neutrinos. An outstanding problem associated with supernovae explosions is how a gravitational implosion turns into an explosion. It is widely recognised that neutrinos are involved in reversing the implosion. I will discuss various neutrino plasma interactions that could result in successful explosions. Another outstanding problem presented is magnetic field amplification in supernovae remnants (SNR). Optical images of SNRs such as Cassiopeia A reveal “knotty” features while X-ray and radio observations show the amplification of magnetic fields about 100 times stronger than those in the surrounding interstellar medium. The idea that a turbulent plasma dynamo was responsible for the field amplification will be discussed.
(Invited) The Orion laser at AWE: system overview and recent experiments
A Randewich
AWE, UK

This talk will outline the use of high power lasers at AWE for high energy density physics, in particular the capabilities of the Orion laser and the experiments carried out on it. Using neodymium doped glass technology, Orion is a combined long (nanosecond) and short (picosecond) pulse dual laser system with 12 beamlines. Uniquely one of the Petawatt short pulse beams can be converted to green light leading to very high contrast for delivery to target, essential for some experiments with intensities approaching $10^{21}$ W cm$^{-2}$. The combination of beams conceptually allows the separation of compression, heating and diagnosis of experiments. The facility is thus able to put matter into hot dense states that would only otherwise be possible using much larger (higher energy) long-pulse-only laser systems. Orion’s combination of lasers is also very flexible and facilitates a wide range of experiments. A large fraction of the facility time is dedicated to material properties experiments, in particular Equation of State and Opacity investigations, but also warm dense matter, X-ray shock, Laser-Driven Radiography and Charged Particle Stopping to name a few. Orion is open for academic access 15% of the time and the campaigns to date have included “Solid Matter at Multi-megabar Pressures”, “Accretion Shocks in Magnetic Cataclysmic Variable Stars”, “Counter-streaming Radiative Shocks” and “Influence of Kinetic Effects and Magnetic Fields on Energy Transport in HEDP”. The talk will very briefly outline a few of these investigations.

Tuesday 24 May

(Invited) Measurements of resistivity in warm dense matter for astrophysical applications
N Booth$^1$, A P L Robinson$^1$, P Hakel$^5$, R J Clarke$^1$, R J Dance$^2$, D Doria$^6$, L A Gizzì$^4$, G Gregori$^3$, P Koester$^4$, L Labate$^4$, T Levato$^4$, B Li$^1$, M Makita$^6$, R C Mancini$^5$, J Pasley$^{1,2}$, P P Rajeev$^1$, D Riley$^6$, E Wagenaars$^2$, J N Waugh$^2$ and N C Woolsey$^2$

$^1$STFC Rutherford Appleton Laboratory, UK, $^2$University of York, UK, $^3$University of Oxford, UK, $^4$IUL, Istituto Nazionale di Ottica, Italy, $^5$University of Nevada, USA, $^6$The Queen’s University of Belfast, UK

Brown dwarfs are an ideal candidate for study with laboratory plasmas as their cores are at temperatures and mass densities comparable to conditions in laser-produced warm dense plasmas. The first brown dwarf was observed in 1995, and as they are relatively cool objects they are difficult to observe, but numerous studies have led to a better understanding of the structures of these objects.

In this talk I will present some of the background in the field of brown dwarf studies and report on recently published results\cite{1} where we have used the measurements of X-ray polarimetry to study material resistivity in warm dense matter. We demonstrate heating of a plastic target with an ultra-intense laser ($I > 10^{20}$ W cm$^{-2}$) to temperatures and densities similar to conditions found within a brown dwarf and measure the polarisation of x-rays emitted from highly ionised sulphur added as a diagnostic tracer to these plastic targets. As both systems are dependent on electron collisions and the coulomb logarithm, any change in the resistivity in the laboratory plasma would therefore imply a similar change in the viscosity of the brown dwarf. We will present the examination of the resistivity models in laser-produced plasmas which allow us to provide tests of the viscosity of matter found at the centre of brown dwarfs.

\cite{1} Booth, N. et al. Laboratory measurements of resistivity in warm dense plasmas relevant to the microphysics of brown dwarfs. Nat. Commun. 6, 8742 (2015).
Relaxation modelling of energy release avalanche in twisted solar coronal loops
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The ideal kink instability in a twisted magnetic flux rope can trigger energy release and plasma heating through magnetic reconnection, which may play a role in heating the solar corona and solar flares [2]. Recent 3D MHD simulations [4] have shown that instability in one twisted thread can disrupt in a stable neighbour, leading to release of free magnetic energy as the threads merge. Subsequently, it was shown that this process could act in a larger system of threads (23), giving the first demonstration from MHD simulations of an avalanche of heating events (as previously postulated in more idealised Cellular Automaton models) [3].

In this presentation, we give an overview of the numerical simulations and then present a new model based on helicity-conserving relaxation [5,6] of multiple flux ropes, which predicts the energy output after a magnetic reconnection event and relaxation. This extends previous work which considered initial flux ropes separated by a current sheet [1]. We first consider a pair of flux ropes, in which one is kink-unstable. We show our results to be in very good agreement with the numerical simulations. The approach is then extended to larger arrays of flux ropes, and the dependence of energy release on the loop parameters is explored. The relaxation approach is far less numerically intensive than 3D simulations: the easy applicability of our method and its reliability paves the way towards modelling larger systems such as active regions of the solar corona. We will also briefly present applications of the model to merging compression approaches for spherical tokamak experiments.

Measurement of magnetic pitch angle in the tokamak edge via back-scattering of microwaves from turbulence

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The edge of a Tokamak plasma is one of the key elements determining the overall stability and performance of the entire device. It is characterized by large values of pressure gradient, current density, turbulence amplitude and flow shear. Measuring these quantities in the edge is crucial in developing and constraining theoretical pictures of stability. However, since this layer of the plasma is typically only a few centimeters thick, it can be challenging to diagnose. In particular, there exists no routine technique for measuring the current density in the plasma edge.

The Synthetic Aperture Microwave Imaging (SAMI) diagnostic is a unique system able to create 2D images of the plasma edge[1]. In addition to the initial design, which only imaged the plasma passively, we employed two additional antennas to send out a modulated signal at the imaging frequency. This signal is Doppler backscattered from turbulent perturbations of the edge returned to the SAMI antenna array. Since turbulence in magnetised plasmas is elongated along magnetic field lines, the largest backscattered amplitude is oriented perpendicular to the field. SAMI’s 2D imaging capability is able to locate this direction and consequently make an independent measurement of the edge’s magnetic field inclination (see figure). This technique is entirely novel, and is the first step in being able to measure the edge current density via microwave Doppler back-scattering.

With the MAST Upgrade currently under way SAMI has recently been moved to the NSTX-U Tokamak in Princeton, USA to acquire data in the first campaigns using both measurement techniques simultaneously. In preparation the diagnostic’s FPGA firmware has been significantly improved to enable the acquisition of the 2D Doppler backscattered data continuously in real-time using a self-designed FPGA based Aurora-PCIe bridge. The data is evaluated post-shot using an NVIDIA Titan X GPU card enabling a 50 fold increase in processing speed over the original serial IDL code enabling inter shot analysis of the 6GB of data generated per shot.

This work will present some of the exciting results this diagnostic produced using MAST data. In addition the results of the development work undertaken in the past 2 years is explained and the initial results obtained from the first NSTX-U runs are presented.

Auger clocking femtosecond collisional plasma dynamics

S M Vinko¹, O Cincosta¹, P Hollebon¹, T R Preston¹, Q Y van den Berg¹, J S Wark¹, G Dakovski², J Krzywinski², M Minitti², T Burian³, J Chalupsky³, V Vozda³, A G de la Varga⁴, P Velarde⁴, H-K Chung⁵, U Zastrau⁶ and R W Lee⁷

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The rate at which atoms and ions within a plasma are further ionized by collisions with free electrons is a fundamental parameter that dictates the dynamics of plasma systems at intermediate and high densities. While collisional ionization rates are well known experimentally in a few dilute systems, similar measurements for non-ideal plasmas at densities approaching or exceeding those of solids remain elusive. Here we illustrate a spectroscopic method capable of measuring rates of collisional ionization dynamics in solid-density plasmas by clocking them to Auger recombination processes. We have recently employed this technique on the LCLS X-ray free-electron laser at SLAC and will present the first experimental results for optically-thin, solid-density Mg and MgF2 plasmas at temperatures up to 100 eV.


Resolving ion acoustic waves in warm dense matter

T G White¹, G Monaco², N J Hartley³, K Appel⁴, T Döppner⁵, L Fletcher⁶, E Galtier⁶, D O Gericke⁷, S Glenzer⁶, P Graham⁸, E Granados⁶, P Heimann⁶, H-J Lee⁶, S LePape⁵, T Ma⁵, B Nagler⁶, A Pak⁵, S Richardson⁶, A Schropp⁶, T Tschentscher⁴, U Zastrau⁴, J Hastings⁶ and G Gregori¹

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The warm dense matter regime (WDM), defined by temperatures of a few electron volts and densities comparable with solids, is a complex state of matter where multi-body particle correlations and quantum effects play an important role in determining the overall structure and equation of state. The study of WDM states represents the laboratory analogue of the astrophysical environments found in the cores of planets and in the crusts of old stars, but also has practical applications for controlled thermonuclear fusion.

Exploiting the small bandwidth of the self-seeded beam at the linear coherent light source (LCLS) we perform inelastic scattering at a small momentum exchange which has allowed the first direct measurement of ion acoustic waves in WDM. This data provides the basis for a direct experimental test of many dense plasma theories through direct comparison with the ion-ion dynamic structure factor. The experimental spectrum is compared to structure factors calculated through both classical and quantum molecular dynamics; exploiting the computational speed-up afforded by orbital-free density functional theory (OF-DFT). Good agreement is found for the energy of the ion-acoustic waves, however, the appearance of a central entropy peak is not captured by the simulations. I will discuss the implications of this discrepancy and present new results from the latest experimental campaign.
Wednesday 25 May

(Invited) Key plasma physics issues for fusion

S Cowley

Culham Fusion for Fusion Energy, UK

I will present the physics that limits fusion performance in current magnetic confinement devices. The plasma turbulence and the stability properties determine the size of ITER and the current demonstration reactor concepts. To obtain smaller and cheaper devices we will have to improve the physics and the exhaust performance. I will review several innovations that show considerable promise.

Modelling of plasma turbulence and detachment in the tokamak divertor with BOUT++

J Leddy¹, B Dudson¹ and N Walkden²

¹University of York, UK, ²Culham Centre for Fusion Energy, UK

In tokamaks the heat is exhausted from the core into the edge plasma where it is then conducted along the field onto a very thin region on the divertor plates. Unfortunately, future fusion devices will generate so much power that the divertor will see a power density too high for any current materials to withstand without melting. To decrease this heat load, the plasma can be forced into a detached regime where much of the thermal and kinetic energy is radiated from the edge plasma and spread volumetrically. This is accomplished when the relatively low temperature plasma in the edge of a tokamak interacts strongly with neutrals near the divertor, which greatly affects the heat flux profiles and potentially the core confinement. Predicting the effect of the neutrals in a future device requires both scaling laws from experimental data and simulation of the plasma/neutral interaction in the divertor [1,2]. BOUT++, a well benchmarked edge plasma code [3], has been modified to include improved treatments of the x-point and divertor sheath, and multiple neutral models have been implemented. With the development of a flexible field-aligned coordinate system, the x-point is better resolved and the divertor geometry is realistically simulated. Both a fluid and a simple recycling model have been implemented to investigate the effect of neutrals, and we have found that turbulence in the neutrals affects the local neutral density and therefore the development of plasma detachment. By focusing the computation on a single divertor leg, detailed simulations of the plasma evolution and neutral interaction show the necessity for the neutrals to remove both energy and momentum from the plasma for a detached regime to emerge. The results will be compared to those of the Monte Carlo neutral code, EIRENE, which has previously been coupled with BOUT++. The divertor simulations then are extended to three-dimensions such that plasma turbulence develops and we examine the relative impact turbulent diffusion and neutral interaction on the resulting heat load spread on the divertor plate. The turbulence localizes areas of strong and weak interaction with the neutrals, and is the dominate effect in setting the plasma profiles at the divertor plate. Similar simulations and analysis are performed on linear devices where the geometry is simplified to look for analogues in detachment evolution.

Evolution of the pedestal during the ELM cycle in JET-ILW plasmas: Comparisons with the EPED model

A E L Lunniss\textsuperscript{1}, C F Maggi\textsuperscript{2}, L Frassinetti\textsuperscript{3}, S Saarelma\textsuperscript{2}, M J Leyland\textsuperscript{1} and H R Wilson\textsuperscript{1}

\textsuperscript{1}University of York, UK, \textsuperscript{2}Culham Science Centre, UK, \textsuperscript{3}Association VR, Sweden

The pedestal is a region of reduced turbulence and strong pressure gradient at the edge of a tokamak plasma. This high pressure gradient typically triggers plasma eruptions called ELMs – Edge Localised Modes – which cause periodic crashes in this steep pressure gradient. By studying the recovery of the pedestal between ELMs, we can learn about the transport and stability properties of this key region of tokamak plasma. The global confinement of the tokamak plasma, and therefore the fusion power in a device like ITER, depends critically on the properties of the pedestal.

Our current understanding of inter-ELM pedestal evolution is epitomised by the EPED model \cite{1, 2}. It states that as the pedestal recovers following an ELM, there is no constraint on its evolution until the kinetic ballooning mode (KBM) boundary is reached. The pedestal gradient is then fixed at the KBM marginal stability boundary, but this steep gradient region widens until the peeling-ballooning (P-B) instability is triggered, which drives the next ELM \cite{1, 2}. The process then repeats. This behaviour has been confirmed on the DIII-D, MAST, NSTX and C-Mod tokamaks \cite{3, 4}. Previous experiments on the JET-Carbon (JET-C) wall, however, showed that the pedestal narrows between ELMs, which is at odds with the EPED model assumptions \cite{5}.

Since the installation of the JET-ITER-Like Wall (JET-ILW), replacing carbon with tungsten and beryllium, a decrease in the pedestal confinement has been observed, primarily due to a drop in the temperature \cite{6}. This has serious consequences for planned JET DT experiments, so understanding the cause is a priority. The results for pedestal stability in the JET-ILW have so far primarily been focussed on the time immediately before the ELM. We have extended this study to explore the full ELM cycle, comparing to the P-B model and the EPED framework to analyse the inter-ELM evolution, seeking further insight into this observed decrease in pedestal performance. The profiles, determined using the JET high resolution Thomson scattering system \cite{6}, are then compared with the KBM and P-B constraints to test the dynamics of the EPED model in JET-ILW. Progress in understanding of reduced confinement compared to the carbon wall will be reported.

This work was supported by the Engineering and Physical Sciences Research Council [EP/K504178/1]. This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053 and from the RCUK Energy Programme [grant number EP/I501045]. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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Finite banana width effect on NTM threshold physics
K Imada\textsuperscript{1}, J W Connor\textsuperscript{2} and H R Wilson\textsuperscript{1,2}
\textsuperscript{1}University of York, UK, \textsuperscript{2}Culham Centre for Fusion Energy, UK

Neoclassical tearing modes (NTMs), if left uncontrolled, can pose a threat to the successful operation of future tokamaks such as ITER. An NTM control system requires the knowledge of threshold physics, whereby sufficiently small magnetic islands heal themselves. Theory and experiments suggest that the threshold island width, $w$, is in the region of 1-2cm, comparable to the trapped ion banana width, $\rho_b$. By expanding in the small ratio of $w/r$, but retaining the ordering $w \sim \rho_b$, we have developed a new drift kinetic theory for the ion response to the magnetic island. This results in a 4D orbit-averaged kinetic equation for the ion response in the toroidal geometry, where the solution depends on the toroidal canonical momentum, $p_\phi$, the helical angle, $\xi$ (labelling the field lines at the rational surface), pitch angle $\lambda$ and kinetic energy $v$. Our new code solves the above equation for the perturbed ion distribution function, taking into account the momentum conservation and quasineutrality, both of which are crucial for determining bootstrap and neoclassical polarisation current perturbations. Our initial results indicate that the simple “fluid-like” picture of density flattening across the island is incomplete for small islands, close to the threshold. Rather, the particle-orbit effect is significant, particularly around the boundary layer surrounding the island separatrix. This is likely to have implications for the NTM drive, and hence for the deployment of NTM control systems, which we ultimately seek to quantify.

(a) Radial profile of the perturbed ion density. Blue circles are the analytic solution in the limit $\rho_b \ll w$, while red crosses are the numerical result in the same limit. Even for $\rho_b/w = 0.1$, the smoothing of the kink at the island separatrix ($x = \pm 0.1$) is prevalent.

(b) Plot of parallel ion flow around the island on $x$-$\xi$ plane. There is a clear flow layer around the island separatrix, consistent with the slab theory prediction.
(Invited) Applied electrostatics and low temperature plasma process for gas cleaning  
A Mizuno  
Toyohashi University of Technology, Japan

Electrostatic precipitation is an old but useful technique of applied electrostatics to control fine particles. For diesel exhaust cleaning, collection performance of particles, PM, can be improved significantly using corona charging prior to diesel particulate filter. In addition, a method to ionize inside fine channels of DPF, or honeycomb-shaped catalyst has been developed. After collecting carbon particles, the discharge inside DPF can be used to regenerate the stuffed DPF (or to oxidize collected carbon particles) at low temperature condition of less than 200 deg. C. These non-thermal discharge plasma can be used to oxidize NO contained in exhaust gas. The oxidation can be made even at room temperature. This feature can be used to achieve deNOx performance at low gas temperature condition such as idling or cold start. This performance is required to meet more tough regulation to be imposed in near future. On board ammonia production is also an important subject to be realized for deNOx of vehicle emission, and is possibly achieved using non-thermal plasma chemical process, which combines plasma with catalyst to improve selectivity and efficiency. In addition to deNOx, several other examples of non-thermal plasma process will be introduced.

Inhomogeneous cloud coverage via the Coulomb explosion of dust in substellar atmospheres  
C R Stark¹, D A Diver² and C Helling³  
¹University of Abertay Dundee, UK, ²University of Glasgow, UK, ³University of St Andrews, UK

Recent observations of brown dwarf spectroscopic variability in the infrared infer the presence of patchy cloud cover. We propose a mechanism for producing inhomogeneous cloud coverage due to the depletion of cloud particles through the Coulomb explosion of dust in atmospheric plasma regions. Charged dust grains Coulomb-explode when the electrostatic stress of the grain exceeds its mechanical tensile stress, which results in grains below a critical radius \( a < a_{\text{crit}} \) being broken up.

This work outlines the criteria required for the Coulomb explosion of dust clouds in substellar atmospheres, the effect on the dust particle size distribution function, and the resulting radiative properties of the atmospheric regions.

Our results show that for an atmospheric plasma region with an electron temperature of \( T_e = 10 \) eV, the critical grain radius varies from 10-9 to 10-6 m, depending on the grains’ tensile strength. Higher critical radii up to 10-5 m are attainable for higher electron temperatures. We find that the process produces a bimodal particle size distribution composed of stable nanoscale seed particles and dust particles with \( a \geq a_{\text{crit}} \), with the intervening particle sizes defining a region devoid of dust. As a result, the dust population is depleted, and the clouds become optically thin in the wavelength range 0.1-10 µm, with a characteristic peak that shifts to higher wavelengths as more sub-micrometer particles are destroyed.

In an atmosphere populated with a distribution of plasma volumes, this will yield regions of contrasting radiative properties, thereby giving a source of inhomogeneous cloud coverage. The results presented here may also be relevant for dust in supernova remnants and protoplanetary disks.
In-situ characterization of the dynamics of a growing dust particle cloud in a direct-current argon glow discharge
L Couëdel, S Barbosa, C Amas and F Onofri
CNRS, France

The dynamics of a growing tungsten (W) nanoparticle (NP) cloud is investigated. NPs are produced from the sputtering of a W cathode in a direct-current argon glow discharge initiated between a 10 cm diameter W cathode and a grounded anode. An argon pressure of 0.6 mbar is set during the experiments [1,2]. The dust particle size distribution (PSD) and the dust particle number concentration (N) are measured by light extinction spectrometry (LES) at different height above the anode. Electron microscopy measurements and Raman spectroscopy of NPs collected at the centre of the anode are performed to study their shape, size and composition. Light scattering at 90° of a vertical laser light sheet passing through the plasma is also used to investigate the spatio-temporal dynamics of the dust cloud. LES consists in passing through the NP cloud a collimated polychromatic beam with spectral intensity I(λi) and wavelengths λi. The measured transmission T(λi) is given by: T(λi) = I(λi)/I0(λi) = exp(-τ(λi)L) where I(λi) is the measured transmitted intensity, L is the probing distance and τ(λi) is the particle system turbidity, i.e. the product of N by the NP mean extinction cross section. This cross section is an integral quantity depending on the properties of each NP size class and its statistical weight in the NP cloud. The transmission spectra can be inversed to recover N and the PSD. Inversion model details are given in Refs. [3,4]. It is found that while growing, the dust cloud is pushed towards the anode and the discharge edge. A new NP generation can grow in the space freed by the first NP generation. Continuous growth by agglomeration, below the LES scanning positions, explains the apparent dissimilarities observed between the in-line optical and the off-line electron microscopy analyses.

Freak waves in negative-ion plasmas: an experiment revisited

I Kourakis$^1$, I S Elkamash$^{1,2}$ and B Reville$^1$

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Extreme events in the form of rogue waves (freak waves) occur widely in the open sea [1, 2]. These are space- and time-localised excitations, which appear unexpectedly and are characterised by a significant amplitude (exceeding 2.5 times the average turbulence level in their environment). Beyond ocean dynamics, the mechanisms underlying rogue wave formation are now being investigated in various physical contexts, including materials science [3], nonlinear optics [4] and plasma physics [5], to mention but a few [6]. Inspired by the ubiquity of this challenging phenomenon, we have undertaken an investigation, from first principles, of the occurrence of rogue waves associated with the propagation of electrostatic wavepackets in plasmas. Motivated by recent experimental and theoretical considerations [7, 8], we have revisited a long-standing problem by focusing on the dynamics of plasmas incorporating negative ions, alongside positive ions and electrons. A multiscale technique is employed to solve the 2-fluid-Poisson system of equations. A nonlinear Schrodinger (NLS) type equation is shown to govern the amplitude of the vector potential. A brief review of existing theories based on non-stationary envelope solutions of the NLS equation is presented (Peregrine soliton, Akhmediev breather, Kuznetsov-Ma breather), and the variation of their structural properties with the relevant plasma parameters is investigated. This work complements our earlier investigation on electromagnetic rogue waves in plasmas [9, 10]. This work was supported from CPP/QUB funding. One of us (I.S. Elkamash) acknowledges financial support by an Egyptian Government fellowship.

(Invited) Micro-discharges in acqueous media: the case of plasma electrolytic oxidation

A Nominé,
The Open University, UK

With the increasing demand in lighter and high performance materials in a context of stronger ecologic legislation, Plasma Electrolytic Oxidation encounters an increasing interest. If anodizing has been used for many decades for growing protective films on the surface of light alloys, its future is compromised by recent REACH legislation which forbids hexavalent Chromium. Moreover, anodised films do not reach the level of performance required for several new applications (biomaterials, aeronautics, sport…).

Plasma Electrolytic Oxidation consists in applying a high voltage (400 – 1000V) and a high current density (1-100 A.dm$^{-2}$) between a work electrode and counter electrodes both immersed in a conductive aqueous electrolyte. While oxide grows, micro-discharges (MD) build up due to dielectric breakdown. These MDs are responsible of the oxide layer growth up to several hundreds of microns and also of the promotion of high temperature crystalline phases (e.g. $\alpha$-$\text{Al}_2\text{O}_3$).

The control and the understanding of the mechanisms underlying PEO discharges are therefore crucial in order to optimise the process. In this talk, an overview of the recent breakthrough in the diagnostics of PEO micro-discharges will be presented and the different mechanisms discussed.

Plasma-controlled solvated electron colloidal chemistry for high quality nanomaterials synthesis

P Maguire$^1$, C Mahony$^1$, C Kelsey$^1$, M Macias-Montero$^1$, D Rutherford$^1$, D A McDowell$^1$, D Diver$^2$ and D Mariotti$^1$

$^1$University of Ulster, UK, $^2$University of Glasgow, UK

Plasma-liquid interactions are complex but offer considerable scope for use in applications from plasma medicine to nanomaterials synthesis [1]. The introduction of individual picolitre micro-droplets into a steady-state low temperature plasma at atmospheric pressure, with control of size, speed and separation offers opportunities for enhanced scope and control of plasma-liquid chemistry. For nanomaterials and quantum dot synthesis, the addition of a liquid phase within the plasma expands considerably the scope for core-shell and alloy formation. The synthesis and encapsulation within a liquid droplet allows continuous delivery of nanoparticles to remote sites for plasma medicine, device fabrication or surface coating.

Delivery of low energy electrons to the liquid surface is a key factor in controlling the plasma-liquid chemistry leading to nanoparticle nucleation and subsequent growth. We have developed a system for exposing single micron-sized droplets to a flux of low energy electrons with exposure times in the range 20µs to >100µs using a low temperature atmospheric pressure microplasma [2]. Nanoparticles with small diameters and narrow polydispersity have been synthesized successfully with a significantly enhanced reaction rate in comparison to traditional colloidal chemistry or radiolytic techniques thus helping to control the nanoparticle size and distribution.

Bridging the gap between global and full fluid models: A rapid semi-analytical model for spatially resolved descriptions of electronegative plasmas

A Hurlbatt, T Gans, and D O'Connell
University of York, UK

Analytical and numerical models allow investigation of complicated discharge phenomena and the interplay that makes plasmas such a complex environment, and there are a number of well-established options. Global models are quick to implement and can have almost negligible computation cost, however only approximate bulk values. Fluid models take longer to develop, and can take days to solve, but provide spatial profiles.

The work presented here details a different type of model, analytically similar to fluid models, but computationally closer to a global model. This semi-analytical model is able to give spatially resolved solutions for the challenging environment of electronegative plasmas.

Solutions are reached in seconds to minutes. This allows broad parameter sweeps that are not practical with more costly models, as well as exposing non-trivial trends that global models cannot capture.

In addition to negative ions, also included are non-isothermal electrons, gas heating, and coupled neutral dynamics. Equations are derived to describe the time averaged spatial profiles of densities, fluxes, and temperatures. Through extended analytical work, normalisations, and numerical schemes, the resulting differential equations can be solved with an initial value type integration scheme. This is found to be hundreds of times faster than boundary value type methods.

Results and trends are analysed for a symmetric capacitively coupled oxygen plasma, and relationships between properties are found to conform to the existing literature. The behaviour of the system is found to change depending on whether or not the self-interaction of charged species is significant compared to the interaction with the neutrals.

The semi-analytical model is shown to agree well with a significantly more detailed and computationally intensive fluid model. In addition to the bulk spatial profiles agreeing both qualitatively and quantitatively, the values of other measured plasma properties agree over a range of system pressures and powers. This comparison is demonstrated to be favourable when contrasted with the results of a global model.

The dynamics of the neutral gas are found to be an important consideration for plasma densities greater than around one part per million. In this model the frictional forces from fast moving ions and thermal energy transfer from hot electrons are the leading cause of disturbance to the neutral properties.
(Invited) Generating neutral beams for advanced plasma etching

M D Bowden¹, A Nomine², A Ayilaran², Y Sutton² and N Braithwaite²

¹University of Liverpool, UK, ²Open University, UK

Etching semi-conductor material with neutral beam has been the subject of research over many years due to its potential in overcoming the limiting effects when etching with established plasma technologies. This presentation will provide background to recent advances in etching techniques and introduce the role of the EU-funded Single Nanometer Manufacturing project in developing European expertise in semiconductor manufacturing technology. The remainder of the talk will focus on the development of a neutral beam source that forms part of this wider project. The source consists of an inductively coupled plasma, operated at low pressure in a pulsed regime. Ions are extracted and neutralises via a grid structure located at one end of the plasma chamber. Measurements of discharge properties are correlated with properties of the extracted beams. Particular attention is given to the surface interaction that are used to neutralise the energetic ions extracted from the system in order to generate the energetic neutral beam that is needed for etching.

We acknowledge support from the European Union under the Framework 7 programme, for the Single Nanometer Manufacturing project.

Pseudospark discharge plasma sourced electron beam for millimeter-wave generation

J Zhao, A W Cross, H Yin, G Shu, L Zhang, W He, D Bowes, K Ronald, G Liu, Y Yin, and A D R Phelps

University of Strathclyde, UK

The pseudospark discharge is a three-phase process happening in an unique hollow cathode structure within a certain low pressure range (typically 50-500 mTorr). During a pseudospark discharge, low temperature plasma is formed that acts as a virtual cathode for extraction of a high-quality electron beam of diameters in the range from millimetres to microns [1-6]. The electron beam has the ability of self-focusing due to the unique structure and the formation of an ion channel generated by the beam front. Simulations have shown that the pseudospark plasma sourced electron beam would propagate within background plasma of density in the range of 1014-16m-3 without any applied guiding magnetic field. This makes it an excellent electron beam source for compact hand-held millimetre-wave devices. Pseudospark discharge experiments of both the single- and multi-gap structures have been carried out to investigate the discharge characteristics and beam generation. An electron beam of ~1 mm diameter carrying a current of up to 10 A and current density of ~108 Am-2 , with a sweeping voltage of 42 to 25 kV and pulse duration of 25 ns was generated from a 4- gap PS discharge. The use of this beam in several beam-wave interaction experiments to generate millimetre waves [7-10] will be presented.


Thursday 26 May

**(Invited)** TAE-induced alpha-particle transport in the \(Q=10\) ITER baseline scenario

**M Fitzgerald**\(^1\), S E Sharapov\(^1\), P Rodrigues\(^2\), A Polevoi\(^3\) and D Borba\(^2\)

\(^1\)Culham Centre for Fusion Energy, UK, \(^2\)Universidade de Lisboa, Portugal, \(^3\)ITER Organization, France

The goal of the international ITER burning plasma experiment is to produce 500MW of fusion power for 50MW of heating power. A baseline scenario with plasma current 15 MA is being considered as the highest priority for achieving this goal of fusion gain \(Q=10\). The burning plasma experiments to be attempted in ITER will differ from previous experiments in that non-thermal fusion alpha-particles must be highly confined, both to ensure machine safety, and to attain conditions required for new burning plasma physics studies. These 3.5MeV non-Maxwellian fusion alpha-particles have characteristic transit speeds that are super-Alfvénic, thereby allowing resonant destabilisation of Alfven normal modes. The toroidal Alfvén eigenmodes (TAEs) have been shown to be particularly dangerous, with up to 70% of neutral beam power being lost to machine components in some experiments due to modes of this type. For assessing the TAE-induced re-distribution of alpha-particles in the ITER Baseline scenario, we have conducted the most comprehensive nonlinear study so far of all relevant TAEs in this scenario, computing their coupled growth and final amplitudes with realistic calculations of the thermal Landau and radiative damping. An earlier linear stability survey of TAEs in ITER provided accurate estimates of the bulk plasma damping of these modes, which could then be used as input to counter drive in the nonlinear calculations. Relatively benign modes highly localised deep inside the plasma were found to be linearly dominant, but it was feared that nonlinear avalanche processes between radially distributed modes could occur. Altogether 129 coupled TAEs, with a complete range of wavelengths in the most unstable domain, were included in the nonlinear HAGIS simulations. Damping was found to play an important role in reducing the final wave field amplitudes of TAEs, down to a factor of 50 below that required for nonlinear avalanche processes to occur. For these TAE amplitudes, stochastic transport of alpha-particles is restricted to a narrow region where predominantly core-localised modes are found. For the flat \(q\)-profile predicted for the ITER baseline scenario, formation of a transport barrier for alpha-particles was found at about a half of the minor radius, thus effectively separating the region of core-localised strongly driven TAEs from that of the weakly driven global TAEs. These results indicate that, at least for the magnetic fields and currents assumed in this baseline scenario, alpha-particles are not sufficiently energetic as to degrade their own confinement through interactions with TAEs. Work is currently underway to include the additional drive from neutral beams.

**MAST upgrade opportunities**

**I Chapman**

Culham Centre for Fusion Energy, UK
Raman amplification in the coherent-wavebreaking regime

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In regimes far beyond the wavebreaking threshold of Raman amplification, we show that significant amplification can occur after the onset of wavebreaking, before phase mixing destroys the coherent coupling between pump, probe and plasma wave. Amplification in this regime is therefore a transient effect, with the higher-efficiency “coherent wavebreaking” (CWB) regime accessed by using a short, intense probe. Parameter scans illustrate the marked difference in behaviour between below wavebreaking, in which the energy-transfer efficiency is high but total energy transfer is low, wavebreaking, in which efficiency is low, and CWB, in which moderate efficiencies allow the highest total energy transfer.

Modelling nonlocal heat transport in fusion relevant plasmas

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In the presence of steep temperature gradients on the scale of a hundred electron mean free paths, the local Spitzer-Harm/Braginskii prediction for heat flow breaks down[1]. This nonlocal heat flow manifests as a significant flux reduction at the steepest part of the gradient, and an increased preheat beyond it. Such conditions are reached in a range of fusion plasmas. In inertial fusion this is most apparent at the interface between the helium gas fill and the gold hohlraum where the laser energy is absorbed. In magnetic fusion, parallel gradients along the scrape-off layer can be considered steep due to the very low density in this region. Initial attempts to model this phenomena with fluid codes using flux limiters have proven flawed due to the arbitrary choice of limiter and the inability to capture the full physics, such as preheat[2]. Alternative models have been suggested, but many of these have not been fully tested. We shall present our work on testing and improving three such models—the ‘SNB’ multi-group diffusion model [3], the Ji-Held moment approach [4, 5] and the Non-Fourier Landau Fluid method suggested by Dimits, Joseph and Umansky[6]—by comparing them with two different Vlasov-Fokker-Planck codes—IMPACT[7], and KIPP[8]. In each case the models have been validated in the local limit and characterised over a range of scalelengths for a linear problem as suggested by Epperlein and Short [9] before moving on to more relevant nonlinear problems.

P:01 Characterising fast electron transport in laser-solid interactions via high energy x-ray emission

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During intense laser plasma interactions with solid targets, fast electrons are accelerated through the target and produce a bright x-ray pulse. Characterising the escaping x-rays from these interactions provides insight into the physics governing the internal dynamics of relativistic electron transport through solid matter. Better understanding of the electron beam source, along with control and enhancement of the subsequent x-ray emission would lead to improvements in radiography applications, with attractive benefits for non-destructive evaluation in the aerospace, nuclear and advanced manufacturing sectors. Presented are methods to characterise both the spectral aspects of the escaping x-ray spectrum and the source size of x-ray generation, in a combined diagnostic. The design is primarily aimed at the hard (100+keV) region of the x-ray spectrum, the challenges of which are also discussed. Preliminary results from an experiment on the Vulcan Laser system are presented. We used an initial version of the device measuring the escaping x-ray source from a 100um Tantalum Target. We show that this source size decreases with increasing x-ray energy and that, interestingly, defocusing the laser spot appears to have little effect on the measured x-ray source size. Thus, indicating that the increase in initial fast electron beam area is being counteracted by a decrease in lateral expansion of the beam from a reduction in global electron divergence through the target.

P:02 Investigating radiation reaction on laser wakefield accelerated electrons

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Next-generation laser facilities, such as the Extreme Light Infrastructure (ELI), are expected to produce intensities which significantly exceed those currently available. At such extreme intensities, a new regime of laser-matter interaction is accessed where neglecting the effect of radiation on the motion of an electron is no longer a valid approximation and quantum-mechanical effects must be taken into account.

Here we present simulation work using the EPOCH Particle-In-Cell code, with which we aim to inform the design and interpretation of future experiments. By illuminating high-energy electrons with an intense laser pulse, it is possible to access the lower end of the quantum regime, i.e. $\alpha \sim 0.2$. With these parameters, we expect to observe significant gamma ray production and substantial losses in electron energy due to radiation reaction. By allowing the electrons to drift after leaving the wakefield accelerator, we enter a geometry where a ‘signal plus background’ measurement may be made. This allows for the simultaneous measurement of electrons which have experienced a range of intensities and non, thus giving a clear signature of radiation reaction (see figures).
Simulation data showing the effect of a high intensity laser interaction on an electron energy spectrum. (Left: Before interaction. Right: After)

**P:03 Laser-driven X-ray and neutron source development for industrial applications of solid-foil plasma accelerators**

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Pulsed beams of energetic X-rays and neutrons from intense laser interactions with solid foils are promising for applications where bright and small emission area sources, capable of multi-modal delivery are ideal. Possible end users of laser-driven multi-modal sources are those requiring advanced non-destructive inspection techniques in industry sectors of high value commerce such as aerospace, nuclear and advanced manufacturing.

We report on experimental work1 that demonstrates multi-modal operation of high power laser-solid interactions for neutron and X-ray beam generation. Measurements and Monte-Carlo radiation transport simulations show that neutron yield is increased by a factor ∼2 when a 1 mm copper foil is placed behind a 2 mm lithium foil, compared to using a 2 cm block of lithium only. We explore X-ray generation with a 10 picosecond drive pulse in order to tailor the spectral content for radiography with medium density alloy metals, the effect of using > 1 ps laser drive on fast electron beam dynamics is discussed. X-ray spectra are deconvolved using spectrometer measurements alongside simulation data generated using the GEANT4 Monte-Carlo code.

We also demonstrate the unique capability of laser-driven X-rays in being able to deliver single pulse high spatial resolution projection imaging of thick metallic objects. Active detector radiographic imaging with a 10 ps drive pulse, of sample objects relevant to the aerospace and nuclear sectors, is presented for the first time, demonstrating that features of 200 µm size are resolved when projected at high magnification.

P:04 Fast ignition using shock accelerated ions from the target corona

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Recently we have suggested that fast ignition with ions might be possible using a scheme in which, towards the end of the compression phase in inertial fusion, an intense short pulse is used to launch a collisionless shock wave to accelerate ions into the compressed core [1]. This is in contrast to other ion fast ignition schemes in which a separate target is envisaged for the generation of the ions. Initial estimates of the energy range of ions moving into the core suggest that ions in the 1-10 Mev range will deposit their energy when the density reaches $10^{25} - 10^{26}$ cm$^{-3}$.

We will report on detailed studies using PIC simulations to identify the range of corona temperatures and shock Mach numbers needed to produce ions of the energy necessary to produce core heating and ignition. Initial studies indicate that ions in the suitable energy range can be produced in the corona and absorbed in the core.

P:05 Stability of trapped-ion orbits around dust in the plasma boundary

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For dust grains smaller than the typical collision lengths of the plasma, collisional effects are often ignored. However, if a background of low-temperature neutrals is present, even infrequent charge exchange collisions can cause a population of low temperature ions to collect in orbit around dust grains.

The collection radius for this effect is large compared to the dust grain – of order $T_e/T_n$ dust radii (where $T_e$ and $T_n$ are the electron and neutral temperatures, respectively). These ions both shield the grain and, since further collisions de-orbit these ions onto the grain, provide another source of current to the dust, altering its charge.

Using Particle-In-Cell simulations, we have extended previous work in the bulk plasma to the presheath/sheath region, where dust is more commonly found. We show that the presheath field causes a high flux of ions past the grain, augmenting the trapped ion population; as a result, even grains much smaller than a Debye length can be entirely shielded by the orbiting ions.

The stability of these orbits under the influence of the sheath field is also investigated for a range of dust grain sizes, to determine the stability of these neutralised dust structures in the plasma edge region. A limiting dust grain size is determined, at which the sheath field is strong enough to strip orbiting ions from the grain.
P:06 A fast chirplet transform for analysing wave activity in time-series

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The discrete-time chirplet transform is an intuitive alternative method for analysis of the periodic components of signals, but has hitherto been unreasonably expensive to compute at reasonable resolutions. With a new algorithm for generating a time-sparse representation of the output of the transform, we overcome this barrier and can explore signals that are difficult to resolve in traditional time-frequency representations. This technique has applications for time series analysis across many domains including solar radio and tokamak diagnostics.

An artificial example of 2 signals crossing in frequency, seen in the time-frequency plot in the top panel. The lower panel shows a subset of a slice of the chirplet transform around the black vertical line in the upper plot. The two component signals are seen as the bright spots in the centre. Note how the signals can be separately identified in the chirplet space while they are overlapping in the traditional time-frequency plot.
P:07 Modelling nonlinear electrostatic oscillations in plasmas

D Diver and E Laing
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The nonlinear 1-D plasma electrostatic oscillation is formulated in an analytic framework that allows closed-form analytic solutions along the characteristics, and solved numerically in configuration space. Additionally a novel iterative analytical form for the finite-amplitude oscillation solution is derived, which compares favourably with the other two techniques. A fresh insight into the evolution of the oscillation is gained, including defining the least achievable density in the nonlinear oscillation as half of the equilibrium value, and relating the associated maximum density achievable in terms of that minimum. Examples of the calculations are shown below: left, the surface plot of the plasma velocity field from direct numerical simulation using characteristics; right, the plot of the analytic form of the solution, for the same parameters and nonlinear behaviour as the case on the left.

In the images above, the horizontal axis labelled ‘kx’ is the normalised distance coordinate, and the axis labelled ‘q’ is normalised time. Note that the oscillation is significantly non-linear in character, showing characteristic steepening of the velocity profile from an initial sinusoidal form. Below is an analytic form of the density profile, showing the minimum density saturating at one half of its initial value, as predicted by the theory.
Microwave start-up of tokamak plasmas

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Long-pulse tokamak fusion devices need to minimise (or eliminate) their reliance on inductive heating and current drive, due to the limit on the achievable volt-seconds created by a central solenoid. In spherical tokamaks (ST), this problem is compounded by the lack of space on the inboard side for shielding, while the low electron density during start-up means that neutral beams shine through the plasma. The solution is for STs to make use of radio frequency (RF) beams. Experiments on the Mega Amp Spherical Tokamak (MAST) at Culham have demonstrated electron Bernstein wave (EBW) assisted plasma current start-up, by generating plasma current up to 33 kA non-inductively with the injection of up to 100 kW of RF power [1]. Experiments of this type rely on the pre-ionization and heating of the plasma under the effect of injected RF power, as well as the initiation of plasma current. During start-up, the magnetic field lines have an open configuration, such that electrons have different orbits, depending on their momentum and starting point. As the interaction between electrons and the RF beam are localised in space, it is therefore necessary to resolve this interaction spatially, which requires a solution to the orbit of each electron. A computationally less expensive method involves solving the electron velocity distribution function, and studying the effect of the RF power by making use of a 0D2V kinetic model. The effect of collisions are assumed to be sufficiently weak, such that the plasma-wave interaction can be described by the Vlasov equation,

\[ \frac{\partial f}{\partial t} - q_e(E + v \times B) \frac{\partial f}{\partial \nu} = 0 \]

Based on experiments done on MAST, it is expected that the distribution function will be significantly distorted, and the current driven by a hot electron tail. The time-evolution of the distribution function is studied under the consideration of several effects, including sources and orbit losses, toroidal loop voltage, and the effect of RF power (diffusion) on EBW and electron cyclotron (EC) heating and current drive, as shown in figure 1.

**Figure 1** - The regions where the particle source, loss and diffusion typically affect the distribution function in momentum space. The distribution function evolves under these terms in time,

\[ \frac{\partial f_e}{\partial t} = \text{source} - \text{loss} + \text{diffusion} + \text{loop voltage} \]

Preliminary results indicate that, under appropriate effects and parameters for MAST, typical densities and driven currents are obtained when compared to experiments.

Multicomponent plasma expansion into vacuum with non-Maxwellian electrons

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The expansion of a collisionless plasma into vacuum has been widely studied since the early works of Gurevich et al [1] and Allen and coworkers [2]. It has received momentum in recent years, in particular in the context of ultraintense laser pulse interaction with a solid target, in an effort to elucidate the generation of high energy ion beams [3, 5].

In most present day experiments, laser produced plasmas contain several ion species, due to increasingly complicated composite targets. Anderson et al [6] have studied the isothermal expansion of a two-ion-species plasma. As in most earlier works, the electrons were assumed to be isothermal throughout the expansion. However, in more realistic situations, the evolution of laser produced plasmas into vacuum is mainly governed by nonthermal electrons. These electrons are characterized by particle distribution functions with high energy tails, which may significantly deviate from the Maxwellian distribution [7].

In this paper, we present a theoretical model for plasma expansion of two component plasma with nonthermal electrons, modelled by a kappa-type distribution [7]. The superthermal effect on the ion density, velocity and the electric field is investigated. It is shown that energetic electrons have a significant effect on the expansion dynamics of the plasma. Different special cases are considered, as regards the relative magnitude of the ion mass and/or charge state. This work was supported from CPP/QUB funding. One of us (I.S. Elkamash) acknowledges financial support by an Egyptian Government fellowship.

Radiation pressure acceleration (RPA) of ions with high intensity lasers is of great interest presently, because it benefits from improved energy scaling compared with thermal acceleration schemes. The favourable scaling of the critical density for longer wavelength ($\lambda=10\mu m$) CO$_2$ laser systems is attractive for RPA, since it allows much lower density targets to be used for ion acceleration. For example, previous work using gas jet targets has demonstrated quasi-monoenergetic proton beams along with ($I/n$) radiation pressure scaling [1]. He$^+$ beams >1MeV using optically induced target shaping in the form of a blast wave were also demonstrated [2]. Target shaping gives shorter density scale lengths at the critical surface, aiding RPA. We have developed this target shaping further with two complementary methods; the previously mentioned optical pre-pulse or an external 532nm YAG beam, incident on a clip at the edge of the jet [3]. This talk will give a summary of the progress made on RPA-driven ion acceleration experiments from the last year, including comparisons of these blast wave generation mechanisms. We also report on the observation of higher quasi-monoenergetic ion bunch energies. Previously unseen ion beam filamentation results will also be presented and discussed.

P:11 Quasi-stable injection channels in a wakefield accelerator

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The use of a particle driver in plasma-wakefield acceleration has the potential to allow electron acceleration to energies orders of magnitude higher than can currently be achieved. In this work we investigate the dependence of the energy gain on the injection position of electrons injected into a wake. Test-particle simulations show previously unobserved complex structure in the parameter space, with quasi-stable injection channels forming for particles injected in narrow regions away from the wake centre. The result is relevant to both the planning and optimisation of experiments making use of external injection.

Figure 1: Plot of final energy against initial position for externally injected particles. Acceleration was carried out over 25 cm in plasma of density $7 \times 10^{14}$ cm$^{-3}$, with a 15% modulation depth.
P:12 Correlating metastable-atom density, reduced electric field, and electron energy distribution in the early stages of a 1-torr argon discharge

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Impressively accurate collisional-radiative models have been used to model plasmas and have been tested by experimental observations in various discharges and pressures. Efforts have been made to simplify these complex collisional radiative models for extracting diagnostic signatures without sacrificing accuracy, however, these simplifications still require algebraic overhead. While the radiation-trapping effects of the often-utilized 2px→1sy transitions (in Paschen’s notation) are taken into account, or even exploited, eliminating the need to account for these effects by observing the 3px→1sy transitions would be preferable in most cases as this simplifies the analysis. DeJoseph et al. [1] first suggested that the argon 420.1-419.8nm line ratio may be useful in detecting metastable argon atoms because of the proximity of the lines. These emission lines have proven to be useful in determining timeaveraged electron temperature [2] by assuming a Maxwellian-like EEDF, and in determining metastable-atom density [3] by incorporating a measured EEDF. Here, the temporal measurement of electron density, metastable-atom density, and reduced electric field are used to infer the dynamic behaviour of the excitation rates that describe electron-atom collision-induced excitation in the positive column of a pulsed argon discharge plasma. Plausible assumptions are invoked regarding the shape of the electron energy distribution function (EEDF), specifically, the inelastic electron-metastable collisions produce highenergy electrons and the electron-electron collisions will cause the EEDF to become more Maxwellian [4]. Direct observation of these excitation rates have been used to predict the temporal behaviour of metastable-atom density in the post-transient stage of a pulsed plasma discharge [5]. Ignoring the Maxwellianising effect of electron-electron collisions allows for the examination, in this work, of correlations between the aforementioned quantities in the transient stage of the discharge. We conclude that the observed line-emission ratio and the predicted line-emission ratio are in quantitative agreement with each other in the transient phase of the discharge and the two ratios qualitatively agree with each other in the initiation phase of the discharge. Ignoring electron-electron collisions allows insight into the otherwise hard-to-measure or expensive-to-measure plasma conditions and the time dependence of these conditions in the transient phase of the discharge. JF is supported by DOE-SCGSR and DE-SC0012515. SN is supported by NSF PHY-1301896.

**P:13 The dusty solitary hydromagnetic wave**

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If many dust grains are added to an ion-electron plasma, on large enough length scales they may be regarded as a third plasma species with relatively high charge and mass. The dust fluid motion and modification of the quasi-neutrality condition can lead to alterations of preexisting waves, or introduce entirely new ones [1]. The solitary hydromagnetic wave, originally studied by Allen and Adlam [2], has recently been revisited by Allen and Gibson (work currently being refereed). As a further extension of this work, we consider the addition of a dust component, studying the modified wave behaviour for arbitrary dust concentration. We present analytic results for the low dust and dust dominated limits and discuss the transition between these two regimes.


**P:14 Surface, liquid and vapour phenomena in electrical discharge formation in saline solutions**

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Electrical discharges in high conductivity solutions, e.g. saline solution, are becoming increasingly important in a number of areas including medicine. We have previously reported both experimental and computational studies of discharge production in saline solution with low voltage (\(~200V\)) pulses (\(~\text{ms}\)) applied to a rod-like tip in saline solution. The studies were designed to elucidate the underlying physics and chemistry of the discharge production and it's development [1,2]. The studies confirmed that vapour layer envelopment of the rod tip, produces electrical isolation that is a prerequisite for breakdown. Here we build upon these prior reports and discuss further results to add in our understanding. These results include characterization of the surface of the powered electrode where the existence of small, thin NaCl structures on the surface indicates that inhomogeneous surface effects play an important role in the discharge generation both by work function reduction and by local electric fields enhancement. In the liquid, shock waves are observed and hydrogen peroxide production rate (\(~0.5\text{mg/min}\)) have been measured as has the time variation of the liquid temperature and conductivity of the liquid through the pulse while in the discharges an estimate of the electron densities (\(4\pm2 \times 10^{20}\text{m}^{-3}\)), through line broadening measurements, has been obtained.


Tokamak scenarios with internal transport barriers can attain much higher fusion performance than standard H-mode plasmas [1]. However, internal transport barriers are prone to disrupt too quickly and violently for machine protection to be routinely possible. It is therefore critical to understand the disruptive process and how to attain steady state internal transport barriers. There is a strong indication from TFTR data [2] that ballooning modes cause the fast disruption of internal transport barriers. We show that this disruptive process can be explained using an innovative analytic model for nonlinear explosive “ballooning” flux tubes.

The stability of a tokamak plasma to nonlinear “ballooning” displacements of a thin elliptical magnetic flux tube is examined. Above a critical pressure gradient the energy stored in a tokamak plasma may be lowered by finite displacements of such tubes but not infinitesimal displacements – i.e. they are metastable. Above a higher critical pressure, the linear ballooning stability boundary, such tubes are unstable to linear (infinitesimal) and nonlinear (finite) displacements. The lowest energy states of meta-stable tubes are calculated in a large aspect ratio circular flux surface model tokamak equilibrium which includes a steep pressure gradient region i.e. a transport barrier. The displacement of the flux tubes in these states is often as large as the pressure gradient scale length, such a state is shown in figure 1. Triggering eruptions of flux tubes into these lower energy states leads to explosive dynamics.

We use a generalized form of Archimedes principle to derive a differential equation which models the dynamics of a flux tube in a large aspect ratio tokamak. We have solved this equation to find the equilibrium states and calculated their relative energy. We have also calculated the time dependent solutions in the presence of drag.

Instabilities limit the pressure in tokamak plasmas. This limit can be a hard, disruptive, limit or a soft limit which may result in a critical pressure profile. Understanding the disruptive process will help us design configurations that have a soft limit, which in turn will allow us to build smaller, more economic fusion power plants.

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Dust contamination in plasmas is a problem in fusion machines. One estimate is that 1 ton of dust will be generated in ITER per year [1] compromising reactor performance. Predicting the transport and fate of dust is therefore an important research area. In collaboration with the University of York and Imperial College London, experimental measurements from the University of Liverpool will be used to verify theoretical dust transport and plasma turbulence models (DTOKS and BOUT++).

A new facility has been constructed at Liverpool with the strongest magnetic flux density (up to 1 Tesla) for dusty plasma studies in the UK. The plasma is generated at 13.56 MHz in a parallel plate capacitively coupled cell. The magnetic field is applied uniformly throughout the plasma by a Helmholtz coil. At low fields (mT) the magnetised electrons confine the Ar plasma inward radially (see Figures 1 and 2) enhancing the emission near the powered electrode edge. Micrometre-sized particles were then levitated, balanced by the sheath electric field and gravity, in the plasma forming a plasma “crystal” (Figure 2).

Rotation of the crystal due to the magnetic field was observed at a pressure of 1 Pa, rf plasma power of 5 W and in a field of 60 mT. This is caused by an E x B drift of the positive ions impacting the dust. Measuring the angular velocity of the dust provides a method for extracting the electric field strength. Preliminary results show the electric field to increase linearly from 0.4 to 1.4 mV / m from the rotation center (Figure 3) in agreement with other researchers [2].

Theoretical studies have shown that a magnetic field changes the dust charge [3] which may be observed as a change in the levitation height of the crystal. However, the magnetic field also alters the plasma density and electron temperature. By combining Langmuir probe, OES and dust diagnostics the behaviour and transport of dust can be studied in detail. Future experiments are also planned at higher field strengths (~1 T) where plasma filamentation have been observed [4].

![Figure 1 – Plasma with 60 mT magnetic field](image1)

![Figure 2 – Dust crystal levitated in Ar plasma without magnetic field](image2)

![Figure 3 – Radial electric field from center of dust crystal](image3)

P:17 Statistically determined dispersion relations of magnetic field fluctuations in the terrestrial foreshock

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We obtain dispersion relations of magnetic field fluctuations for two crossings of the terrestrial foreshock by Cluster spacecraft. These crossings cover plasma conditions which differ significantly in their plasma \( \beta \) but not in the properties of the encountered ion population, both showing shell-like distribution function. Dispersion relations are reconstructed using two-point instantaneous wave number estimations from pairs of Cluster spacecraft. The accessible range of wave vectors, limited by the available spacecraft separations, extends to, approximately, \( 2 \times 10^4 \) km. Results show multiple branches of dispersion relation, associated with different power of magnetic field fluctuations. We find that Sunward propagating fast magnetosonic waves and beam resonant modes are dominant for the high plasma \( \beta \) interval, while the dispersions of magnetically dominated interval include Alfvén and fast magnetosonic modes propagating Sunward and unit-Sunward.

P:18 The charging of non-spherical objects in a plasma

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The calculation of electron and ion currents to an object immersed in a plasma is a classic problem of plasma physics, originally in the context of Langmuir probes and more recently applied to the charging of spacecraft and dust in plasmas. The currents are often calculated using the orbit-motion limited (OML) theory [1], which gives simple analytic expressions in the case of spherical and cylindrical objects. However, naturally-occurring objects in a plasma come in a wide range of shapes; examples include elongated astrophysical dust in planetary rings and the interstellar medium, flakes of wall material in tokamak plasmas, plasmas containing liquid droplets which may be deformed by rotation, fields and plasma flows, and fractal aggregates in planetesimal formation and silicon processing plasmas.

This work extends the OML theory to spheroids by numerically evaluating the integrals for the collected currents, allowing accurate predictions to be made for the charging of such nonspherical objects. The results show that spherical OML provides a reasonable approximation for the charging of a considerable range of shapes, although highly deformed objects draw a significantly smaller ion current from the plasma than that given by spherical OML, and hence are more negatively charged than spheres. These results are verified using the plasma octree code pot, which simulates the motion of individual ions and electrons in a small region surrounding the object and, as such, makes no assumptions based on the Boltzmann relation for electrons. More general cases, where plasma flows and magnetic fields may be present, are also considered.

In high confinement mode, the level of energy and particle transport at the plasma edge in a tokamak is reduced and a steep pressure gradient is formed in the outer region of the plasma which gives rise to a pressure pedestal. The heightened plasma pressure at the edge leads to a higher density and temperature in the core as well, thus positively affecting the global confinement. The edge pedestal structure determines the boundary condition of the heat transport of the plasma core, thus the understanding of the physical processes governing the behaviour of the edge transport barrier is crucial in order to predict the plasma performance in future devices such as ITER. One of the vital questions regarding ITER is the effect of the deuterium-tritium mixture on the pedestal. From the plasma physics point of view, the main difference when the isotope of the main ion is modified is the change in ion Larmor radius. This influences the transport in the plasma, thereby affects the pedestal structure and confinement. Previous isotope experiments on JET showed that the scaling of the edge confinement with the isotope mass is strongly positive [1]. However, isotope studies in hydrogen and deuterium on JT-60U found that the pedestal structure depends weakly on the isotope mass [2]. In the upcoming JET campaigns - with the new ITER-like wall (ILW) and improved edge diagnostics capabilities - discharges in H, D and T will be carried out providing opportunity to assess the isotope scaling of the pedestal.

This contribution introduces the outline of a recently started PhD project aiming to investigate the pedestal structure in JET ELMy H-mode plasmas in different isotopes. The experiment plan to reveal the isotope effects is presented. The strategy includes discharges in each isotope (H, D and T) allowing the investigation of the isotope scaling of the pedestal structure, the pedestal confinement, the ELMs size and frequency and the type I/type III ELM threshold. The plan is to execute series of discharges in all three isotopes in order to match different plasma parameters. A set of discharges will be performed by keeping the engineering parameters (toroidal magnetic field, plasma current, input power) constant in each isotope. Another series will be carried out to obtain plasmas at same stored energy. Isotope identity discharges are also planned to match dimensionless parameter profiles such as normalized ion Larmor radius, poloidal beta and collisionality. Furthermore, the effect of isotope mixtures on the pedestal conditions will also be investigated. H and T discharges will be executed in future JET campaigns, but in D already a comprehensive gas and power scan has been completed during the 2013/2014 experimental campaign [3]. This has been extended to the low power part of the domain in the 2015/2016 campaign in order to reach the type I/type III ELM threshold. The analysis of these discharges in terms of the pedestal structure and the ELM behaviour are also presented.

P:20 Features in the ion emission of Cu, Al and C plasmas produced by ultrafast laser ablation

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The bi-modal nature of charge integrated ion kinetic energy distributions [1], that result from ultrafast laser produced plasmas, is discussed in this paper. A negatively biased Faraday cup was used as a charge collector to measure ion distributions from three different solid targets which had been irradiated with an ultrafast laser in the fluence range 0.1 – 1J/cm². A bi-modal time of flight distribution is found for all three targets (C, Al and Cu). In the case of the metallic targets (Al and Cu) high- and low-kinetic energy peaks exhibit quite different dependencies on laser fluence whereas for the semi-metallic target (C), both peaks scale similarly with ultrafast laser fluence. The results are discussed within the framework of a one dimensional capacitor model resulting in ion acceleration [2].


P:21 Solitary structures with ion and electron thermal anisotropy

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In this work, we present a comprehensive study of evolution of electrostatic solitary structures in magnetized plasmas with ion and electron thermal anisotropy. The anisotropies of ions and electrons are modelled with the Chew-Goldberger-Low (CGL) double adiabatic equations and anisotropic bi-Maxwellian velocity distribution, respectively. The electrons are treated as inertialess fluid. We assume that the electron thermal anisotropy enters to the dynamics of solitary structures through the magnetic field line stochasticity. We found that negative electron thermal anisotropy ($T_{e\perp}/T_{e\parallel} > 1$) helps in the formation of large amplitude solitary structures which are in broad agreement with observational data from earth’s magnetosphere. The scenario is relevant in space plasmas such as those in the auroral regions of earth’s magnetosphere and other planetary atmospheres. We also outline a possible extension of the above work with more realistic polybaric pressure model.
The interaction of ultrashort intense laser pulse with gas plasmas represents a new class of scenarios that could lead to powerful (megawatts to gigawatts) terahertz (THz) radiation sources [1]. In particular, the method of laser interaction with ambient air via field-induced ionization is conceived as a very efficient one due to its convenient setup and the demand of relatively low laser intensities at 1014~1016 W/cm². This configuration has been intensively explored with few-cycle pulses or two-color laser pulses. The underlying mechanisms are not very clear until recently that it was explained in comprehensive aspects by the ionization-current model [2]. However, the investigations so far are limited to Gaussian drive pulses and, for linearly polarized pulses, only linearly polarized THz waves can be produced.

In the present paper, we investigate the conversion of THz radiation from gas ionization irradiated by linearly polarized Laguerre-Gaussian (LG) laser pulses [3], another eigenmode of Gaussian beams that has an azimuthal phase variation and well-defined orbital angular momentum (OAM) [4]. The application of LG pulses has recently been extended to relativistic laser-plasma interactions. Here, our results show that, compared with using a Gaussian driver, the use of LG pulses can lead to widely tunable THz radiations in terms of either the transverse field pattern or polarization state, dependent on specific laser-target parameters employed. For few-cycle LG pulses, typically sub-cycle THz vortex beams having the same polarization as the driver can be produced due to collective plasma response. They are followed by radiations having a fixed transverse field pattern, determined by the azimuthal mode of the LG driver and its initial phase. The peak field amplitude of associated THz radiations is fixed but its transverse position rotates around the centre axis for different initial phases due to the phase compensation given by the azimuthal variation of the driver. The overall polarization state can be adjusted and can appear as radially polarized under proper conditions. Further extension to two-color LG pulses as the driver is also analysed. These findings are verified using three-dimensional particle-in-cell simulations.


P:23 Measurement of the charge on an isolated probe in a non-thermal equilibrium plasma at atmospheric pressure

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Theories of probes in collisional plasmas have been studied for many decades. However accurate experiment verification has been severely lacking. We injected spherical micron-sized water droplets into a low temperature rf plasma at atmospheric pressure with an estimated electron density of $10^{12}$ cm$^{-3} - 10^{14}$cm$^{-3}$. Single droplets were exposed to the plasma for ~100us and the accumulated charge on the droplets, due to ion and electron bombardment, was measured in flight using downstream electrodes. The estimated gas temperature, from OES, was 330K and the optical in-flight measurements of droplet diameter indicate a reduction in mean diameter from 15um to 13um due to plasma exposure.

P:24 Laser plasma effects in water

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We report effects on water produced by laser induced breakdown in bulk water and near the air-water interface (AWI). Laser light is sent into a water cell parallel to the water-air interface and focused below the surface. The plasma breakdown is produced by a Nd:Yag laser at 1064 nm (9 ns pulse width, 100-250 mJ/pulse energy). Light is observed at 90 degrees to the laser beam propagation axis using two synchronized intensified-CCD cameas and a spectrometer. The plasma emits light in the optical range up to several hundred nanoseconds after the laser pulse. As the plasma cools, shockwaves and bubbles, observed by shadowgraphy, are generated and last for microseconds and milliseconds, respectively. Provided the laser focus is sufficently close to the air-water interface, expanding bubbles penetrate the water surface which results in ejection of macroscopic water droplets into the air to hights up to 50 centemeters. As the bubble breaks up micro-bubbles are formed in the water in the neighborhood of the ignition point and last for times long compared to all other processes. The slow turbulent dissapation of the micro-bubbles produces a memory effect for the water and modifies the plasma ignition and subsequent water response to the next laser pulse. Plasma time and space emission data as well as data on the photomechanical effects will be presented along with COMSOL Multiphysics modelling. Data will be presented on other liquids including Glenlivet and Bushmills.
P:25 Image plate and scanner characterisation

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The Central Laser Facility (CLF), based at the Rutherford Appleton Laboratory, UK delivers high power laser experimental beam time for use by the UK research community and their international collaborators. Laser plasma experiments that take place use a combination of diagnostics to analyse the plasma conditions present within an experimental campaign and as such the characterization of diagnostics is of importance to the research community that use them. One such diagnostic is image plate and the associated scanning machine, model FLA5000, which are regularly used at the CLF to record and read data from high power laser interaction experiments. The image plates available (MS, SR, TR types) are all sensitive in varying degrees to ionizing radiation as well as electrons and neutrons. Image plates are used to detect and record information while the scanner is used to read and digitize it. Investigations have taken place to verify linearity of response, resolution limits and noise levels of the combination of MS, SR and TR-type image plates with the FLA5000 scanner at the CLF in response to x-rays from an Fe⁵⁵ source. Details of the tests carried out and results are presented.

P:26 Hydrodynamics driven by intense short-pulse laser-plasma interactions

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When an intense short-pulse laser interacts with a solid target -keV temperatures maybe generated in dense plasma. This can result in a variety of interesting hydrodynamic phenomena. In this presentation we will consider some recent investigations of this type, including shock-wave and hydrodynamic instability studies driven by short pulses. Approaches to simulating such experiments will also be described- typically involving multiple codes used in series to capture different stages of the evolution of the target, from the pre-pulse, through the main pulse and the subsequent hydrodynamic behavior. Finally we will consider some possible future directions for such research.
Theory and particle-in-cell (PIC) simulations are presented describing non-thermal cyclotron radio emission [1,2] from the Earth’s auroral region. For the Earth this radiation is known as Auroral Kilometric Radiation (AKR). Similar mechanisms are thought to be responsible for some of the cyclotron emissions observed from more distant astrophysical environments.

A laboratory experiment has been carried out [3,4] that has successfully simulated these electron cyclotron emissions. In parallel with the laboratory experimental simulations, numerical PIC simulations [5] have helped to confirm the instability leading to the emissions is driven by a horseshoe electron velocity distribution. Theoretical analysis and PIC simulations using the code VORPAL have shown that the instability has a significant negative axial wavenumber (backward wave component) [6]. The backward wave character of the emission is evidenced by an oblique wave front propagation angle with respect to the axis of the system as shown in Fig.1. The magnitude of the negative axial wavenumber reduces with increasing energy spread.

Figure 1. Contour plot of $E_y$ in x-z plane at $t=1348t_{ce}$ for (a) 2% (b) 6% Gaussian energy spreads.

This paper describes experiments and numerical modelling to quantify the power balance in microwave generated high intensity discharge (HID) lamps containing mercury. Although HID lamps containing metal halides and high pressure sodium lamps are more efficacious than high pressure mercury lamps, these provide a valuable research tool in developing numerical models for lamps, since the physical properties of mercury atoms are well known.

Previous studies for microwave discharges in Hg have been restricted to calculations of the temperature profile, the total and visible radiation as function of electric power input [1,2,3]. Therefore, in this work, the effect of Hg dose and the electric power on radiation were experimentally studied and compared with the simulations results. The aim of this work is to validate the numerical model and to extend it to calculate the Ultraviolet, Visible and Infrared radiation generated by a microwave discharge.

A modified version of the "skin effect” [1] model was employed to determine the temperature profile and power balance in high pressure mercury plasma sustained by a microwave discharge generated at 2.45GHz, within a cylindrical cavity, TM010 mode [2]. This configuration is represented on figure 1.

![Cavity Vessel Discharge Cavity](image)

Figure 1. Scheme of a cylindrical cavity containing the vessel discharge, TM010 mode.

By combining the numerical and experimental results, we found that greater efficacy could be obtained by increasing the mercury dose or the electric power applied to the discharge. From the modelling results, we can conclude that an increase on the electric power increases the total power radiated which is in agreement with the results obtained by Waymouth [1, 4]. However, in all cases the efficiency of production of visible radiation was less than that in comparable mercury discharges containing electrodes.

Optical generation of multi-component plasma with Gaussian optics, axicons, and axilenses

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Langmuir waves in plasmas are widely used for acceleration of particles such as electrons [1]. In high-intensity laser-plasma interaction, all gaseous media are easily ionised by the laser pulse driver (or even by the prepulse) due to its high electric fields. In contrast, electron-beam driven plasma waves, which have complementary advantages to laser-driven plasma acceleration [2], require preionisation of the gaseous media.

Optical preionisation for plasma wakefield acceleration demands laser pulses irradiating the medium in a large volume above the intensity threshold of tunnel ionisation, which substantially differs from typical high-intensity laser-plasma-interaction. Low ionisation threshold species such as alkali metal vapours or gaseous hydrogen are suitable candidates in order to generate a comparably cold, but large volume plasma with moderate laser powers. In contrast to Gaussian optics such as lenses and parabolic mirrors, optical elements such as axicons and axilenses are advantageous to generate these large volume plasmas [3] with comparably low ponderomotive force.

Theory, simulations, and experimental results on optical preionisation of different media will be discussed. Experimental findings obtained with Bessel beams generated by an axilens at the Facility for Advanced Accelerator Experimental Tests (FACET) located at the Stanford Linear Accelerator Center (SLAC) as substantial part of the “E210: Trojan Horse” plasma wakefield acceleration experiment led by University of Strathclyde will be presented.

P:30 Generation of Warm Dense Matter by isochoric heating of a Ti-wire

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Matter at near-solid density and temperatures exceeding several eV up to a few 100 eV can be created by using short laser pulses to heat matter in the so-called “isochoric heating” approach. This means that the heating process should be faster than the hydrodynamic expansion of the target. In principle, “isochoric heating” experiments can be performed by focusing short-pulse, high intensity laser pulses onto foil targets. At laser intensities above 10\textsuperscript{18} W/cm\textsuperscript{2}, a high flux of relativistic electrons is generated during the laser-matter interaction. The laser is absorbed in a plasma layer at critical density, whereas relativistic electrons can penetrate into over dense regions of the target and deposit energy therein. In this work, we present an experiment on the generation of WDM by using a wire geometry with high aspect ratio as a target. The wire geometry leads to a confinement of the relativistic electron currents. Due to this confinement, the process of volumetric heating by electrons is maintained in large target depths. The experiment was carried out at the PHELIX-lasers at the GSI in Darmstadt. Ti-wires with a diameter of 50 µm and a length of 3-4 mm were irradiated. The laser was focused on the tip of the wires to intensities up to 10\textsuperscript{21} W/cm\textsuperscript{2}, with a contrast of 10-10. High spatial resolution K-shell X-ray spectroscopy was used to measure the isochoric heating induced by the relativistic electrons propagating along the wire up to 1 mm depth. Radiation of highly charged He and H-like Ti-ions and Ka-satellites have been measured with high spectral resolution using a focusing spectrometer with spatial resolution (FSSR). The FSSR consists of a spherically bend quartz crystal as a dispersive element. For the first time it was possible to distinguish surface target regions heated by mixed plasma mechanisms from those heated only by the relativistic electrons that generate warm dense matter with temperatures up to 55 eV. Our results are compared to simulations that highlight both the role of electron confinement inside the wire and the importance of resistive stopping powers in warm dense matter.
Plasma optical modulators for intense lasers

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As a unique nonlinear optical media, plasma is not subject to a damage limit by high power lasers. Therefore it can find wide applications in the manipulation of high power lasers, such as, guiding of laser pulses by a plasma channel for laser-driven particle acceleration \cite{1}, amplification of laser pulses to extreme high power in plasma media \cite{2}, shaping laser pulses by plasma mirror or lens \cite{3,4}, and compression of laser pulses by plasma gratings \cite{5}, etc. Here we report a type of plasma optical modulators \cite{5}.

Optical modulators can be made nowadays with high modulation speed, broad bandwidth, while being compact, owing to the recent advance in material science and microfabrication technology. However, these optical modulators usually work for low intensity light beams. The proposed plasma-based optical modulator can directly modulate high power lasers with intensity up to the $10^{16}$ W/cm\textsuperscript{2} level to produce an extremely broad spectrum with a fractional bandwidth over 100\% within few picoseconds, extending to the mid-infrared regime in the low-frequency side. This concept relies on two co-propagating laser beams in a sub-mm-scale underdense plasma, where a drive laser pulse first excites an electron plasma wave in its wake while a following carrier laser beam is modulated by the plasma wave. The laser and plasma parameters suitable for the modulator to work are presented. Such optical modulators may enable new applications in the high field physics.

\begin{thebibliography}{9}
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\end{thebibliography}
P:32 Electrostatic electron cyclotron instabilities near the upper hybrid layer

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Ionospheric modification experiments studying stimulated electromagnetic emission (SEE) have revealed a variety of clearly distinguishable spectral components within the sidebands of the reflected O-mode pump wave [1-3]. A feature that has stimulated particular interest is the broad-upshifted-maximum feature [4], occurring under the double resonance region where the pump frequency is close to both the upper hybrid frequency and a harmonic of the cyclotron frequency. In the present context, a numerical and theoretical study is presented of an electrostatic electron cyclotron instability involving Bernstein modes in a magnetized plasma. The instability is driven by ring-like high-energy tails of the electron distribution, created due to collisions or stochastic heating near an electron cyclotron harmonic, when the upper hybrid frequency is somewhat above the electron cyclotron harmonic. The resulting electrostatic waves have frequencies near or below the cyclotron harmonic frequency and can mode convert to ordinary mode waves on plasma inhomogeneities, escaping the plasma. The results presented from both PiC and Vlasov simulations have relevance to both ionospheric modification experiments and laboratory experiments where microwaves are injected into overdense plasma.

The role of plasma instabilities in the onset of detachment in the York linear plasma device

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Plasma detachment, in which the fluxes of power and particles to the target plates of a tokamak divertor are substantially reduced, is a key component of the exhaust power handling strategy in next step fusion devices. On ITER, for example, it is expected that partial plasma detachment will be essential for steady-state operation [1] in order to reduce the expected power flux (predicted to be a minimum of 15 MWm⁻² [2]) to below the maximum allowable value for a reasonable tungsten divertor plate lifetime (approximately 10 MW m⁻² [3]). Although detachment can be routinely accessed in most of the present generation of tokamaks, there remain significant open questions on the physics of detachment. These include the importance of certain atomic and molecular processes, and the possible role of instabilities in detached plasmas [4]. Linear plasma devices can play a significant role in addressing many aspects of the basic physics of detached plasmas, taking advantage of their simplified geometry, steady state operation and good diagnostic access compared to tokamak divertors. Here we report on ongoing studies from the York Linear Plasma Device (YLPD) to characterise the detachment of a hydrogenic magnetised plasma column with typical temperatures of 5-10eV and densities of the order of 10¹⁸m⁻³. Using a combination of fast camera imaging, arrays of electrostatic probes and spatially resolved high resolution spectroscopy, we demonstrate that the onset of detachment in the YLPD appears to be correlated to intermittent radial plasma transport events arising from instabilities at the edge of the plasma column. We describe planned upgrades to the diagnostic systems that will allow better characterisation of these findings and finally, we present initial attempts to model detached plasma on YLPD using the BOUT++ edge plasma computational framework.

Ellipsoidal plasma mirror focusing of high power laser pulse to ultra-high intensities (~$10^{22}$ Wcm$^{-2}$)

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Throughout the history of high-power laser-plasma science new avenues of research have been enabled by increasing the achievable peak laser intensity. These include laser-driven particle acceleration, radiation sources, relativistic optics, laboratory astrophysics and warm dense matter. In the next few year laser systems expected to achieve focused intensities in the range $10^{22} - 10^{23}$ Wcm$^{-2}$, such as APOLLON [1] and the extreme light infrastructure (ELI) [2] facilities will commence operation, enabling the exploration of ultra-intense laser-plasma phenomena.

To explore this regime with the facilities available today, parameters of the drive laser pulse must be improved beyond present capabilities; primarily focal intensity and pulse temporal intensity contrast. One approach to achieve higher intensities is to implement a small F-number (F/#) focusing optic, to form relatively small focal spots. Such optics are typically expensive and susceptible to damage from target debris due to close proximity to the interaction target.

To enhance both focal intensity and pulse contrast simultaneously, in a cost effective way, we have developed a low F-number (~F/1) confocal ellipsoidal focusing plasma mirror (FPM). The single-use disposable nature of plasma based optics allows debris issues to be avoided, and additionally its ability to sustain extremely large electromagnetic fields mean they are much smaller than conventional focusing optics.

We present the design, development and testing of such an optic, produced for use on the Vulcan petawatt laser system at Rutherford Appleton Laboratories. A factor of 2.5 reduction in the focal spot size was achieved when compared to F/3 focusing with a conventional (solid state) optic, indicating a $\times 3.6$ enhancement in peak intensity, accounting for changes in plasma mirror reflectivity and focal spot quality. The sensitivity of the optic to misalignment is also investigated to test its feasibility. An example use of the FPM in an investigation of laser-driven proton acceleration is demonstrated. The increase in peak laser intensity results in a factor 2 increase in the maximum energy of protons accelerated of a thin foil positioned at the focus of the FPM, consistent with TNSA laser intensity scaling.

This study helps to bring plasma-based optical technology closer to maturity and will have wide ranging impact on many laser plasma interaction research areas.


Surface and volume mode coupling experiments for high power mm-wave sources

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The principles of wave dispersion and mode coupling are well-established in plasma physics and can also be applied to the realisation of novel high power mm-wave radiation sources. The terms “dispersion engineering” and “transformational electromagnetics” are used to describe these methods in novel electromagnetic radiation source development.

In the present work, a comparison of theory, modelling and measurements of periodic surface lattice (PSL) structures [1] is reported. In situations where a structure may support several modes, volume and surface wave coupling can result in the formation of a stable eigenmode. The formation of such eigenmodes is relevant to improved mode selectivity and the realization of high power mm-wave and THz coherent sources [2-4].

The cavity dimensions of traditional electromagnetic sources tend to decrease as the wavelength of the source radiation decreases, in order to keep the excited cavity mode as a single low order mode thus avoiding less efficient multi-mode excitation. This in turn limits the output power of mm-wave and THz sources, compared with corresponding RF and microwave sources. An approach that can be used to mitigate this is to introduce methods of mode selection in over-moded cavities. The specific method studied here uses periodic surface lattices (PSLs) created by manufacturing shallow periodic perturbations on a metal surface. Periodic structures can be one, two or three dimensional. The present study employs two dimensional (2D) periodic perturbations to couple surface modes to volume modes in an overmoded structure to create a well-defined eigenmode.

In a “proof-of-principle” experiment it has been demonstrated that it is possible to form a stable eigenmode by mode-locking surface and volume modes, as shown in Fig. 1. These results are supporting the design of future millimetre-wave radiation sources in the 100GHz to 1THz frequency range for several potential applications, including plasma diagnostics.

Plasma dynamics at the surface interface in radio frequency discharges

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The plasma-surface interface of a low temperature, low pressure plasma system is difficult to characterise, however it is key for applications within industry. We have developed methodology based on newly augmented fast optical techniques which can probe the wafer region relevant to industrial processes. The experimental set up will consist of a low pressure oxygen plasma produced in a GEC reference cell system.

Experimental techniques include phase resolved optical emission spectroscopy (PROES), energy resolved actinometry (ERA)[1] and retarding field energy analyser (RFEA). A two-dimensional hybrid plasma simulation code is used to simulate the operating conditions of the plasma at pressures of 1 – 100 Pa with typical powers of 50 – 500 W in order to improve understanding of the experimental results.

The optical emission measurements exploit the direct and dissociative electron impact excitation dynamics of the relevant oxygen and argon lines. Through the ratio of the chosen excitation functions and their energy dependence we determine both the atomic oxygen density and the mean electron energy above the electrode surface.

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The principle of inductively coupled plasma is to induce an RF current in a plasma by driving an RF current in an adjacent coil. The RF current generated in the plasma flows in a skin depth which is usually defined within a framework of a collisionless plasma. In this paper we consider the general case of inductive discharge with a capacitive coupling typical of radio-frequency ion thrusters (RIT). The generalized model of an inductive discharge with a capacitive component establishes a connection between the external currents and voltages and average spatial parameters characterizing the plasma. The role of design and circuit parasitic capacitances, and also the impact of near-wall and nearelectrode capacitances of gas discharge chamber and acceleration system of RIT are analysed. The estimation of the parasitic capacitances for three models of RIT, viz. RIT-8, RIT-10 and RIT-50 is performed. Nominal powers and inner diameters of the ceramic chambers of RIT-8, RIT-10 and RIT-50 are ~ 300 W and 8 cm, 500 W and 10 cm, and 35 kW and 50 cm respectively.

The inductor branch is modeled by the components associated with inductor circuit. Parallel to inductive circuit the capacitive circuit is coupled. It is modeled by the series capacitance defined by total action of all parasitic capacitances and by the resistance defined by ohmic and stochastic electron heating in gas discharge.

On the base of wave model of radio frequency discharge it is shown that due to the plasma reaction the inductance of inductor coil may vary substantially depending on the geometry of the gas discharge chamber and the density of the discharge plasma. Since the radius of inductor coils of RIT is comparable with radii of corresponding discharge chambers the effects of short inductor coil were taken into account. With the help of the mathematical models of the discharge, the computer code has been developed and calculations have been performed. The numerical results for three different models of RIT allowed to study the change in the inductance while discharge was burning. Experimental and numerical results are in a good agreement.

![Graph showing the inductance of three RIT models vs electron density.](image)
P:38 K-edge shift under different plasma environments

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This poster relates to an experiment carried out at the Central Laser Facility (CLF) in October last year. The atomic physics of Chlorine under warm dense matter conditions was investigated by studying its K-edge shift. It was a similar experiment to one carried out by Bradley et. al [1] at CLF in 1987, however, we hoped to improve it using the technologies available to us today. It was possible to initially carry out detailed simulations using Hyades, while the ability to use the CPA beam increased the temporal resolution. The use of CCDs also provided improved detector resolution and sensitivity.

Three factors affecting the K-edge shift were investigated: continuum lowering, degeneracy and pressure ionisation. One long pulse beam was incident on a Bismuth back lighter while four long pulse beams were incident on the sample target to drive a shock. CHCl and KCl were used as sample targets. Diagnostics used included 3 Si crystal spectrometers, a x-ray streak camera, an optical streak camera and a VISAR system. Figure 1 shows typical images obtained using one of the spectrometers.

It was evident that the K-edge was red shifted and broadened in the hot dense plasma, as shown in figure 2, and that there was a larger shift as the delay time was increased.

Figure 1 - Shift in K-edge with CHCl target

Figure 2 - a) Obtained using long pulse beam on Bi back lighter.
   b) Obtained using 4 long pulse beams to drive a shock on a CHCl target.
