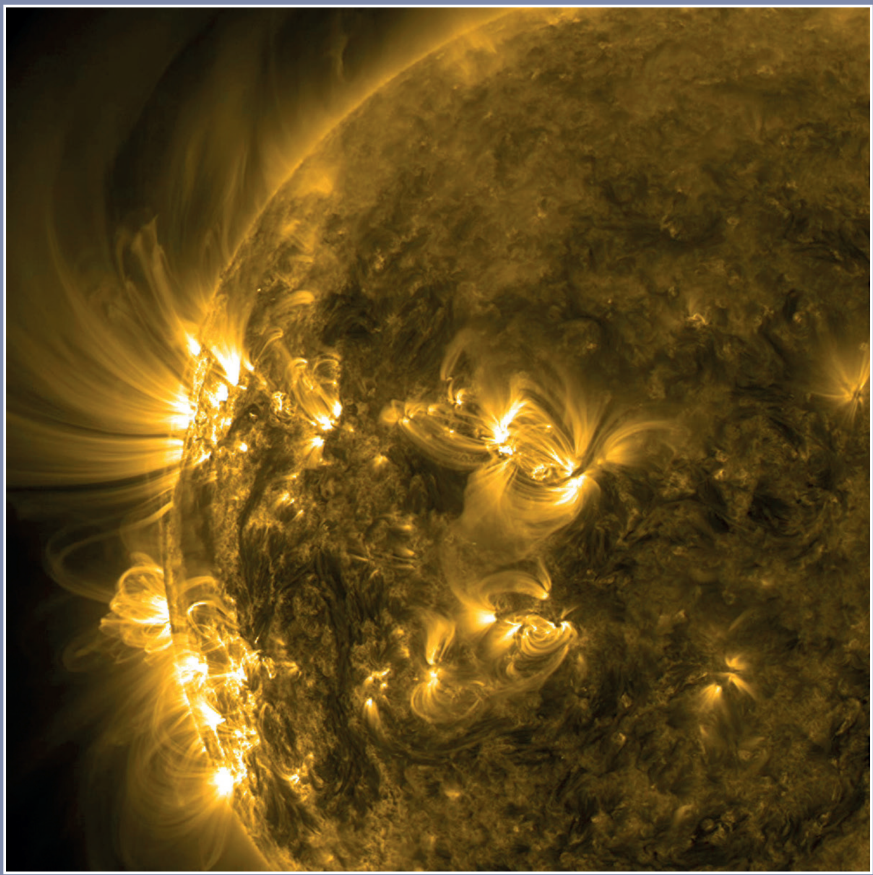
Programme and Abstract Book



44th IOP Plasma Physics Conference

3–6 April 2017
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IOP Institute of Physics

Contents

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Monday 3 April

11:00	Registration
12:00	Lunch
13:00	Welcome
13:10	**(Invited) Some remarks on collisionless current sheet equilibria** Thomas Neukirch, University of St Andrews, UK
13:50	**Temporally resolved optical probing of picosecond laser propagation in underdense and near-critical density plasmas** Zoë Davidson, University of Strathclyde, UK
14:10	**(Culham Thesis Prize) Diagnosis and applications of laser wakefield accelerators** Jason Cole, Imperial College London, UK
14:50	Refreshment break
15:10	**(Invited) The role of turbulence in tokamak edge transport** Istvan Cziegler, University of York, UK
15:50	**Vlasov simulations of fast stochastic electron heating near the upper hybrid layer** David C. Speirs, University of Strathclyde, UK
16:10	**Efficient solution to multi-temperature Riemann problem coupled with front-tracking for gas dynamics simulations** Danail Vassilev, First Light Fusion Ltd., UK
16:30	**Plasma enhanced Pulsed laser deposition of CuO and Cu_2O thin films** Sudha Rajendiran, University of York, UK
16:50	Refreshment break
17:10	Poster introductions
17:30	Posters

Tuesday 4 April

09:00	**(Invited) Inside an ion Larmor Orbit** Ruth Bamford, STFC, UK
09:40	**A new criterion to describe crossed-beam energy transfer in laser-plasma interactions** Raoul Trines, STFC Rutherford Appleton Laboratory, UK
10:00	**(Invited) The role of plasma-surface interactions in low-temperature plasmas** Andrew Gibson, York Plasma Institute, UK
10:40	Refreshment break
11:00	**(Invited) The UK's central laser facility** John Collier, STFC, UK
11:40	**Influence of environmental parameters on the Kelvin-Helmholtz instability at the magnetopause** Matthieu Leroy, KU Leuven, Belgium
12:00	**Optimized up-down asymmetry to drive fast intrinsic rotation in tokamak reactors** Justin Ball, École Polytechnique Fédérale de Lausanne, Switzerland
12:20	**Particle acceleration by lower-hybrid turbulence in the laboratory** Alexandra Rigby, University of Oxford, UK
12:40	Lunch
13:40	Excursions
18:30	**Evening outreach: 'Plasma Science takes 5'**

Wednesday 5 April

09:00	**(Invited) Laser-driven charged particle beam structures induced by diffraction** Martin King, University of Strathclyde, UK
09:40	**Intermittent transport in the divertor of MAST and TCV** Nick Walkden, Culham Centre for Fusion Energy, UK
10:00	**Mass transfer in surface dielectric barrier discharges** Alex Shaw, Loughborough University, UK
10:20	Refreshment break
10:40	**(Invited) Accessing high confinement conditions in hydrogen and mixed species plasmas in JET** Jon Hillesheim, CCFE, UK
11:20	**High energy and efficiency proton acceleration from relativistically transparent laser-foil interactions** Adam Higginson, University of Strathclyde, UK
11:40	**Modelling of plasma-liquid interactions** Joshua Holgate, Imperial College London, UK
12:00	IOP Plasma Group AGM
12:30	Lunch
13:30	**(Invited) Analysis of low temperature atmospheric plasma polymerisation processes for innovative coating applications** Kirsty McKay, University of Liverpool, UK
14:10	**Investigations on the role of inferior phase velocity laser plasma wakefield in proton acceleration** Supriya Rai, University College London, UK
14:30	**Ion cyclotron emission as a diagnostic of the time evolution of edge density during ELMs in KSTAR plasmas** Benjamin Chapman, The University of Warwick, UK
14:50	**Proton imaging of stochastic magnetic fields** Archie Bott, University of Oxford, UK
15:10	Refreshment break
15:30	**Pulsed laser breakdown in water and its aftermath** Bill Graham, Queen's University Belfast, UK
15:50	**Some problems with the ponderomotive force** David Burton, Lancaster University, UK
16:10	Poster introductions
16:30	Poster session
19:00	Conference dinner

Thursday 6 April

09:00	**(Invited) The physics currently limiting the thermonuclear fusion yield on the National Ignition Facility** Robbie Scott, RAL Central Laser Facility, UK
09:40	**Particle acceleration during merging-compression plasma start-up in the MAST spherical tokamak** Ken McClements, Culham Centre for Fusion Energy, UK
10:00	**The role of vibrational states of CO_2 in the conversion of CO_2 to CO using radio-frequency atmospheric pressure plasmas** Alexander Foote, University of York, UK
10:20	**Theory of the sheath and maximum ion energies in target normal sheath acceleration** Holger Schmitz, STFC, Rutherford Appleton Laboratory, UK
10:40	Refreshment break
11:00	**(Invited) Physics and technology innovations for compact tokamak fusion pilot plants** Jonathan Menard, Princeton Plasma Physics Laboratory, USA
11:40	**MAST upgrade: A facility to advance understanding of power exhaust in tokamaks** James Harrison, Culham Centre for Fusion Energy, UK
12:00	**(Invited) Solar flares and energetic particles** Eduard Kontar, University of Glasgow, UK
12:40	Lunch
	MAST-U Research Forum (The MAST-U research forum runs from Thursday afternoon and all day Friday)

Poster programme

P1 **The collisionless transient pinch**
John Allen, University College, Oxford, UK

P2 **The PLATINUM project: Pulsed laser accelerators for the inspection of nuclear materials**
Ceri Brenner, STFC Central Laser Facility, UK

P3 **Channeling optimization of high-intensity laser beams in millimeter-scale plasmas**
Luke Ceurvorst, University of Oxford, UK

P4 **Nonlinear self-consistent kinetic simulations of the anomalous Doppler instability of suprathermal electron populations in fusion plasmas**
Samuel Irvine, University of Warwick, UK

P5 **Extended interaction oscillator based on a pseudospark-sourced electron beam**
Adrian Cross, University of Strathclyde, UK

P6 **Fourier-Vlasov simulations of cyclotron instabilities in plasma**
Bengt Eliasson, University of Strathclyde, UK

P7 **An algorithm for analysis of filaments in fast camera data**
Tom Farley, Culham Centre for Fusion Energy, UK

P8 **Improving understanding of divertor detachment via atomic physics and spectroscopy**
Daljeet Singh Gahle, Culham Centre for Fusion Energy, UK

P9 **Experimental observation of beam intensity profile modification and transient phase during cross beam energy transfer**
Kevin Glize, STFC, Rutherford Appleton Laboratory, UK

P10 **Reduced kinetic simulations of particle acceleration during magnetic reconnection**
Philippa Browning, University of Manchester, UK

P11 **Ball-pen Probe in strongly magnetised low-temperature plasma**
Brandon Harris, University of Liverpool, UK

P12 **Combined effects of trapped energetic ions and resistive layer damping on the stability of the resistive wall mode**
Yuling He, Dalian University of Technology, China

P13 **Nonlinear waves in the terrestrial quasiparallel foreshock**
Bogdan Hnat, University of Warwick, UK

P14 **Time-resolved characterisation of the evolution of electrostatic collisionless shocks**
Thomas Hodge, Queens University Belfast, UK

P15 **Plasma micro-reactors: potential and practical challenges for chemical engineering**
Thomas Holmes, University of Sheffield, UK

P16 **Argon photoionisation**
Rachael Irwin, Queen's University Belfast, UK

P17 **Ion streaming instability of dust-acoustic surface waves in a Lorentzian complex plasma slab**
Young-Dae Jung, Hanyang University, South Korea

P18 **Quantitative shadowgraphy and proton radiography for large intensity modulations**
Muhammad Kasim, University of Oxford, UK

P19 **Intrinsic suppression of resistive drift-wave turbulence in linear device geometry**
Jarrod Leddy, University of York, UK

P20 **Photoabsorption of Ca, Pb and Bi in the vacuum ultraviolet region – towards controlled resonance-enhanced high harmonic generation**
Hu Lu, Dublin City University, Ireland

P21 **Spatial organisation of tokamak flow structures**
Ben McMillan, University of Warwick, UK

P22 **QDB: A new database of plasma chemistries and reactions – concept and exemplar verification**
Anna Dzarasova, Quantemol Ltd., UK

P23 **Understanding detachment onset in MAST-U using SOLPS**
David Moulton, Culham Centre for Fusion Energy, UK

P24 **Study of Mg He-like intercombination line in optically thin solid density plasmas**
Gabriel Pérez Callejo, University of Oxford, UK

P25 **Complex phase space representation of wave equations using the Wick symbol calculus**
Naren Ratan, University of Oxford, UK

P26 **Experimental paths to improve the physics basis for high $q_{||}$ exhaust strategies**
Matthew Reinke, Oak Ridge National Laboratory, USA

P27 **Modelling ion cyclotron emission from beam-injected ions in the large Helical Device**
Bernard C G Reman, University of Warwick, UK

P28 **Design, operation and measurement of a penning discharge**
Kevin Ronald, University of Strathclyde, UK

P29 **Adiabaticity breaking in direct laser acceleration of electrons**
Alex Robinson, Central Laser Facility, UK

P30 **Optimisation of plasma amplifiers**
James Sadler, University of Oxford, UK

P31 **Spatial distribution of plasma parameters in a dc-magnetron discharge and influence of the discharge power**
Christian Saringer, Montanuniversität Leoben, Austria

P32 **Attosecond absorption in two dimensions**
Alex Savin, University of Oxford, UK

P33 **Influence of plasma backgrounds including neutrals on SOL filaments using 3D simulations**
David Schwörer, Dublin City University, Ireland

P34 **Modelling heating and ablation of dust in a plasma**
Luke Simons, Imperial College London, UK

P35 **Production of low energy spread accelerated electrons at the AWAKE experiment: LWFA as a potential solution**
Barney Williamson, University of Manchester, UK

P36 **Resistive wall modes stabilization by feedback control in HL-2M tokamak**
Guoliang Xia, Culham Centre for Fusion Energy, UK

P37 **Simulations of edge localised modes**
Siobhan Smith, University of York, UK

P38 **Plasma application for bio-oils chemical detoxification: from harmful to useful**
Thomas Holmes, University of Sheffield, UK

P39 **Investigation of efficiency exciplex DBD lamp excited by electrical generators of various types**
Dmitry Schitz, Immanuel Kant Baltic Federal University, Russia

P40 **Hybrid kinetic-hydrodynamic model of high-pressure gas discharges under strong overvoltages**
Natalia Semeniuk, Institute of High Current Electronics, Russia

P41 **Observation of anomalous inward particle pinch in ADITYA tokamak**
Harshita Raj, Institute for Plasma Research, India

P42 **MHD modeling of the capillary discharge plasma and the future prospects**
Anatoliy Shapolov, Institute of Physics University of Pecs, Hungary

P43 **Exact Vlasov-Maxwell equilibria for asymmetric current sheets**
Thomas Neukirch, University of St Andrews, UK

P44 **X-ray emission from petawatt laser driven nanostructured Ni targets**
Oliver Humphries, University of Oxford, UK

P45 **Time integrated optical emission studies of laser produced lead plasma:**
measurements of transition probabilities of the 6p7s → 6p2 transition array
Javed Iqbal, Pakistan

(Invited) Some remarks on collisionless current sheet equilibria

T Neukirch

University of St Andrews, UK

The theory of collisionless plasma equilibria has a long history and is well established. Due to a combination of curiosity and potential applications to space and astrophysical plasmas, over the past few years there has been a renewed interest in finding equilibrium distribution functions for collisionless current sheets with particular properties, for example for cases where the current density is parallel to the magnetic field (force-free current sheets). In this talk I will try to give an overview of these recent developments, discuss potential applications and mention some open questions.

Temporally resolved optical probing of picosecond laser propagation in underdense and near-critical density plasmas

Z E Davidson[1], A Higginson[1], B Gonzalez-Izquierdo[1], S D R Williamson[1], D Farely[2], K L Lancaster[2], E Montgomery[3], D Neely[1,3], P McKenna[1] and R J Gray[1]

[1]University of Strathclyde, UK, [2]University of York, UK, [3]Central Laser Facility, Rutherford Appleton Laboratory, UK

A challenge for many researchers investigating intense laser-plasma interactions experimentally is capturing enough data from a single event to fully understand the dynamics of the interaction. Pump-probing techniques are commonly used to image the interaction, however to build a profile of the interaction in time most methods require many repeat shots. Such an approach is inherently susceptible to shot-to-shot variations and therefore often fail to provide a reliable insight into the evolution of the interaction. Using a new temporally resolving 4-channel optical probe we demonstrate 2D multi-frame measurements of intense laser plasma interactions in a single shot.

In an experiment conducted on the Vulcan laser system at Rutherford Appleton Laboratories we were able to directly observe the evolution on the picosecond timescales of intense laser propagation in underdense and near-critical density plasmas in a single shot at multiple time frames. Here we will present the development of this technique and the results of an investigation into the dynamics of self-focusing and filamentation in an underdense plasma. With this powerful new technique we aim to gain new insights into a range of nonlinear ultrafast plasma dynamics which are highly sensitive to initial conditions and therefore shot-to-shot variations.

(Culham Thesis Prize) Diagnosis and applications of laser wakefield accelerators

J M Cole[1], N C Lopes[1, 2], K Poder[1], M Streeter[1, 3], D R Symes[4], J C Wood[1], S P D Mangles[1] and Z Najmudin[1]

[1]Imperial College London, UK, [2]Universidade de Lisboa, Portugal, [3]Lancaster University, UK, [4]Rutherford Appleton Laboratory, UK

Laser wakefield accelerators have witnessed rapid development over the past two decades, driven by advances in laser technology and modelling capability, and the quality of the electron beams they are capable of producing continues to improve. In this talk I will outline the physical principles behind laser wakefield acceleration and how their ultrafast spatiotemporal dynamics may be studied indirectly through the plasma instabilities seeded by the laser pulse. I will also discuss several interesting uses for the electron and photon beams generated in such laser-plasma interactions, import for both fundamental physics research and real-world applications.

(Invited) The role of turbulence in tokamak edge transport

I Cziegler

University of York, UK

Turbulence has long been known to dominate cross-field transport in toroidal magnetic confinement devices. As such, the ubiquitously observed regimes of global confinement are various states of turbulence. Phase transitions between these are inherently interesting from the perspective of understanding turbulence, but also carry a crucial significance for making fusion viable. The longest known and most obvious of such transitions is the low- to high-confinement (L-H) transition. High confinement (the "H-mode") is characterized by large temperature and density gradients at the plasma surface providing a much higher core pressure and hence fusion power. Access to the H-mode is tied to a threshold heating power PLH above which the transition can occur. The parametric dependences of PLH are vitally important for the design of future plasmas, with several – such as those on main species isotope, method of auxiliary heating, plasma rotation – still unaccounted for in theory or scaling laws. Among these, one of the largest effects is the up-down asymmetry of magnetic configurations with a single poloidal null. The power threshold in an equilibrium in which the ion grad-B drift points toward the poloidal null (X-point) is approximately half as high as in the opposite case. Since the discovery of the H-mode, some intermediate regimes have also been found. One remarkable feature of the asymmetry of magnetic geometry is the difference in the intermediate regimes to which each configuration leads, with limit-cycle oscillating (LCO) regimes typical of H-mode-favoring geometries, and the "Imode" of the opposite. The I-mode is an intriguing alternative regime combining high heat confinement with strong mass transport. New results address the up-down asymmetry and offer an insight into the background of the range of plasma parameters in which I-modes can be maintained (the "I-mode window") as one of nonlinear dynamics. Interactions between turbulent structures and between turbulence and large-scale flows are discussed and their dependence on geometry addressed.

Vlasov simulations of fast stochastic electron heating near the upper hybrid layer

D C Speirs[1], B Eliasson[1], L K S Daldorff[2,3] and A Najmi[2]

[1]University of Strathclyde, UK, [2]The Johns Hopkins University Applied Physics Laboratory, USA, [3]NASA Goddard Space Flight Center, USA

Ionospheric modification experiments conducted using high frequency, L-O mode electromagnetic waves have shown the induced formation of magnetic field-aligned density striations in the ionospheric F-region [1, 2]. These striations are observed in association with lower and upper-hybrid turbulence and significant electron heating within the striation. The initial electron heating to temperatures of >4000K is believed to be a prerequisite for the formation of suprathermal electron tails by strong Langmuir turbulence [3]. Such tails can result in the ionisation of neutrals and the formation of descending artificial ionospheric layers (DAILS) [4]. In the current context, we present the results of 1D and 2D numerical simulations conducted using a Vlasov-Maxwell code [5] to study the mode-conversion / coupling of an L-O mode pump wave to trapped upper hybrid waves within a density striation. Subsequent multi-wave parametric decay is observed leading to lower-hybrid turbulence and high amplitude electron Bernstein waves which (once exceeding the threshold amplitude for stochasticity) can result in significant electron heating. The electron temperatures observed of >5000K in simulation are sufficient to initialise the formation of suprathermal electron tails as a precursor to generating descending artificial ionospheric layers (DAILS).

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[2] A. Najmi et al., J. Geophys Res., 119 (2014), 6000-6010.
[3] B. Eliasson et al., J. Geophys Res., 117 (2012), A10321.
[4] T. Pederson et al., Geophys. Res. Lett., 36 (2009), L18107.
[5] B. Eliasson, Transport Theory and Statistical Physics 39 (2010), 387-465.

Efficient solution to multi-temperature Riemann problem coupled with front-tracking for gas dynamics simulations

D Vassilev, N Niasse, R Ramasamy and B Tully

First Light Fusion Ltd., UK

Numerical models capturing hydrodynamic instabilities and shocks are of crucial importance for understanding HEDP and designing different experimental components. Interface tracking methods, and specifically the front-tracking method with a static Eulerian mesh and a moving Lagrangian interface, have been applied to these types of problems with a best-in-class success [1, 2]. Such an approach requires solution of the Riemann problem for Euler's equations for both the cell-centered Eulerian states and the contact states that are stored at each vertex of the Lagrangian interface.

We have implemented a front-tracking code, HyTrac [3], and validated its hydrodynamic capability for robustly modelling shock transmission through high Atwood number interfaces using experiments on a two-stage light gas gun [4, 5]. In order to include fusion relevant conduction physics in HyTrac, we have split the energy into electron and ion components; in doing so, we believe we have, for the first time, implemented a two-temperature front-tracking code with an exact Riemann solver. In this work, an approach based on [6] is extended to solve two temperature model for analytic and tabular equations of state. Numerical tests and code comparison to FLASH [7] are presented to validate the method.

[1] J. Glimm, J. W. Grove, Y. Zhang *Interface Tracking for Axisymmetric Flows*, SIAM J. Sci. Comput., 2002, Vol. 24, No. 1, pp. 208236

[2] R. L. Holmes, G. Dimonte, B. Fryxell, M. L. Gittings, J. W. Grove, M. Schneider, D. H. Sharp, A. L. Velikovich, R. P. Weaver and Q. Zhang, *RichtmyerMeshkov instability growth: experiment, simulation and theory*, J. Fluid Mech., 1999, vol. 389, pp. 5579

[3] R. Ramasamy, N. Bevis, J.W.S. Cook, N.A.Hawker, D. Huggins, M. Mason, N. Niasse, A. Venskus, D. Vassilev, T. Edwards, H. Doyle, B.J. Tully, *Hytrac: A Numerical Code for Interface Tracking*, First Light Fusion Ltd. (to be submitted)

[4] J. Skidmore, H. Doyle, B. Tully, M. Betney, P. Foster, T. Ringrose, R. Ramasamy, J. Parkin, T. Edwards, N. Hawker, *Shock induced cavity collapse*, 2016, 58th Annual Meeting of the APS Division of Plasma Physics, Volume 61, Number 18 : http://meetings.aps.org/Meeting/DPP16/Session/ GO8.14

[5] M. Betney, P. Foster, T. Ringrose, T. Edwards, B. Tully, H. Doyle, N. Hawker, *Experimental and numerical investigation of cylindrical and hemispherical jet formation*, 2016, 69th Annual Meeting of the APS Division of Fluid Dynamics, Volume 61, Number 20 : http://meetings.aps.org/Meeting/ DFD16/Session/G5.8

[6] N. Ya. Moiseev and E. A. Shestakov, *Solution of the Riemann Problem in Two- and Three- Temperature Gas Dynamics*, Computational Mathematics and Mathematical Physics, 2015, Vol. 55, No. 9, pp. 15471553

[7] FLASH *code* http://flash.uchicago.edu/site/flashcode/

Plasma Enhanced Pulsed Laser Deposition of CuO and Cu_2O thin films

S Rajendiran, D Meehan and E Wagenaars

University of York, UK

In recent years, CuO and Cu_2O thin films have gained interest due to their potential application in solar cells, magnetic storage devices, gas sensors, superconducting materials and catalysts [1,2]. For most of these applications, it is important to grow a high-quality, stoichiometric thin film of a single phase of copper oxide. This has proven to be challenging using standard deposition methods, e.g. magnetron sputtering and pulsed laser deposition, where the structural properties of the film depend strongly on the growth conditions [3].

The concept of pulsed laser deposition (PLD) is relatively straightforward: a high-power laser is directed onto a target of the desired composition. The material is ablated and transferred to a substrate, where it deposits as a thin film of the same stoichiometry. However, in practice, deposited metal-oxide films are often oxygen deficient and a low-pressure oxygen atmosphere is needed to achieve stoichiometric thin films. The phase of the deposited films also depends on the details of the growth conditions making it a difficult process to control in detail [4]. Furthermore, for metal-oxide films, a high substrate temperature is often needed as well as a large laser power because of the high melting temperature of most metal oxides.

We have developed the Plasma-Enhanced Pulsed Laser Deposition (PE-PLD) technique in which we incorporate an inductively coupled RF plasma (ICP) in a standard PLD setup to allow a better control of the stoichiometry and phase of the thin film. Moreover, it allows the use of pure copper targets, instead of copper oxide ones, with all the necessary oxygen coming from the oxygen ICP source, and the use of non-heated substrates.

In our experiment, we use 99.9% pure copper targets and quartz substrates. A Nd:YAG laser (532 nm, 10 Hz, 34 mJ per pulse) is synchronised to an ICP plasma which was operated at 500W with a duty cycle of 10%.The ICP plasma was a Gaseous Electronics Reference (GEC) cell, a standardised plasma system used extensively in the plasma etching community.

Our experiments were conducted at 1 Pa, 2 Pa, 5 Pa and 10 Pa oxygen ICP pressures.
X-ray Diffraction (XRD, Rigaku smartlab) was used to identify the crystal phase of the thin film, whereas the stoichiometry was determined using Scanning Electron Microscopy – Energy Dispersive X-ray spectroscopy (SEM-EDX, JEOL-JSM7800F).

Our results show that a slight change in the operating pressure of the ICP results in a notable change in the crystal phase and stoichiometry of the thin film. At 1 Pa, the crystal structure orientation is purely Cu_2O, but by increasing the pressure to 2 Pa there was a notable change in the XRD measurements showing a mixed phase of Cu_2O and CuO. At 5 Pa we found that the film was purely CuO with stoichiometric composition (50.1% Cu and 49.9% O). A further increase to 10 Pa shows a film that still possesses the CuO crystal phase orientation but with a non-stoichiometric composition (28% Cu and 72% O)

In conclusion, we have shown that with PE-PLD it is possible to create high-quality copper oxide thin films using a pure metal target in combination with inductively-coupled RF plasma in oxygen. By tuning only the operating pressure of the ICP we were able to tune the film composition from single-phase Cu_2O to single-phase, stoichiometric CuO.

[1] A. Luque, A. Martí, Phys. Rev. Lett. 78(26), 5014 (1997)
[2] C.V. Cojocaru, F. Ratto, C. Harnagea, A. Pignolet, F. Rosei, Microelectron. Eng. 80(448),2005
[3] A A Ogwu, E Bouquerel, O Ademosu, S Moh, E Crossan and F Placido, J. Phys. D: Appl. Phys. 38(266),2005
[4] Aiping Chen, et al., Vacuum 83(6), 2009

(Invited) Inside an ion Larmor orbit

R Bamford

STFC Rutherford Appleton Laboratory, UK

Finite Larmor orbit and kinetic effects are at the forefront of concern in laboratory and space plasmas. Wherever there is a boundary, such as at the edge of a tokamak or at a laser driven collisionless magnetized shocks, kinetic effects play a primary role. The larger the Larmor orbit more finite Larmor radius effects become important. The results lead to very different outcomes to that predicted by MHD models.

In space plasmas the physical dimensions are so large that a spacecraft is generally very much smaller than the gyro parameters. Even the Debye sphere radius is 5 to 10 meters. This offers an opportunity of measuring plasma parameters inside these dimensions without significantly perturbing the system.

Two examples of kinetic scale processes in space will be presented that have laboratory counter parts.

The first is acceleration of ions at collisionless magnetized shock fronts. In space this occurs at shock fronts of coronal mass ejections close to the sun. Very large and narrow electric fields form at the shock jump that result in rapid ion acceleration along the shock front. These Solar Energetic Particle events reach Earth in 20-40 minutes creating disruption to technology. Similar processes can occur in laser driven collisionless magnetized shock waves in plasmas that produce extremely high (10^10 V/m) narrow electric fields responsible for rapid ion beam acceleration.

The second example is where the magnetic object is of the order or smaller than the ion Larmor radius. An example are the small crustal magnetic anomalies on the Moon to create mini-magnetospheres. The crustal anomalies are small, permanent patches of magnetic field (~100s km, ~300nT) that numerous international spacecraft, with plasma diagnostics onboard, have passed through. What they have seen is that collisionless shocks can form producing diamagnetic cavities. The data from the satellites observing these structures has now been compared directly with 3-D particle-in-cell code simulations using OSIRIS, and plasma kinetic theory that show excellent agreement.

These will be shown in the presentation and how they explain a 400 year old mystery of the ‘Lunar Swirls’.

A new criterion to describe crossed-beam energy transfer in laser-plasma interactions

R Trines[1], H Schmitz[1], E P Alves[2], F Fiúza[2], J Vieira[3], L O Silva[3] and R Bingham[1,4]

[1]STFC Rutherford Appleton Laboratory, UK, [2]SLAC National Accelerator Laboratory, USA, [3]Universidade de Lisboa, Portugal, [4]University of Strathclyde, UK

Crossed-beam energy transfer (CBET) between laser beams in underdense plasma is ubiquitous in both direct-drive and indirect-drive inertial confinement fusion. To understand the impact of this process on the final shape of the laser beams involved, as well as their imprint on either hohlraum walls or target surface, a detailed spatial and temporal description of the crossing beams is needed. We have developed an analytical model and derived new criteria describing both the spatial structure and temporal evolution of the beams after crossing. Numerical simulations have been carried out justifying the analytical model and confirming the criteria. The impact of our results on present and future multi-beam experiments in laser fusion and highenergy-density physics, in particular the "bursty" nature of beams predicted to occur in NIF experiments, will be discussed.

(Invited) The role of plasma-surface interactions in low-temperature plasmas

A R Gibson[1,2]

[1]University of York, UK, [2]Université Paris-Saclay, France

Low-temperature plasmas are widely used and researched in a variety of contexts. Specific applications include the etching and deposition of nanoscale structures in the semiconductor industry, electric propulsion of spacecraft, negative ion sources for neutral beam heating of fusion devices and as reactive species sources in biomedicine. In all of these cases the plasmas used are bounded by surfaces and as a result plasma-surface interactions play a crucial role in defining the plasma properties. These interactions act as sources and sinks of charged and neutral particles and facilitate energy transfer processes which can act to heat and cool the plasma. The importance of these interactions is such that they can influence all aspects of the plasma equilibrium, from the dynamics of electron heating to the neutral gas temperature.

However, for a given plasma-surface combination a complete picture describing all possible plasma-surface interaction processes is rarely known. As a result, numerical simulations of low-temperature plasmas, where probabilities for various plasma-surface interactions are used as boundary conditions, often fail to accurately predict the results of experimental investigations. In this work, insight is sought into several key plasma-surface interaction processes using a combination of advanced zero-, one- and two-dimensional numerical simulations and experimental measurements. In particular, the role of atomic neutral species surface recombination, excited neutral species surface de-excitation, neutral thermal energy accommodation and electron and ion bombardment induced secondary electron emission probabilities in defining the properties of low-temperature plasmas will be discussed. Examples of the importance of these plasma-surface interaction processes will be presented in the frame of several distinct low-temperature plasma applications including plasma etching, electric propulsion and as radical sources in biomedicine. In this context, areas where plasma-surface interactions may be harnessed to optimize each application will be discussed.

Acknowledgement: Funding is acknowledged through the LABEX Plas@Par project, ANR-11-IDEX-0004-02, UK EPSRC Manufacturing Grant (EP/K018388/1) and the York-Paris Collaborative Research Centre.

(Invited) The UK's central laser facility

J Collier

Central Laser Facility, STFC Rutherford Appleton Laboratory, UK

2017 marks the 40th anniversary of the creation of a Central Laser Facility (CLF) in the UK for academics to conduct plasma physics research using lasers. From its humble beginnings as a two roomed laser called Vulcan, the CLF has developed into one of the world's leading centres for multi-disciplinary science and innovation using lasers. 40 years on from its first experiments in plasma physics, today the CLF is active with lasers across the physical, chemical, environmental and bio & life sciences, as well as in cultural heritage. It works with a large national and international Community of research scientists that are operating at the forefront of their respective fields and require access to the most advanced and sophisticated laser based facilities available, as well industry, different agencies of the State such as the National Health Service, the Home Office, the Ministry of Defence and a wide range of international partners including the European Commission.

Its five primary facilities include the world's most powerful lasers, with science programmes ranging from fusion energy, laboratory astrophysics and material science through to the pursuit of a new generation of miniaturized particle accelerators and advanced time resolved X- and g- Ray imaging capabilities for medical and security applications. It's large scale facilities for life & environmental science research are amongst the most advanced laser based microscopy and nanoscopy systems available anywhere, capable of "seeing" individual proteins in living cells, and its facilities for fundamental chemical and condensed matter dynamics research operate in the atto-second domain – the timescale of electronic motion. A vigorous and continuous technology development programme ensures its international competitiveness. Academic access to CLF is via independent peer review and the model established 40 years ago ensures that all of CLF's facilities are completely free to use for any academic researcher that wishes to use them.

Based at the Rutherford Appleton Laboratory (RAL) 30 km south of Oxford, the CLF is located at the heart of the "Harwell Campus", and co-located with some of the UK's other major science facilities the including the ISIS neutron spallation source, the Diamond synchrotron, the Harwell Space Cluster, High Performance Computing and other leading scientific resources. This dynamic research environment enables a cross-fertilisation of science and technology development.

The CLF also has a rich history of innovation and societal / economic impact over several decades. From its earliest days, for example, the origins of laser eye surgery for corneal reshaping, now commonplace on the high street, can be formally traced back to early experiments in the CLF. Through to its latest spinout, Cobalt Light Systems Ltd, which has commercialised CLF patented techniques for "through barrier" detection, developing a range of products, for example, for detecting liquid explosives concealed in containers (e.g. plastic bottles) that have seen widespread uptake by major airports throughout Europe and further afield. This is supporting the goal of European and US authorities to lift restrictions on liquids and gels on board aircraft.

In 2010 the CLF established a technology transfer centre (CALTA - The Centre for Advanced Laser Technology and Applications) to facilitate the development and commercial exploitation of its advanced & scalable diode laser technology (DiPOLE - 100J@10Hz) and to pioneer new and novel applications of extreme photonics to the benefit of wider society. DiPOLE technology is being deployed on a Czech Republic project called Hilase, the European XFEL in Hamburg and the EC's Extreme Light Infrastructure (ELI) project, and the CLF is at an advanced stage of planning for a new facility to drive scientific and industrial exploitation of these high power lasers.

In this presentation I will elaborate on the science, technology and innovation of the CLF and give a flavour of the scientific and societal scope of its work.

Influence of environmental parameters on the Kelvin-Helmholtz instability at the magnetopause

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The process dominating the development of a large boundary layer at the interface between the solar wind (SW) and the magnetosphere (MS) during northward interplanetary magnetic field is still not fully understood. However the Kelvin-Helmholtz instability (KHI), which can induce magnetic reconnection events through its non-linear phase vortices, being the major actor is in good agreement with the observations around the magnetopause so far. Numerous numerical studies have investigated the topic with many interesting results but most of these were considering two-dimensional situations with simplified magnetic configuration and often neglecting the inhomogeneities for the sake of clarity.

Given the typical parameters at the SW/MS interface, the situation must be considered in the frame of Hall-MHD, due to the fact that the current layers widths and the gradient lengths can be in the order of the ion inertial length. As a consequence of Hall-MHD creating a third vector component from two planar ones, and also because flow and magnetic field variations in the equatorial plane can affect the field configuration at a distance in all directions and not only locally, the simulations must also be performed away from the equatorial plane and a three-dimensional treatment is necessary.

In this work, different configurations than can occur in the KHI scenario are studied in a three-dimensional (3D) Hall-MHD setting, where the double midlatitude reconnection (DMLR) process exposed by Faganello, Califano et al. is triggered by the equatorial roll-ups. Their previous work is extended here with in particular a larger simulation box and the addition of a density contrast and variations of the interface configuration. The influence of various parameters on the growth rate of the KHI and thus the efficiency of the DMLR is assessed. In the scope of assessing the effect of the Hall term on the physical processes, the simulations are also performed in the MHD frame. These different configurations may have discernible signatures that can be identified by spacecrafts diagnostics, therefore fields and particles data that would be recorded by spacecrafts during such an event are simulated and compared to real in-situ data.

Optimized up-down asymmetry to drive fast intrinsic rotation in tokamak reactors

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Up-down asymmetric tokamaks, or tokamaks with poloidal cross-sections that lack mirror symmetry about the midplane, spontaneously rotate. Plasma rotation is commonly used in current experiments to stabilize MHD instabilities. However, it is unclear if future, larger devices like ITER or a reactor will have sufficiently fast rotation. From ideal MHD, we derive physical tokamak equilibria and demonstrate that breaking up-down symmetry with lower-order shaping effects (e.g. elongation and triangularity) will be easier to accomplish in an experiment. Furthermore, using analytic gyrokinetics we argue that low-order shaping will also drive faster intrinsic rotation. Next, using nonlinear gyrokinetic simulations we optimize the low-order shaping effects to maximize the rotation. These simulations indicate that up-down asymmetry can drive the rotation needed to provide MHD stabilization in an ITER-like device. Lastly, we compare our results to preliminary experiments on the TCV tokamak.

This work has been carried out within the framework of the EUROfusion Consortium and funded in part by a EUROfusion researcher grant. Additional funding came from the RCUK Energy Programme (grant number EP/I501045). Computing time for this work was provided by the Helios supercomputer at IFERC-CSC and a CINECA award under the ISCRA initiative.

Particle acceleration by lower-hybrid turbulence in the laboratory

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Lower-hybrid waves occur in a variety of laboratory and space environments. They are thought to be one of the main mechanisms of electron heating in the presence of a magnetic field through their ability to be in simultaneous Cerenkov resonance with both magnetised electrons traveling along the field lines and ions traveling transverse to the field. This property allows the lower-hybrid waves to accelerate electrons well above the thermal pool. Here, we present laboratory results and numerical simulations from a recent experiment at the LULI laser facility at Ecole Polytechnique (France). A laser driven plasma flow was impacted upon magnetised and non-magnetised obstacles, generating a shock. A variety of diagnostics were used to characterized the plasma, shock formation and accelerated electrons. We show that the excess X-ray emission in the presence of an external magnetic field can be attributed to electrons accelerated by lower-hybrid waves.

(Invited) Laser-driven charged particle beam structures induced by diffraction

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During the interaction of ultra-intense laser light (>10^{20} $\mathrm{Wcm^{-2}}$) with ultra-thin (nanometrescale) targets, a variety of collective plasma behaviours can be observed. These can be exploited for the acceleration of ions over micron-scale lengths, the production of high harmonic generation and potentially as a non-linear, high-energy synchrotron source. The underlying plasma dynamics can change dramatically when the previously overdense target becomes transparent to the laser pulse. This can occur due to expansion and heating of the target to relativistic temperatures during the interaction. The resultant relativistic plasma frequency is reduced below that of the incoming laser pulse, allowing the remainder of the pulse to propagate in what is known as relativistic self-induced transparency (RSIT). We have previously shown that such behaviour can drive electron-jet like structures, which can influence the resultant accelerated ion energies [1] and spatial profiles [2]. For targets that undergo RSIT, a critical observation has been made showing that the transparency can occur in a localised aperture dictated by the diameter of the laser focal spot. As this aperture is typically on the order of the laser wavelength, the high intensity pulse can undergo diffraction as it propagates. For the first time we demonstrate that this diffraction effect can directly influence the electron [3] and ion [4] structures at the rear of the target. By varying the laser polarisation, the diffraction pattern can be altered, resulting in drastic changes to the plasma dynamics. This can facilitate a crucial route for providing controllable dense plasma structures through variation of the incident laser pulse parameters.

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Intermittent transport in the divertor of MAST and TCV

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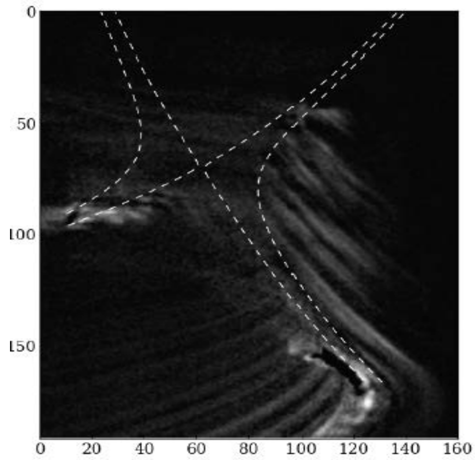
To fully utilise the potential of the tokamak for electricity production via nuclear fusion, power and particle loading to materials must be controlled. Much of the power and particle flux incident onto material surfaces in a tokamak is handled in the divertor. Current extrapolations to next-stage fusion devices yield intolerable, machine limiting heat fluxes to the divertor which require mitigation [1,2]. Several pathways to mitigation exist. These include altering the magnetic field topology in the divertor (as in the super-X and snowflake divertors) or operating in the detached divertor regime, where a buffer of neutral gas exists close to the divertor target that cools the plasma. To fully understand and exploit these solutions however a robust understanding of transport processes in the divertor volume is required.



Enhanced image of the MAST divertor volume. Highlighted between the dashed white lines is the QXR.

High resolution, wide angle high speed imaging has been successfully implemented in the MAST divertor in recent years [3,4,5] and has demonstrated the existence of three classes of filamentary structure in the divertor. In this work the interaction between these areas of instability is examined and the role played by the X-point is assessed. Several measurement techniques applied to the camera footage show a region of quiescence in the scrape-off layer (SOL) around the X-point. This quiescent X-point region (QXR) spans from the separatrix to the Ψ_N=1.02 flux-surface, which encompasses approximately an efolding length of the heat-flux at the divertor. By comparison with synthetic signals, this quiescence is attributed to quiescence in the plasma conditions local to the QXR and not to screening of neutrals or the impact of the camera viewing geometry. Scanning a significant region of the operating space of MAST shows that the QXR is ubiquitous. Outside of the QXR, in the outer SOL, filamentary structures born upstream connect directly to the divertor target. Within the QXR however, this connection is halted by the X-point. Lower in the divertor leg within the QXR this allows for the emergence of higher frequency filamentary objects that are localized to the divertor and may be related to weaker divertor leg instabilities that cannot survive when upstream filaments are dominant. This provides a complex multi-region picture of transport in the divertor, which is supported by previous measurements made elsewhere. Finally, initial results from highspeed imaging of the TCV snowflake divertor with a camera view similar to that of MAST will be presented. Several features of the MAST data can be found in the TCV data. Of particular interest is the presence of filaments localised to the divertor legs which may aid in spreading fluxes and increasing the total wetted area of the divertor.

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[2] R.P.Wenninger et al, Nuclear Fusion **55** (2015) 063003
[3] J.R.Harrison et al, Journ. Nuc. Mater. **463** (2015) 757
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Mass transfer in surface dielectric barrier discharges

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Surface dielectric barrier discharges (S-DBDs) have been reported in recent years for a number of biomedical and agricultural applications, including hand cleaning, preparation of plasma-activation water, seed treatments and in-package food treatments. In these systems, the plasma is typically remote and it does not come into contact with the sample being treated. Notwithstanding that configurations where samples are placed in direct contact with the plasma are possible, the plasma treatment in these systems is in general indirect and transport from the surface discharge to the sample being treated is normally assumed to be dominated by diffusion.

In this paper, we demonstrate that the transport of reactive species from the discharge to the sample can be strongly influenced by the electrode design of the surface discharge and that jets perpendicular to the discharge surface can be generated by electrohydrodynamic (EHD) interactions[1] (see Fig 1), thereby enhancing the transport of reactive species. In particular, we have studied the degradation of potassium indigotrisulfonate solutions exposed to S-DBDs generated in devices with annular electrodes of diameters varying between 10mm and 50mm. All the devices were driven at constant linear power density (Watts per cm of plasma length) and although local plasma properties remained the same in all the devices, a three-fold efficacy enhancement was observed for devices of diameter ~30mm due to EHD effects[2].

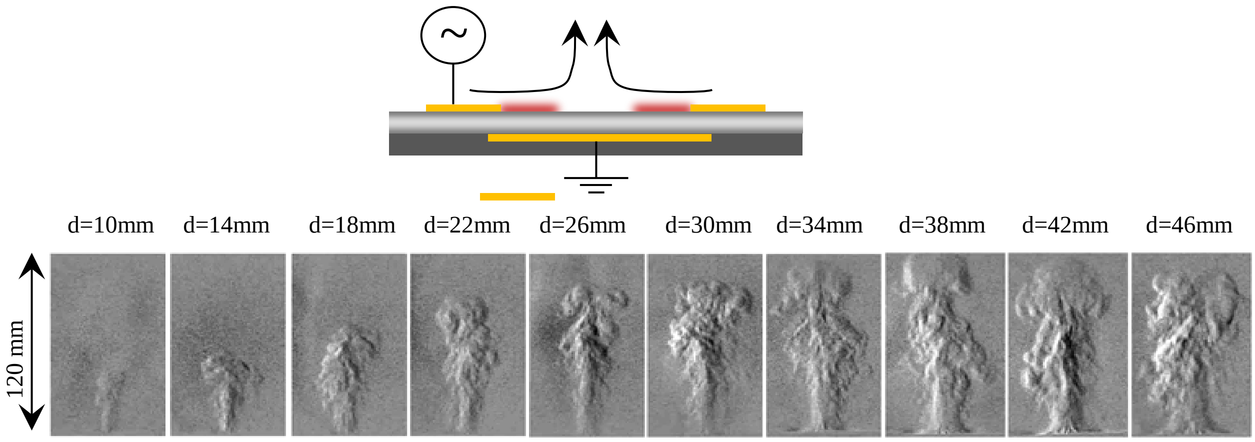

Figure 1. Schematic of S-DBD annular device and Schlieren images of the induced jets.

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(Invited) Accessing high confinement conditions in hydrogen and mixed species plasmas in JET

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*See the author list of "Overview of the JET results in support to ITER" by X. Litaudon et al. to be published in Nuclear Fusion Special issue: overview and summary reports from the 26th Fusion Energy Conference (Kyoto, Japan, 17-22 October 2016)

Experiments in the JET tokamak, the largest currently operating fusion experiment in the world, have investigated high confinement, or "H-Mode," access conditions in hydrogen and mixed ion species plasmas, with an ITER-like tungsten/beryllium wall (JET-ILW). The ITER experimental tokamak, currently under construction, is designed to produce 500 MW of power from fusion reactions in mixed species deuterium-tritium plasmas. This prediction is based on accessing H-mode conditions, where a large pressure gradient is developed and sustained at the plasma edge. H-mode access is characterized by a threshold in power, P_{L-H}, above which an edge transport barrier forms and the plasma transitions from low to high confinement mode – the so-called L-H transition. Initial experiments in ITER will be performed with hydrogen or helium plasmas. Extrapolations for P_{L-H} from current experiments to ITER have considerable uncertainties, including on isotopic dependence and effects in mixed species plasmas. Previous experiments have generally found that PL-H is about a factor of two higher in hydrogen than in deuterium or helium, which have comparable threshold values. New experiments in JET-ILW find there is also a strong dependence on heating method, where while for plasmas using only ion cyclotron resonance heating P_{L-H} increases about a factor of two from deuterium to hydrogen plasmas, the difference can be a factor of three or more for plasmas heated only with neutral beam injection. Experiments have also been performed in hydrogen-deuterium and hydrogen-helium mixtures. The dependence of PL-H on mixture ratio is non-linear, with most change observed at small concentration ratios $n_H/(n_H+n_D)0.8$, while little change is observed over a broad intermediate range between 20% and 80%. Similar behavior is observed in experiments using up to 8% helium seeding in hydrogen plasmas. Implications of the results for the initial operational phases of ITER and comparisons to theoretical predictions will be discussed.

High energy and efficiency proton acceleration from relativistically transparent laser-foil interactions

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The study of ion acceleration driven by ultraintense ($>10^{20}$ Wcm^{-2}) laser-foil interactions has received considerable interest over the past decade, motivated by the possibility to produce a compact particle accelerator capable of generating a high flux ion beam with a tunable spectrum, in a short pulse. Here, we present a study of ion acceleration using ultra-thin (<100 nm) target foils, irradiated by pulses from the Vulcan laser at the Rutherford Appleton Laboratory, focused to a peak intensity of $6x10^{20}$ Wcm^{-2} . We demonstrate that for target foils with an optimal thickness for transparency-enhanced acceleration, it is possible to accelerate proton beams with maximum energies in excess of 94 MeV, and with a laser-to-proton conversion efficiency of up to 12%.

Measurements of the dependence of maximum proton energy on the thickness of plastic foils will be presented. In addition, we will discuss how the proton maximum energy at the optimum target thickness scales with laser intensity. Data from both aluminium and plastic targets are compared, with clear differences observed between the two materials. Experimental results are supported by 2D particle-in-cell simulations using the fully-relativistic EPOCH code. These simulations are used to explore the transparency-enhanced ion acceleration regime and demonstrate that a dense electron jet is responsible for driving a local enhancement in the sheath field, which couples additional energy into the proton beam.

Modelling of plasma-liquid interactions

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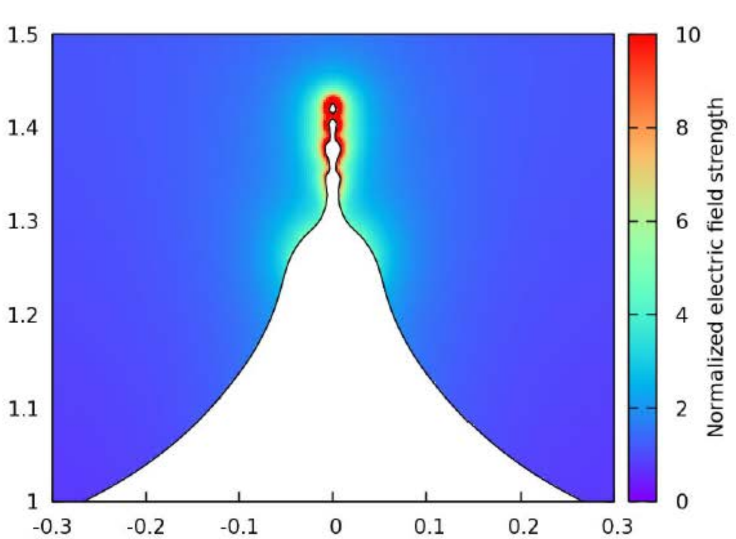
Plasma-liquid interactions are an increasingly important topic in the field of plasma science and technology with applications in nanoparticle synthesis, catalysis of chemical reactions, material processing, water treatment, sterilization and plasma medicine [1]. This particular work is motivated by the plasma-liquid interactions inherent in magnetic confinement fusion applications, either due to melt damage of the metal walls or in new liquid metal divertor concepts [2]. The ejection of molten droplets has been observed in both cases and is of considerable concern to the implementation of a successful fusion device. The stability of the liquid surface must be better understood. Furthermore the ejected droplets have been observed to undergo intriguing breakup processes which will influence the material redeposition and impurity transport due to the metal droplets; these breakup mechanisms should also be investigated.

Here a 2D axisymmetric code for plasma-liquid interactions is introduced. This code comprises a Navier-Stokes equation solver, which uses the level-set method to calculate surface tension and to evolve the surface of the liquid, and the liquid surface is coupled to a plasma region via electric fields and plasma pressure. This provides an adaptable platform for simulations of plasma-liquid interactions; examples are considered such as the stability of liquid surfaces under electric fields and ion impact in a plasma sheath and droplet deformation and breakup due to charge accumulation, electric fields, and plasma flows.



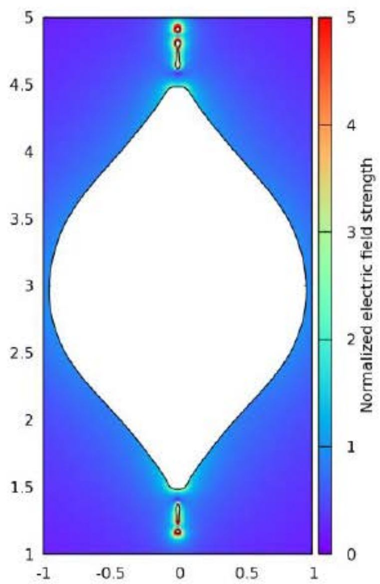


Figure 1 (left): Cone formation and spraying of droplets from an initially flat liquid surface in a perpendicular electric field. Figure 2 (right): Disruption of an overcharged droplet immediately after sub-droplet emission.

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(Invited) Analysis of low temperature atmospheric plasma polymerisation processes for innovative coating applications

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The use of low temperature atmospheric plasmas for polymerisation and its application to innovative applications such as antimicrobial coatings is receiving growing interest. The need to understand these processes is also ever increasing, especially when the surfaces are expected to interact with complex materials, such as bacteria, in an efficient and effective manner. In this talk we will look at using real-time and post treatment diagnostics and analysis techniques such as ambient mass spectrometry and Fourier transform infrared spectrometry (FTIR) to investigate the formation and deposition of 'simple' polymers such as Acrylic Acid and Allylamine under various conditions [1,2] . We also discuss the effect of different substrates can have on the coating adherence and properties. By studying these 'simple' polymer systems we can start to build our understanding which in turn allows us better understand the mechanisms which govern and influence more complex processes. In this case, we are interested in using atmospheric pressure plasmas to covalent graft antimicrobial peptides (AMPs) to surfaces, without the need for complex and timeconsuming chemical processes, while maintaining their functionality. The ability to design and fabricate surfaces and materials that are antimicrobial is of great importance various industries such as biomedical materials, water purification, food storage and processing. Antimicrobial peptides (AMPs) are an innate part of the immune response that are produced by all complex organisms which display antimicrobial activities against a broad range of Gram negative and Gram positive bacteria, including those resistant to established antibiotic drug therapies, mycobacteria, enveloped viruses, parasites and fungi. As such the immobilization of AMPs represent a promising new generation of biomimetic antimicrobial surfaces [3].

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Investigations on the role of inferior phase velocity laser plasma wakefield in proton acceleration

S Rai

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With the advent of intense lasers, the study of the interaction of matter with extreme fields in ultrashort time has been a fascinating field. Laser plasma interactions based acceleration of electron and ions are by-product of this revolution. Particle accelerators have wide range applications from biology to high energy particle physics. Laser plasma accelerators promise sustainability of huge electric fields (>100GeVm^{-1}), with which suppressed randomization of particles in phase space pave way for compact accelerators. There are various mechanisms for accelerating proton-target normal sheath acceleration (TNSA), radiation pressure acceleration (RPA) or shock acceleration. If an obstacle moves through a medium with a velocity higher than the specific velocity of sound, then a shock wave is formed. This is a known phenomenon from the supersonic jets. In plasma, such a perturbation generates collision less shock waves; which accelerate particles if they move faster than the critical Mach number. To apply this acceleration mechanism, we prefer a target which is close to the critical density. The paper studies the theoretical optimization and numerical simulations of various parameters to maximise the acceleration of proton in the slow wakefield in the interaction zone. The short and long counter propagating laser pulses in the spatially varying plasma density generates a slow phase velocity beat wave, in response to which the protons are trapped and hence accelerated. Though the forward propagating wakefield is shock excited, adjusting the plasma density and amplitude of backward propagating laser pulse gives a control on trapping and acceleration process. The effect of wakefield damping can be mitigated by introduction of long nanosecond laser pulse. This in turn induces Raman instabilities, increasing the amplitude of forward propagating laser pulse via Backscattered Raman amplification, could be handled by optimizing the pulse profile. Large gradient of the plasma density suppresses the growth of instabilities in the region of generation of wakefield but elsewhere the chirp on long pulse is required.

Ion cyclotron emission as a diagnostic of the time evolution of edge density during ELMs in KSTAR plasmas

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Spectrally structured ion cyclotron emission (ICE) is detected alongside ELMs in KSTAR deuterium plasmas. For KSTAR ICE where the separation of spectral peak frequencies is close to the proton cyclotron frequency at the outer plasma edge, our orbit calculations suggest that the driver may be a subset of centrally-born fusion protons on passing orbits. It is observed on KSTAR that the cyclotron harmonic structure of the ICE spectrum usually chirps down, on sub-microsecond timescales, during an ELM crash; upward chirping is observed in a few cases. We report 1D3V PIC code modelling of this scenario for KSTAR ICE. We simulate the self-consistent nonlinear full orbit dynamics of energetic and thermal ions and electrons, in combination with the electric and magnetic fields. Multiple simulation runs enable us to infer the theoretical dependence of ICE spectral structure on bulk plasma parameters, notably density. By matching these observations to the dependence of ICE on local density that we infer from our PIC simulations, we obtain sub-microsecond resolution of the evolving edge density during the ELM crash. The downward ICE chirps reflect the density collapse during the crash, while the rare upward chirps may be due to locally rising edge density associated with ELM filaments.

This work used the EPOCH code, part funded by the UK EPSRC grants EP/G054950/1, EP/G056803/1, EP/G055165/1 and EP/ M022463/1. This work was supported in part by RCUK Energy Programme grant EP/I501045, NRF Korea grant 2014M1A7A1A03029881 and Euratom.

Proton imaging of stochastic magnetic fields

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Recent laser-plasma experiments [1, 2, 3] report the existence of dynamically-significant magnetic fields, whose statistical characterisation is essential for a complete understanding of the physical processes these experiments are attempting to investigate. In this talk, I will outline how a proton imaging diagnostic can be used to determine a range of relevant magnetic field statistics, including the magnetic energy spectrum. To achieve this goal, we explore the properties of an analytic relation between a general magnetic field and the flux image created upon imaging that field previously derived [4] under simplifying assumptions typically valid in actual radiographic set-ups. We conclude that, as in the case of regular electromagnetic fields [4], features of the beam's final distribution often display a universal character determined by a single, field-scale dependent parameter – the contrast. For stochastic magnetic fields, we establish the existence of four contrast regimes – linear, non-linear injective, caustic and high-contrast – under which flux images relate to their parent fields in a qualitatively distinct manner. As a consequence, it is demonstrated that in the linear or non-linear injective regimes, the path-integrated magnetic field experienced by the beam can be extracted uniquely, as can the magnetic energy spectrum under further statistical assumptions. These statements fail to be true in the caustic or high-contrast regimes. We also discuss complications to the contrast paradigm arising for inhomogeneous, multi-scale stochastic fields, which can encompass many contrast regimes. The results presented in this paper are of consequence in providing a comprehensive description of proton images of stochastic magnetic fields, with applications for improved analysis of individual radiographs, or for optimising implementation of proton imaging diagnostics on future laser-plasma experiments.

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Pulsed laser breakdown in water and its aftermath

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Pulsed laser induced breakdown in water has been explored almost since the invention of the laser. In the current study we are revisiting this topic to determine if these plasmas can be used to develop diagnostics and shed some light on aspects of general plasma initiated chemistry and turbulence in liquids.

Here the plasmas are created in "water" with focused, 10 ns, 50 to 250 mJ, Nd:YAG laser (1064 nm) pulses. Time and space resolved images of the micro-plasmas created along the length of the laser beam are imaged using two separately triggered, 2 ns gated, ICCD cameras. Time resolved spectra are also acquired.

It is found that the breakdown patterns along the laser beam depend strongly on laser repetition rate and sequence number of laser pulse, strongly broadened Balmer Hα and Hβ lines are observed at delays of up to 200 ns and indicate plasma densities are of the order of 10^{17} cm^{-3} (these are ~ 10^{14} cm^{-3} in our electrically produced plasmas [1]) and the previously reported intermittent generation of conical white light in forward direction is also detected. However the focus here is on the associated bubbles, the radial shock fronts and turbulence that accompany the plasma production. These can be clearly seen using shadowgraph. At 350 ns after the laser pulse the measured shockwave speeds are ~ 1900 m/sec, decreasing to a constant value ~1485 m/sec, i.e. close to the speed of sound in water, after about 1000 ns. In our electrically produced plasmas only pressure waves are observed.

When the laser beam is parallel and focused very close to the air-water interface, macroscopic water droplets are ejected into the air to heights of up to 50 cm. As the bubbles break 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 slower turbulent dissipation 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.

We hope to be able to share results of the ongoing extension of our electrically produced plasma chemistry modeling into this regime [2].

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Some problems with the ponderomotive force

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The ponderomotive force is a familiar and widely used idea in plasma physics and particularly in the area of laser-plasma interactions. The familiar form for the force in a purely oscillatory field is readily obtained, but in a travelling wave the problem becomes more complicated. We consider the most basic problem of a particle moving in an electrostatic wave, coming from a region of zero field into a region of increasing wave intensity and being reflected. For this problem a formula for the ponderomotive force has been given, as a special case, by Bauer et al (Phys. Rev. Lett. 75, 4622, 1995). This is derived from an averaged Lagrangian technique, while for the same problem a ponderomotive potential has been obtained from Hamiltonian methods by Cary and Kaufman (Phys. Rev. Lett. 39, 402, 1977). These latter authors do not give an explicit formula for the force, but we show that it yields the same result as that given by Bauer et al. To test this analytic formula we compare its predictions with the results of an exact integration of the equation of motion, smoothed over the fast oscillations.

Up to a certain value of wavenumber we find excellent agreement between the exact and analytic results, but then we reach a value at which the analytic formula encounters a singularity while the exact solution remains well behaved. As the wavenumber is further increased we encounter a parameter range where the particle, after reflection, is initially accelerated in the outward direction but its velocity then falls as it moves down the intensity gradient. Such a change in the sign of the acceleration can be given by the Bauer et al formula, but we show that with this formula it is impossible for the acceleration to make the transition that we see. In fact, it can be seen that such a transition cannot be obtained from any Lagrangian with a quadratic dependence on the field amplitude. Either the acceleration is always down the intensity gradient, in the familiar way, or always up the intensity gradient. Finally, a further increase in wavenumber brings us to a regime where the particle's peak velocity reaches the wave phase velocity and it is given an abrupt kick to a higher velocity. Our conclusion is that expressions in the literature for ponderomotive force and ponderomotive potential in a travelling wave have a limited range of validity and that there are parameter ranges in which no ponderomotive potential quadratic in the electric field amplitude can be valid when used in a Lagrangian. The familiar and longstanding problem of the ponderomotive force would thus seem to warrant further study in view of its relevance to such topics as Raman amplification, laboratory astrophysics and laser wakefield acceleration.

(Invited) The physics currently limiting the thermonuclear fusion yield on the National Ignition Facility

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The National Ignition Facility (NIF) was designed with the goal of demonstrating thermonuclear ignition via the 'indirect-drive' laser inertial confinement fusion approach. Initial Deuterium –Tritium implosions were performed in 2011, during the 3 year National Ignition Campaign. To date ignition has not been achieved, although significant progress has been made, both in terms of increasing the fusion yield and understanding those mechanisms limiting the yield.

This talk will outline the key physics of the 'central hotspot' approach to laser inertial confinement fusion. It will then go on to discuss the key physical mechanisms which are understood to be currently limiting the thermonuclear yield of NIF. The talk will conclude by introducing a new mechanism which may explain many previous unexplained experimental results, potentially offer a route towards higher gains with the current NIF laser.

Particle acceleration during merging-compression plasma start-up in the MAST spherical tokamak

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The merging-compression method of plasma start-up in the Mega Amp Spherical Tokamak (MAST) involved the creation of two plasma tori with parallel currents, which merged at the vacuum vessel midplane due to their mutual attraction. Magnetic reconnection occurred in this process causing strong heating of both ions and electrons on millisecond timescales, and resulting in a plasma equilibrium with a single set of closed flux surfaces [1]. The merging process also resulted in the prompt acceleration of substantial numbers of ions and electrons to highly supra-thermal energies. Accelerated ions (deuterons and protons) were detected using a neutral particle analyser (NPA) at energies in the tens of keV range during merging in early MAST pulses [2], while nonthermal electrons have been detected indirectly in more recent pulses through microwave bursts. However no increase in soft X-ray emission was observed until later in the merging phase, by which time strong electron heating had been detected using Thomson scattering measurements. This suggests that the nonthermal electrons producing the microwaves had energies below the threshold (~1 keV) for producing soft X-rays, and hence that the acceleration process resulted in higher ion energies than electron energies. This may have been due to stochasticity in the magnetic field, which produces cross-field transport of particles at a rate proportional to their parallel velocity [3]. Thus, in the presence of stochastic fields, electrons are transported away from the acceleration site more rapidly than ions. We have used a test-particle code CUEBIT to model ion acceleration in the presence of an inductive toroidal electric field with a prescribed spatial profile and temporal evolution based on two-fluid simulations of the merging process [4]. The magnetic field used in the modelling includes a poloidal component consistent with this electric field. The simulations yield particle distributions (Fig. 1) with properties similar to those observed experimentally [2], for example the fact that protons are accelerated to higher energies than deuterons, as expected from simple estimates [2].

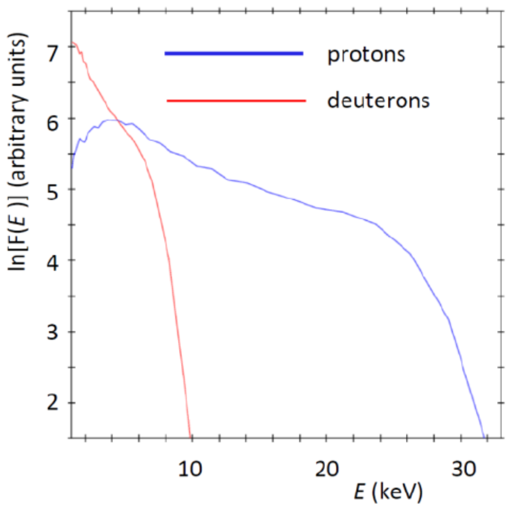

Figure 1: Simulated fast ion spectra during merging-compression in MAST

This work has received funding from the RCUK Energy Programme (grant number EP/I501045) and from Euratom.

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[4] A. Stanier et al., Phys. Plasmas **20** (2013) 122302. Fig 1 Simulated fast ion spectra during merging-compression in MAST.

The role of vibrational states of CO_2 in the conversion of CO_2 to CO using radiofrequency atmospheric pressure plasmas

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Low temperature plasmas can be used for the in situ generation of CO, from relatively non-toxic CO_2. CO is very useful in many industrial chemical processes and so, via low temperature plasmas, CO_2, a waste product, can be converted into a valuable chemical. The key challenges in using this method, for CO production, are optimising the energy efficiency, maximising the conversion of CO_2 into CO and then separating the CO from the other species produced in the plasma. The electron temperature in these plasmas is relatively low, 1-2 eV, and much lower than the bond energy of CO_2, 5.5 eV, and so the vibrational states of CO_2 are very important in the dissociation process.

The vibrational levels can lower the activation energy of key reactions and lead to an overall more energetically efficient process. Very high yields of CO, greater than 90%, have been achieved at atmospheric pressure using argon as a carrier gas with admixtures up to 1.0% and a maximum energy efficiency of 7.0% is found with a 2.0% admixture of CO_2. The plasma generated in continuous and spatially homogeneous and is driven at a frequency of 40.68 MHz. A zero dimensional global model has also been used to simulate the chemical kinetics of the plasma to determine the dominant dissociation processes and is in good agreement with the experimentally determined yields. The model is used to determine how important a role the vibrational states of CO_2 are, in a highly collisional plasma, to the production of CO. The dissociation of CO2 is found to be a two stage process with electron first vibrationally exciting CO_2 into a state very close to the dissociation limit and then a collision with an atom of either argon or oxygen causes the molecule to dissociate. Most of the atomic oxygen produced in the dissociation is recycled in further dissociating collisions with CO_2 so that the main products are CO and O_2, as desired.

Theory of the sheath and maximum ion energies in target normal sheath acceleration

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Target Normal Sheath Acceleration (TNSA) is a method for accelerating ions using high intensity laser pulses hitting solid density targets. Relativistic electrons travel through the target forming a space charge sheath at the rear surface. The electric field in this sheath accelerates ions to high energies. For pulse durations shorter than the electron traversal time the fast electrons forming the sheath will have a non-equilibrium distribution with a beam like component. For longer times the electrons can reach equilibrium in the form of the Maxwell-Jüttner distribution. I present a kinetic theory of the rear sheath for arbitrary electron distribution function. It is found that the far field is determined by the high energy tail of the distribution. When accounting for electrons escaping the sheath region a finite potential drop over the sheath is found. The finite potential drop implies a maximum energy for ions being accelerated in the sheath field.

(Invited) Physics and technology innovations for compact tokamak fusion pilot plants

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For magnetic fusion to be economically attractive and have near-term impact on the world energy scene it is important to focus on key physics and technology innovations that could enable net electricity production at reduced size and cost. The tokamak is presently closest to achieving the fusion conditions necessary for net electricity at acceptable device size, although sustaining high-performance scenarios free of disruptions remains a significant challenge for the tokamak approach. Previous pilot plant studies have shown that electricity gain is proportional to the product of the fusion gain, blanket thermal conversion efficiency, and auxiliary heating wall-plug efficiency. In this presentation, the impact of several innovations is assessed with respect to maximizing fusion gain. Potential innovations include optimizing tokamak aspect ratio and shaping, high-temperature superconductors (HTS) for high-field and high-current-density magnets, kinetic stabilization of macroscopic instabilities, the reduction and control of turbulence and/or low edge recycling (for example using lithium walls), and advanced divertor configurations. The interplay between a range of physics and technology innovations for enabling compact pilot plants will be described.

MAST upgrade: a facility to advance understanding of power exhaust in tokamaks

J R Harrison[1], S Y Allan[1], S Elmore[1], A R Field[1], G M Fishpool[1], A Kirk[1], B Lipschultz[2], R Martin[1], D Moulton[1], R Scannell[1], A J Thornton[1], and the MAST Upgrade Team[1]

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The exhaust of heat and particles from the core of burning fusion reactors such as DEMO presents a significant challenge to handle with existing materials due to the extremely high heat fluxes to surfaces that make up the divertors of tokamaks. In DEMO, the divertor heat flux is estimated to be around $100MWm^{-2}$. This far exceeds the level that can be safely deposited to existing suitable materials of around $10\text{-}20MWm^{-2}$ in steady-state [2]. A possible solution is the use of novel divertor configurations. These include the Super-X, xdivertor [4] and snowflake configuration [5], which offer benefits compared with the conventional divertors widely used in existing tokamaks by increasing the area over which power is deposited to plasma-facing surfaces and in some cases improve the access and controllability of divertor detachment.

The MAST Upgrade tokamak will start operating in 2017 with unique capabilities to produce conventional and novel divertor configurations to allow for detailed studies and comparison in a single device. The two closed divertor chambers are surrounded by 7 poloidal field coils per chamber (giving 14 in total) allow for careful control of the magnetic geometry, including strike point location, field line length within the divertor, poloidal flux expansion and how their variation across the scrape-off layer, whilst keeping the shape of the core plasma unchanged. The divertor design is optimised to reduce the leakage of recycled neutral particles escaping from the divertor, thereby maximising losses of momentum and energy through collisions between the plasma and neutral species and facilitating access to detachment. The performance of the divertor, in terms of dissipating energy and momentum from the plasma, has been studied in detail with the SOLPS code, and predicts that the Super-X configuration facilitates access to detachment, reducing the upstream density needed to reach detachment by a factor ~2. A suite of diagnostics, including an extensive array Langmuir probes, visible and infra-red imaging cameras, coherence imaging, UVvisible spectroscopy, bolometry and Thomson scattering will be used to measure the profiles of electron density, temperature, radiative power losses and the heat flux to divertor surfaces with high accuracy.

The flexible magnetic geometry, together with an extensive suite of diagnostics make MAST Upgrade an exciting new facility for advancing our understanding of power exhaust in tokamaks.

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(Invited) Solar flares and energetic particles

E Kontar

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During periods of sporadic flare activity, the Sun releases energy stored in the magnetic field into the plasma of the solar atmosphere. This is an extremely efficient process, with a large fraction of the magnetic energy going into plasma particles. The solar flares are accompanied by prompt electromagnetic emission virtually over the entire electromagnetic spectrum from gamma-rays down to radio frequencies. The Sun, through its activity, also plays a driving role in the Sun-Earth system that substantially influences geophysical space. Solar flare energetic particles from the Sun are detected in interplanetary space by in-situ measurements making them a vital component of the single Sun-Earth system. Although a qualitative picture is generally agreed upon, many processes solar flare processes are poorly understood. Specifically, the processes of acceleration and propagation of energetic particles interacting on various physical scales remain major challenges in solar physics and basic plasma physics. In the talk, I will review the current understanding of solar flare energetic particles focusing on recent observational progress, which became possible due to the numerous spacecraft and ground-based observations.

(P1) The collisionless transient pinch

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The mechanism of the transient pinch at low densities, outlined in an early paper by Rosenbluth, has been studied in detail. The thickness of the surface current layer is found to be the electron inertial length (c/ω_{pe}). The electron and ion trajectories have been calculated, the latter being essentially due to the electrostatic field which transfers the **j**x**B** force from the electrons to the positive ions. The collapse velocity is comparable to the Alfvén velocity, but the theory of magnetohydrodynamics (MHD) is not applicable to collision-free plasmas.

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(P2) The PLATINUM project: pulsed laser accelerators for the inspection of nuclear materials

C M Brenner[1], S Kar[2], J Jowsey[3], C P Jones[4], S R Mirfayzi[2], D R Rusby[1,5], C Armstrong[1,5], A Alejo[2], L A Wilson[1], R Clarke[1], H Ahmed[2], N M H Butler[5], D Haddock[1], A Higginson[5], A McClymont[1], C Murphy[6], M Notley[1], P Oliver[1], R Allott[1], C Hernandez-Gomez[1], P McKenna[5], D Neely[1] and T B Scott[4]

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High-power (> 100 TW) laser-solid interactions drive micro-scale electron accelerators that can generate bright, point-like sources of high-energy x-rays, ions and neutrons. These laser driven beams are of particular interest for industrial, nuclear and security applications where imaging and/or inspection through large and dense objects is required. At the UK's Central Laser Facility (CLF) the Vulcan laser has been operational at petawatt level for over a decade to study the underlining physics behind the beam generation and in recent years has also been used to demonstrate their potential for applications across many high-value sectors [1]. The CLF is now developing high repetition rate capability, via its novel DiPOLE system [2] – a high average power, diode-pumped laser system capable of delivering 100 J pulses at 10 Hz. This allows for a laser-driven multi-modal beamline for waste monitoring applications to be envisioned.

The PLATINUM project is a 3-year STFC-funded programme of collaboration between CLF, University of Bristol, Queen's University Belfast and Sellafield Ltd to demonstrate proof of concept imaging and inspection with realistic and lifesize samples relevant to nuclear waste assay and drum monitoring.

In previous work a small scale sample nuclear waste package, consisting of a 28mm diameter uranium penny encased in grout, was imaged by absorption contrast radiography using a single pulse exposure from an x-ray source driven by a high-power laser [3]. The Vulcan laser was used to irradiate a tantalum foil, in order to generate a bright burst of highly penetrating x-rays (with energy >500keV), with a source size of <0.5mm. BAS-TR and BAS-SR image plates were used for image capture, alongside a newly developed large area Thalium doped Caesium Iodide scintillator-based detector coupled to CCD chips. The uranium penny was clearly resolved to sub-mm accuracy over a 30 cm^2 scan area from a single shot acquisition. In addition, neutron generation was demonstrated in situ with the x-ray beam, with a single shot, thus demonstrating the potential for multi-modal criticality testing of waste materials. This feasibility study successfully demonstrated non-destructive radiography of encapsulated, high density, nuclear material.

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(P3) Channeling optimization of high-intensity laser beams in millimeter-scale plasmas

L A Ceurvorst[1], N Ratan[1], M F Kasim[1], J Sadler[1], P A Norreys[1,2], H Habara[3], K A Tanaka[3,4], S Zhang[5], M Wei[6], S Ivancic[7], D H Froula[8] and W Theobald[7]

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Channeling experiments were performed at the OMEGA EP1 facility using relativistic intensity (>10^{18} W/cm^2) kilojoule laser pulses through large density scale length (~390–570 μm) laser-produced plasmas, demonstrating the effects of the pulse's focal location and intensity as well as the plasma's temperature on the resulting channel formation. The results show deeper channeling when focused into hot plasmas and at lower densities as expected. However, contrary to previous large scale particle-in-cell studies, the results also indicate deeper penetration by short (10 ps), intense pulses compared to their longer duration equivalents. This new observation has many implications for future laser-plasma research in the relativistic regime.

(P4) Nonlinear self-consistent kinetic simulations of the anomalous Doppler instability of suprathermal electron populations in fusion plasmas

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The anomalous Doppler instability (ADI) is a key relaxation mechanism for suprathermal electron populations in magnetic confinement fusion (MCF) plasmas. The underlying physics of the ADI involves a shift of energy from parallel to perpendicular electron motion, accompanied by the excitation of waves at frequency and wavenumber (ω, k, θ) satisfying the anomalous Doppler resonance condition. Here we present 2D3V particle in cell (PIC) simulations used to extend recent studies of the ADI [1, 2]. Our results verify the 1977 analytically based conjecture [3], whereby the ADI gives rise to a small positive slope in the parallel electron distribution. We show that the existence of a positive slope can excite waves in a separate region of (ω, k, θ) space to that of the ADI. We also show that in addition to this wave-particle instability, a collective wave-wave instability [4] plays a significant role. Finally we explore the possibility of utilizing 3-wave triads in order to infer characteristics of the parallel electron distribution. The results assist understanding of the role of the ADI in fast timescale effects in MCF plasmas.

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(P5) Extended interaction oscillator based on a pseudospark-sourced electron beam

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The pseudospark discharge is a form of low-pressure gas discharge, capable of generating extremely high currents within short rise times by means of a hollow cathode structure [1,2]. A high-quality electron beam is generated during the discharge process, which possesses high current density and brightness, as well as the ability to self-focus via ion channel focusing [3]. Simulations have shown that the pseudospark plasma sourced electron beam would propagate within background plasma of density in the range of 10^{14} to10^{16} m $^{-3}$ without any applied guiding magnetic field [4]. This makes it an excellent electron beam source for millimetre-wave generation [5].

A W-band (75-110 GHz) Extended Interaction Oscillator (EIO) millimetre-wave source was designed and constructed to operate in the 2π mode for the first experiments because of its shorter interaction length, high interaction impedance and high gain per unit length [6]. The beam voltage was designed to be centred at 30.5 kV, which is suitable for a four-gap pseudospark discharge.

This newly developed device combines the merit of a short interaction circuit in the EIO and the high current density property of the pseudospark-sourced electron beam to generate W-band coherent radiation [6]. Experimental results will be presented to show that with a 35 kV discharge voltage, the EIO successfully produced W-band radiation pulses with 38 W peak power and 20 ns duration, which agrees well with the 3D Particle-in-Cell (PIC) simulations using MAGIC. Simulations also demonstrate the capability of extending this concept to higher frequencies [7].

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(P6) Fourier-Vlasov simulations of cyclotron instabilities in plasma

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We present numerical simulation results of the Vlasov-Maxwell system, using a Fourier transform method in velocity space [1]. With the increase of computer power, Vlasov simulations are becoming more tractable. The Fourier-Vlasov code has been parallelized to run on clusters of computers [2,3]. The Fourier transform method, with absorbing boundary conditions in the Fourier transformed velocity space, reduces the numerical recurrence effect and minimizes problems with numerical heating in the simulations. We will show recent results in higher dimensions where the Vlasov solver has been used to investigate wave generation via the electromagnetic and electrostatic electron cyclotron instabilities [4,5] in non-isothermal magnetised plasmas including couplings to electron Bernstein modes.

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(P7) An algorithm for analysis of filaments in fast camera data

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An improved understanding of plasma exhaust is required to minimise the power and particle loads to plasma facing materials, which is crucial to the development of a nuclear fusion power plant. Coherent filamentary structures play a dominant role in turbulent cross-field particle transport [1]. These intermittent structures propagate outwards far from the last closed flux surface, widening the scrape off layer (SOL) and increasing particle transport to the walls. In some cases filaments have been shown to be responsible for at least 50% of the particles in the SOL [2]. The properties of filaments, their dependence on plasma parameters and their origins and evolution must be understood in order to optimise SOL dynamics to minimise erosion of plasma facing surfaces and maximise the lifetime of a fusion reactor.

An algorithm has been developed to identify and measure filaments in unfiltered fast camera images. The algorithm currently operates under the assumptions that filaments follow field lines and are homogeneous along them. First, background subtraction, noise reduction and sharpening enhancements are applied to the camera images to highlight transient features and reduce the effects of pixel noise. Next, the paths of a large number of magnetic field lines generated from EFIT++ equilibria are projected onto the camera images using the calcam code. Integrating the pixel intensities along the field lines leads to a 2D grid of field line intensities in the machine R-ϕ plane, from which local maxima and minima in intensity are identified. A local background intensity is calculated, and a fixed height contour taken for each maxima, to which an ellipse is least squares fitted. The fitted ellipses give the position, size and orientation of the detected filaments.

A synthetic camera diagnostic has been developed to extensively test the accuracy and capabilities of the algorithm. By generating synthetic camera frames containing filaments with parameters drawn from experimentally informed random distributions of position, width and amplitude, the outputs of the algorithm can be compared to precisely known inputs. This has enabled further refinement of the algorithm and compensation for systematic errors, in addition to estimations of uncertainties and identifications of the strengths and limitations of the technique.

The algorithm will be utilised to produce large databases of filament measurements in order to ascertain the dependence of filament properties on machine plasma parameters and improve understanding of the factors that control SOL profiles.

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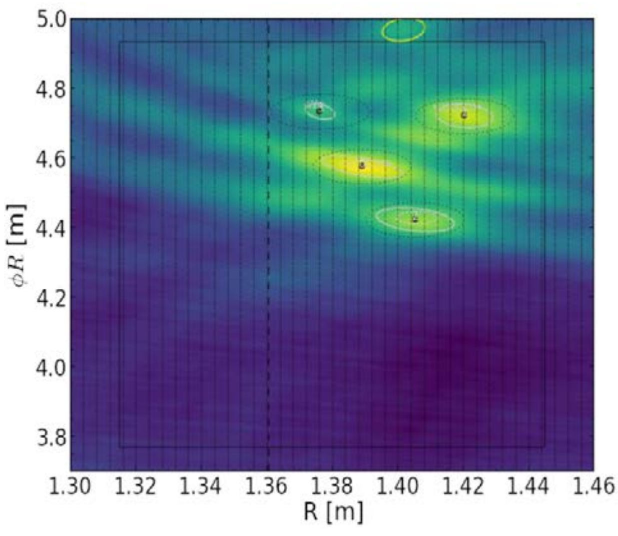

Figure 1: Plot of 'integrated' field line intensity in the R-phi plane. Dashed white ellipses show the position and size of synthetic filaments, while solid white ellipses indicate detected filaments. Dashed black ellipses indicate detection thresholds and the vertical dashed black line shows the location of the separatrix.

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(P8) Improving understanding of divertor detachment via atomic physics and spectroscopy

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Divertor detachment is currently the leading solution to the steady-state heat flux problem in magnetic confinement fusion devices. The plasma heat exhaust in a burning fusion reactor is expected to be several times the engineering limit of the target surface, hence this understanding is a necessary step for continuous operation[1]. However, the physics of detachment onset and sensitivity to feedback control is not well understood and has yet to be accurately modelled by current modelling codes. Hence the relationship between divertor physics and fundamental plasma processes needs to be further developed.

Important insights into the relationship between plasma physics, atomic and molecular processes and divertor detachment can be gained from optical spectroscopy in the near-IR to near-UV range. For this reason, these diagnostics are widely used in magnetic confinement fusion and found to be an integral analytical technique. This is seen in the work at ASDEX-Upgrade where this was used to elucidate and classify the three discrete stages of detachment onset[2].

The electron temperature, T_e, can be inferred through a detailed analysis of high-n deuterium Balmer emission intensity, T_e, and the electron density, n_e, from the shape of the high-n Balmer lines, typically dominated by Stark broadening at low T_e, high ne conditions that are typically observed during detachment onset[3]. Furthermore, the spatial distribution of spectral emission from multiple low to mid-Z impurity charge states, for example from nitrogen or carbon, can be used to infer Te across the divertor[1].

This contribution describes current developments in preparation for MAST Upgrade operation in late 2017. The first experiments will explore the relationship between magnetics configurations with detachment onset and continuation. This will be done using a spectrometer with multiple viewing chords will be used to monitor passive spectral line emission from the divertor with high spatial resolution (~1cm) and time resolution (<20ms) in order to evaluate the spatial distribution of ne and Te across the divertor. Comparison of these measurements with the state-of-the-art SOLPS code to identify plasma physics that the code cannot full explain or express[4].

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[4] E. Havlickova et al., Plasma Phys. Control. Fusion **57** (2015) 115001

(P9) Experimental observation of beam intensity profile modification and transient phase during cross beam energy transfer

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When crossing into plasmas, laser beams couple themselves to the plasma modes and could experience energy transfer. This mechanism, involving induced stimulated Brillouin scattering is known as cross beam energy transfer (CBET) and is playing a major in inertial confinement fusion experiments. Thus, it has been deeply studied and its integrated properties have been characterized through simulation and experiment. However, fine scale study still has to be performed in order to shed some light on CBET development at the speckle size scale, resulting from spatial smoothing. Moreover, this energy transfer is also studied in the context of plasma amplifiers.

The experiment has been performed at the LULI2000 facility from LULI laboratory [1]. Cross beam energy transfer from a pump beam to a seed one has been studied into a preformed, expanding, $T_e = 1$ keV, $n_e = 0.05\ n_c$, 2.5 μm Mylar foil plasma. The first random phase plate (RPP)-smoothed interaction beam, the pump, had a 1.5 ns pulse with an energy of 20 J (10^{14} W/cm^2) at 526.5 nm. The second RPP-smoothed interaction beam, the seed, had a shorter pulse duration of a few picoseconds at 526.5 nm. The seed focal spot was set to be twice larger than the pump one in order to clearly observe energy transfer. The two beam interaction has been studied through variation of the seed pulse duration and incident intensity. CBET has been diagnosed with the help of a highly resolved 2D spatial imaging of the seed beam transmitted light.

Amplification of a picosecond-pulse beam by a lower intensity nanosecond-pulse beam has been evidenced for the first time. The energy transfer growth is characterized by a transient phase of a few picoseconds followed by a steady state regime. The fine scale study has enabled us to observe the spatial modifications of the seed beam intensity profile because of CBET along with the temporal evolution of the speckle intensity distribution. The experimental results are compared to the numerical predictions of the three-dimensional laser-plasma interaction code SECHEL [2]. Qualitative agreement has been found between experimental and numerical results, even though the simulations tend to underestimate CBET level.

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(P10) Reduced kinetic simulations of particle acceleration during magnetic reconnection

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Magnetic reconnection is responsible for many non-stationery phenomena in space and laboratory plasmas. A substantial part of the energy released during the reconnection is carried by non-thermal energetic particles, which may affect the structure and dynamics of the reconnection region. Magnetohydrodynamic (MHD) approach cannot adequately describe nonthermal particle acceleration and transport, while the full kinetic treatment is too computationally expensive. We explore the possibility of part kinetic/partMHD description of mildly non-thermal magnetised plasma. The idea of the proposed hybrid approach is to describe the parallel (to magnetic field) motion of particles using the drift-kinetics (with arbitrary parallel velocity distribution), while using MHD description for perpendicular transport. We discuss the applicability and limitations of this method and demonstrate several test models.

(P11) Ball-pen probe in strongly magnetised low-temperature plasma

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Magnetic fields drastically affect Langmuir probe measurements, making it challenging to extract valid plasma information such as plasma density, electron temperature and plasma potential. This is especially problematic, with magnetised electrons, in the electron retardation region and near the plasma potential where the probe current voltage characterisation becomes distorted. Recently, ball-pen probes have been developed to work within a magnetic field and have been used to measure the plasma potential in fusion plasmas [1]. Ball-pen probes obtain the plasma potential by altering the collection of ion and electron currents, by a retractable probe collector, inside an insulating tube [2]. Ball-pen probes have been previously applied in low-temperature plasmas, but only in magnetic field strengths up to 100 mT [3]. In this experiment, different ball-pen designs were investigated under various magnetic field strengths up to 0.6 Tesla, in a low-temperature RF Argon plasma. The impact of varying the size of the collection area, the shape of the probe tip and the thickness of the surrounding insulator has been studied. Plasma potential measurements, as well as an investigation of the effect of different recession depths, are compared to an emissive probe over a range of pressures and powers. The results from these experiments provide valuable insight into ball-pen probe design and verification of existing ball-pen probe theories.

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(P12) Combined effects of trapped energetic ions and resistive layer damping on the stability of the resistive wall mode

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We have carried out a systematic investigation of the stability of the resistive wall mode (RWM), in the presence of both the resistive layer damping including the toroidal favorable average curvature effect (the GGJ effect), and the drift kinetic damping from trapped energetic ions. The eigenvalue of the mode is obtained by numerically solving the dispersion relation, derived for a large aspect ratio circular plasma with simplified equilibrium radial profiles. The dispersion relation is numerically solved for a model plasma, for the purpose of systematic investigation of the RWM stability in multi-dimensional plasma parameter space including the plasma resistivity, the radial location of the resistive wall, as well as the toroidal flow velocity. The stability of the RWM is mapped out in either 1D or 2D parameter spaces involving the plasma resistive (the Lundquist number), the toroidal flow speed, and the distance *b/a* of the resistive wall to the plasma. We find that without GGJ effect, a finite plasma resistivity destabilizes the RWM. On the other hand, plasma flow can stabilize the mode in the presence of a finite resistivity, thus opening stability windows in the *b/a* parameter space, in a similar way as the ideal MHD prediction. The flow stabilization is more effective at large Lundquist number. It is found that the toroidal favourable average curvature in the resistive layer contributes a significant stabilization of the RWM. The GGJ stabilization, from inside the resistive layer, greatly enhances the RWM stability. In fact this damping physics alone, without plasma flow and without drift kinetic damping, can result in the full mode stability at large Lundquist number. In the presence of flow, the stability domain is further widened compared to the cases without the GGJ effect. On the other hand, the GGJ effect generally does not introduce a substantial modification to the real frequency of the mode. The precessional drift resonance damping of trapped energetic ions acts synergistically with the GGJ effect for the mode stabilization, further widening the stable domain in the 2D parameter space of the plasma flow speed versus the Lundquist number. Furthermore, two traditionally assumed inner layer models are considered and compared in the dispersion relation, resulting in different predictions for the stability of the RWM. Generally the resistive kink layer model, which has previously been assumed in literatures for studying the flow stabilization of the RWM, predicts less stability compared to the resistive tearing mode model. This holds even when the GGJ term is excluded from the tearing layer model.

(P13) Nonlinear waves in the terrestrial quasiparallel foreshock

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We provide strongly conclusive evidence that the cubic nonlinearity plays an important part in the evolution of the large amplitude magnetic structures in the terrestrial foreshock. Large amplitude nonlinear wave trains at frequencies above the proton cyclotron frequency are identified after nonharmonic slow variations are filtered out by applying the empirical mode decomposition. Numerical solutions of the derivative nonlinear Schrödinger equation, predicted analytically by the use of a pseudopotential approach, are found to be consistent with the observed wave forms. The approximate phase speed of these nonlinear waves, indicated by the parameters of numerical solutions, is of the order of the local Alfvén speed. We suggest that the feedback of the large amplitude fluctuations on background plasma is reflected in the evolution of the pseudopotential.

(P14) Time-resolved characterisation of the evolution of electrostatic collisionless shocks

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Collisionless shock waves (CSW) arise in plasma when an abrupt change in plasma conditions is not caused by binary collisions but the collective behaviour of the plasma. CSW are thought to be highly common in astrophysical environments due to the low ambient density. It is thought that shocks caused by supernova remnants expanding into the interstellar medium accelerate particles that are responsible for cosmic rays measured high in the Earth's atmosphere. CSW can also be found in our solar system as planetary bow shocks and interplanetary shocks [1,2,3].

Intense laser-plasma interactions provide a way to launch CSW in conditions relevant to astrophysical plasmas. The interaction of an intense laser pulse with a solid target produces dense plasma, which flows with high velocity, into an ambient background medium. CSW are generated by the sudden expansion of this dense plasma into a tenuous ionized background.

Previous studies by the group [4] have determined initial conditions required to create shocks and characterized their formation and initial evolution. In a recent experiment, we have built upon this, to follow the evolution of the shock over a longer temporal window. Shocks are observed by using a laser accelerated proton beam as a charged particle probe for radiography. This allows simultaneous measurement of the spatial profile, electric field distribution and shock front propagation velocity over a relatively large temporal window, with high temporal and spatial resolution. We present results obtained using the VULCAN laser at the Rutherford Appleton Laboratory showing development and evolution of a pair of shocks from a compressed plasma shell, as previously observed in [4]. These observations follow the indications provided by PIC simulations by Dieckmann et al. [5].

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(P15) Plasma micro-reactors: potential and practical challenges for chemical engineering

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Micro-reactors are an essential component of lab on a chip and plant on a chip technology. Many chemical processes have been demonstrated to occur in plasmas, but so far ozone generation is the only plasma chemical synthesis process to be used on a large/commercial scale. Despite this there is clear potential for plasmas as a medium for chemical engineering.

Some of the most important factors governing chemical reactions in plasma environments are identified, such as material selection, role of catalysis, and residence time. These are compared with key aspects of current chemical engineering science to investigate the potential for its integration with plasma science. The lifetime and operational parameters of a range of micro-plasma units reported in the literature are also compared.

Micro-plasma unit lifetime was found to be a major limitation in many cases, and potential solutions to this lifetime problem are outlined. Another obstacle, the chemical selectivity of conventional plasma “reactors”, is thought to be improvable with the incorporation of catalysts into plasma systems. Available literature suggests that the field of “plasma catalysis” is still in its infancy, but has great potential. Computer simulation capabilities are another limitation, and lack of availability of kinetic data is a critical bottleneck. However, overcoming these obstacles could pave the way for plasma chemical engineering to further develop into a discipline in its own right. From the available data of plasma chemical reaction kinetics, existing materials and plasma chemical engineering principles, it is possible to develop an approach to the design of plasma micro-reactors with more optimal parameters.

(P16) Argon photoionisation

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This poster relates to an experiment carried out at the Central Laser Facility (CLF) in August last year. We wanted to photoionise Argon gas using a x-ray line radiation field, produced by an irradiated tin(Sn) foil target. We also wanted to achieve a higher value of ξ (photoionisation parameter) than has previously been achieved in this type of experiment. Previous experiments at the GEKKO-XII laser facility [1] and using z-pinches at Sandia [2], were only able to achieve 6-25erg cms^{-1}.

Diagnostics used included silicon crystal spectrometers, a mica crystal spectrometer, a pinhole camera, a x-ray streak camera and Thomson scattering. A gas cell was used which allowed the density of the gas to be controlled and once the chamber was placed under vacuum, the Argon could be released into the gas cell at pressures between 100mBar and 1500mBar.

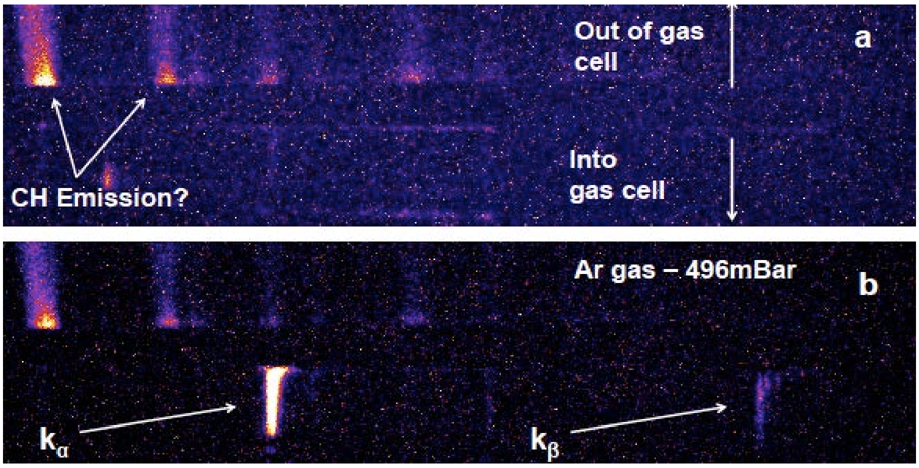

Figure 1: Images obtained using Mica spectrometer
a) Without Sn foil target b) With Sn foil target

Figure 1: shows mica spectrometer results with and without the Sn foil target. The k_α and k_β emission from the Argon are shown in 5b and prove that we have achieved photoionization of Argon gas. Higher values of ξ were also achieved, as high as 40erg cms^{-1}.

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(P17) Ion streaming instability of dust-acoustic surface waves in a Lorentzian complex plasma slab

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The growth rate of the dust-acoustic surface wave in the semi-infinite complex plasma with an ion streaming passing through the plasma at rest is analytically derived. We have adopted the Lorentzian distribution for electrons to investigate the nonthermal property of plasma on the growth rate. We find that the growth rate of the surface wave increases as the wave number increases and it is always larger than that of bulk wave, especially in the realm of large wave numbers. The nonthermal effect of Lorentzian electrons in the high-energy tail is found to enhance the growth rate. It is also found that the density and speed of streaming ion would increase the growth rate. The growth rate of surface wave is compared with that of bulk wave for various physical parameters.

(P18) Quantitative shadowgraphy and proton radiography for large intensity modulations

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Shadowgraphy is a technique widely used to diagnose objects or systems in various fields in physics and engineering. In shadowgraphy, an optical beam is deflected by the object and then the intensity modulation is captured on a screen placed some distance away. However, retrieving quantitative information from the shadowgrams themselves is a challenging task because of the non-linear nature of the process. Here, a novel method to retrieve quantitative information from shadowgrams, based on computational geometry, is presented for the first time. This process can also be applied to proton radiography for electric and magnetic field diagnosis in high-energy-density plasmas and has been benchmarked using a toroidal magnetic field as the object, among others. It is shown that the method can accurately retrieve quantitative parameters with error bars less than 10%, even when caustics are present. The method is also shown to be robust enough to process real experimental results with simple pre- and post-processing techniques. This adds a powerful new tool for research in various fields in engineering and physics for both techniques.

(P19) Intrinsic suppression of resistive drift-wave turbulence in linear device geometry

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Linear devices provide an axial magnetic field that serves to confine a plasma in cylindrical geometry as it travels from the source to the strike point. Due to perpendicular transport, the plasma density and temperature will have a roughly Gaussian radial profile with gradients that drive instabilities, such as resistive drift-waves. These instabilities cause perturbations to grow, resulting in either saturated turbulence or, in some cases, the development of turbulence is suppressed. When the plasma emerges from the source, there is a time, $\tau_{\parallel}$, that describes the lifetime of the plasma based on parallel velocity and length of the device. As the plasma moves down the device, it also moves azimuthally according to $E \times B$ and diamagnetic velocities. There is a balance point in these parallel and perpendicular times that sets the stabilisation threshold. We simulate plasmas with a variety of parallel lengths and magnetic fields to vary the parallel and perpendicular lifetimes, respectively, and find that there is a clear correlation between the saturated RMS density perturbation level and the balance between these lifetimes. The threshold of marginal stability is seen to exist where $\tau_{\parallel} \approx 10\ \tau_{\perp}$. This is also associated with a ratio of $\tau_{\perp}\gamma* \approx 100$, where $\gamma*$ is the drift-wave linear growth rate, indicating that the instability must exist for roughly 100 times the growth time for the instability to enter the nonlinear growth phase. We explore the root of this correlation and the implications for linear device design.

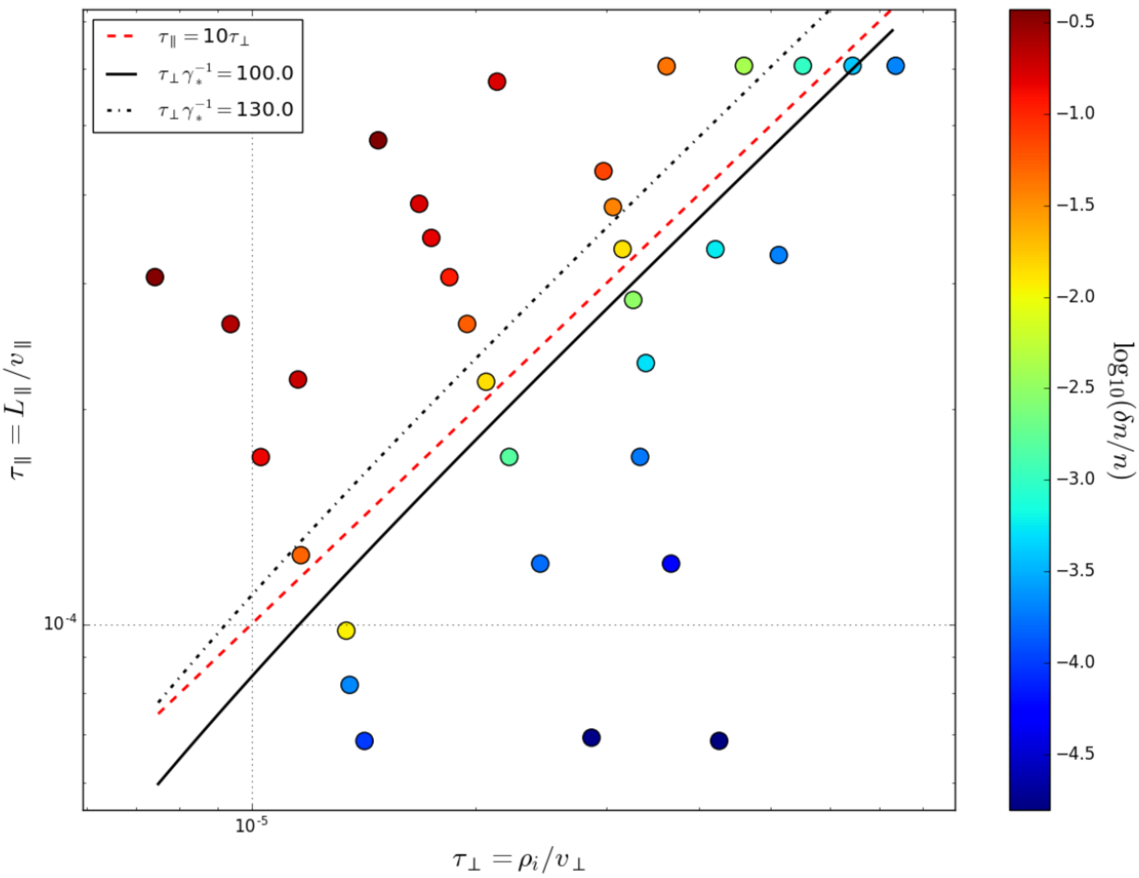

Figure 1: The balance required between parallel and perpendicular times is shown with a clear trend in density perturbation magnitude. The stability threshold is drawn around $\tau_{\parallel} \approx 10\ \tau_{\perp}$ and $\tau_{\perp}\gamma* \approx 100$, indicating a minimum linear growth time for the development of turbulence.

(P20) Photoabsorption of Ca, Pb and Bi in the vacuum ultraviolet region – towards controlled resonance-enhanced high harmonic generation

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A significant body of work exists on the study of photoionization processes in rare gas atoms where electron correlation has been revealed as a key physical mediator leading to the observation of giant photoionization resonances, single photon-multiple electron excitation and/or ionization, etc. In contrast metal atoms and ions have been much less studied. The current project centres on a study of vacuum ultraviolet (VUV) photoabsorption of metal atoms and ions using laser plasma generated radiation[1]. In particular metal atoms or ions that could act as candidates for resonantly enhanced high harmonic generation (HHG) [2] are a key target of the work. Photoabsorption spectra have been measured using the well-established Dual Laser Plasma (DLP) photoaborption technique [1]. The absorption spectra from lowly charged ions of calcium, lead and bismuth have been obtained.

The main focus of the work presented will be on using the DLP technique to establish the conditions for which the population of a particular ion stage is maximised, as a function of time and space. A good deal of work has already appeared in the literature on HHG from plasma plumes [3], and the next steps of this project will be to explore HHG in these optimised plasma, where individual ion stages are isolated and maximised. For example, calcium has an exceptionally high total cross section in the region of the 3p-3d resonances for the first and second spectrum. We will investigate if the efficiency of the resonance enhancement of a single (21^{st}) harmonic in calcium plasma plumes can be improved for ideal plasma conditions.

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(P21) Spatial organisation of tokamak flow structures

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Various generation mechanisms for the formation of plasma flow structures in tokamaks have been proposed, both on the turbulence and global length scales. These are intended to explain the wide variety of plasma flow structures observed experimentally, including short-wavelength zonal flows, large scale equilibrium toroidal flows, and sharp flow gradients at internal transport barriers. Two basic generation mechanisms for turbulence scale flows (zonal flows) have been proposed. One is spontaneous structure formation through turbulent self-reinforcement of existing flows, which manifests as a modulational instability in the linear regime. The other is the so-called 'toroidal nonlinear coupling' mechanism, that is associated with rational surfaces (where field lines close after a few turns around the tokamak); because this mechanism involves the background geometry, it has a different linear signature, and gives rise to flows with a particular phase signature. These mechanisms have been considered separately but typically compete with each other. We show, using gyrokinetic simulations, that the overall result is sharp flow structures near low-order mode rational surfaces, but that elsewhere the flows are not locked to the rational surfaces. This has interesting experimental implication for toroidal and poloidal flows, especially where the magnetic shear is low or reversed, and the effect of the rational surface leads to a perturbation over $\sim$ 100 gyroradii. For example, it provides a mechanism to explain sharp, time-stationary flow structures in discharges though local mechanisms.

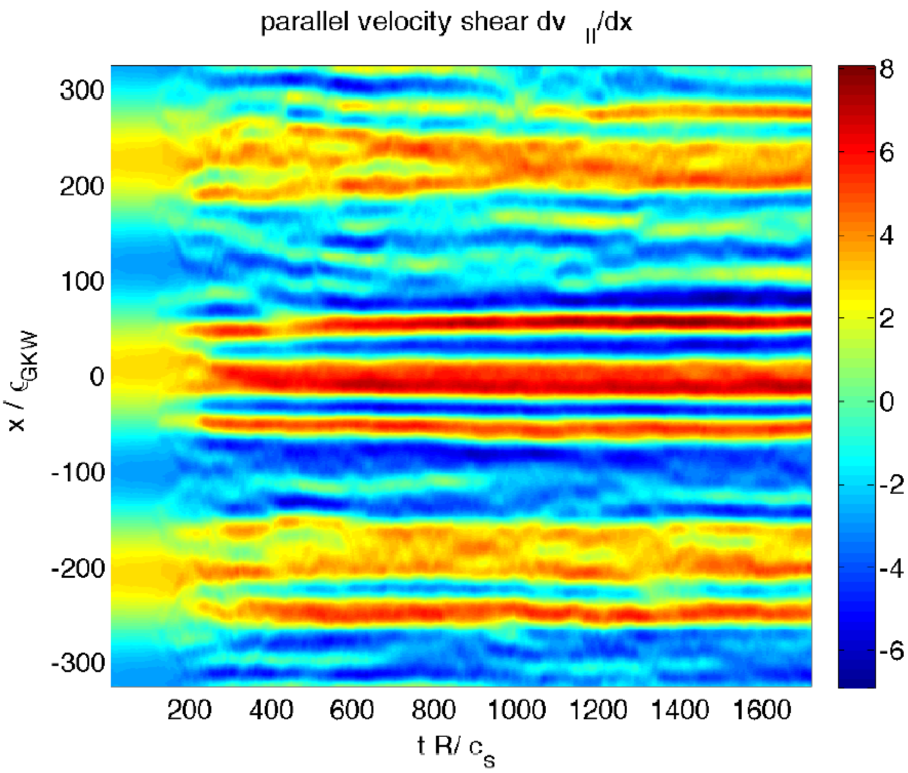

Figure. 1: Toroidal flow shear versus time and radius in a simulation of low-shear tokamak: structures are strongest near the middle of the domain x = 0 where the field line closes on itself after one turn.

(P22) QDB: A new database of plasma chemistries and reactions – concept and exemplar verification

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A key goal of the presented research project PowerBase is to produce new integration schemes which enable the manufacturability of 3D integrated power smart systems with high precision through-silicon via etched features. The necessary high aspect ratio etch is performed via the Bosch process. Investigations in industrial research often use trial and improvement experimental methods. Simulations provide an alternative way to study the influence of external parameters on the final product, whilst also giving insights into the physical processes.

An important part of any plasma simulation is a correct set of both gas phase and surface reactions. Gas phase reactions include processes induced by electron impact and reactions between heavy particles, both electrically charged and neutral. Surface reactions can take place both at the wafer and the reactor walls. All these reactions affect the surface process rates at the wafer either directly or indirectly by changing the chemical composition of the plasma. Unfortunately, reliable data for the complex process gases are scarce, especially for surface and neutral-neutral gas phase reactions.

We seek to remedy this with our chemistry database QuantemolDB, a repository for thousands of plasma related gas phase reactions. The aim is not only to collect the data, but also to verify specific reaction sets against experiments. We present such an effort for chemistries containing for example SF6 and flourocarbons using 2D simulations of industrial reactors used in the PowerBase project. In these simulations, we varied the rate coefficients for neutral-neutral reactions, focussing on reactions which directly impact the densities of reactive species, and the surface reactions at the reactor walls and the wafer. The influence of these variations on the absolute etch/deposition rates as functions of power, pressure, and flow rate, as well as their radial distributions across the wafer is discussed.

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(P23) Understanding detachment onset in MAST-U using SOLPS

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The forthcoming MAST-U tokamak will assess the efficacy of the Super-X divertor (figure 1) in reducing the upstream collisionality at which target detachment (whereby the plasma moves off the target plate, reducing target particle and heat fluxes) occurs. Previous edge plasma simulations by [Havlíčková et al. 2014] using the SOLPS code predict that the Super-X configuration on MAST-U will reduce the required upstream density for detachment onset by a factor ~3 relative to the conventional configuration. However, the details of the physics driving detachment onset in MAST-U SOLPS simulations has not been investigated, until now.

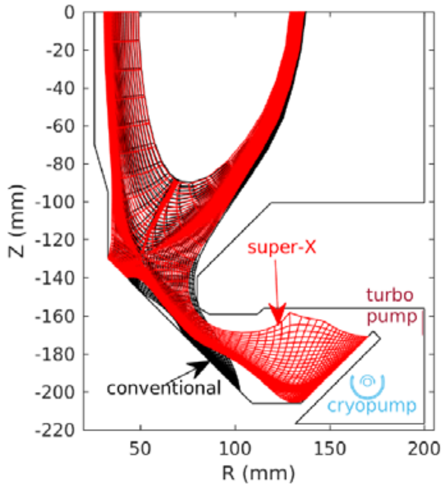

Figure 1: Numerical grid for the MAST-U Super-X and conventional configurations. The Super-X makes use of increased total flux expansion and neutral compression to reduce target heat loads.

Here we assess – by means of particle, pressure and heat balance routines – the physics responsible for a rollover in the target ion flux (a key signature of detachment onset) as the upstream plasma density is increased in SOLPS simulations. These recently-developed postprocessing routines produce similar plots to those shown previously by [Kotov and Reiter 2009]. Importantly, however, they now include the sources from interactions between the plasma and D atoms, D2 molecules and D2 + ions, allowing us to assess the relative importance of various neutral-plasma reactions in dissipating total pressure and heat.

A key result of our work is that elastic collisions with D2 molecules are found to be the primary mechanism by which the total pressure at the divertor entrance is dissipated by neutrals. This dissipation of total pressure, which occurs after the heat has been dissipated (primarily by radiation), is essential for the target ion flux rollover to take place. We use the two-point model formulation equations [Stangeby et al. 2015] to understand how the various heat and pressure loss mechanisms affect a rollover in the target density. We will also assess the role of intrinsic carbon impurities in this process.

[1] Havlíčková E et al. 2014 Contrib. Plasma Phys. 54 449
[2] Kotov V and Reiter D 2009 Plasma Phys. Control. Fusion 51 115002
[3] Stangeby P C et al. 2015 APS 2015 (available at http://starfire.utias.utoronto.ca/divimp/publications/Stangeby_APS_18Nov15.pdf)

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]. To obtain further information on the data and models underlying this paper please contact PublicationsManager@ccfe.ac.uk*. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

(P24) Study of Mg He-like intercombination line in optically thin solid density plasmas

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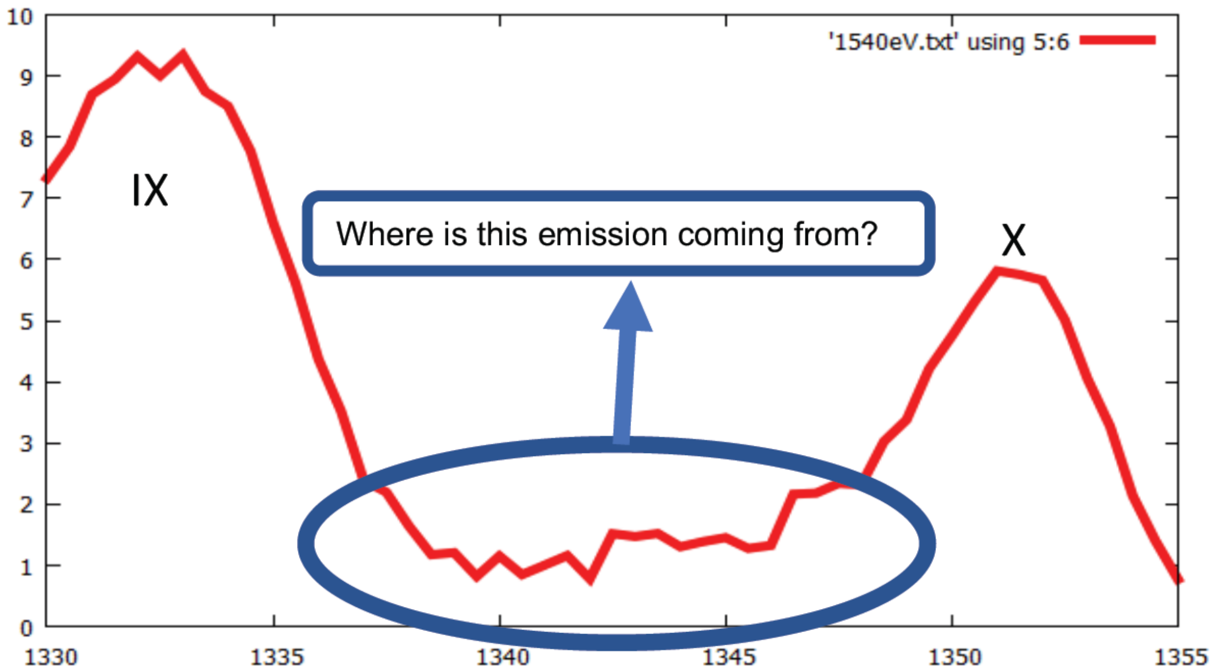
Solid density plasmas can be created in well defined conditions using high power X-ray lasers.[1,2] If the target is thin enough it can be considered 'Optically thin' and so its spectrum can be analyzed without explicitly taking into account any opacity effects.

The simulation code FLYCHK has been used to study the K-shell emission spectrum of a Mg plasma created from a solid density target, in the energy range between the Li-like and He-like resonance lines (1330-1355eV) and the results compared with the experimental data. We show the emission in this energy range is mostly caused by the Li-like satellite states rather than by the He-like intercombination line, and note that FLYCHK cannot reproduce the He-a line-shape.



[1] S.M. Vinko *et al.*, Nature, **482,** 49 (2012)
[2] O. Ciricosta *et al.*, PRL **109,** 065002 (2012)

(P25) Complex phase space representation of wave equations using the Wick symbol calculus

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The phase space representation of a wave equation is an equation of motion for the wave field's distribution in position, wave vector and frequency. It has been applied in condensed matter to describe thermal conduction as the propagation of phonons in a temperature gradient [1], in the statistical description of waves in a turbulent plasma [2, 3], and in the (non-statistical) description of classical wave propagation and geometrical optics [2, 4–6].

Here we derive a complex phase space representation of linear and nonlinear wave equations. The equations are derived using the Wick symbol calculus [7, 8], a mathematical tool which uses Gaussian wavepackets [9, 10] to generalize many convenient properties of the Fourier transform to a local setting. The product formula of the Wick symbol calculus allows us to derive exact equations for the phase space distribution and so to describe phenomena such as harmonic generation resulting from subwavelength variations in the refractive index of the medium. A general purpose asymptotic expansion of the product formula allows us to treat dispersion, refraction, and photon acceleration, as well as nonlinear effects such as ponderomotive forces.

We present the analytical background for the Wick symbol calculus and apply it to derive complex phase space representations of an equation describing wave propagation in a medium and the nonlinear Schrödinger equation. Numerical solution of the nonlinear Schrödinger equation demonstrates the description of solitons as wave phase space vortices driven by a ponderomotive force. The complex wave phase distribution of some incoherent wave fields is shown to be highly structured, in particular containing zeros resulting from dislocations in the phase of the distribution [11].

[1] R. E. Peierls, *Quantum theory of solids*, 23 (Oxford University Press, 1955).
[2] A. A. Galeev and R. Z. Sagdeev, in *Basic Plasma Physics I*, edited by A. A. Galeev and R. N. Sudan (North-Holland, 1983) Chap. 4.2, pp. 367–418.
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(P26) Experimental paths to improve the physics basis for high $q_{||}$ exhaust strategies

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Recent work[1,2] has derived simple models to estimate required fraction of impurities necessary to reach detachment, while complementary modelling has estimated the window in multiple plasma parameters to maintain the detachment front between the target and the x-point[3] . These can be used to examine the existence and controllability of fusion reactor operating points with a detached divertor, enabling rough device optimization in a wide configuration space, including toroidal and poloidal magnetic field, device size, aspect ratio and divertor configuration. While limited in accuracy compared to full-scale, 2D fluid simulations, such simple models enable critical parameters to be identified for further study and validation. These models are reviewed along with implications for how they can be strengthened to improve the physics basis for reactor-relevant tokamak exhaust strategies. Achieving detachment at high $q_{||}$ (> 1 GW/m2) depends strongly on the non-equilibrium ionization distribution of extrinsically seeded impurities which enhances their radiating efficiency. Beneficial advancements in radiated power measurements are discussed along with improvements in utilizing/deploying impurity spectroscopy to benchmark model predictions. Such measurements are also shown to be important in accurately measuring PSOL, the power crossing the separatrix, which has been shown to be an important control parameter for the location of the detachment front. Techniques for validating the scaling of impurity fractions1,2 using existing experiments are outlined. Limitations with the simple models are also summarized along with plans for improvement.

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[3] B. Lipschultz, F. I. Parra and I.H. Hutchinson, Nucl. Fusion. **56** 056007 (2016)

(P27) Modelling ion cyclotron emission from beam-injected ions in the Large Helical Device

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[1]Warwick University, UK, [2] Culham Science Centre, UK, [3]National Institute for Fusion Science, Japan, [4]Kyushu University, Japan, [5]Pohang University of Science and Technology, Korea

Suprathermal ion cyclotron emission (ICE) is detected from all large tokamak and stellarator plasmas. Its frequency spectrum has narrow peaks at sequential cyclotron harmonics of the energetic ions at the outer mid-plane edge of the plasma. ICE was the first collective radiative instability driven by confined fusion-born ions observed in deuterium-tritium plasmas in JET and TFTR, and the magneto-acoustic cyclotron instability (MCI) is the most likely emission mechanism. ICE is proposed as a diagnostic for confined energetic ions in ITER (R O Dendy and K G McClements, Plasma Phys. Control. Fusion 57 044002 (2015)). Contemporary ICE measurements are now taken from the LHD stellarator at sampling rates far higher than for first generation ICE (K Saito, H Kasahara et al. Fus. Eng. Des. 84 1676 (2008)). A corresponding advanced modelling capability for the MCI emission mechanism has been developed using a 1D3V PIC-Hybrid code (L Carbajal et al., Phys. Plasmas 21 012106 (2014)) which simulates the self-consistent full kinetic dynamics of energetic and thermal ions and electro-magnetic fields with massless neutralising electron fluid. We focus on MCI regimes for plasma conditions appropriate to ICE measurements associated with neutral beam injected ions in LHD, from sub-Alfvénic through to super-Alfvénic scenarios. For the first time, we are able to follow a variety of Alfvénic behaviours, and particularly the sub-Alfvénic MCI into the nonlinear saturated regime, thereby strengthening the link to measured LHD ICE spectra.

This work was supported in part by the RCUK Energy Programme [grant number EP/I501045], NIFS budgets ULHH029, S06ULRR504, NRF Korea grant no. 2014M1A7A1A03029881 and Euratom.

(P28) Design, operation and measurement of a penning discharge

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To enable experiments investigating the non-linear saturation of beam plasma interactions, and hence to benchmark 2D PiC simulations of these processes, it is desired to form a plasma column, exceeding 1m in length, in a cylindrical waveguide with a diameter ~5cm. This tightly constrains the space for the plasma source. A Penning apparatus was designed and constructed to address this requirement. Such a discharge operates inside a cylindrical anode linked by a uniform magnetic field. The magnetic field prevents the electrons reaching the anode whilst the ends of the anode cylinder are closed by cathode electrodes, providing extended path lengths for the electrons in the apparatus and allowing the discharge to be maintained at low pressures ($\sim 10^{-3}$mB). When a bias of a few kV was applied to the anode, the discharge ignites, establishing the plasma column. Up to a few 10's mA were provided to the discharge through a current limiting resistor, by a current regulating switched mode power supply in either a partially-modulating or continuous mode.

Langmuir probe measurements are problematic for this configuration, due to the fact that any electrostatic perturbation of the discharge symmetry results in a very strong modification in the discharge behaviour. Moreover the strong magnetic field makes it difficult to interpret the IV characteristic of the probe. Instead the plasma density at the end of the column was inferred by observing the spectrum of plasma oscillations using a spectrum analyser connected to a small electric dipole antenna polarised along the bias magnetic field. These indicated a plasma density at the end of the trap which varied with discharge current. With a 20mA current the plasma density at the end of the trap was estimated to be $1\text{x}10^{16}\text{m}^{-3}$.

To support this estimate of the plasma density at the edge of the plasma, and to determine the density averaged along the length of the plasma column, an interferometric technique was implemented using a chirping microwave signal around 9.5GHz and simultaneously measuring the phase shifts in the R and L polarised modes using a vector network analyser over a wide range of currents. At 20mA the average density was estimated to be approaching $\sim 4\text{x}10^{16}\text{m}^{-3}$.

The paper will describe the design and operation of the discharge and the diagnostics used to estimate the plasma density.

(P29) Adiabaticity breaking in direct laser acceleration of electrons

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For many years there has been an interest in "Direct Laser Acceleration" of electrons in ultra-intense laser-plasma interactions. By this we mean electron acceleration that occurs when a laser pulse interacts with an electron in the presence of an electromagnetic field that is self consistently generated due to the laser pulse disturbing the plasma. An example of such a field would be the strong quasi-electrostatic field created as a laser pulse expels electrons to produce an "ion channel". As the electron energy accessible by DLA scales as a_0^2 , there is considerable interest in the extent to which DLA accounts for the highly energetic component of the fast electron population in the pre-plasma that is always present in laser-solid interactions.

In order to fully understand the role that DLA plays in laser-plasma interactions we need to understand all the facets facets of it as an acceleration mechanism. The energy scaling has received a lot of attention, as has the various fiel d configurations under which it can occur. What has not received so much attention is how adiabaticity breaking can occur, an in particular, how it can occur so as to ensure a large irreversible energy gain.

Here we present some of our recent insights into this problem by considering the interaction of a laser pulse with an electron that is already undergoing a violent relativistic oscillation in an ion channel. We show that adiabaticity bre aking can be seen to occur very straighforwardly and obviously in this scenario, and that this may be a conceptual t emplate for a more general view of adiabaticity breaking in DLA.

(P30) Optimisation of plasma amplifiers

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Raman amplification in a plasma offers a promising way to compress laser pulses without the limitations of solid state optics. Despite promising analytical and computational results suggesting efficiencies over 50% and compression ratios over 10,000, experimental progress has been limited. A raft of 1,200 Particle-in-Cell simulations is presented, identifying the optimal parameter space regions. Many previous experiments have used parameters where kinetic effects in the plasma wave severely hamper energy transfer. A further investigation finds that short, powerful seed pulses work best.

(P31) Spatial distribution of plasma parameters in a dc-magnetron discharge and influence of the discharge power

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[1]Montanuniversität Leoben, Austria, [2]University of West Bohemia, Czech Republic, [3]MIBA High Tech Coatings, Austria

Nowadays, magnetron sputtering is one of the most prevalent plasma-assisted thin film deposition techniques in academia and industry. Due to the non-equilibrium process conditions occurring in such a magnetron discharge, the synthesis of films with extraordinary properties and microstructures is possible. The key to comprehending this deposition process lies in a thorough understanding of the discharge and the effects present. Although these magnetron sputtering discharges have been extensively studied since their advent in the early seventies, open questions on how the plasma parameters influence the thin film deposition still remain. Therefore, we have investigated the spatial distribution of the electron energy probability function (EEPF) and other plasma parameters in the central part of a planar magnetron sputtering discharge by the use of an electric probe. Measurements were performed at several axial and radial distances from a planar 100 mm diameter titanium target in order to obtain a spatial characterization of the discharge. Based on the position within the discharge we found that the central part of the magnetron plasma can be divided into three zones, each possessing a particular shape of the EEPF (see Figure). While above the target centre (zone 1) a Druyvesteyn-like probability function prevailed (denoted by D), it changed gradually with increasing radius via a bi-Maxwellian (zone 2, marked by b-M) to a Maxwellian distribution function at the edge of the discharge (zone 3, denoted by M). A high electron density is present in zone 1 with electrons having sufficient energy to take part in inelastic scattering processes. Contrarily, only low energetic, thermalized electrons are present in zone 3 which can be described by a Maxwellian probability function. The investigation of the EEPF also allowed conclusions on how the electrons are moving within the discharge. In a second step, the discharge power was varied within one order of magnitude between 300 and 3200 W to assess the influence of the discharge current on the spatial distribution of the plasma characteristics. An increase of the discharge power led to a linear promotion of the plasma density in all zones, while the influence on the energy of the electrons and the plasma potential was mainly confined to zone 1. The floating potential and the EEPF remained unaltered at power levels of 800 W and above. At a lower power, a strongly non-linear behaviour was observed. Hence it can be concluded that a homogenous plasma is only established once a critical power is exceeded.

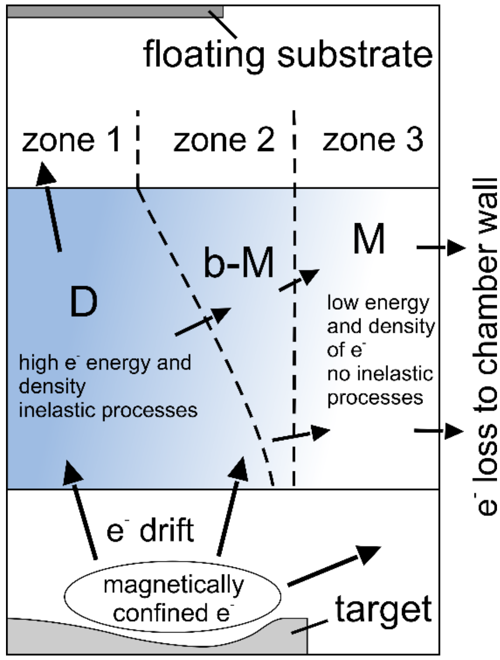

Figure 1: Zonal division of the discharge proposed for the central region of a magnetron discharge. The arrows indicate the motion of the electrons.

(P32) Attosecond absorption in two dimensions

A Savin[1], A Ross[1], M Serzans[1], R Trines[2], N Ratan[1], R Scott[2], B Spiers[1], R Bingham[2] and P Norreys[1]

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Two dimensional particle-in-cell simulations of the interaction between intense laser pulses and over-dense plasmas are shown to display evidence of the Zero Vector Potential (ZVP) absorption mechanism previously presented in one dimension by *Baeva et al.* [*Physics of Plasmas*, **18**, 056702, (2011)]. The electrons in the plasma absorb energy from the incident radiation over atto-second timescales forming coherent bunches of fast electrons that co-propagate with the zeroes in the vector potential of the laser field. Measures of the dependence of the fast electrons' energy on both laser field intensity and plasma density are presented and compared with the predictions of the one dimensional simulations and theory given by *Baeva et al.* The formation of the coherent electron bunches also has consequences for the efficiency of High Harmonic Generation (HHG). Simulation results showing that the ZVP absorption mechanism improves the efficiency of HHG are presented.

(P33) Influence of plasma backgrounds including neutrals on SOL filaments using 3D simulations

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Filaments are field aligned density and temperature perturbations, which in tokamaks, can carry a significant amount of particles and heat from the last closed flux surface to the far scrape-off layer (SOL) [1]. In order to design next generation machines, understanding this non diffusive transport mechanism is beneficial to predict wall fluxes, as not only tritium retention and dust production are major issues, but also thermal fluxes [2].

We have carried out non-linear, three-dimensional simulations, including neutral-plasma interactions, using the STORM [3] module for BOUT++ [4]. The heat and particle influx is varied, generating self-consistent 1D profiles that reproduce both low and high recycling regimes. Filaments where seeded on the backgrounds, and the resulting filament motion was studied. Additional to density and temperature scans, a scan in filament size was performed. This increases the understanding of filaments and their scaling with plasma background, in the experimentally relevant regime.

These filaments' radial velocity showed a linear increase in mid-plane background temperature T, lying between the $T^{\frac{1}{2}}$ scaling for inertial limited and the $T^{\frac{3}{2}}$ scaling for sheath limited filaments [5]. The suitability of the target temperature as well as the average temperature instead of the upstream temperature as scaling quantities have been studied. With the exception of low temperatures, an increased upstream density results in a decreased radial velocity.

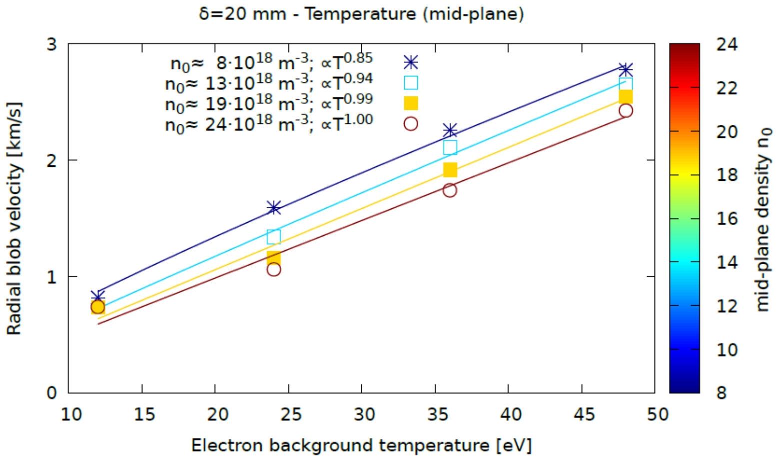

Figure 1: Maxima of radial filament velocities in dependency of background density and temperature.

[1] D. D'Ippolito, et al., Physics of Plasmas (1994-present), vol. 18, no. 6, p. 060501, 2011.
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[3] L. Easy, et al., Physics of Plasmas, vol. 21, no. 12, 2014.
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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]. To obtain further information on the data and models underlying this paper please contact PublicationsManager@ccfe.ac.uk*. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

(P34) Modelling heating and ablation of dust in a plasma

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Plasmas containing nanometre to micrometre sized particulate matter are common throughout space plasmas[1] and are particularly important for plasma etching in the micro-chip industry as well as for stable plasma confinement in Tokamaks[2,3]. Contamination of plasmas in tokamaks is particularly important as if these particles reach the hot core they rapidly evaporate and leave impurities in the plasma, reducing the fusion yield by radiating heat[4].

The distribution of dust contamination is directly related to the heat load experienced and the mechanisms of heat lost whilst in a particular plasma region. The relative influence of several heat energy exchange mechanisms including secondary electron emission, thermionic emission, bombardment by plasma species, neutral recombination, evaporative and radiative cooling on dust heating is simulated. These simulations estimated the ablation of spherical dust particles of different elemental compositions relevant to Dust generated from plasma facing components in a Tokamak. The temperature dependence of intrinsic properties and the particle size were investigated in detail to understand their effects on the ablation rate. Through this analysis, the regions of a tokamak where trapped dust is likely to produce higher levels of impurity are identified.

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(P35) Production of low energy spread accelerated electrons at the AWAKE experiment: LWFA as a potential solution

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The AWAKE experiment [1] is a proof-of-principle plasma wakefield accelerator at CERN that has recently been commissioned and begun its first data taking period. In the experiment a beam of high energy protons drive large amplitude electrostatic waves in a plasma, which can be used to accelerate electrons injected into the accelerating phase of these wakefields. AWAKE is the world's first plasma wakefield accelerator to use a proton driver, and this unique scheme will help the experiment to directly inform the design of future plasma based colliders such as the proposed VHeP [2].

The first phase of the experiment will demonstrate microbunching of an SPS proton bunch via the Self Modulation Instability (SMI), necessary for the proton bunch to resonantly drive wakefields in the plasma. Initial experiments have observed the onset of this instability (figure 1), which until now has only been seen in simulation. The next phase of the experiment will characterise the strength of the wakefields generated by a modulated proton bunch, and aims to bring 15 MeV injected electrons from an RF electron gun and booster structure up to 1 GeV. This will conclude the first experimental run at AWAKE.

A challenge for the second run of the experiment, beginning in 2021, is to accelerate injected electrons while maintaining the beam quality. This places specific requirements on the electron injector that are difficult to achieve with the current RF based accelerator, given the space available to the beam line.

For example, a low energy spread of the electron bunch is preserved if the accelerating field is uniform across it. To remain entirely in the accelerating phase of the wakefield injected electron bunches must have short durations of between 166 fs and 333 fs. Laser-driven plasma wakefield accelerators (LWFA) are capable of producing bunch durations on the order of a few femtoseconds while fulfilling the kA beam current requirements for loading the wakefields. Consequently a LWFA has been proposed as the upgraded electron source at AWAKE [3]. Using numerical simulations I will study different injection scenarios and LWFA configurations to design the most suitable injection scheme for the requirements of the experiment. I will discuss the considerations for installing such a novel accelerator in a practical setting and present the initial results from my research.

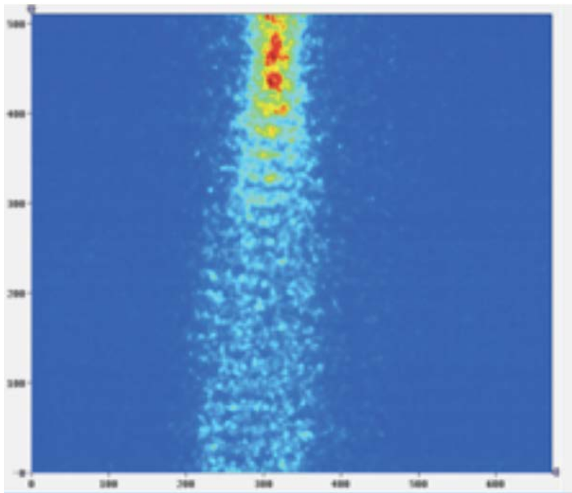

Figure 1: Initial experiment results from the AWAKE experiment showing a proton beam modulated on the order of a plasma wavelength. http://awake.web.cern.ch/awake/

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[2] A. Caldwell and M. Wing, 2015, 'VHEeP: A very high energy electron–proton collider based on proton-driven plasma wakefield acceleration', PoS, XXIII International Workshop on Deep-Inelastic Scattering

[3] P. Muggli et al., 2014, 'Injection of a LWFA Electron Bunch in a PWFA Driven by a Selfmodulated Proton Bunch', IPAC14

(P36) Resistive wall modes stabilization by feedback control in HL-2M tokamak

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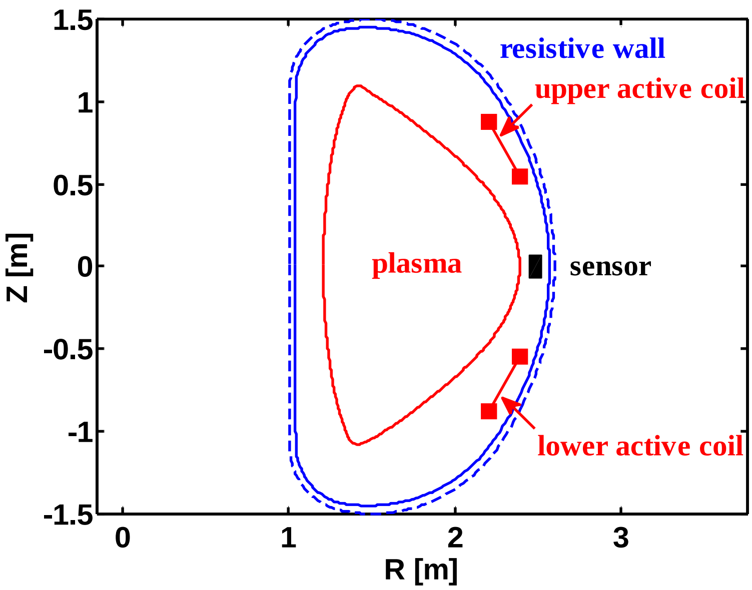
HL-2M, currently under construction at Southwestern Institute of Physics, China, is an upgrade device of the HL-2A tokamak. The major plasma radius and minor radius are 1.78 m and 0.65 m respectively. HL-2M will be installed with an ITER-like double vacuum vessel and will be able to operate with a double or single null configuration. One of the major objectives of HL-2M is to create high temperature, high density plasmas for a significant time. Resistive wall modes (RWMs) are instabilities that would be stable with a perfectly conducting wall but with a resistive wall grow on a timescale characteristic of the instability diffusing into the wall. They are one of the biggest obstacles to the achievement of such advanced tokamak plasmas. Therefore, understanding and controlling this dangerous macroscopic instability is very important for HL-2M tokamak. There are two sets of resonant magnetic perturbation (RMP) coils around the poloidal section which can also be used to control RWMs. It is found that the optimized position and width of the feedback coils can make stabilization of the RWMs more robust. In addition, optimization of the phase difference of the feedback gains between the upper and lower active coils can lead to a better suppression of the RWMs with either proportional (P) controller or proportional and derivative (PD) controller. This work is supported by the Royal Society K. C. Wong International Fellowship and by the National Natural Science Foundation of China with Grant No. 11605046.



The plasma boundary and the HL-2M double wall shapes

(P37) Simulations of edge localised modes

S Smith[1,2], S Pamela[1], H Wilson[2], B Dudson[2] and G Huijsmans[3,4]

[1]CCFE, Culham Science Centre, UK, [2]University of York, UK, [3]CEA, IRFM, France, [4]Eindhoven University of Technology, The Netherlands

ITER, a future tokamak device, will be required to operate in high confinement mode (Hmode) to obtain a ratio of fusion power to heating power of Q=10. Edge localised modes (ELMs) are events which occur during H-mode triggered by steep pressure and current gradients. In experimental observations ELMs appear as filamentary structures, which expel heat and particles onto plasma facing surfaces. The peak heat fluxes generated from type-I ELMs may damage the tungsten divertor plates in ITER [1]. Gaining an improved understanding of ELMs is important [2] for quantifying and minimising the predicted damage. Whilst there is a good understanding of linear MHD and the peeling-ballooning model, a full explanation of nonlinear ELM phenomena is unclear. Codes are being developed to observe the nonlinear evolution of ELMs, with the aim to make clear comparisons to experimental observations enabling the predictions of ELM size, frequency and heat flux. Progress using the two nonlinear MHD codes BOUT++ [3] and JOREK [4] for simulations of ELMs will be discussed; for example to observe the effects of including diamagnetic drift within simulations, as well as comparisons with linear ideal MHD simulations from ELITE [5]. A circular cross-section test case will be used as a benchmark leading to simulations of ELMs on machines such as JET, MAST, MAST-U and NSTX.

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(P38) Plasma application for bio-oils chemical detoxification: from harmful to useful

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Plasma technology has been widely used for many industrial applications, including materials processing and liquid treatment. A relatively new application field for plasma driven processes is the bio/food sector. Bio-fuels in particular could be produced from different sources including crops such as wheat, corn, soybean and *Jatropha curcas Linn*. At the same time these crops are also edible which results in the well-known "food vs fuel" conflict.

Low temperature plasma based technology is a possible option to rapidly alter the output of bio-stock processing to fuel or food according to market demand. This technology could increase overall efficiency of bio-stock utilisation by reducing wastage.

In this work, *Jatropha curcas Linnstock* was targeted as it can potentially be used as fuel and food source. However, its utilisation as a food source is limited by the presence of natural carcinogenic compounds, Phorbol Esters (PE). PE are known by their stability at high temperatures, up to 160 °C, hence thermal treatment for detoxification is not preferable. Moreover, chemical detoxification treatment is also not beneficial as it will increase production cost, as a neutralisation process is required before the detoxified product is consumed.

The application of plasma to detoxify PE content by attacking its chemical bonds with ozone molecules was investigated. It was shown, using synthetic PE samples, that significant reduction of PE can be achieved in less than 30 minutes with an ozone plasma driven process. It is expected that this result will contribute to the wider application of plasma technology, particularly in the food sector.

Keywords: carcinogenic, food supply, ozone, plasma application.

(P39) Investigation of efficiency exciplex DBD lamp excited by electrical generators of various types

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Excimer and exciplex lamps are gas discharge spontaneous UV or VUV sources [1]. The virtues of such lamps from the standpoint of their application are high photon energy (3.5 – 10 eV), a narrow emission band, and the possibility of scaling and selecting an arbitrary geometry of the emitting surface [2]. Three different electrical generators have been designed and used to supply an exciplex DBD lamp in order to elucidate the influence of each one of these methods over the system performance; the first method consists on supplying the lamp with short bipolar voltage pulses; the second and third methods are based on semi-resonant converters were current pulses, of controlled duration and magnitude, are injected into the lamp. For each one of the generators, measurements of the lamp and supply efficiency, are performed and analyzed, at different levels of power (up to 130 W) and operating frequencies (60-90 kHz). From the experimental results, the pulsed voltage mode approach has allowed to obtain the highest lamp efficiency (7%), yet the maximum supply efficiency is offered by the resonant mode supplies. On the basis of the lamp and the supply efficiencies, the whole system performance is analyzed.

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(P40) Hybrid kinetic-hydrodynamic model of high-pressure gas discharges under strong overvoltages

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As is known the direct solution of Boltzmann kinetic equation is of great interest for theoretical investigation of various gas discharges. Such approach gives the most important information about the discharge and its evolution by providing electron and ion distribution functions at given time point. The complete numerical solution of Boltzmann equations for multi-component gas discharge plasma is quite challenging even for one-dimensional problems due to high computational costs. That is the reason why gas discharges are usually described in terms of simplified moment models with drift-diffusion approximation or particle-in-cell approaches with Monte-Carlo collisions. Main disadvantage of these techniques is that the description of fast particles (e.g. runaway electrons) is considerably difficult, especially for high pressures and strong overvoltages.

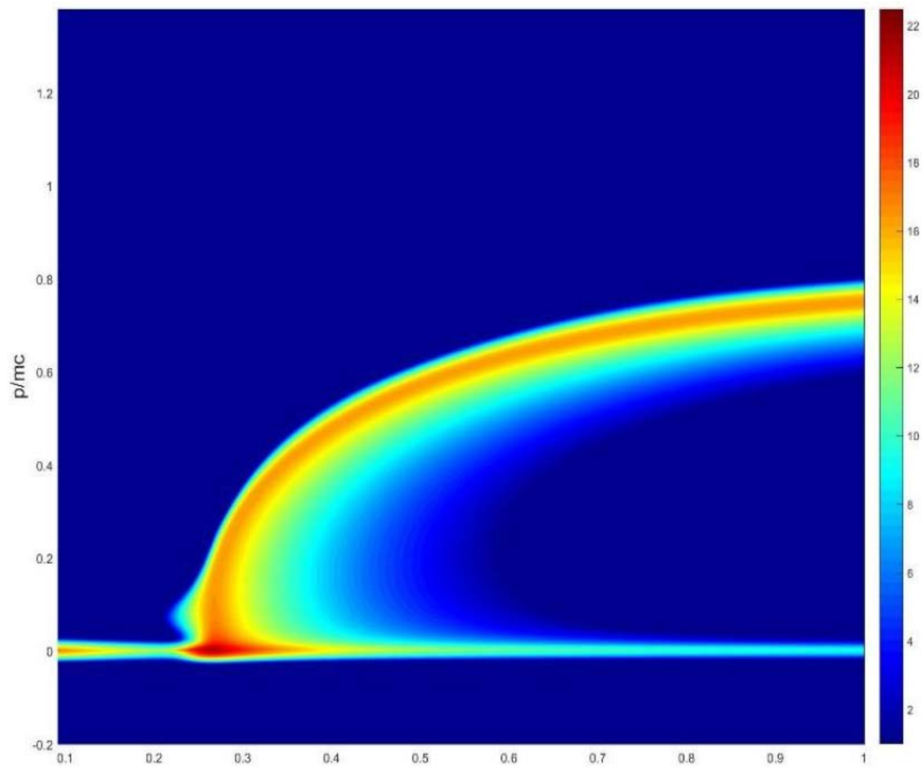

Figure 1: Runaway electrons distribution function in logarithmic scale for the 1D-axisymmetric nanosecond discharge configuration

Here we present novel hybrid theoretical approach for the discharge simulation in dense gases. Within the framework of hybrid mathematical model, plasma hydrodynamics and kinetics are both used describing the dynamics of different components of low-temperature discharge plasma. As an example, we apply the proposed approach to one-dimensional coaxial relativistic gas diode. Namely, it was shown that electrons power spectrum contains a group of electrons with the so-called "anomalous" energies (above the maximal applied voltage value) that were not correctly predicted before, but exists it various experiments.

(P41) Observation of anomalous inward particle pinch in ADITYA tokamak

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Gas fueling and its cross field transport in tokamaks is an indispensable regime of research in Fusion research. Fusion scientists across the globe aim to achieve faster and deeper fuel penetration enhance and maintain high density plasma, which is essential to realize the goal of Fusion reactor. ADITYA tokamak is medium sized ohmically heated air-core tokamak with a circular poloidal graphite limiter, a major radius (R) of 75 cm and a minor radius (a) of 25 cm. In ADITYA hydrogen gas fueling is done by applying electrical pulses of suitable magnitude and time duration to a piezo valve placed through one of the bottom ports. Multiple hydrogen gas puffs have been used to enhance and maintain the electron density during plasma flat top, with a precise control. In a number of high quality discharges, peaks in Hα emission as well as in the temporal evolution of Soft X-ray (SXR) emission and chord averaged electron density, coinciding with each gas puff pulse has been observed, suggesting presence of inward particle pinch.. These peaks observed in Hα, SXR and plasma density occur with a time lag to each other. As the Hα emission comes from the edge region and the SXR emission comes from the core region, the difference in their peaking time after each gas pulse gives the time taken by the fuelled gas to get ionized and reach plasma core from edge. This time difference has been used to characterize pinch transport of the fuelled hydrogen in ADITYA tokamak, which turned out be several times faster than that predicted by existing theories. In this paper the fast pinch transport of fuelled Hydrogen observed in ADITYA has been discussed and compared with the existing theories and observations on fuel transport in tokamaks.

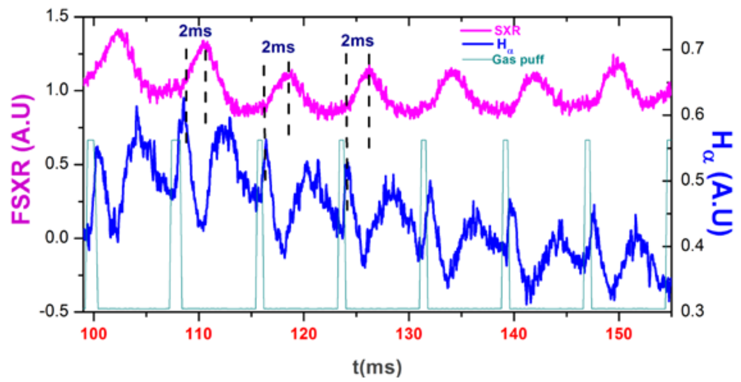

Figure 1: Plot showing multiple gas puffs, temporal profile of Hα with peaks corresponding to each gas pulse, and peaks in central Soft X-ray profile corresponding to gas puff.

(P42) MHD modeling of the capillary discharge plasma and the future prospects

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Raising problems: Rapid development of high energy technologies involve investigation of non-LTE high density plasmas, which then is a subject of growing interest among scholars and researchers dealing with such topics. In this sense, our research group constructed a capillary discharge X-ray laser operating with a high peak electric current pulse. For the further development, we had to understand the physical processes of the plasma produced inside the capillary, while this pulse evolves. In terms of computed results, this problem forces us to choose an appropriate model. The only model that met our requirements is the magnetohydrodynamic (MHD) model, which treats plasma as a charged fluid. Although numerous model can be found in literature [1, 2, 3] and online free source codes can be used, but part of them were developed for ordinary plasmas, others for fusions and astrophysical problems. In our case, the produced plasma shrinks due to Lorenz-force arising from magnetic field induced by electric current flowing through capillary. This phenomenon is called Z-pinch, since electric current flows along capillary z-axis.

Our philosophy was to start the model construction with an as simple as possible model, and then, in accordance with our experiences, to increase its degree of freedom step by step. As a result, first we derived the so-called simplified MHD model [4], where we assumed uniform spacial distribution of main plasma variables (particle number density, current density and temperature). Due to geometry of the capillary, it was obvious to choose cylindrical coordinate system, where we used the Lagrangian specification of the flow field[1]. Thus, the Z-pinch plasma dynamics simplified to an axially symmetric problem, where a ”plasma cylinder” shrinks and expands in time.

Future prospects: Continuing our philosophy, we increased the system’s degree of freedom by involving radial dependency. Leaving the previously chosen coordinate system unchanged, we switched to the Eulerian specification of the flow field. According to our experimental observations, the plasma compression proceeds homogeneously and isotropically, until it reaches its peak, so that, it was a good approach to suppose that the main plasma variables remains uniform to the all of space directions except radial. Preliminary results showed, that during the discharge there are time intervals, when the plasma column shows waveguide properties, which can be used in stabilization of EM pulse propagating through the plasma.

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(P43) Exact Vlasov-Maxwell equilibria for asymmetric current sheets

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The NASA Magnetospheric Multiscale mission has made in-situ diffusion region measurements of asymmetric magnetic reconnection for the first time[1] . In order to compare to the data obtained from kinetic-scale observations, it would be useful to have initial conditions for particle-in-cell simulations that reproduce the equilibrium physics of magnetopause current sheets as accurately as possible, i.e. self-consistent Vlasov-Maxwell equilibria that model the magnetosheath-magnetosphere asymmetries in pressure and magnetic field strength. We present new and exact equilibrium solutions of the VlasovMaxwell system that are self-consistent with one-dimensional and asymmetric Harris-type current sheets, with a constant guide field. The distribution functions are found using Jeans' theorem and can be represented as a combination of three shifted Maxwellian distribution functions. This equilibrium describes a more general magnetic field configuration than previously known exact solutions[2] , and has different bulk flow properties.

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(P44) X-ray emission from petawatt laser driven nanostructured Ni targets

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Nanostructured samples irradiated by intense short pulse lasers present new opportunities to create ultra-high energy density systems near solid density. These samples have also been shown to enhance X-ray emission yields by over an order of magnitude in certain conditions, making them of interest to X-ray backlighting and radiography applications in laser plasma experiments. Here we present details of the spectroscopic signature of Ni nanowire samples irradiated by the Orion laser at AWE. These results provide first estimates of the conditions achievable at relativistic intensities, and will guide future research investigating the electronic structure of heated nanowire samples at the LCLS FEL and the Orion laser.

(P45) Time integrated optical emission studies of laser produced lead plasma: Measurements of transition probabilities of the 6p7s → $6p^2$ transition array

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We present new data on the optical emission spectra of the laser produced lead plasma using a pulsed Nd:YAG laser at 1064 nm (pulse energy 400 mJ, pulse width 5 ns, 10 Hz repetition rate) in conjunction with a set of miniature spectrometers covering the spectral range from 200 nm to 720 nm. Well resolved structure due to the 6p7s → $6p^2$ transition array of neutral lead and a few multiplets of singly ionized lead have been observed. The electron temperatures have been calculated in the range (9000 - 10800) ± 500 K using four methods; two line ratio, Boltzmann plot, Saha-Boltzmann plot and Morrata method whereas, the electron number densities have been determined in the range (2.0 – 8.0) ± 0.6 $\times 10^{16}$ cm^{-3} using the Stark broadened line profiles of neutral lead lines, singly ionized lead lines and hydrogen Hα-line. Full width at half maximum (FWHM) of a number of neutral and singly ionized lead lines have been extracted by the Lorentzian fit to the experimentally observed line profiles. Furthermore, branching fractions have been deduced for eleven lines of the 6p7s → $6p^2$ transition array in lead whereas the absolute values of the transition probabilities have been calculated by combining the experimental branching fractions with the life times of the excited levels The new results are compared with the existing data showing a good agreement.

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