42nd IOP Plasma Physics Conference

30 March 2015 – 2 April 2015
Kents Hill Park Training and Conference Centre, Milton Keynes, UK

http://plasma15.iopconfs.org
Programme

Monday 30 March

11:00  Registration and refreshments
       Kent's Hill Park Training and Conference Centre

12:30  Lunch
       Rooms 129/130

13:30  Welcome
       Nick Braithwaite, Open University, UK (Conference Chair)
       Rooms 121/121a/123

13:40  (Invited) Electron transport and ion acceleration in intense laser driven opaque gas targets
       Nicolas Dover, Imperial College, UK

14:20  Hollow ion spectral formation at ultra-high laser intensities
       Nigel Woolsey, University of York, UK

14:40  A 200GHz backward wave oscillator based on a pseudospark electron-beam
       Adrian Cross, University of Strathclyde, UK

15:00  Electron acceleration by magnetic collapse during decoupling
       Euan Bennet, University of Glasgow, UK

15:20  Refreshments

15:40  (Culham Thesis Prize) Role of low-temperature electrical resistivity in defining fast electron beam transport in relativistic laser-solid interactions
       David MacLellan, University of Strathclyde, UK

16:20  Poster Introduction
       Room 129/130

17:00  Posters, exhibition and reception
       Room 129/130

19:00  Close of day - Dinner
       Restaurant
Tuesday 31 March

08:30  Refreshments

09:00  (Invited) Rumours of the death of discharge lighting are greatly exaggerated
Graeme Lister, Ceravision Limited, UK

09:40  Particle trajectories in a solitary hydromagnetic wave; a demonstration of the mechanism of the (jxB) force in a collisionless plasma
John Allen, University of Oxford, UK

10:00  3D modelling of microwave propagation through turbulent density profiles in fusion relevant plasmas
Matthew Thomas, University of York, UK

10:20  Refreshments

10:40  (Invited) Pulsed laser deposition of metal oxide thin films
Erik Wagenaars, University of York, UK

11:20  Brownian motion of dust grains in partially-ionised plasma
Euan Bennet, University of Glasgow, UK

11:40  Amplification and generation of ultra-intense twisted laser pulses via stimulated Raman scattering
Raoul Trines, STFC Rutherford Appleton Laboratory, UK

12:00  X-point modelling using non-field-aligned coordinate systems in BOUT++
Brendan Shanahan, University of York, UK

12:20  Lunch

13:20  Transfer to Berrill Lecture Theatre (Open University)

14:00  (Invited) Hydrodynamic turbulence in laboratory and astrophysical plasmas
Gianluca Gregori, University of Oxford, UK

14:40  Aerosol droplet charge control via rapid plasma transport
Colin Kelsey, University of Ulster, UK

15:00  The dependence of tungsten fuzz growth on He ion fluence in the range \(10^{24} - 10^{28}\) m\(^2\)
Thomas Petty, University of Liverpool, UK

15:20  (Invited) International Year of Light 1: Design and plasma process challenges for ultra high speed (100Gbps+), photonic integrated circuits
Andy Carter, Oclaro, UK

15:50  Refreshments - delegates can take this opportunity to walk from Berrill to the Robert Hooke foyer to hear some information on Rosetta

16:10  (Invited) International Year of Light 2: Laser absorption spectroscopy as a sensitive optical diagnostic in low temperature plasmas
Grant Ritchie, University of Oxford, UK
16:40  Vorticity deposition and structure generation in colliding blast wave experiments
Alex Robinson, STFC Rutherford Appleton Laboratory, UK

17:00  End of session - delegates can take this opportunity to walk from Berrill to the Robert Hooke foyer
to hear some information on Rosetta

17:40  International Year of Light & Plasma Physics Group Outreach Session
Non-Visual Impacts of Light
John Stocks, Ceravision, UK

Cosmic light: the story of everything
Lucia Marchetti, Open University, UK

How to slow atoms with light, and how to slow light with atoms
Calum MacCormick, Open University, UK
Wednesday 1 April

08:30 Refreshments

09:00 *(Invited) Plasma waves in the radiation belts of Earth and Jupiter*
Richard Horne, British Antarctic Survey, UK

09:40 Laser diffraction effects on the Rayleigh-Taylor instability of radiation pressure accelerated thin foils
Bengt Eliasson, Strathclyde University, UK

10:00 Simulating DC magnetron sputtering devices with Opera-3d
Derek Monahan, Cobham Technical Services, UK

10:20 Refreshments

10:40 *(Invited) Plasma-surface interactions under extreme condition*
Thomas Morgan, Dutch Institute for Fundamental Energy Research, Netherlands

11:20 Characterisation of a radio frequency excited plasma cathode for electron-beam gun power optimisation
Sofia Del Pozo, Brunel University & TWI, UK

11:40 A convergent fast electron beam for laser-fusion applications
Robbie Scott, STFC Central Laser Facility, UK

12:00 Plasma Physics Group AGM

12:40 Lunch

13:40 *(Invited) Pedestal confinement and stability of JET-ILW ELMy H-modes*
Costanza Maggi, Culham Science Centre, UK

14:20 Ionization in an MHD-Gas interaction simulation
Alasdair Wilson, University of Glasgow, UK

14:40 Poster Introduction

15:20 Refreshments

15:40 Poster Session

16:40 Close of day
Thursday 2 April

08:30 Refreshments

09:00 (Invited) Large-scale astrophysical and laboratory plasmas as testbeds for exploring fundamental multiscale non-linear processes
Sandra Chapman, University of Warwick, UK

09:40 Understanding the exhaust of power at the edge of MAST in preparation for future tokamaks, including MAST-U with its closed divertor
Sarah Elmore, Culham Science Centre, UK

10:00 TBA

10:20 Refreshments

10:40 (Invited) Electron kinetics inferred from observations of microwave bursts during edge localised modes in the Mega-Amp Spherical Tokamak
Simon Freethy, CCFE, UK

11:20 Three dimensional magnetohydrodynamic simulation of lineary polarised Alfvén wave dynamics in Arnold-Beltrami-Childress magnetic field
David Tsiklauri, Queen Mary University of London, UK

11:40 Neutral Vlasov kinetic theory of magnetized plasmas
Cesare Tronci, University of Surrey, UK

12:00 (Invited) Cosmic ray acceleration
Tony Bell, University of Oxford, UK

12:40 Lunch and close of conference
Posters

Poster session 1 – Monday 30 March

P:01 Plasmas produced in conducting solutions
W G Graham, Queen’s University Belfast, UK

P:02 Studies of physical and chemical aspects of a cool plasma jet.
W G Graham, Queen’s University Belfast, UK

P:03 Simulations of the plasma response to applied 3D Fields in tokamaks
D A Ryan, University of York, UK

P:04 Numerical simulation of Langmuir probes in magnetised plasmas
S Murphy-Sugrue, Culham Centre for Fusion Energy, UK

P:05 Laser Induced Breakdown Spectroscopy (LIBS) in cratered targets
B Delaney, Dublin City University, Ireland

P:06 Anisotropic emission from an aluminium laser produced plasma
G A Wubetu, Dublin City University, Republic of Ireland

P:07 Laser produced plasmas in liquid environments
N Walsh, Dublin City University, Ireland

P:08 X-ray imaging of inertial confinement fusion capsules at Orion
S Gales, AWE, UK

P:09 Design of direct drive implosion targets on Orion
J E Coltman, AWE, UK

P:10 Self-consistent absorption and transport models for short pulse laser-matter interaction
M G Ramsay, AWE Aldermaston, UK

P:11 Numerical modelling of laser-plasma interaction
W Hanks, Dublin City University Dublin, Ireland

P:12 Single-shot fourier transform spectroscopy for Laser Induced Breakdown Spectroscopy (LIBS)
S J Davitt, Dublin City University, Ireland

P:13 Extreme ultraviolet absorption measurements of low Z, low density, low temperature plasmas at the Orion Laser Facility
L M R Hobbs, AWE, UK

P:14 Numerical simulations to study transient evolution of linear kinetic Alfvén wave in inhomogeneous plasma
R Goyal, IIT Delhi, India

P:15 Laboratory simulations of magnetospheric cyclotron instabilities
K Ronald, University of Strathclyde, UK
Conical guides for fast electrons generated via resistivity gradients
A P L Robinson, STFC Rutherford-Appleton Lab, UK

Tokamak stability in the presence of weak non-axisymmetric magnetic perturbations
C J Ham, Culham Centre for Fusion Energy, UK

Poster Session 2 - Wednesday 1 April

Jet formation from locally heated laser-irradiated targets
H Schmitz, STFC Rutherford-Appleton Lab, UK

Preparations for inelastic ion impact excitation in future fusion plasmas: A unified semi-classical, impact parameter approach implemented in the ADAS framework
M Bluteau, University of Strathclyde, UK

Determining the saturation threshold of electromagnetic cascades caused by counter-propagating 10PW laser pulses
C Slade-Lowther, University of York, UK

Structure factor measurements for warm dense iron
S White, Centre for Plasma Physics, UK

Plasma mirror characterisation on the picosecond timescale
P S Foster, Central Laser Facility, STFC, UK

Transport in tokamaks with tilted elliptical flux surfaces
J Ball, University of Oxford, UK

Temporal contrast enhancement in high power laser systems employing optical parametric amplification techniques
A Sharba, Queen’s University Belfast, UK

ELITE and extension to Low Toroidal Mode Number
A E L Dowsett, University of York, UK

Measurement of the radial electric field in the boundary plasma of MAST and its impact on turbulence
N R Walkden, CCFE, Culham Science Centre, UK

Plasma source for neutral beam etching
Y Sutton, Open University, UK

Fast-neutron generation by laser-driven deuterium ions from ultrathin targets
A Alejo, Centre for Plasma Physics, Queen’s University of Belfast, UK

The effect of plasma inhomogeneity on (i) radio emission generation by non-gyrotropic electron beams and (ii) particle acceleration by Langmuir waves
D Tsiklauri, Queen Mary University of London, UK
P:30 The dependance of tungsten fuzz growth on He ion fluence in the range $10^{24}$-$10^{28}$ m$^2$
T J Petty, University of Liverpool, UK

P:31 Modelling heat pulse propagation in Large Helical Device
S C Chapman, University of Warwick, UK

P:32 ELM occurrence times in relation to the phase evolution of global plasma measurements in JET
S C Chapman, Centre for Fusion, UK

P:33 Suppression of Relativistic Laser Beam Filamentation via Elliptical Beam Profile
T W Huang, STFC Rutherford-Appleton Lab, UK
Abstracts

(Invited) Electron transport and ion acceleration in intense laser driven opaque gas targets

N P Dover¹, O Tresca², N Cook³, R Kingham¹, C Maharjan³, M N Polyanskiy², P Shkolnikov², I Pogorelsky² and Z Najmudin¹

¹Imperial College London, UK, ²Brookhaven National Laboratory, USA, ³Stony Brook University, USA

High intensity CO₂ lasers operate at a longer wavelength (\(\lambda_L \sim 10 \mu\text{m}\)) than the more widespread near-infrared lasers typically used for high intensity laser plasma interactions. Due to the longer wavelength, plasmas with near atmospheric densities are above the critical density, meaning gaseous targets can be used to study the interaction of intense lasers with opaque plasmas. These interactions are known to generate copious amounts of relativistic electrons, which then propagate through the plasma. For a low-density target the relativistic electrons can be of comparable density to the background plasma, enhancing the growth of various beam-plasma instabilities [1-3]. Understanding beam-plasma transport is important for many applications of high intensity laser-plasma interactions, in particular ion acceleration and fast ignition of inertially confined fusion targets.

We investigated the transport of laser produced electron beams in an opaque gas target. A high intensity CO₂ laser (\(a_0 \sim 1\)) irradiated over critical density hydrodynamically shaped helium gas (\(n_e \sim 10^{19} \text{cm}^{-3}\)), generating energetic electrons. The electrons propagated into the target, forming filaments that were measured by transverse shadowgraphy and interferometry. Numerical modelling and analytical considerations confirm the filaments form due to transverse filamentation instability driven by a high beam to background ratio \(\alpha \sim 0.1\). Filament lengths extended up to 800 \(\mu\text{m}\) with width < 20 \(\mu\text{m}\), narrowing with increased plasma density.

Understanding the beam-plasma interaction is also important for interpretation of recent experiments demonstrating the generation of multi-MeV ion beams from electrostatic collisionless shocks [4-5]. The properties of the shock depend on the plasma temperature profile, and are therefore inextricably linked to the heating resulting from the electron beam- plasma transport. The subsequent implications for scaling of ion energies to higher laser intensities will be discussed.

Hollow ion spectral formation at ultra-high laser intensities

N Woolsey¹, R Crowston¹, L Doehl¹, P Durey², R Dance², N Butler², P McKenna², S Pikuz³, A Faenov³, C Gregory⁴, N Booth⁴, J Green⁴, D Rusby²,⁴, C Armstrong²,⁴, D Neely⁴, R Lotzsch⁵, I Uschmann⁵, J Colgan⁶ and Ellie Tubman¹

¹University of York, UK, ²University of Strathclyde, UK, ³Russian Academy of Science, Russia, ⁴STFC, UK, ⁵Friedrich Schiller Universität Jena, Germany, ⁶Los Alamos National Laboratory, USA

An ultra-intense laser (>1020 W/cm²) solid interaction can lead to intense beams of relativistic electrons and these electrons may generate intense x-ray emission through ionisation and excitation processes in the solid and via bremsstrahlung and other scattering processes. Recent measurements show emission spectra dominated by unusual spectral features. These features are interpreted as due to transition in hollow ions, ions with multiple electrons missing from inner atomic shells. The spectra can be reproduced by detailed but only if the atomic systems are pumped by an intense radiation field. This talk will describe the experiments and data interpretation which gives insight into the target and laser interaction physics.
A 200GHz backward wave oscillator based on a pseudospark-generated electron beam

A W Cross, H Yin, D Bowes, W He, K Ronald, G Liu, Y Yin, L Zhang, D C Speirs, C W Robertson and A D R Phelps

University of Strathclyde, UK

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 unique hollow cathode structure [1-6]. A high-quality electron beam is generated during the later phases of the discharge process, which possesses high current density and brightness, as well as the ability to self-focus via ion channel focusing. This makes it an excellent electron beam source for millimeter-wave generation.

Backward wave oscillators (BWOs) are simple, versatile sources of high frequency radiation which do not require the presence of a feed millimeter wave signal. A BWO using a sinusoidally corrugated slow-wave structure has been simulated using the particle-in-cell code MAGIC-3D and has been shown to generate millimeter wave radiation at 200 GHz in the presence of a 0.8 mm cross-sectional diameter electron beam. The BWO slow wave structure has been manufactured and an output horn has been designed and constructed for use with the structure.

Beam experiments with a 4-gap, 42 kV pseudospark discharge have shown an electron beam current of 4 A that was propagated through the BWO interaction region. Recent results on the generation of millimeter wave pulses from a 200GHz BWO based on a pseudospark-generated electron beam will be presented.

Electron acceleration by magnetic collapse during decoupling
E D Bennet¹, H E Potts¹, L F A Teodoro² and D A Diver¹

¹University of Glasgow, UK, ²NASA Ames Research Center, USA

This paper identifies the non-equilibrium evolution of magnetic field structures at the onset of large-scale recombination of an inhomogeneously ionized plasma. The context for this is the universe during the epoch of recombination. The electromagnetic treatment of this phase transition can produce energetic electrons scattered throughout the Universe, localized near the edges of magnetic domains. This is confirmed by a numerical simulation in which a magnetic domain is modelled as a uniform field region produced by a thin surrounding current sheet. Conduction currents sustaining the magnetic structure are removed as the charges comprising them combine into neutrals. The induced electric field accompanying the magnetic collapse is able to accelerate ambient stationary electrons (that is, electrons not participating in the current sheet) to energies of up to order 10keV. This is consistent with theoretical predictions. The localized electron acceleration leads to local imbalances of charge which has implications for charge separation in the early Universe.


(Culham Thesis Prize) Role of low-temperature electrical resistivity in defining fast electron beam transport in relativistic laser-solid interactions
D A MacLellan

University of Strathclyde, UK

The use of high-intensity lasers to create extreme states of matter has stimulated significant attention in recent years. Of particular interest is the physics of fast electron transport during the interaction of a high-intensity laser pulse with solid density matter. This is not only important from a fundamental standpoint, but also from a practical perspective since energy transport by fast electrons underpins important applications, including the fast ignition approach to inertial confinement fusion, the development of laser-driven ion and radiation sources and investigation of warm dense matter.

In this talk I will present results obtained during my PhD research on fast electron transport in solids irradiated by intense laser pulses. I will focus on three specific areas: (1) the effect of lattice structure in defining the material low-temperature resistivity and thus on fast electron transport properties [1, 2]; (2) the influence of the low-temperature resistivity profile in defining fast electron transport patterns [3], including the possibility to optically ‘tune’ the beam properties [4]; and, (3) the role of lattice-melt-induced resistivity gradients on fast electron transport [5]. These closely related strands of investigation reveal novel new insights into the complex physics of fast electron transport in dense plasma, and the potential for application [6].

(Invited) Rumours of the death of gas discharge lighting are greatly exaggerated

G Lister
Ceravision Limited, Milton Keynes, UK

Research in electric light sources has played an important role in the understanding and development of plasma physics from the time Irving Langmuir introduced the word “plasma” to describe an ionized gas in 1928. In fact, Langmuir’s experiments on simple incandescent light bulbs led to the discovery of the Langmuir sheath [1], the basis of one of the most important plasma diagnostic tools still used today. In the first half of last century, fundamental research into gas discharges was supported by a number of lighting companies, resulting in important contributions to the understanding of plasma science. As we move forward in the 21st C, newer technologies, such as Light Emitting Diodes (LEDs) offer exciting challenges to the way we think about lighting, and the advances in this technology over the past decade has been remarkable. Whilst acknowledging the successes achieved in LED development, there have been parallel advances in “traditional” gas discharge lamp technology, as well as new products with attributes that provide an attractive alternative to LEDs under certain circumstances. This is particularly true for light sources operating at higher power in excess of 400 W.

The underlying physics of discharge lamps has been well understood for many decades (see, for example [2] and references therein). However, progress has often been hindered by materials issues and technological barriers. The development of small, efficient and inexpensive electronics in the 1980s has led to the appearance of a number of “electrodeless” products on the market, thus eliminating the major failure mechanism of gas discharge lamps. This has been matched by the improvement of electrode technology in fluorescent lamps, such that lifetimes of 100,000 hours are now possible for both electroded and electrodeless technologies. Advances in ceramic materials technology have resulted in metal halide products with excellent “white” light and colour rendition. These advances have been complemented by improvements to lamp lumen maintenance factors.

One of the most exciting developments in gas discharge lighting has been the emergence on the market of electrodeless metal halide lamps, referred to in the lighting industry as “plasma” lamps. These lamps are operated by radio frequency power supplies, using either a magnetron at a frequency of 2.45 GHz or a solid state RF source, operating at 433 MHz. Unlike traditional HID lamps, plasma lamps do not require an outer jacket and hence they are virtually point sources, allowing for optimal optical distribution when placed in a luminaire. The absence of electrodes, in addition to increasing lamp life, allows the introduction of radiating chemical species that would otherwise destroy the electrodes. These lamps also operate efficiently at electric powers of 400 W and above, where LEDs have to date proved less efficient.

Advances in lighting research have not been limited to the visible spectrum. The generation of UV radiation for purification treatment of water and air, using excilamps, has become increasingly important from an environmental standpoint, and there is a flourishing research literature on this subject (see for example [3] and references therein). The traditional approach has been to use dielectric barrier or corona discharges, but once again, as a result of advances in materials and electronics, exciting challenges lie ahead in the attempt to increase UV production efficiency and the effectiveness of the destruction of pollutants.

Particle trajectories in a solitary hydromagnetic wave; a demonstration of the mechanism of the \((jB)\) force in a collisionless plasma.

J Gibson\(^1\) and J E Allen\(^1,2\)

\(^1\)Imperial College London, UK, \(^2\)University of Oxford, UK

An early paper on a solitary wave in a collision-free plasma [1], namely a hydromagnetic wave propagating at right angles to a magnetic field, is further examined. The trajectories of both ions and electrons have been calculated for different wave velocities, up to the limiting value of twice the Alfvén velocity. The study clearly illustrates the fact that the positive ions move under the action of an electric field and the magnetic force has a negligible effect on their trajectories. The study shows that the macroscopic \((jB)\) force, i.e. that acting on the whole plasma, is transmitted to the ions \(\text{via\ an\ electrostatic\ field.}\) An infinitesimal difference in electron and ion densities in a quasineutral plasma can produce significant potential differences, a fact known for more than eighty years, as exemplified by the work of Tonks and Langmuir [2].

A review of the well-known Bennett pinch [3] was presented at the EPS Plasma Physics Conference in 2010 [4]. It was pointed out that the well-known Bennett relation was originally derived, not by employing a Magnetohydrodynamic model, as described in the textbooks, but by considering the two separate assemblies of electrons and ions. A conclusion that one can draw from the original theory is that the positive ions are contained by an electrostatic field and are not affected to any noticeable extent by magnetic forces. This is in contradistinction to the description of magnetic confinement to be found in the literature in which ions gyrate around the magnetic field lines.

3D modelling of microwave propagation through turbulent density profiles in fusion relevant plasmas

M Thomas¹, A Köhn², T Williams¹, R Vann¹ and J Leddy¹

¹University of York, UK, ²Universität Stuttgart, Germany

We have investigated microwave propagation past density fluctuations in a Magnetically confined fusion relevant plasma. Microwaves are important in a tokamak for use either by diagnostics or for heating and current drive. The microwave diagnostic system by active or passive probing provides a significant breadth of information. This includes plasma properties such as temperature and density profiles along with plasma field properties such as the magnetic field pitch angle and potentially current density profile. In addition to diagnostics the heating and current drive is instrumental in start-up along with providing a means for instability control. Microwave usage in a tokamak by any of these means requires propagation or interaction in the plasma edge. The plasma edge is the most turbulent region in a magnetically confined fusion plasma. Therefore for targeting specific spatial locations or for injecting a specific amount of power within the plasma one must know the extent to which the wave is scattered. To this end a full wave 3D code developed at the University of York called EMIT-3D has been used to model a microwave beam propagating past turbulent density filaments. Moreover the research employed a 2D full wave code called IPF-FDMC not only for benchmarking purposes but to investigate to what extent the physics was 2D and not 3D. Below displays an example of the output from IPF-FDMC for a wave propagating through turbulence.

Figure 1: An example of the output from IPF-FDMC for a wave propagating through turbulence. By means of these tools we have conducted a parameter scan of varying turbulent structure size with relation to the beam vacuum wavelength and varying turbulent amplitude. The turbulent profile used was the Hasegawa-Wakatani drift wave turbulence model that was simulated through BOUT++. we have now been able to quantify the structure size that provides the largest amount of scattered power and to quantify how this scattering scales with increased turbulent amplitude. In addition to the parameter scan the 3D code was used to model propagation at an angle to the background magnetic field and thus turbulent filamentary structures. It was found that this showed effects inherently 3D in nature not seen in 2D simulations.

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(Invited) Pulsed laser deposition of metal oxide thin films

E Wagenaa1, S Rajendiran1, J Colgan2 and A Rossall1

1University of York, UK 2Los Alamos National Laboratory, USA

Metal oxide thin films such as ZnO, Al2O3, MgO, and TiO2 that are produced using plasma-based methods are widely used in industry and academia, e.g. in microelectronics, photonics, catalysts and as possible indium-free transparent conductors. Traditionally, many of the thin-film materials have successfully been developed using mainly empirical methods. Nowadays, however, novel thin films often have increased complexity and associated development costs. Therefore, today’s challenge is to systematically design and construct films and materials using a bottom-up approach, with the ultimate vision of developing a capability to design the desired properties rather than finding them empirically. Therefore thin-film deposition techniques that are versatile and offer enhanced control of film properties and quality are needed.

Pulsed Laser Deposition (PLD) is a widely used, plasma-based deposition technique that suffers, like most alternative thin-film deposition techniques, from limitations in film quality control and predictability because of a lack of fundamental understanding of the underlying physical processes. The overall aim of our research is to combine experiments and modelling to develop a detailed understanding of all the relevant fundamental science, allowing us to develop a predictive computer model of the film growth and enabling us to design thin films for specific applications.

The PLD process can be described as three phases with distinctly different physics involved: laser ablation, plume dynamics and interactions, and thin-film formation. The laser ablation process is conceptually simple, the very rapid boiling of solid material by a pulsed laser. Despite the apparent simplicity of the process, numerous studies in this field have identified a much more complex process in which there is an interplay of different physical processes such as melting and vaporisation (ps time scale), multi-photon ionisation and inverse Bremsstrahlung absorption (few ns time scale) and plume expansion (ns-μs time scale). Optical emission spectroscopy combined with a 2D hydrodynamic code (POLLUX) and the Los Alamos plasma kinetics code ATOMIC are used to study the plasma composition and plasma light emission during this part of the PLD process.

After the laser pulse has finished there is no more energy input into the plasma. However, the plume has only travelled a few mm from the target surface and has not yet reached the substrate, which is typically a few tens of mm away. In this phase of PLD, the plasma plume travels with a velocity of roughly 1-100 km/sec towards the target. Inside the plasma plume, collision chemistry changes the composition of the plume via e.g. electron impact ionisation and 3-body electron-ion recombination. Furthermore, often there is a low-pressure gas background introduced in the PLD vacuum chamber to optimise the film properties. During the plume propagation phase, the ablation plasma will interact with this (reactive) gas background, resulting in further chemistry and change of composition.

Finally, the actual deposition and growth process, i.e. the way the impinging plasma is transformed into a thin film, needs to be understood. To fully grasp the underlying physics and importantly balances of these different processes, several groups have studied them at an atomistic level using molecular dynamics (MD) simulations.

Finally, a new form of PLD is introduced, plasma-enhanced PLD (PE-PLD). In PE-PLD we combine the laser-produced metal ablation plasma with an electrically produced oxygen plasma. With this method a Zn target is ablated which subsequently expands in an oxygen plasma rather than neutral oxygen gas. This oxygen plasma contains well-characterised and controllable, reactive oxygen species such as atomic oxygen, ozone and singlet delta oxygen. This method offers additional control of the Zn and O interactions and concentrations in the depositing ZnO plasma.
Brownian motion of dust grains in partially-ionised plasma

E D Bennet\textsuperscript{1}, D A Diver\textsuperscript{1}, H E Potts\textsuperscript{1}, C Mahony\textsuperscript{2}, P Maguire\textsuperscript{3}, D Mariotti\textsuperscript{2}, D Rutherford\textsuperscript{2}, C Kelsey\textsuperscript{2} and N Hamilton\textsuperscript{2}

\textsuperscript{1}University of Glasgow, UK, \textsuperscript{2}University of Ulster, UK

Understanding the processes governing the dynamics of dust grains in a discharge plasma is a central component of an innovative collaborative project on bacteria detection. We have previously reported\cite{1} a mechanism for delivering a precise, known amount of charge onto a microscopic aerosolised target by passing it through a microplasma and subsequently exploiting the Rayleigh charge instability during evaporation. A related problem is that of dust diffusion in partially-ionised plasma – how do the microscopic dynamics of ions interacting with the sheath affect the macroscopic dynamics of the dust grain as it moves through the plasma?

Dust grains immersed in a partially-ionised plasma will be subject to Brownian motion like any other small particle, buffeted by a mixture of (dominant) neutrals and plasma, with the latter forming a sheath around the particle. Brownian motion forces the sheath around the grains to move, incurring changes in the impacting ion flux that can represent an additional drag term, changing the classical Brownian diffusion. We present analysis for a variety of discharge conditions.

\cite{1} E D Bennet et al, “Stability of evaporating charged liquid drops as a method for charging microparticles”, IOP Plasma Conference 2014

Amplification and generation of ultra-intense twisted laser pulses via stimulated Raman scattering

J Vieira\textsuperscript{1}, R M G M Trines\textsuperscript{2}, E P Alves\textsuperscript{1}, R A Fonseca\textsuperscript{1,3}, J T Mendonça\textsuperscript{1}, R Bingham\textsuperscript{2,4}, P Norreys\textsuperscript{2,5} and L O Silva\textsuperscript{1}

\textsuperscript{1}Instituto Superior Técnico, Portugal, \textsuperscript{2}STFC Rutherford Appleton Laboratory, UK, \textsuperscript{3}Lisbon University Institute, Portugal, \textsuperscript{4}University of Strathclyde, UK, \textsuperscript{5}University of Oxford, UK

Raman amplification of Gaussian laser pulses has been demonstrated successfully in numerical simulations. However, the amplification of higher-order transverse laser modes is mostly unexplored territory. Here we show, for the first time, that Laguerre-Gaussian laser pulses, with orbital angular momentum (OAM) and characterised by doughnut shaped intensity profiles, can be amplified to ultra-high intensity via Raman amplification. Although such pulses are available at intensities below material breakdown thresholds, ultrahigh intensity OAM laser pulses have not been produced until now, precluding their use for relativistic laser-matter interactions experiments.

We will demonstrate that seed laser pulses carrying OAM can be Raman-amplified to Petawatt powers even if the pump laser pulse does not carry any OAM at all, that Raman scattering can be used to create new OAM modes by combining existing ones, and that OAM modes can be created via amplification of special combinations of TEM modes in the seed pulse. This work will open new research directions and solve long-standing problems in high energy density science, compact plasma based accelerators and light sources.
X-point modelling using non-field-aligned coordinate systems in BOUT++

B W Shanahan¹, B D Dudson¹, P Hill¹, F Avino², I Furno² and A Fasoli²

¹University of York, UK, ²Ecole Polytechnique Fédérale de Lausanne, Switzerland

X-point configurations in tokamak geometries are critical in determining edge and scrape off layer (SOL) dynamics and hence particle and heat flux onto plasma facing components [1]. Alternative configurations which attempt to reduce fluxes to material surfaces have been proposed [2], but their efficacy relies on cross field transport in the region near null points, which is currently poorly understood. Additionally, simulations of instabilities and turbulence in X-point configurations are challenging due to the limitations of field-aligned coordinate systems: X-point dynamics are often extrapolated based on nearby flux surfaces, which could exclude relevant physics.

Here we present the results of 3-dimensional driftwave turbulence simulations in X-point configurations using coordinate systems which are not aligned to the magnetic field. The studies have been performed using a cold ion fluid model originally developed for blob studies [3,4]. The effects of an external X-point field have been explored in simulations originally intended to determine the feasibility of experimentally studying X-point configurations in a linear plasma device [5]. These studies have been extended to toroidal geometries by simulating blob dynamics in complex configurations within the TORPEX device [6], as shown in the figure below. The extension of these studies to tokamak devices will also be discussed.

(Invited) Hydrodynamical turbulence in laboratory and astrophysical plasmas

G Gregori
University of Oxford, UK

The visible matter in the Universe is turbulent and magnetized. For example, turbulence in galaxy clusters is produced by mergers and by jets of the central galaxies and believed responsible for the amplification of magnetic fields. Here we report on experiments looking at the collision of two laser-produced plasma clouds as well as the interaction of a plasma flow with a static grid, mimicking in the laboratory hydrodynamic turbulence in presence of self-generated magnetic fields. By measuring the spectrum of the density fluctuations, we infer developed Kolmogorov turbulence. From spectral line broadening, we estimate a level of turbulence consistent with turbulent heating balancing radiative cooling. We show that the magnetic field is amplified by turbulent motions, reaching a nonlinear regime that is a precursor to turbulent dynamo. Thus, our experiment provides a promising platform for understanding the structure of turbulence and the amplification of magnetic fields in the Universe.
Aerosol droplet charge control via rapid plasma transport

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Transport of liquid droplets through a non-thermal equilibrium microplasma should result in evaporation and droplet charging, among other possible effects. The magnitude of the charge, up to the Rayleigh limit, will depend on droplet size and plasma parameters as well as net recombination in the plasma afterglow/transition region where quasi-neutrality is not maintained. Evaporation within the plasma will reduce size and hence the charge acquired. However for short plasma transport times the evaporation may be limited. Charged droplets exiting the plasma would then evaporate without losing charge until the Rayleigh limit is reached. Through control of plasma transport and evaporation, droplet charging with enhanced accuracy and increased magnitudes may be possible.

We have developed a system for entraining micron-sized droplets (5 – 60 μm) within a narrow rf-driven cylindrical helium/neon microplasma operated at atmospheric pressure. Transport times can be varied between 20 μs to >100 μs. Droplets exit the plasma with a velocity distribution within a parabolic envelope, figure 1(a), and droplets with net charge have been observed up to ~10 mm from the plasma exit. The plasma induced evaporation results in an average diameter reduction of < 3 μm, figure 1(b). We are also currently exploring the droplet chemistry and its potential dependence on electron bombardment as well as the possibility of transferring the charge to single bacteria cells trapped within each droplet. Other applications under investigation include nanomaterials synthesis in droplets.

Figure 1: (a) velocity distribution (relative to average gas speed) of droplets at ~2.5 mm from plasma exit with (filled) and without (empty) plasma. Some (~10%) larger slow droplets (shaded yellow) are observed mostly without plasma exposure. (b) Average diameter and velocity changes due to plasma exposure. Central coordinate of each ellipse indicates arithmetic mean while ellipse outline represents 1 standard deviation.
The dependence of tungsten fuzz growth on He ion fluence in the range $10^{24}$-$10^{28}$ m$^2$

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Tungsten (W) nanostructure, commonly referred to as tungsten fuzz, has been studied for several years now [1, 2]. It manifests as a modification of the W surface into a layer of nano-scopic morphology when the surface is exposed at high temperature (> 900 K) to bombardment by energetic (> ~30 eV) helium (He) ions. The phenomenon has been replicated numerous times in laboratory plasmas and could potentially occur in ITER, the next generation fusion device under construction in France. Recent collaborative experiments between the University of Liverpool and the University of California at San Diego have been conducted with the aim of examining the growth of tungsten fuzz at 1120 K, over a wide range of He ion fluence to better understand prior inconsistencies in the rate of growth. For instance, in Ref [2] the thickness of the tungsten fuzz layer is shown to scale with the square root of the exposure time. However, low He fluence ($<10^{24}$ He+/m$^2$) exposed cases, conducted at low He$^+$ ion flux [3] compared with [2], show fuzz layer growth much slower than that observed in [2]. An expanded set of fuzz layer growth data, made in a magnetron device [3], PISCES-A, and PISCES-B [2, 4], and taken over a wide range of He fluence ($10^{24}$-$10^{28}$ He+/m$^2$), suggest that the growth expression in [2] is consistent with a more general fluence dependent power law with an exponent close to 0.5. The observed trend in the new data set further shows that other influences can also affect the growth of tungsten fuzz. Specifically, new data suggest that an incubation fluence of $2-3 \times 10^{24}$ He+/m$^2$ is necessary for the observation of initial surface morphology, a W atom deposition flux can lead to an enhancement in the rate of fuzz growth, and trace impurity fluxes can limit the growth of the fuzz layer at high fluence, consistent with the process of physical erosion [4]. The new data, and the implications for these findings will be discussed at the meeting.

Design and plasma process challenges for ultra high speed (100Gbps +) photonic integrated circuits

A Carter
Oclaro, Northamptonshire, UK

The demand for bandwidth in our information age continues to increase dramatically. 100Gbps optical interfaces on single optical channels are now being widely deployed, effectively applying RF techniques to the 196THz range optical carriers; in systems, up to 100 such carriers are optically multiplexed onto single fibres giving capacity per fibre in the 10 TBps range. Following this, 200, 400Gbps and ‘superchannel’ interfaces are required, increasing capacity further as well as facilitating routing and switching of the optical data. Photonic Integration is an absolutely key technology to meet this need, driving major demands for waveguide and optical element dimensional precision. In a typical InP based photonic circuit fabricated at Oclaro, there may be modulator elements, detectors and tunable lasers, all of which have to operate to very tight specifications and be manufactured with high yield. Such a circuit may have 6 stages of epitaxial growth, with layers that have to be aligned with nanometer precision in the growth direction.

In the presentation, the design and process challenges for these photonic circuits will be presented and how plasma based processes are an essential part of our toolkit for their manufacture.
(Invited) Laser absorption spectroscopy as a sensitive optical diagnostic in low temperature plasmas

G Ritchie
Department of Chemistry, University of Oxford, UK

Atoms, radicals and ions, present often in trace amounts have a disproportionately large effect on the physical and chemical properties of low pressure molecular plasmas. Accurate measurements of absolute number densities of such highly energised species are crucial in developing models for these complex systems. This talk will illustrate the development of cavity enhanced laser spectroscopy for the quantitative detection of these species and the contribution that high resolution absorption spectroscopy can make to understanding the physical and chemical properties of low pressure plasmas.

Vorticity deposition and structure generation in colliding blast wave experiments

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Consider a situation in which two blast waves are launched synchronously in a uniform ambient medium and collide. As the shocks propagate through the cavity of each remnant the propagation through non-uniform density implies that vorticity deposition should occur. Since the interior of a well-developed (i.e. Sedov-Taylor-like) blast wave should have relatively weak density gradients, one may expect that this vorticity deposition will not have any significant consequences. Here we show that persistant deviations from selfsimilarity can produced enhanced regions of vorticity deposition in this scenario which leads to very significant structure generation. The deviations are capable of doing this even when the blast wave is no longer strictly 'young' due to their persistant nature.

Outreach International Year of Light

(Invited) Non-visual impacts of light

J Stocks
Ceravision, UK

Light allows us to see, to visualise the world around us, but what other effects does light have on our bodies and biological systems. This talk is an introduction to the many ways light impacts our lives other than for photopic daylight vision. What is scotopic and mesopic vision. How does the 24hour solar day affect our body clock, what are circadian rhythms and how does light impact on our health and wellbeing will be discussed. Increasingly scientists and health professionals are paying greater attention to these non visual impacts of light studying subjects such as Seasonal Affective Disorder, night shift working, phototherapy and many other aspects of the interaction of light with human biological systems. This talks provides a glimpse into this fascinating and rapidly developing field.
(Invited) Cosmic light: the story of everything

L Marchetti

Open University, UK

Astronomy is the science that studies the light set-off by the celestial bodies to understand our Cosmos. Cosmic light in fact tells us the story of our Universe and of what sits in it. Studying the light emitted by stars and galaxies we can understand their properties (e.g. temperature, distance, age, constituents) and thus interpret how they have been formed and how they might have changed with time. Investigating the intensity variation of the light emitted by a star we can discover new planets. Studying the light reflected and absorbed by a planet or by a planet's atmosphere we can study its composition and the story of its formation. Besides light has a constant speed and thus it takes time to travel from one point to another. For this reason, whenever we observe the light of a very distant object we are actually looking back in time when its light has been set-off. Everything works like a cosmic time machine that allows us to see until the very first instants of our Universe and thus to investigate how and when everything has started. This talk is an introduction and an overview of the many astronomical questions we are trying to answer by simply studying light (and darkness) in space and how we are able to pursue our studies thanks to the more and more sophisticated technology of our age.

(Invited) How to slow atoms with light, and how to slow light with atoms

C MacCormick

Open University, UK

The talk will focus on the trapping and cooling of atoms using light, and the dramatic slowing of light in very cold and dense clouds of atoms. In order to understand these techniques, I will discuss the Doppler effect and a little bit of quantum mechanics. We will also be able to “see” trapped atoms formed in the lab, hopefully we may be able to observe even a single atom!
Plasma waves in the radiation belts of Earth and Jupiter
R B Horne
British Antarctic Survey, UK

The Earth's magnetosphere contains a rich variety of plasma waves. Over the last few years there has been a focus of research to understand those waves that contribute to the acceleration, transport and loss of energetic electrons that make up the Van Allen electron radiation belts and contribute to their variability. Here we present a summary of some of the most important wave modes, including whistler mode chorus, plasmaspheric hiss, magnetosonic and electromagnetic ion cyclotron (EMIC) waves. We describe how these waves can cause electron acceleration and loss via Doppler shifted cyclotron resonance assuming quasi-linear diffusion. We show results from the BAS Radiation Belt Model, which simulates the radiation belts on a global scale, and which show how each type of wave affects the trapped electron flux on a global scale. We also show an application where these simulations are being used for space weather forecasting as part of an international project funded by the EU, and provide forecasts for satellite operators in real time. Finally we show some of the similar wave modes that are observed at Jupiter and Saturn, such as whistler mode chorus, EMIC and Z mode waves, and discuss how these waves contribute to the formation of the radiation belts at these planets, taking into account that the moons rather than the ionosphere are the main sources of plasma at these planets and the fact that they are rapidly rotating bodies.

Laser diffraction effects on the Rayleigh-Taylor instability of radiation pressure accelerated thin foils
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We present a theoretical model for the Rayleigh-Taylor (RT)-like instability for a thin foil accelerated by an intense laser, taking into account diffraction effects due to the finite wavelength of the laser wave. The diffraction effects become important when the laser light is scattered off the periodic structures arising from the instability of the foil, and significantly modify the growth rate of the RT-like instability when the perturbations on the foil have wavenumbers comparable to or larger than the laser wavenumber. In particular, the growth rate has a maximum at the resonance arising when the perturbation wavenumber approximately equals the laser wavenumber. The standard RT instability due to a pressure difference between the two sides of a foil, is approximately recovered for perturbation wavenumbers smaller than the laser wavenumber, while in the opposite case, when the perturbation wavenumbers are larger than the laser wavenumber, the reflected laser light is evanescent and the growth rate is smaller than that of the Rayleigh- Taylor instability. Differences in the results for different polarizations and angles of incidence of the laser light are discussed. Preliminary comparisons with particle-in-cell simulation results show good agreement with the theoretical model, with a maximum growth rate for perturbation wavelengths near the laser wavelength. The presented model has significance to radiation pressure acceleration of thin foils, where RT-like instabilities are significant obstacles for the realization of mono-energetic ion beams needed for medical applications.
Simulating DC magnetron sputtering devices with Opera-3d

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Opera-3d is a professional multi-physics simulation tool that is widely used in the field of electro-magnetic design. This paper presents recent work adopting the Opera-3d Charged Particle simulation package to model DC magnetron sputtering devices. In this novel approach to magnetron simulation one models charged particle generation and transport as interacting emitters (surface and volume) and current carrying beams. By utilizing algorithms from the fields of Finite-Element-Analysis (FEA), plasma physics, ray-tracing and Monte-Carlo methods, it is possible to model large devices with arbitrarily complex 3d geometries.

(Invited) Plasma-surface interactions under extreme conditions

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One of the largest challenges for the next-generation experimental tokamak ITER (and beyond to its eventual successor DEMO) is the problem of heat exhaust. In the ITER divertor extremely high heat and particle fluxes on the order of 10-20 MW m\(^{-2}\) and \(10^{24}\) particles m\(^{-2}\) s\(^{-1}\) will interact with the plasma facing material. In addition Edge Localized Modes (ELMs) will deposit several GW m\(^{-2}\) on a timescale of 0.5-1 ms which can damage and even melt the plasma surface. Under such conditions the surface is pushed far out of equilibrium and in turn the surface perturbs the plasma such that the near-surface region operates in the “strongly-coupled” regime [1]. With the exception of Alcator C-Mod [2] previously no tokamak or laboratory device was capable of mimicking such conditions, which motivated the development of the Pilot-PSI [3] and Magnum-PSI [4] linear devices. These unique machines produce low temperature (\(T_e \sim 1-3\) eV) and high density (\(n_e \sim 10^{20-21}\) m\(^{-3}\)) plasmas which well replicate the conditions expected in the ITER divertor, and can also produce pulsed plasmas to simulate ELMs [5]. Using these devices the power handling, long term erosion and evolution of plasma facing materials for ITER and DEMO can be studied, as well as the self-organisation effects and novel structures which occur under such conditions. An overview of results from the machines will be given showing how they are addressing urgent questions for ITER, helping to develop advanced divertors for DEMO and beyond, and exploiting non-equilibrium for plasma processing.

Characterisation of a radio frequency excited plasma cathode for electron beam gun power optimisation

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Electron beam guns can be used for additive manufacturing of objects in metal. A plasma cathode was investigated for use as an electron source for material processing applications. Plasma cathodes have advantages over thermionic cathodes as they do not wear. Optical Emission Spectroscopy (OES) was used to characterise the radio frequency (RF) excited plasma cathode in order to develop a higher electron emissivity.

A test setup was developed in previous work [1] for carrying out plasma diagnosis experiments without generating an electron beam. Further work has been carried out with different gases such as krypton and argon. Design modifications on the gun body and experimental apparatus were made in order to carrying out plasma diagnosis experiments at the same time as generating a beam.

OES was used in this new design to understand how key plasma parameters (material, geometry, electrode gap, plasma pressure) affect the plasma characteristics with the ultimate aim to find the optimum configuration. Collisional – Radiative Models are recommended to determine electron density and temperature [2] for this type of plasma (low temperature argon at 0.5 to 1 mbar). Measurements indicate that electron density (and by extrapolation emissivity) were dependent upon RF excitation power and gas pressure.

New designs of the plasma chamber and electrodes will be simulated and optimised to maximise the electron density in the plasma. Optical spectroscopy results will be compared with the electron emissivity. Trials will be carried out at ~60kV accelerating potential to examine the processing performance of the gun.


A convergent fast electron beam for laser-fusion applications

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STFC Central Laser Facility, UK

In this work we present a simple, novel, geometry for ultra-high-intensity laser-solid interactions, that generates a convergent fast-electron beam. Using massively-parallel particle-in-cell simulations, it is shown that the fast-electron beam focuses within the target, with the focal length determined by the interaction geometry. As the fast electron beam’s intensity peaks within the target (i.e. within the Deuterium-Tritium fuel region), this scheme may offer a route to achieving fast-ignition with reduced laser energy.
(Invited) Pedestal confinement and stability of JET-ILW ELMy H-modes

C F Maggi and JET Contributors
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JET has recently modified its plasma facing components from full C (JET-C) to an all metal wall, using the materials planned for ITER: Be in the main chamber and W in the divertor (JET-ILW). As a consequence, certain properties of pedestal stability and confinement are modified, pointing to more complex physics than that currently included in pedestal models used to predict ITER plasma performance [1].

In JET-ILW, the energy confinement of low beta H-modes is significantly lower than that in JET-C, due to the need for higher D2 gas rates, required to combat the influx of W through the pedestal into the core plasma leading to high core radiation. Changes in the D recycling flux from JET-C to JET-ILW may also play a role in cooling the edge pedestal. On the other hand, when the effective neutral recycling is reduced, e.g. by placing the strike points close to the divertor pumping duct, good confinement can be recovered. In such cases the pressure gradient before the type I ELM crash is in agreement with the limit set by finite-n peeling-ballooning (P-B) instabilities.

At high triangularity ($\delta$) plasma shape and low beta, a further degradation in pedestal pressure of $\sim$30% is observed compared to JET-C [2]. The beneficial effect of plasma shaping on pedestal stability is lost and similar pedestal pressures are found at low and high $\delta$. Within the P-B framework, the operational point is near the ballooning boundary, thus no increase in pedestal pressure with plasma shaping is predicted, due to the strong reduction in edge bootstrap current. In contrast, the pedestal pressure of high $\delta$, high beta H-modes is $\sim$30% higher than at low $\delta$.

At low D2 gas injection the pedestal pressure increases rapidly with power, contributing to the weak power degradation of global confinement observed in high beta H-modes [3]. These pedestals are found at the P-B stability boundary. Increasing core pressure stabilizes the ballooning modes due to the increased Shafranov shift, thereby raising the P-B stability boundary. The pedestal height is also increased as a result of the decrease in pedestal collisionality, leading to higher bootstrap current and thus access to higher edge stability. However, with increasing D2 gas injection the beneficial effect of beta is strongly reduced and the pedestals are found to be deeply stable to P-B instabilities [1], indicating that missing physics in the models is required to explain the onset of the ELM instability.

The reduction in energy confinement of low beta, high $\delta$ ILW H-modes can be largely compensated by seeding N2 in the divertor [4]. The marginal P-B mode stability at the end of the ELM cycle is resumed, with the increase in pedestal height being due to broadening of the pedestal pressure width at constant gradient [5]. A mechanism is put forward, which interprets the observed edge stability improvement as due to a combination of two effects [6]: an increase in ion dilution and a reduction in separatrix temperature, induced by N radiation, which positively affects the pedestal P-B stability.

[1] C F Maggi et al., 25th IAEA FEC, St Petersburg, Rusian Federation, EX/3.3.
Ionization in an MHD-Gas interaction simulation

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Introduction

The study of partially ionized plasmas is important in a number of astrophysical situations (e.g. brown dwarf atmospheres [1]) and is vital for the study of laboratory plasmas. In a partially ionized MHD-plasma neutral and ionized species coexist, with disturbances in one producing a dynamical response in the other through momentum coupling induced by their relative motion. These interactions between a neutral gas and a plasma defines a hybrid medium that has aspects of each, but does not only sustain the pure modes of the individual species. Additionally, if this interaction is sufficiently strong, then ionization of the neutral can take place: Alfvén’s mechanism [2] allows neutral breakdown if the relative speed exceeds a critical threshold \( v_c \). The underlying physical mechanism depends on accelerating pockets of unbalanced electron populations to non-equilibrium distributions in sub-nanosecond timescales [3] and so is not appropriately described in the fluid limit. We construct a non-linear MHD-gas hybrid scheme here that incorporates the physics of both limits.

Formally, single-fluid MHD cannot incorporate ionization, but by making the fluid plasma a proxy for free electron density, some impact ionization can be inferred as long as the internal energy of the neutral gas contributes to the overall energy balance in each computational cell.

Results

A flow or any wave motion in a magnetized gas-plasma system, in either of the species, will provide a relative velocity that can result in AI [4]. If this relative motion between species does induce some measure of AI then the dynamics of the whole system are affected. In particular a low density region of gas will cause large velocity flows to ‘fill in’ resulting in large relative velocity and high degree of ionization. An example of low amplitude disturbances resulting in new plasma created by AI is shown in fig 1. We show AI as capable of producing significant changes to both the local and global ionization fraction.

Figure 1: A density map of new plasma created by Alfvén ionization.

(Invited) Large-scale astrophysical and laboratory plasmas as testbeds for exploring fundamental multiscale non-linear processes

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Fully non-linear processes which couple across spatio-temporal scales, such as reconnection and turbulence are ubiquitous in astrophysical fields and flows. They are key mechanisms for plasma heating and particle acceleration from the energy contained in large scale plasma flows and magnetic fields. Turbulence and the formation and propagation of coherent structures are also central to understanding anomalous transport and diffusion in large-scale confined plasmas for magnetically confined fusion (MCF). These processes can be observed in-situ at first hand in our solar system using satellite-borne instrumentation. We now have a rich collection of such observations and in particular, multi-point and high time resolution observations spanning magnetohydrodynamic and kinetic scales. Large scale MCF experiments are also comprehensively diagnosed. Alongside this, it is now becoming feasible to perform numerical simulations that capture the full non-linear physics self-consistently down to kinetic scales, in three dimensions. Comparing theory and simulations with data requires us to be quantitative, under the somewhat difficult circumstances of a finite sized observed system with limited time-stationarity. Methods to address these challenges have potential cross-over between laboratory and space plasmas in both the simulations and the data analysis tools.
Understanding the exhaust of power at the edge of MAST in preparation for future tokamaks, including MAST-U with its closed divertor

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A significant factor in the design of future machines is the handling of power exhausted from the tokamak edge via the “near” and “far” regions of the scrape-off layer. It is now well documented that the transport in this region features filamentary plasma structures, but the precise relationship between these and the measured average profiles is still an active area of research. Improving the understanding of this relationship is likely to improve the effectiveness of designs for the divertor and first wall structures that handle the fluxes. This has been highlighted during the divertor design of MAST-Upgrade using experimental observations of filaments in MAST.

This work is a review using the most recent evidence of filament and power fall-off dimensions obtained using, time- and space-resolved experimental observations of the filamentary structures and their radial and toroidal extent through comparison with the experimentally measured average profiles of power and other variables. A representative set of diagnostics have measured MAST “L-mode” plasmas; including a divertor infra-red camera, visible imaging of the divertor, Langmuir probes and retarding field energy analysers (RFEAs) at the outer mid-plane and divertor target.

For the first time in L-mode plasmas, using the infra-red camera, the width of the clearly observed large filaments at the mid-plane has been determined using their measured footprint at the target and the detailed magnetic field geometry. The filament width at the mid-plane has then been found to be between 5 and 7 cm, which is consistent with previous mid-plane visible imaging measurements of the filament width \cite{1} which showed this to be between 7 and 9 cm. The filament width is then approximately 10 times the fall off length of the related average profile at the mid-plane, suggesting that concentration on these large filaments may distract from the main mechanism that carries the major fraction of power to the divertor.

Visible imaging was used to track the propagation of intermittent filaments of plasma in the region between the X-point and the divertor target plates, the so-called private-flux region. These filaments enhance transport perpendicular to magnetic field lines, thereby spreading the deposition of plasma over a larger area of the divertor target. The data collected provide experimental evidence for the existence of filaments propagating within this private flux region, and that was not previously thought to be a region where these intermittent structures propagate in such a way. The influence of these filaments on particle deposition in the divertor was investigated using data from the camera and Langmuir probes. Data from otherwise similar plasmas with different levels of plasma current showed that the filaments were not strongly determining the particle flux deposition pattern in the private flux region in the divertor.

Mid-plane RFEA measurements of plasma within the large filaments show that it has much hotter ions than the average for the plasma through which they move. The Ti values are as high as 60 eV, when compared to averaged profiles with values around 30eV. These relatively high temperature measurements are also found with the divertor RFEA which measures filament Ti \textasciitilde 30 eV reaching the divertor target at a distance of \textasciitilde 9 cm from the strike point (in comparison with \textasciitilde 10eV or less for the background plasma).

Work supported by the RCUK Energy Programme and EUROfusion

\cite{1} B D Dudson et al., Plasma Phys. Control. Fusion 50 (2008) 124012
Edge localised modes (ELMs) have been observed to give rise to extremely intense bursts of microwave emission in the Mega Ampere Spherical Tokamak (MAST). The bursts have intensities up to 40dB above the core thermal emission and are often accompanied by short lived rises in edge soft X-ray emission. These observations are new for MAST, but the phenomenon is not specific to spherical tokamaks [1-4]. Until now, no satisfactory explanation of the emission has been presented. It is shown using the non-ideal MHD code JOREK that parallel electric fields of the order of kVm$^{-1}$ can develop in a narrow region close to the separatrix during the ELM crash phase. Fields of this magnitude will create runaway tails in the electron distribution. These electrons can drive the Anomalous Doppler Instability (ADI) [5,6], rapidly accumulating perpendicular momentum and radiating more than 1% of the tail energy in the process. Simulations with the particle-in-cell code EPOCH reveal that the ADI takes place on timescales of a few hundred electron cyclotron periods, and radiation should be expected primarily in the form of mode-converted electron Bernstein waves near the local upper hybrid frequency. Experimentally, the peak emission frequency is observed to be at $1.3-1.4\omega_{ce}$, where $\omega_{ce}$ is the electron cyclotron frequency measured at the outboard midplane. This agrees with our prediction that the electric field is developed in a narrow region near the separatrix. The soft X-ray edge emission enhancement at the time of the ELM crash is consistent with a population of superthermal electrons extending to $\sim 10\text{keV}$ and of fractional density of order $10^{-3}$. It is concluded that electron kinetics can play a significant role in ELM dynamics.

[1] C H Fuchs, M E Austin, Phys. Plasmas 8, 5 (2001);
Three dimensional magnetohydrodynamic simulation of linearly polarised Alfven wave dynamics in Arnold-Beltrami-Childdress magnetic field

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Previous studies (e.g., Malara et al., Astrophys. J. 533, 523 (2000)) considered small-amplitude Alfven wave (AW) packets in Arnold-Beltrami-Childress (ABC) magnetic field using WKB approximation. They draw a distinction between 2D AW dissipation via phase mixing and 3D AW dissipation via exponentially divergent magnetic field lines. In the former case, AW dissipation time scales as $S^{1/3}$ and in the latter as $\log(S)$, where $S$ is the Lundquist number. In this work [1], linearly polarised Alfven wave dynamics in ABC magnetic field via direct 3D magnetohydrodynamic (MHD) numerical simulation is studied for the first time. A Gaussian AW pulse with length-scale much shorter than ABC domain length and a harmonic AW with wavelength equal to ABC domain length are studied for four different resistivities. While it is found that AWs dissipate quickly in the ABC field, contrary to an expectation, it is found the AW perturbation energy increases in time. In the case of the harmonic AW, the perturbation energy growth is transient in time, attaining peaks in both velocity and magnetic perturbation energies within timescales much smaller than the resistive time. In the case of the Gaussian AW pulse, the velocity perturbation energy growth is still transient in time, attaining a peak within few resistive times, while magnetic perturbation energy continues to grow. It is also shown that the total magnetic energy decreases in time and this is governed by the resistive evolution of the background ABC magnetic field rather than AW damping. On contrary, when the background magnetic field is uniform, the total magnetic energy decrease is prescribed by AW damping, because there is no resistive evolution of the background. By considering runs with different amplitudes and by analysing the perturbation spectra, possible dynamo action by AW perturbation-induced peristaltic flow and inverse cascade of magnetic energy have been excluded. Therefore, the perturbation energy growth is attributed to a new instability. The growth rate appears to be dependent on the value of the resistivity and the spatial scale of the AW disturbance. Thus, when going beyond WKB approximation, AW damping, described by full MHD equations, does not guarantee decrease of perturbation energy. This has implications for the MHD wave plasma heating in exponentially divergent magnetic fields.


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Neutral Vlasov kinetic theory of magnetized plasmas

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The low-frequency limit of Maxwell equations is considered in the Maxwell-Vlasov system. This limit produces a neutral Vlasov system that captures essential features of plasma dynamics, while neglecting radiation effects. Euler-Poincare reduction theory is used to show that the neutral Vlasov kinetic theory possesses a variational formulation in both Lagrangian and Eulerian coordinates. By construction, the model recovers all collisionless neutral models employed in plasma simulations. Then, comparisons between the neutral Vlasov system and hybrid kinetic-fluid models are presented in the linear regime.
Observations of high energy phenomena in astrophysics have advanced remarkably in the past decade. With gamma-ray telescopes and high resolution x-ray telescopes we can now observe particle acceleration to TeV energies as and where it occurs. Cosmic ray detectors give a much improved picture of the spectrum and composition of accelerated particles. Observations have led to new theories with overlaps to the plasma physics of magnetic field generation and energetic electron transport in laser-produced plasmas. This talk will review the present understanding of cosmic ray acceleration with particular reference to the underlying plasma physics.
Poster session 1

P:01 Plasmas produced in conducting solutions

M L Karim, K R Stalder and W G Graham
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Plasmas produced in liquids are receiving increasing attention as their novel physics and chemistry lead to increasing applications [1]. It has been established that generally a localized change from liquid to vapour phase precedes plasma production. In our previous studies [2-4] we have investigated, through both experiment and computer modelling, aspects of the vapour layer formation, temporal changes in the current and power draw of the plasma itself, as well as the optical intensity of the plasma via PMT measurements. Here by using multiple simultaneous measurements we will present measurements of the correlation of the electrical and spectral properties of the plasma with the plasma dynamics.

In the present experiment the electrode, a 0.5mm diameter tungsten wire, protruding by 0.5mm from a tight fitting glass dielectric tube with a conical tip, is immersed in saline solution. The electrode is driven by a square wave negative voltage of up to 300V with duration of a few ms. A grounded titanium plate is also immersed in the liquid. The voltage and current are monitored on a four-channel oscilloscope along with the output of an electrode-facing photomultiplier and the gate of an ICCD camera onto which the electrode region in imaged. The ICCD is used to capture 100 to 1μs duration images of the plasma formation and, through back lighting, the vapour layer. The rising edge of the current signal initiates a delayed trigger for the data acquisition. The voltage-current characteristics of the breakdown event can be captured and correlated with the plasma production. We find that typically the vapour layers on the electrode, prior to plasma production, are approximately spherical beyond the electrode tip with a diameter of ~1 mm and the plasma is typically confined to a region close to or at the inner vapour-liquid interface and to covers ~ 40% of that surface area.

Studies of physical and chemical aspects of a cool plasma jet

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We, and others, have been using kHz atmospheric pressure plasma jets operating in helium to investigate the effectiveness of cool plasmas in a number of medical applications, in our case mainly as an antimicrobial agent [1,2]. While there have been encouraging results from these studies to optimize their performance and convince potential users will require a full understanding of the physical and chemical processes that produce and sustain the specific plasma jet used in obtaining the reported biological effects. We have been using fast imaging measurements to study the development of our specific jet [3] from its source, electrical breakdown between the two coaxial electrodes on the outside wall of a 4 mm diameter quartz tube (one driven with a 6kV pulse at 20kHz) and through which helium gas flows, at 2 slm, to the creation of an ionization front and this front’s progress through ambient air to its interaction with various solid, liquid and biological surfaces. The imaging is complemented by space resolved emission spectroscopy. This provides some initial insight into the plasma induced chemistry e.g. the observation and intensities of emission from O, H, OH and NO and measurements of the gas temperature in the jet. The emission spectra from N₂ also indicate that such plasmas can be sustained while maintaining gas temperatures close to ambient. The plasma and its reactive components spread across all the surfaces it makes contact with and, with this particular jet configuration and operating conditions, the presence of a substrate material seems to have only a very localized effect on the plasma jet behaviour and chemistry.

P:03 Simulations of the plasma response to applied 3D fields in tokamaks

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Applying 3D magnetic perturbations to 2D tokamak plasma equilibria is a promising option for suppressing Edge Localised Modes, an explosive instability which has negative consequences for the development of a tokamak-based fusion power plant. The plasma response to such 3D perturbations can dramatically modify the plasma state, and also modifies the perturbation itself. Using the code MARS-F, the linearized equations of resistive magnetohydrodynamics are solved, in order to calculate the plasma response to 3D magnetic perturbations. The code employs realistic tokamak geometry, and plasma equilibria and kinetic profiles derived from experimental measurements from the ASDEX-Upgrade tokamak in Germany. Results show that the plasma response determines to a great extent which of the possible coil configurations produces the maximum 3D perturbation, which has implications for future experiments.

P:04 Numerical simulation of Langmuir probes in magnetised plasmas

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Langmuir probes are a powerful diagnostic tool capable of measuring plasma density and temperature with high spatial and temporal resolution. The interpretation of probe data becomes complicated once the plasma is magnetised and requires complex probe theories that are only applicable over certain operating regimes. No theoretical model is capable of converting probe measurements into plasma parameters that are consistent with other diagnostics over a large range of operating parameters.

A detailed study is underway using Particle-In-Cell (PIC) simulations to alleviate the problems of probe interpretation in magnetised plasmas. These simulations can be used to construct probe IV curves for a range of plasma densities and temperatures, creating a model database of IV curves. These IV curves can then be compared to experimental IV curves in order to diagnose the experimental plasma. PIC codes can also be used to carry out parameter scans to investigate how kinetic effects influence the shape of probe IV curves potentially guiding theoretical work in this area.

A 1D PIC code has been developed and benchmarked against the established Berkeley code XES\textsuperscript{1} \cite{1}. Test cases have been run with a 3D PIC code and the difficulties in setting up a PIC code to represent a physical plasma will be discussed. Preliminary work has begun on comparing the results to theoretical predictions with experimental comparisons to follow.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement number 633053 and from the RCUK Energy Programme [grant number EP/I501045].

\cite{1} C K Birdsall, A B Langdon (2004) \textit{Plasma Physics Via Computer Simulation}
P:05 Laser Induced Breakdown Spectroscopy (LIBS) in cratered targets

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When a high power laser interacts with a surface in air it ablates material from the surface and forms a plasma, accompanied by a shockwave at the plasma front. Over subsequent shots a crater is formed as the laser drills into the material. As the crater gets deeper the plasma becomes somewhat confined within it. This confinement leads to the shockwave getting deflected back towards the plasma front causing an increase in collisional processes, which lead to a higher number of atoms and ions in high-energy states, thus increasing the emission intensity of the plasma [1, 2].

Time-resolved emission imaging has been employed to investigate the size and shape of a laser-produced tin plasma. To date it has shown a change in plasma shape with increasing crater depth which suggests that plasma confinement, within the crater, is also changing key plasma parameters such as the temperature and density distribution. Time and space resolved emission spectroscopy is currently being carried out to characterize the plasma as crater depth increases. We are also investigating the effect of cratering on signal-to-background ratio, a key determinant of the limit-of-detection for LIBS. Results from both imaging and spectroscopy will be presented at the conference.


Acknowledgment

I am an INSPIRE doctoral candidate and acknowledge support from the Irish Research Council under the Government of Ireland Postgraduate Scholarship Scheme and support from the Science Foundation Ireland Grant No. 12/IA/1742.
P:06 Anisotropic emission from an aluminium laser produced plasma

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In this work, anisotropic emission from a laser produced plasma has been studied using time integrated emission spectroscopy and the results have been interpreted in the framework of radiatively re-combining plasmas.

In a laser produced plasma, dichroic anisotropies in the emission can occur [1]. In some cases the background broadband emission is found to be polarised [2] and in other cases the discrete line emission is found to be polarised [3]. When a laser plasma is produced from a pure atomic target (in our case, aluminium) the broadband emission is made of electronic transitions where the initial state is in the continuum (either free – free transitions or free – bound transitions). It has been found that anisotropies in the broadband emission can lead to an increase in the signal to background ratio of the spectrum under study. This result is of interest to those studying Laser Induced Breakdown Spectroscopy (LIBS). In fact, an entire subset of LIBS is dedicated to studying the polarisation resolved spectra from multi-species targets (PRLIBS).

The polarisation dependence of the line emission has been studied in aluminium before [3]. However, these studies focussed on narrow spectroscopic windows and very little has been reported on the mechanisms that lead to the anisotropy of the line emission. Hence, we have explored PRLIBS on an Aluminium (Al) target in vacuo and in air using a Q-switched Nd: YAG nanosecond laser pulses. This was achieved by placing a dichroic polarizer in front of a time integrated optical spectrometer. We find that the plasma emission exhibits a small but distinct anisotropy. We find that, depending on the power density regime in which we study that either the line emission or the continuum exhibit a greater polarization effect. In the work presented here, we present results which show a strongly polarized line emission.

Interest in the area of laser ablation in liquids (LAL) has seen significant growth in recent times due to the multitude of application areas where it can play an important role. While much work has been carried out on pulsed ablation of materials in vacuum and gas ambient, comparatively little research has been done on ablation in liquid media. As a result a fundamental understanding of the basic physics underlying ablation in liquids is still insufficient [1]. The objective of the present work is to investigate the fundamental processes occurring during ablation of solid targets in a liquid. Time resolved imaging in air and water was carried out on an aluminium target and the dynamic plasma expansion behaviour was studied as a function of laser energy. The expansion in air was found to follow a general shockwave expansion model. Similar behaviour was observed in water at early times, followed by a contraction of the plasma expansion which was attributed to a cooling effect and has been seen in comparable studies [2]. The contraction of the plasma was found to proceed more rapidly as the laser pulse energy is increased.

Time resolved spectroscopy studies of aluminium were also carried out in air and water at different laser energies as a complementary diagnostic technique to further probe the characteristic behaviour of a plasma created in a liquid environment and to make a comparison to the case in air. For a plasma expanding in air, broadband emission was the dominant observation in the initial stages of the plasma lifetime followed by line emission in the later phases. Optical emission from a plasma created in water ambient was found to be weaker than that observed in air. In this case broadband emission was observed which was rapidly quenched in agreement with findings from similar works reported in the literature for single pulse plasma emission underwater [3]. No line emission was observed for a plasma formed in liquid which was attributed to the short duration of the laser pulse (~6ns) in line with findings from related works where longer pulse durations were found to produced narrow line emission [4,5].

Acknowledgements

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P:08 X-ray imaging of inertial confinement fusion capsules at Orion
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AWE, UK

X-ray self-emission has been used to assess the implosion performance of direct drive capsules. Deuterium filled glass capsules were irradiated with 10 long pulse beams at 3ω. The laser pointing was adjusted with the aim of varying the implosion symmetry. Time resolved images were acquired using 2 gated x-ray cameras and time integrated images were acquired with pinhole cameras.

P:09 Design of direct drive implosion targets on Orion
J E Coltman
AWE, UK

The Orion laser facility provides a platform for performing direct drive capsule implosion experiments. The predicted level of capsule performance for these types of experiments is uncertain, largely due to the reduced number of laser beams (10), compared to facilities such as OMEGA (60), which limit the drive symmetry. To this end, following a 1D design study of capsule phase space, preliminary experiments have been performed to evaluate the performance of deuterium (DD) filled targets.

An exploding pusher design is desirable both for robustness and for future applications. The optimum capsule, selected from the study, taking into account facility and target fabrication constraints, satisfies design criteria on the 1D clean fusion yield, capsule dynamics and implosion time. The nominal target was a silica glass shell of radius 250±10μm and thickness 2.3±0.5μm, filled with 10atm. of DD gas.

The work presented here focuses on the design of an optimum exploding pusher capsule. Some of the initial experimental results are included for comparison.
P:10 Self-consistent absorption and transport models for short pulse laser-matter interaction
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In order to support experimental campaigns on short-pulse laser facilities, or develop point designs for fast ignition, laser interaction simulations with peak densities at, or approaching, solid density are required. Simulating high-density plasmas places severe constraints on the use of standard particle-in-cell (PIC) techniques to solve Maxwell’s equations and the particle equations of motion, limiting the spatial and temporal scales which can be easily modelled. Recent increases in high performance computing (HPC) capabilities have helped to reduce the limitations on collisionless PIC simulations, but detailed modelling of collision-dominated regimes remains too computationally expensive to be performed on a regular basis. In order for detailed, collisional PIC simulations to run within a reasonable timeframe, novel approaches to modelling high density material must be employed. For the purposes of modelling laser-plasma interactions, however, these approaches must be consistent with retaining a full PIC model in the low density laser interaction region.

The approach proposed by Cohen, Kemp & Divol [1] has been adapted for the PIC code EPOCH. This model utilizes a ‘hybrid’ description for the plasma which replaces the standard Maxwell field solver in regions of high electron density (≥100nc) with a field update based on Ohm’s law. This approach relaxes the grid and time step constraints, permitting simulations to be run at a lower resolution while also dramatically reducing numerical self-heating.

The results of 2D simulations of short pulse laser interactions with solid density targets will be presented. The material heating predicted by hybrid EPOCH will be compared with that returned by the Monte-Carlo electron transport code THOR [2], as well as recent experimental results [3].


P:11 Numerical modelling of laser-plasma interaction
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The project is concerned with the development of a one dimensional model for the interaction of intense lasers with the stagnation layer formed at the collision front between two (or more) colliding laser produced plasmas.

The equations we are using which describe the laser-plasma interactions are inspired by the work of Rambo and Denavit [1]. In their research, these equations were solved using finite difference numerical methods. In our research, finite difference and finite element numerical methods were considered and studied, and we wish to use a finite element method for our simulations, and to exploit the most sophisticated algorithmic techniques to date.

In preparation for the modelling of plasmas, we have tested our approach on advection-diffusion partial differential equations. We are now extending this technique to fluid equations, and ultimately laser plasma equations including electric fields. Our finite element approach utilises the widely successful B-Splines polynomial basis (in fluid dynamics and most recently, in atomic physics dynamics) [2,3].

We are developing a portable single-shot Fourier transform spectrometer for application in laser induced breakdown spectroscopy (LIBS) [1] with a particular emphasis on remote or stand-off LIBS [2]. The device, based on a design by Harvey and Padgett [3], has many inherent features that give it performance advantages over a portable grating spectrometer. For example it does not require an entrance slit thereby increasing the throughput (the so-called Jacquinot advantage). Furthermore it can operate with minimum or even no collection optics in some circumstances. As a Fourier transform spectrometer it also benefits from the Fellget advantage. Combining Fellget and Jacquinot will result in a greater signal to noise ratio (SNR) compared to its grating-based counterparts. In addition the instrument can also measure the spectrum from a short or ultrashort pulsed source in a single shot just like a traditional grating spectrometer.

Our preliminary tests with low pressure discharge lamps have shown a gain in signal to noise ratio of at least four over traditional portable grating spectrometers, in stand-off mode with further optimisation ongoing. We are currently carrying out preliminary tests on the use of the instrument for LIBS. We will present the spectrometer design and some results on its performance with continuous wave and laser plasma pulsed sources.


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A series of experiments have been devised to explore the materials properties of low Z elements in a low density, low temperature regime (around a few mg/cc, 10s eV). In this regime departures from ideal-gas behaviour are expected to be small, however other models (e.g. Thomas-Fermi) predict large discrepancies. In order to resolve the difference between these two models a series of absorption measurements are planned based on face-on radiography using a point-projection backlighter source. The aim of the campaign is to determine the change in ionisation as a function of material density, determining the change in internal energy of the material, with the additional challenge of producing the low Z plasma in local thermodynamic equilibrium.
P:14 Numerical simulations to study transient evolution of linear kinetic Alfvén wave in inhomogeneous plasma

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The ion heating mechanism in solar corona due to Alfvén waves is major objective of present day space research. The Hinode data which has provided strong evidence for the presence of Alfvén waves in the corona and in coronal loops, has lead laboratory investigations and numerical simulations of Alfvén wave propagation and damping. The inhomogeneous plasmas may incorporate different MHD modes. In this paper the propagation of linear Kinetic Alfvén waves (KAWs) in inhomogeneous magnetized plasma has been studied while including inhomogeneities in transverse and parallel directions relative to the background magnetic field. The semi-analytical technique and numerical simulations have been performed to study the KAW dynamics when plasma inhomogeneity is incorporated in the dynamics. The propagation of KAWs in inhomogeneous magnetized plasma is expected to play a key role in energy transfer and turbulence generation in space and laboratory plasmas. The inhomogeneity scale lengths in both directions may control the nature of fluctuations and localization of the waves. We present a theoretical study of the localization of KAWs, variations in magnetic field amplitude in time, and variation in the frequency spectra arising from inhomogeneities. The relevance of the model to space and laboratory observations is discussed.
**P:15 Laboratory simulations of magnetospheric cyclotron instabilities**

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Cyclotron coupling between electrons and waves is thought to occur in both polar and equatorial regions of the Earth’s magnetosphere. An experiment, scaled to microwave frequencies, supported by numerical simulation and theoretical analysis, has investigated cyclotron emissions from an electron beam moving into a waveguide with an increasing magnetic field. Magnetic compression produces an electron distribution with a large and quantified, degree of velocity spread, as may be expected in the natural environment. The measurements and simulations indicate wave production efficiencies which are consistent with the magnetospheric observations and with theoretical predictions, preferentially polarised and propagating nearly perpendicularly to the magnetic field. The effectiveness of the wave generation mechanism is shown to be mitigated by the addition of a quasi-neutral background plasma in two distinct ways: The efficiency is reduced, whilst the emission acquires an increasingly variable nature, suggesting alternative competing near-threshold mechanisms. The project also considered the generation of signals in radiation modes where the wavevector has a significant component parallel to the bias magnetic field. Strong wave emission continued to be observed close to (but slightly downshifted from) the cyclotron frequency, with the E-field polarised perpendicular to the bias B-field. These measurements may have relevance to the radiation belts. Simulations, benchmarked against the experiments, have also been used to study cyclotron emissions from beams in unbound environments, particularly relevant to the polar magnetosphere.


**P:16 Conical guides for fast electrons generated via resistivity gradients**

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Substantial work has been done on investigating the possibility of using engineered magnetic field structures to guide, focus, and mitigate the divergence of beams of multi-MeV laser-generated electron beams in solid density targets. The magnetic fields are engineered by engineering resistivity gradients (via different material usage) into the targets. The fields are then self-generated at these interfaces in the presence of fast electron flow. Here we present the results of our study of a conical guide. Note that this conical guide inverse tapers as one moves away from the laser source, i.e. the radius of the cone increases on moving into the target.

We show that reflections from the conical wall lead to a mitigation in the divergence of the fast electron beam, both in theoretical terms and in 3D numerical simulations. Therefore the conical guides may be a target type that is readily manufacturable, and can be used for experimental investigations of guiding that exploits engineered resistivity gradients.
The ITER tokamak, currently under construction, will be run in high confinement mode (H-mode) to demonstrate the large fusion power gain required to make commercial fusion power production viable. H-mode tokamak scenarios have a large plasma pressure gradient at the edge of the plasma. However, H-mode plasmas are prone to edge-localized modes (ELMs), which are explosive instabilities of this edge pressure gradient. In current machines ELMs are tolerable. However, in ITER they are predicted to shorten the lifetime of the divertor [1] and so they must be controlled. One method of ELM control is to apply magnetic perturbations using non-axisymmetric coils outside the plasma [2]. The mitigation (increase in frequency and thus smaller ELMs) and suppression (complete removal) of ELMs has been demonstrated in several machines using this approach. There is a good understanding of the stability of axisymmetric plasmas to ELMs, based on peeling-ballooning modes [3]. The assumption of axisymmetry means that modes with different toroidal mode numbers are decoupled, leaving only poloidal mode coupling. The edge stability of axisymmetric tokamak plasmas can be rapidly calculated using codes such as ELITE [4]. However, when magnetic perturbations are applied the plasma is no longer axisymmetric. The calculation of non-axisymmetric equilibrium and stability is numerically challenging because different toroidal mode numbers (as well as different poloidal modes) are coupled. We develop a proposal by Hegna [5] to calculate the stability of tokamak plasmas with magnetic perturbations applied. This approach assumes that the non-axisymmetric field is small compared to the axisymmetric field, which we will show to be satisfied in the case of ELM control by magnetic perturbations. This method should be numerically fast, allowing parameter scans to be carried out which will allow the optimization of magnetic perturbation coil design and configuration. First results of this approach will be shown.

Work supported by the RCUK Energy Programme and EUROfusion

Astrophysical jets have been the subject of investigations for many years. They are ubiquitous and occur at many different length scales. Their formation mechanism is not fully understood. It is thought that some jets are formed by the wind from a young star interacting with an inhomogeneous plasma. We present simulations of a novel method of generating jets in the laboratory by locally heating the target using fast electrons. High energy electrons generated by the interaction of a high intensity laser with the front surface of a target can be guided using strong magnetic fields. These fields are self-generated at gradients of the resistivity inside the target. Using this guiding mechanism a localised return current can be set up that heats the target in a well-defined and confined region. This region, in turn, drives a blast wave into the low density region behind the target. By tailoring the geometry of the rear surface the outflow is focused into a narrow jet. We observe jets with aspect ratios of over 15 and Mach numbers between 2.5 and 4.3.
P:19 Preparations for inelastic ion impact excitation in future fusion plasmas: a unified semi-classical, impact parameter approach implemented in the ADAS framework

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In most plasmas, the dominant excitation mechanism of impurity or fuel ions is electron impact excitation (EIE), and ion impact is often neglected in calculations. However, for the conditions in beam heated fusion devices, and especially future high power machines like ITER, these effects must be considered more fully. The general reason for the neglect of ion species is because they are moving too slowly to produce large excitation rates. The projected plasma temperatures for ITER raise ion speed distributions markedly, neutral beam injection (NBI) energies move into the MeV range, and even electron collisions must include kinematic relativistic corrections. From the fusion plasma point of view, ion colliders must be considered for a range of impurity elements, and their collision energies are such that not only quadrupole but primary dipole transitions of the target must include ion impact contributions in the calculation of effective rates. New calculations are summarized here which span all of these conditions.

To determine the ion impact excitation rates, we adopt a semi-classical, impact parameter based approach that involves integrals along a classically determined orbit. This provides accurate results while also being much less computationally demanding than a full quantum mechanical approach. In addition, it incorporates the correct relativistic kinematics of the colliding particle, meaning this approach can be applied directly to EIE involving relativistic electrons that will be relevant at ITER. The theoretical details of this approach for nuclear excitation is rigorously covered by Alder et al in [1], and we consolidate the necessary alterations for application to atomic excitation [2, 3, 4, 6]. Within ADAS (Atomic Data and Analysis Structure), a general set of codes and associated data are being incorporated, exploiting the above extended semi-classical approach. These mass-produced data fulfill the needs for comprehensive general collisional-adiative (GCR) modelling of plasmas spanning key isoelectronic and isonuclear sequences. Defining samples of interest to the fusion and astrophysical plasma communities will be presented from our preliminary, ion excitation and effective plasma rate results.

Determining the saturation threshold of electromagnetic cascades caused by counter-propagating 10PW laser pulses

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Predicted advances in laser intensity have prompted interest in modelling laser-plasma interactions in the strong-field QED regime. Prolific pair production by a cascade process in this regime has been investigated in [1, 2] for counter-propagating laser pulses. This was done for both linearly and circularly polarised light in the intensity range $10^{23} - 10^{24}$ W cm$^{-2}$. Work on laser-plasma interactions using similar laser set-ups with solid density or gas targets has looked at pair and $\gamma$-ray production within this intensity range (e.g. [3]). The consensus is a rapid increase in production rates with laser intensity. However, the saturation threshold of these pair cascades has not been determined.

We present simulations of pair cascades in an initially underdense (~0.01$n_{crit}$) hydrogen plasma interacting with counter-propagating beams of $I \gtrsim 10^{24}$ and wavelength 1$\mu$m. Simulations are done using the PIC code EPOCH over a period of ~100 fs for a plasma slab thickness of a few$\mu$m. It is expected that the production rate will saturate with time. We discuss the relative importance of the following on saturation: (1) the plasma becoming overdense during the cascade; (2) radiative losses due to $\gamma$-ray emissions.


Structure factor measurements for warm dense iron

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X-ray scattering has been used as a diagnostic of the ion-ion structure factor for samples of warm dense iron using a novel geometry. The samples were created by laser driven shocks which were in turn generated with the VULCAN laser facility. The samples consisted of layered targets with 5 microns of CH coated onto 20 microns of Fe. Laser irradiation of the CH side resulted in a strong shock that heated and compressed the Fe to over 1eV at >13g/cc. As the shock emerged from the rear of the foil a separate 100ps laser pulse was used to drive a V foil creating an efficient source of He-like radiation at 5.2keV. This radiation was collimated by a pinhole arrangement and was incident on the rear side of the Fe foil. Scattering at angles varying from 70-135° was detected by HOPG based crystal spectrometers. The geometry of the experiment and preliminary analysis of data will be presented.
P:22 Plasma mirror characterisation on the picosecond timescale
PS Foster1,2, A Sellers3, D Symes1, M Zepf2, D Neely1, RP Pattathil1
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With recent advances in high power laser science, the light intensity level achievable is set to increase by several orders of magnitude in the near future. In this scenario, the pulse contrast – the ratio of the peak of the pulse to its baseline - is critically important in determining the interaction conditions met by the peak of the pulse. High-harmonic generation and ion-acceleration from ultra-thin foils are two research fields highly sensitive to the pre-formed plasma and target-decompression that occur once the laser pulse intensity has increased above ~10^{13}Wcm^{-2}. Although there are several methods to clean-up the temporal profile of the pulse in nanosecond timescales, using a plasma mirror is perhaps the only way to reliably improve the pulse contrast on picosecond timescales. The plasma mirror is essentially a fast switch turned on by the high intensity part of the pulse as it produces transient plasma, reflecting part of the incident pulse. The enhancement in contrast supplied by a plasma mirror is determined by the ratio of the plasma reflectivity to its cold reflectivity, governed by the efficiency of the anti-reflective optical coatings fielded. This is a reasonable model at early times of low intensity, however the behavior on the few picosecond timescale, where the intensity starts to rise significantly, is not well characterised. In this presentation I report on experimental measurements of plasma mirror behavior in this near-time domain together with some modeling offering insights into the dominant factors influencing the performance of this dynamic optical switch.

P:23 Transport in tokamaks with tilted elliptical flux surfaces
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Recent work demonstrated that breaking the up-down symmetry of tokamaks removes a constraint limiting intrinsic momentum transport, and hence toroidal rotation, to be small.[1] We show, through MHD analysis, that ellipticity is most effective at introducing up-down asymmetry throughout the plasma. Using GS2, a local δf gyrokinetic code that self-consistently calculates momentum transport, we simulate tokamaks with tilted elliptical poloidal cross-sections and a Shafranov shift. These simulations illuminate both the magnitude and poloidal dependence of nonlinear momentum transport. The results are consistent with TCV experimental measurements [2] and suggest that this mechanism can generate sufficient rotation to stabilize the resistive wall mode in reactor-sized devices. Furthermore, preliminary linear and nonlinear results indicate that tilting elliptical flux surfaces directly reduces the energy transport at low temperature gradients, but increases it at high temperature gradients. This work has been carried out within the framework of the EURofusion Consortium and J.B and F.I.P have received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053, as well as the RCUK Energy Programme (grant number EP/I501045). The views and opinions expressed herein do not necessarily reflect those of the European Commission.

P:24 Temporal contrast enhancement in high power laser systems employing optical parametric amplification techniques

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Promising high intensity laser applications are limited by the prepulses and the amplified spontaneous emission, therefore, a clean ps and ns scale contrast would be ideal. For this purpose, a low gain optical parametric amplifier has been designed and preliminarily tested. Pulses of 500 fs duration at 1053 nm are frequency doubled and then converted back to the input wavelength in an optical parametric process. Total efficiency greater than 14% has been obtained in idler beam of contrast better than 10^9, currently limited by the detection threshold. The system will be the temporal cleaning stage at TARANIS laser front end at Queen’s University Belfast. A theoretical model of the system has been developed by numerically solving the nonlinear coupled equations. The beam divergence, the group velocity mismatch, the pump depletion and the finite spectral bandwidth of the pulse have been taken into account in the calculations. The model predicts the efficiency, the temporal profile, the spatial profile, the resulting beams quality and the temporal contrast, which are in good agreement with the experimental findings. The high contrast beam will be used in laser-induced plasma experiments.
The high confinement, H-mode, of operation provides superior confinement in a tokamak plasma due to the edge transport barrier that forms. This is known as the pedestal and provides a high edge pressure gradient and therefore, a high bootstrap current. However, this mode of confinement is associated with short wave length instabilities at the edge of the plasma that trigger filamentary eruptions called edge localised modes (ELMs). These are a major concern for the next step tokamak fusion device ITER. Extrapolating the largest eruptions from today’s tokamaks to ITER conditions indicates that they would cause excessive erosion of the exhaust components when ITER operates at its full fusion performance, unless effectively controlled. These instabilities are widely believed to be caused by edge magnetohydrodynamic, MHD, instabilities known as peeling-ballooning modes that originate in the high pressure gradient of the pedestal, but can extend into the plasma core. Edge Localised Instabilities in Tokamak Equilibria (ELITE) [1] is a code that has been optimised to enhance understanding of these instabilities. It uses insight gained from analytical studies of peeling-ballooning modes to provide an efficient way to calculate the edge ideal MHD stability properties of tokamaks [1,2]. The efficiency is gained by exploiting the high toroidal mode number, n, of peeling-ballooning modes and expanding in this quantity. The result is valid down to n~4.

There exist tokamak scenarios, such as the quiescent H-mode (QH-mode), where there are no ELMs, and the pedestal characteristics are determined by low toroidal mode number (n~1-3) activity [3]. Thus a saturated kink-type edge harmonic oscillation (EHO) provides an ELM free regime with density control, allowing for similar performance plasmas to H-mode [3]. In order to study this behaviour with ELITE, the code’s mathematical formalism has been extended to arbitrary-n, with the aim of providing further insight into the structure and behaviour of low-n modes. This has been implemented into the ELITE code. Initial results show good agreement with the original ELITE formalism at n~10-15 when there is a superconducting wall on the plasma. However, there are discrepancies when the wall is removed and the modes are allowed to interact with the vacuum. This is something that is currently being investigated. Once complete, this new arbitrary-n version of ELITE will allow the study of the ELM free regimes, in particular QH-mode for ITER.


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Measurement of the radial electric field in the boundary plasma of MAST and its impact on turbulence

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Particle transport in the plasma edge and scrape-off layer (SOL) of magnetically confined plasmas has a significant non-diffusive component [1]. This component of particle transport is mediated by the intermittent ejection of large, filamentary plasma objects known as blobs into the plasma periphery. This can lead to uncontrolled and unpredictable particle transport to first-wall materials which, in a reactor environment, could provide a significant risk of erosion and excess fuel retention. Measurements on the JET [2], ASDEX-Upgrade [3] and DIII-D [4] tokamaks have demonstrated a link between the production of blobs and the radial shear layer, a region of strong radial gradients in the plasma flow. Quantification of this relationship is hindered by uncertainty introduced by the need to use multiple diagnostics to measure both the flow profile and fluctuation statistics. Using a ball pen probe (BPP) on the Mega Amp Spherical Tokamak (MAST) this issue is avoided and the radial shear layer is quantitatively identified as a birth region of plasma blobs and holes.

The BPP [5,6] is a novel probe design which makes a direct measurement of plasma potential by shielding fluxes to the probe collection surface along the magnetic field line. Since no first-principles model for the probe exists, careful validation of the probe measurement has been obtained by comparison of the resulting electron temperature measurement with a Thomson scattering diagnostic on MAST, COMPASS and ASDEX-Upgrade. On MAST this comparison has been used to constrain the uncertainty in the plasma potential measurement. From the plasma potential the radial electric field can be extracted. Over a scan in both electron density and plasma current in L-mode the radial electric field is observed to grow with increased plasma current. In all cases the radial electric field exhibits a change in sign close to the boundary between open and closed field lines (the separatrix) which can be identified as the radial shear layer.

A separate Langmuir probe (LP), located locally on the face of the BPP, is used to collect fluctuation statistics of the ion saturation current simultaneously with the measurement of the radial electric field. This allows properties of the fluctuation probability distribution functions (PDFs) to be compared directly with properties of the radial electric field. The skewness of the PDF characterizes the tendency of the fluctuations towards large positive or negative events, thereby implying the presence of blobs or holes (negative depressions of plasma density). The skewness is observed to decrease to zero as the gradient of the radial electric field reaches a maximum. This provides quantitative evidence that the centre of the radial shear layer is a local production region of blobs and holes. It is hoped that future analysis of this relationship using a BPP will advance the understanding of blob production and intermittent transport.

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P:27 Plasma source for neutral beam etching

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Etching semi-conductor material with neutral beam has gained popularity as a research topic in recent years due to its potential in overcoming the limiting effects when etching with established plasma technologies. This poster presents the progress in developing and characterising a neutral beam source. An Oxford Instruments etching system was adapted to include two biased electrodes which extract the charged ions from the highly dense, inductively coupled plasma. The further addition of a neutralising component uses the interaction between an ion and the surface to form a neutral particle for etching.

Two neutraliser designs manufactured from carbon and gallium arsenide wafers will be presented. The carbon design features 1mm diameter holes, drilled to a depth of 10mm and spaced at regular intervals across the surface. The gallium arsenide design has a ‘Venetian blind’ style array of polished and cleaved wafers angled so as to maximise the interaction between ion and surface. Results for both targets are presented on the ion velocity distribution as determined through measurements with an ion energy analyser and from the temperature rise resulting from neutral and ion particles impacting a stainless steel foil disc. The suitability of both target designs in providing sufficient neutral beam flux for etching is discussed.
Fast-neutron generation by laser-driven deuterium ions from ultrathin targets

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An ultra-short burst of fast neutrons has a wide range of applications in science, industry, healthcare and security. However, the limitation in accessing large facilities has led to an increasing interest in finding a table-top source for academic research and industrial applications. Laser-driven ion accelerators have been investigated as a possible solution \cite{1,2}, commonly by using the ions accelerated via the so-called Target-Normal Sheath Acceleration (TNSA) \cite{3,4} mechanism impinging on suitable neutron converter targets in a beam-fusion scenario. Despite of being a robust mechanism, TNSA exhibits a slow ion energy scaling with respect to the incident laser intensity ($E_{\text{ion}} \propto I_{L}^{1/2}$), with a beam predominantly formed by protons. Here we present neutron generation using intense laser radiation pressure driven ion acceleration \cite{5,6}. The Radiation Pressure acceleration (RPA) holds the advantage of generating higher energy ion beams, including heavy ions, with high laser-ion conversion efficiency and low divergence. Unlike typical experiments, where a secondary converter target is needed to generate the neutrons, a beamed flux of neutrons above 10^9 n/sr was produced from the primary target itself when RPA mechanism is involved, with the neutron flux increasing further while using a secondary catcher target. Such intense beam of directed pulse of fast neutrons is well suited for ultra-fast radiography of materials with high spatial-resolution.

\begin{thebibliography}{9}
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\bibitem{2} D P Higginson et al., Phys. Plasmas 17, 100701 (2010).
\end{thebibliography}
P:29 The effect of plasma inhomogeneity on (i) radio emission generation by non-gyrotropic electron beams and (ii) particle acceleration by Langmuir waves

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Extensive particle-in-cell simulations of fast electron beams injected in a background magnetised plasma with a decreasing density profile were carried out. These simulations were intended to further shed light on a newly proposed mechanism for the generation of electromagnetic waves in type III solar radio bursts [1]. Here recent progress in an alternative to the plasma emission model using Particle-In-Cell, self-consistent electromagnetic wave emission simulations of solar type III radio bursts will be presented. In particular, (i) Fourier space drift (refraction) of non- gyrotropic electron beam-generated wave packets, caused by the density gradient [1,2], (ii) parameter space investigation of numerical runs [3], (iii) concurrent generation of whistler waves [4] and a separate problem of (iv) electron acceleration by Langmuir waves in a background magnetised plasma with an increasing density profile [5] will be discussed. In all considered cases the density inhomogeneity-induced wave refraction plays a crucial role. In the case of non- gyrotropic electron beam, the wave refraction transforms the generated wave packets from standing into freely escaping EM radiation. In the case of electron acceleration by Langmuir waves, a positive density gradient in the direction of wave propagation causes a decrease in the wavenumber, and hence a higher phase velocity \( v_{ph} = \frac{\omega}{k} \). The k-shifted wave is then subject to absorption by a faster electron by wave-particle interaction. The overall effect is an increased number of high energy electrons in the energy spectrum.

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The dependence of tungsten fuzz growth on He ionfluence in the range $10^{24}$-$10^{28}$ m²

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Tungsten (W) nanostructure, commonly referred to as tungsten fuzz, has been studied for several years now [1, 2]. It manifests as a modification of the W surface into a layer of nano-scopic morphology when the surface is exposed at high temperature (> 900 K) to bombardment by energetic (> ~30 eV) helium (He) ions. The phenomenon has been replicated numerous times in laboratory plasmas and could potentially occur in ITER, the next generation fusion device under construction in France. Recent collaborative experiments between the University of Liverpool and the University of California at San Diego have been conducted with the aim of examining the growth of tungsten fuzz at 1120 K, over a wide range of He ion fluence to better understand prior inconsistencies in the rate of growth. For instance, in Ref [2] the thickness of the tungsten fuzz layer is shown to scale with the square root of the exposure time. However, low He fluence ($<10^{24}$ He+/m²) exposed cases, conducted at low He⁺ ion flux [3] compared with [2], show fuzz layer growth much slower than that observed in [2]. An expanded set of fuzz layer growth data, made in a magnetron device [3], PISCES-A, and PISCES-B [2, 4], and taken over a wide range of He fluence ($10^{24}$-$10^{28}$ He+/m²), suggest that the growth expression in [2] is consistent with a more general fluence dependent power law with an exponent close to 0.5. The observed trend in the new data set further shows that other influences can also affect the growth of tungsten fuzz. Specifically, new data suggest that an incubation fluence of 2-3 ×10²⁴ He⁺/m² is necessary for the observation of initial surface morphology, a W atom deposition flux can lead to an enhancement in the rate of fuzz growth, and trace impurity fluxes can limit the growth of the fuzz layer at high fluence, consistent with the process of physical erosion [4]. The new data, and the implications for these findings will be discussed at the meeting.

P:31 Modelling heat pulse propagation in large helical device

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It is known that rapid edge cooling of magnetically confined plasmas, induced by pellet injection, can trigger heat pulses that propagate rapidly inward. These can result in either large positive or negative deviations of the electron temperature at the core. A set of particularly detailed measurements was obtained in Large Helical Device (LHD) plasmas [S. Inagaki et al, Plasma Phys. Control. Fusion 52 (2010) 075002], which are considered here. By applying a travelling wave transformations, we extend the model of R. O. Dendy, S. C. Chapman and S. Inagaki, Plasma Phys. Control. Fusion 55 (2013) 115009, which successfully describes local temporal evolution in these plasmas, to include also spatial dependence. The extended model comprises two coupled nonlinear first order ODEs for the (x,t) evolution of the deviation from steady state of two independent variables: the excess electron temperature gradient and the excess heat flux, both of which are measured in the LHD experiments. Pulse velocity is also defined in terms of plasma quantities. We compare the model results against LHD datasets using appropriate initial and boundary conditions. Sensitivity of this nonlinear model with respect to plasma parameters, initial conditions and boundary conditions is investigated. We conclude that this model is able to match experimental data for the time-evolving temperature profiles of pulses, across a broad radial range from the plasma edge to the plasma core.

P:32 ELM occurrence times in relation to the phase evolution of global plasma measurements in JET

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Understanding the ELMing process is central to fusion plasma physics, given the correlation between ELMing and enhanced confinement regimes, and the constraints on ELM magnitudes in ITER plasmas. New insight is provided by analysing the sequence of occurrence times of ELMs in JET plasmas, in relation to the time-evolving phase of signals measured in full flux toroidal loops in the divertor region. The JET full flux loop signals VLD2 and VLD3 capture aspects of the global dynamics of the plasma including large scale plasma motion, plasma dynamics in the divertor region, and mutual interaction with the control system. The signal amplitude is proportional to the voltage induced by changes in poloidal magnetic flux. We consider JET plasmas where a steady H-mode is sustained over several seconds; all the observed ELMs are intrinsic, there is no intent to pace ELMs by external means, and ELM occurrence times are determined from Bell emission at the divertor. Here we report how the VLD2 and VLD3 phases evolve in time ahead of an ELM: there is a build-up to the ELM on a timescale of 2ms to 5ms, during which the VLD2 and VLD3 signals progressively align to the previously identified phase (S C Chapman et al., Phys. Plasmas 21 062302 (2014)) at which ELMs preferentially occur. The VLD2 and VLD3 signals also become phase synchronized with each other, consistent with the emergence of coherent global dynamics in the integrated current density. Self-generation of global motion could arise from nonlinear feedback between the multiscale dynamics of the plasma and its interacting environment, including the control system, as we first suggested in Proc. 41st EPS Conference on Plasma Physics, http://ocs.ciemat.es/EPS2014PAP/pdf/P1.010.pdf. These new results further support the conjecture that intrinsic ELMs may be “self-kicked”, and that full flux loop signals could assist in ELM prediction or mitigation.

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*See the Appendix of F Romanelli et al., Proc. 25th IAEA Fusion Energy Conference 2014, St Petersburg, Russia
P:33 Suppression of Relativistic Laser Beam Filamentation via Elliptical Beam Profile

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The multiple filamentation (MF) process of intense Gaussian laser beams of different radial profiles in plasmas is investigated. It is shown that it is possible to suppress the filamentation instability by using an elliptically distributed Gaussian laser beam. When a high-power relativistic elliptically Gaussian laser beam propagates through an underdense plasma, it will break up into a regular filament pattern in contrast to the random-distributed filaments of a circular laser beam and most of the laser power is concentrated into a central filament. For a highly elliptical beam, it experiences an asynchronous and anisotropic diffraction process in the plasma channel, the unstable diffractive ring structures in the circular case cannot be produced and the azimuthal modulational instability is thereby suppressed. The new findings are also verified in our fully relativistic three-dimensional particle-in-cell simulations.