49th IOP Annual Plasma Physics Conference

27–30 March 2023
St Catherine's College, Oxford, UK

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Timetable

Monday 27 March 2023

Time	Type	Speaker
From 12pm	**Registration**	
12:45pm	**Lunch**	
1:50pm	Welcome	Kate Lancaster
2pm	Invited speaker (Culham Thesis Prize)	Alex Picksley
2:40pm	Contributed talk	Simon Opie
3pm	**Break**	
3:25pm	Sponsor flash talk	Ashley Crane, Amplitude Laser
3:30pm	Invited speaker	Eva Loss
4:10pm	Contributed talk	Edward Parr
4:30pm	Invited speaker (Rutherford Communication Prize)	Aaron Ho, Luca Vialetto
4:50pm	**Drinks reception and poster session**	
6:30pm	**Close**	

Tuesday 28 March 2023

Time	Type	Speaker
8:30am	**Arrival refreshments**	
9am	Invited speaker	Cyd Cowley
9:40am	Contributed talk	Jack Halliday
10am	Invited speaker	Stephanie Yardley
10:40am	**Break**	
11:15am	Invited speaker	Francisco Suzuki-Vidal
11:55am	Contributed talk	Olli Tarvainen
12:15pm	Contributed talk	Tajinder Singh
12:35pm	Close	
12:45pm	**Lunch**	
From 1:50pm	**Free time/tours** **Ashmolean Museum tour** (Beaumont St, Oxford OX1 2PH) at 2:30pm finishes at 3:30pm; you are welcome to make your own way, or if you would like to walk in a group, please meet in the JCR Lounge for a prompt 2pm leave. **First Light Fusion Ltd tour**, please meet in the JCR Lounge at 1:50pm for a prompt 2pm leave by bus.	
5:45pm	**Evening public lecture** Refreshments served from 5:45pm and lecture starts at 6:30pm (Martin Wood Lecture Theatre, Parks Road, Oxford OX1 3PU). Please make your own way to the venue.	
7:30pm	**Lecture finishes**	

Wednesday 29 March 2023

Time	Type	Speaker
8:30am	Arrival refreshments	
9am	Invited speaker	Adelbert Goede
9:40am	Contributed talk	Christina Ingleby
10am	Contributed talk	Stefano Merlini
10:20am	Contributed talk	Yuyao Wang
10:40am	Break	
11am	IOP Plasma Physics Group AGM	
11:40am	Invited speaker	Thomas Woedtke
12:20am	Contributed talk	Evgeny Gorbunov
12:40pm	Contributed talk	Maurizio Giacomin
1pm	Lunch	
2pm	Invited speaker	Karen Aplin
2:40pm	Contributed talk	Alexander Liptak
3pm	Contributed talk	Archie Bott
3:20pm	Break	
3:50pm	Invited speaker	James Oliver
4:30pm	Contributed talk	Adam Fraser
4:50pm	Contributed talk	Jergus Strucka
5:10pm	Contributed talk	Muhammad Asif Shakoori
5:30pm	Close	
7:30pm	Drinks reception	
8pm	Conference Dinner	

Thursday 30 March 2023

Time	Type	Speaker
8:30am	Arrival refreshments	
9am	Invited speaker	Daniel Kennedy
9:40am	Contributed talk	Camille Granier
10am	Contributed talk	Benjamin Harris
10:20am	Invited speaker	Aarón Alejo
11am	Break	
11:20am	Invited speaker	Mike Jackson
12pm	Contributed talk	Lou Holland
12:20pm	Contributed talk	Robert Paddock
12:40pm	Contributed talk	Marko de Leyen
1pm	Lunch	
2pm	Close and depart	

Invited Speakers

Cold atmospheric plasma applications in medicine

Thomas von Woedtke[1,2], Klaus-Dieter Weltmann[1,3]
[1]Leibniz Institute for Plasma Science and Technology (INP Greifswald), Greifswald, Germany
[2]Greifswald University Medicine, 17475 Greifswald, Germany, [3]Greifswald University, 17487 Greifswald, Germany

The Influence of Divertor Design on Detachment Control

Cyd Cowley[1,2], B Lipschultz[1], D Moulton[2]
[1]York Plasma Institute, University of York, United Kingdom, [2]UKAEA-CCFE, Culham Science Centre, United Kingdom

The erosion performance of selected tungsten coatings by ion beam and plasma sources compared to calculated predictions for fusion energy plasma facing surface applications

Zeyad Ali, James Bradley, David Cox, James Dutson, Mike Jackson[1], Sarah Thornley, Vladimir Vishnyakov, Erik Wagenaars, Yuri Zhuk
[1]Tokamak Energy, United Kingdom

Low density plasma waveguides for multi-GeV laser Wakefield accelerators

Alexander Picksley
Culham Thesis Prize Winner

The Origins of Solar Energetic Particles

Dr Stephanie Yardley
University of Reading, United Kingdom

Electromagnetic Instabilities in high-b Spherical Tokamaks

D Dickinson, M Giacomin, Dr Daniel Kennedy, B Patel, C.M Roach
UK Atomic Energy Authority (UKAEA), United Kingdom

Sparks in space: electrical processes at the planets

Professor Karen Aplin
University of Bristol, Bristol, United Kingdom

Stabilized radiation pressure acceleration and neutron generation in ultrathin deuterated foils

Aarón Alejo
Universidade de Santiago de Compostela, Spain

CoffeeBreakDown

Aaron Ho[1], Luca Vialetto[2]
Rutherford Plasma Physics Communication Prize
[1]The Dutch Institute for Fundamental Energy Research (DIFFER), The Netherlands, [2]Kiel University, Germany

CO2 conversion via coupled plasma-electrolysis process

Adelbert Goede
The Dutch Institute for Fundamental Energy Research (DIFFER), The Netherlands

Applications of Bayesian Inference in Radiation Reaction Experiments

S. P. D. Mangles[1], Eva Los[1]
[1]Imperial College London, London, United Kingdom

The projectile approach to inertial confinement fusion and opportunities for collaborations

Dr Francisco Suzuki-Vidal
First Light Fusion, United Kingdom

Instabilities driven by fast particles in the JET DT campaign

James Oliver
UK Atomic Energy Authority (UKAEA), United Kingdom

Cold atmospheric plasma applications in medicine

Thomas von Woedtke[1,2], Klaus-Dieter Weltmann[1,3]
[1]*Leibniz Institute for Plasma Science and Technology (INP Greifswald), Greifswald, Germany*
[2]*Greifswald University Medicine, 17475 Greifswald, Germany,* [3]*Greifswald University, 17487 Greifswald, Germany*

Invited Speaker VIII, March 29, 2023, 11:40 - 12:20

Plasma medicine means the direct application of physical plasma on or in the human body for therapeutic purposes. For a direct application on living tissue, cold atmospheric pressure plasma (CAP) is used, i.e. plasma generated in atmospheric air environment with temperatures lower than 40°C at the target site of plasma treatment. In recent years, mainly two basic concepts of CAP sources were tested and partially applied for medical purposes: dielectric barrier discharges (DBD) and plasma jets [1,2,3]. Because CAP chemistry is dominated by nitrogen and oxygen chemistry, biological plasma effects that are potentially useful for medical applications are predominantly based on effects of reactive (redox-active) oxygen and nitrogen species (ROS, RNS), leading to the classification of plasma medicine as a field of applied redox biology [4]. Initially, focus of clinical application of CAP was in the field of wound healing. This promising application is based on the very effective inactivation of a broad spectrum of microorganisms by CAP and, above all, its ability to directly stimulate tissue regeneration [5]. Several CAP sources are CE-certified as medical devices, opening up the possibility of broad clinical use of CAP. In Germany, a guideline for physicians on the "Rational therapeutic use of cold physical plasma" has been in place since February 2022, especially related to wound healing. Besides this, several other indications for plasma application are taken into consideration including dermatology/skin diseases, local infection control, and dentistry. Because CAP's potential to induce controlled cell death (apoptosis) in cancer cells, plasma application for cancer treatment is now an important research field [6]. To consolidate medical plasma application and to optimize and further develop medical plasma devices, a more in-depth knowledge of control and adaptation of plasma parameters and plasma geometries is in focus of current research to get suitable and reliable plasma sources for different therapeutic requirements [7].

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[2] Th. von Woedtke, S. Reuter, K. Masur, K.-D. Weltmann. Plasmas for medicine. Phys. Rep. 530 (2013) 291-320
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[7] Th. von Woedtke, S. Emmert, H.-R. Metelmann, S. Rupf, K.-D. Weltmann. Perspectives on cold atmospheric plasma (CAP) applications in medicine. Physics of Plasmas 27 (2020) 070601

The Influence of Divertor Design on Detachment Control

Cyd Cowley[1,2], B Lipschultz[1], D Moulton[2]
[1]York Plasma Institute, University of York, United Kingdom, [2]UKAEA-CCFE, Culham Science Centre, United Kingdom

Invited Speaker IV, March 28, 2023, 09:00 - 09:40

For high power tokamaks, it will be vital to find solutions to the high heat and particle loads expected on divertor targets. One promising solution is operating with a detached divertor, where high-temperature conduction-dominated plasma is not in direct contact with material, but instead ‘detaches’ and terminates some point upstream of the divertor targets. This
location in which the plasma transitions from a high temperature conduction-dominated plasma to a colder, partially ionised gas is referred to as the detachment front.

Divertor detachment can be achieved and controlled through fuelling, seeding plasma impurities, and varying machine power. How detachment can be accessed and controlled using these controllers may be vital for future machines, since pushing a plasma into a deeply detached regime may negatively impact core performance and pumping of helium ash.

One predicted way of changing the relationship between detachment and machine controllers is by changing the configuration and topology of a divertor. The quasi-analytical detachment location sensitivity (DLS) model [2,3] allows prediction of detachment front movement in different divertor geometries. Several key predictions from this model are the positive effect a long connection length and high magnetic flux expansions have on detachment position control. These models have been compared against SOLPS-ITER simulations, both in idealised geometries such as those in Figure 1, and of more realistic tokamak geometries. Predictions from simple modelling are also compared to experimental camera and spectroscopy data from the MAST-U tokamak†.

In general, the broad predicted effects of alternative divertor features upon detachment access and control seem apparent in both simulation and experiment, though there is disagreement with regards to the exact strength of these effects. Better matching between DLS prediction
and simulation occurs in high-power, impurity-loss dominated plasmas, as seen in Figure 2. Understanding of the effects geometry plays on detachment can be used to design next generation reactor-like tokamaks, in conjunction with other physics and engineering constraints.

References

[1] D. Moulton et al, Plasma Physics and Controlled Fusion, vol. 59, no. 6, 2017.
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† See the author list of J.R. Harrison et al 2019 Nuclear Fusion 59 112011

The erosion performance of selected tungsten coatings by ion beam and plasma sources compared to calculated predictions for fusion energy plasma facing surface applications

Zeyad Ali, James Bradley, David Cox, James Dutson, Mike Jackson[1], Sarah Thornley, Vladimir Vishnyakov, Erik Wagenaars, Yuri Zhuk
[1]*Tokamak Energy, United Kingdom*

Invited Speaker XIII, March 30, 2023, 11:20 - 12:00

In fusion energy devices plasma erodes the reactor surfaces. Plasma facing materials have many requirements and tungsten satisfies many of these including low tritium retention, good thermal conductivity, high melting point and good erosion resistance. More requirements especially machinability, mechanical stability, lower weight and lower cost can be achieved if tungsten coatings are combined with copper as a base material.

The erosion rate must be known to estimate the lifetime of plasma facing components. In the present study a set of erosion experiments were undertaken to measure the sputter yield with partner organisations; Helium ion beam erosion at Huddersfield University, Helium plasma erosion at University of Liverpool, Argon plasma erosion at Plasma Quest Ltd and Xenon ion beam erosion at University of Surrey.

This work compares erosion of tungsten sheet, tungsten coated on copper by chemical vapour deposition, tungsten deposited by the additive manufacture and tungsten coating laid down by thermal plasma spray.

Low density plasma waveguides for multi-GeV laser Wakefield accelerators

Alexander Picksley
Culham Thesis Prize Winner

Invited Speaker, March 27, 2023, 14:00 - 14:40

Laser-driven plasma accelerators (LPAs) aim to provide a reliable, robust alternative to conventional technology for real-world applications and for future energy frontier colliders. A key challenge of their development is achieving multi-GeV electron energy gain in a single LPA stage. This requires high-intensity laser pulses to propagate over meter-scales, equivalent to tens of Rayleigh ranges, in low-density plasma. Among many available techniques to guide high intensity laser pulses, hydrodynamic optical-field-ionized (HOFI) plasma channels [1-3] provide an ideal way to meet the challenging requirements of a multi-GeV LPA stage. These are generated by focusing an ultrashort pulse into neutral gas, forming a hot column of plasma via optical field ionization, which expands hydrodynamically to form a plasma channel. In the first half of this talk, we discuss the development of meter-scale, low-loss plasma channels suitable for multi-GeV LPAs. This can be achieved employing a “conditioning” (or “self-waveguiding”) pulse to ionize the neutral collar surrounding a HOFI structure and increase its depth [4,5]. In the second half of this talk, we explore another advantage of optically generated channels – the potential to sculpt the plasma density along the LPA. We show how the density down-ramp generated between neutral gas immediately prior to the channel and the channel itself can be used to trap electrons. We present results of a recent experiment at the Gemini TA3 laser (RAL) in which ~ 1 GeV bunches, with few percent-level energy spread, were generated by sub-100 TW laser pulses.

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The Origins of Solar Energetic Particles

Dr Stephanie Yardley
University of Reading, United Kingdom

Invited Speaker V, March 28, 2023, 10:00 - 10:40

Solar energetic particles (SEPs) are accelerated by magnetic reconnection-driven processes during solar flares and by coronal mass ejection (CME)-driven shocks. Large gradual SEP events, associated with high energy protons (up to tens of GeV) can cause hazardous space weather conditions at Earth and hence pose a severe radiation risk for crewed spaceflight and a significant threat to near-Earth technological assets. However, we currently do not fully understand where SEPs originate from and what specific features in a solar active region could be the sources of SEPs. In this work, we have used observations from multiple space-based missions along with magnetic field modelling to identify the source of SEPs and the important role that the magnetic field configuration surrounding the active region, the magnetic connectivity and CME propagation direction play in the escape and arrival of SEPs at Earth.

Electromagnetic Instabilities in high-b Spherical Tokamaks

D Dickinson, M Giacomin, Dr Daniel Kennedy[1], B Patel, C.M Roach
[1]UK Atomic Energy Authority (UKAEA), United Kingdom

Invited Speaker XI, March 30, 2023, 09:00 - 09:40

Electromagnetic microinstabilities are likely to dominate transport in high b next generation spherical tokamaks (STs) such as STEP [1]. To be economically competitive, ST power plant designs require a high b (the ratio of thermal pressure to magnetic pressure) and sufficiently
low turbulent transport to enable steady-state operation. In plasma where be is sufficiently high, the curvature of the confining magnetic field and the plasma kinetic gradients can excite electromagnetic instabilities such as Kinetic Ballooning modes (KBMs) and Microtearing Modes (MTMs). The KBM is driven by electrons and ions at binormal-scales approaching the ion Larmor radius (kyri 1), propagates in the ion diamagnetic direction, and is closely related to the ideal ballooning mode of MHD [2]. MTMs excite radially localised current layers on rational surfaces, are primarily driven unstable by the electron temperature gradient, and propagate in
the electron diamagnetic direction. They generate magnetic islands on rational surfaces that tear the confining equilibrium flux surfaces and enhance electron heat transport. In devices where b exceeds a certain threshold value, KBMs and MTMs can become the dominant instabilities
and sources of transport in the plasma core, and local linear gyrokinetic (GK) simulations find that this is likely to be the case for STEP [3]. These two modes, and the nonlinear interactions between them, will likely play a crucial role in setting the transport levels in the core of such a device, and dictate the confinement times attainable in next-generation STs. Fully understanding the transport impacts of these modes is one of the major physics questions which must be answered to build confidence in the feasibility of designs of future ST power plants.

Whilst GK simulations have thus far proven to be a very accurate tool in modelling turbulent transport in predominantly electrostatic regimes at low b, obtaining saturated nonlinear simulations of plasmas with unstable KBMs and MTMs has proven computationally and conceptually challenging. Local simulations suffer from the so-called high b runaway [4] that is still not
fully understood, where turbulent amplitudes and transport levels grow to very large values once a threshold b is exceeded. Some of the first local nonlinear electromagnetic gyrokinetic simulations for conceptual ST equilibria predicted very large magnetic flutter transport from low wavenumber MTMs, with heat fluxes often orders of magnitude greater than the available heating power [5]. However, recent investigations that retain only MTMs and exclude KBMs by neglecting dBk, reveal a strong sensitivity of the heat flux to parallel dissipation and velocity pace resolution. With sufficient resolution or dissipation to avoid numerical instabilities, recent MTM-only turbulence simulations saturate cleanly at much reduced electron heat flux [see Figure (1)].

This contribution will discuss electromagnetic turbulence in next generation high b STs, briefly reviewing local nonlinear electromagnetic gyrokinetic simulations to date and presenting recent advances in our understanding of the key factors that influence the saturation of the turbulence, including the crucial impact of including compressional magnetic perturbations.

References:

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[4] M.J. Pueschel, P.W. Terry, and D.R. Hatch, Physics of Plasmas 21, 055901 (2014).
[5] "Microstability and transport in high beta spherical tokamaks" D. Dickinson, M. S. Anastopoulos-Tzanis, A. Bokshi, R. Davies, M. Giacomin, D. Kennedy, B. S. Patel, L. Richardson, C. M. Roach, H. R. Wilson, JOINT VARENNA-LAUSANNE INTERNATIONAL WORKSHOP THEORY OF FUSION PLASMAS [invited oral] (2022)

Sparks in space: electrical processes at the planets

Professor Karen Aplin
University of Bristol, Bristol, United Kingdom

Invited Speaker IX, March 29, 2023, 14:00 - 14:40

Most of us have felt awe and wonder when experiencing - preferably, from a safe distance - the majesty of a thunderstorm. As well as its spectacular displays, lightning is a hazard, and affects atmospheric chemistry. It is associated with specific types of cloud and meteorological processes, as well as being implicated in the origins of life on Earth. For these reasons, lightning has long been seen as a significant phenomenon. However, there is more to atmospheric electricity than just lightning: its quieter and less well-known sibling exists in every planetary atmosphere as a continual flow of ions and electrons, and can form a global-scale electrical circuit with lightning acting as a “battery”. The iconic Voyager 1 mission was the first to photograph an extra-terrestrial thunderstorm at Jupiter in 1979. Since then, lightning has been detected on most other Solar System planets. On Earth, small currents away from thunderstorms can affect clouds, interact with particles from dust or pollution and even potentially influence the weather. Similar non-thunderstorm processes may also act in other planetary atmospheres, such as Titan and Venus. In this talk I will provide the unifying scientific background and context for the study of atmospheric electricity, and describe past, present, and future observations.

Stabilized radiation pressure acceleration and neutron generation in ultrathin deuterated foils

Aarón Alejo
Universidade de Santiago de Compostela, Spain

Invited Speaker XII, March 30, 2023, 10:20 - 11:00

Despite the significant interest in bright neutron sources, with applications in fields such as basic science, security, or material science, the large footprints and high running costs of conventional neutron facilities has limited the number of laboratories offering these beams. In this context, these has been a growing interest in compact, accelerator-driven neutron sources, with laser-based solutions being arguably one of the most appealing alternatives [1]. Further to advantages such as cost-effectiveness, compactness and radiation confinement by closedcouple experiments, these neutron beams would also benefit from the intrinsically appealing
characteristics of laser-based accelerators, such as high brilliance and ultra-short burst duration.

Most of the efforts in the generation of a laser-based neutron source have focussed on a double-target configuration, the so-called pitcher-catcher scheme, in which the interaction of a high-power laser with the first target accelerates an ion beam which subsequently impinges the second target, where a neutron beam is produced via nuclear reactions [2]. Unlike this method, here we present an alternative approach based on the generation of neutrons from a single target [3]. In the Light Sail (LS) regime of Radiation Pressure Acceleration, the laser compresses and propels forward the irradiated portion of an ultra-thin target, leading to efficient acceleration
of ions in a narrow spectral bandwidth and divergence cone. The extreme densities reached in the compressed target for prolonged periods of time are shown to be an efficient means to produce copious amounts of neutrons. However, a key requirement for efficient LS acceleration,
and therefore neutron generation, is to maintain the integrity of the ultra-thin target over the duration of the laser pulse. Here we present a possible route to avoid premature termination of LS acceleration from ultra-thin foils, achieved by adding a high-Z surface layer. As a result of this stabilisation, not only a narrow-band ion beam is produced, but also a fast neutron source with fluxes exceeding 109 n/sr was produced at optimum conditions, exceeding by more than an order of magnitude the isotropic flux measured from thicker CD targets under similar interaction conditions.

References
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[2] S. Kar et al., New Journal of Physics, 18(5), 053002 (2016)
[3] A. Alejo et al., Phys. Rev. Lett. 129(11), 114801 (2022

CoffeeBreakDown

Aaron Ho[1], Luca Vialetto[2]
Rutherford Plasma Physics Communication Prize
[1]The Dutch Institute for Fundamental Energy Research (DIFFER), The Netherlands, [2]Kiel University, Germany

Invited Speaker III, March 27, 2023, 16:30 - 16:50

With this application, we present a new podcast-style YouTube channel about plasma science and applications. We are two postdoctoral researchers working in the field of plasma physics. The novelty of our channel is that we try to connect topics from fusion plasmas to low-temperature plasmas for industrial applications. Our original concept, which came during the pandemic period (summer 2021), was to create a platform for students to share their work and ideas. As our channel matured, we expanded our activities to include experienced researchers and professors. Now, we aim to provide a relaxed environment for scientists in any strata to share their expertise, thoughts and experiences working in their specialized domains of plasma science. Our format consists of long-form audio and video recordings, ranging from 30 minutes to 1 hour, of informal conversations with invited guests. While broad topics of mutual interest are agreed-upon before recording, we also encourage guests to explore the tangents occurring from natural discussion during the recording via follow-up questions. This aims to paint a better picture of how the mind of a scientist truly works, as we found that expressing the more creative and human side of science is crucial in capturing the minds of listeners. Our channel currently includes 25 episodes on plasma science and applications, and is widely appreciated by members inside and outside of the field, as suggested by the analytics (with >3000 views and >300 hours of total watch time).

The submission can be found online on YouTube:
https://www.youtube.com/@breakdownpodcast

CO_2 conversion via coupled plasma-electrolysis process

Adelbert Goede
The Dutch Institute for Fundamental Energy Research (DIFFER), The Netherlands

Invited Speaker VII, March 29, 2023, 09:00 - 09:40

In the quest for large scale, long duration renewable electricity storage, conversion into high energy density chemicals and fuels features high on the agenda of the energy transition. In particular, enabling long haul transportation requires high energy density fuels, aviation being the extreme case. The EU project KEROGREEN on CO_2 neutral kerosene, synthesised from air and water, powered by renewable electricity, offers a tantalising prospects. CO_2 feedstock is split by plasma driven dissociation followed by electro-chemical O_2 separation and CO purification by pressure swing adsorption. Subsequently, kerosene is synthesised by Water Gas Shift production of Syngas (H_2 and CO) followed by the synthesis of kerosene through the Fischer-Tropsch process and optimised by Hydrocracking. The fuel cycle is closed by re-capturing CO_2 emitted during flight by ground based air capture. Because the synthesised kerosene contains no sulphur and produces no soot (no aromatic compounds), it meets future air pollution standards. Synergism between plasma activated species and novel perovskite electrodes of the oxygen selective membrane is shown to increase productivity. Results presented show that the product stream of the coupled plasma-electrolysis process contains 91% less oxygen and 138% more CO than supplied by plasmolysis alone. In addition, durability tests (~100hrs) show better stability of the perovskite electrode material for the coupled process than for CO_2 electrolysis alone. This synergy between electrically driven plasmolysis and electrolysis opens up a novel route to CO_2 conversion into valuable CO feedstock for the synthesis of hydrocarbon fuels.

Applications of Bayesian Inference in Radiation Reaction Experiments

S. P. D. Mangles[1], Eva Los[1]
[1]*Imperial College London, London, United Kingdom*

Invited Speaker II, March 27, 2023, 15:30 - 16:10

Radiation reaction, the recoil of a charge upon emitting radiation, is the subject of ongoing theoretical and experimental research, particularly in highly intense electromagnetic fields where quantum effects become significant. Various suitable theories have been proposed but have yet to be validated experimentally. These models (and their implementations in particle-in-cell codes) inform a wide range of research topics, from the radiative properties of quasars to laser-solid target experiments using the next generation of high power lasers: an understanding of the accuracy of different models of radiation reaction, and their regimes of applicability, is critical.

Radiation reaction models can be tested by colliding high intensity laser pulses with high energy electron beams. The laser electric field is Lorentz boosted, and thus approaches the critical field of quantum electrodynamics in the collision rest frame. Electron beams produced by laser wakefield accelerators have small transverse sizes, short durations and can be readily synchronized with the colliding laser pulse. They are therefore well suited to these experiments.

We have developed a Bayesian inference method which can retrieve the parameters that govern the collision between the electron bunch and laser pulse, including the electron phase space distribution, which is not normally well known. The Bayesian framework provides natural methods for estimating the uncertainties on the inferred parameters and for comparing the validity of different models of radiation reaction.

The projectile approach to inertial confinement fusion and opportunities for collaborations

Dr Francisco Suzuki-Vidal
First Light Fusion, United Kingdom

Invited Speaker VI, March 28, 2023, 11:15 - 11:55

First Light Fusion is developing a new approach to inertial fusion that uses a high-velocity projectile as the driver. The key that enables this different driver choice are the corresponding target designs, which have a unique aspect, which is the “amplifier”. The amplifier focuses the shockwaves produced on projectile impact, delivering substantially higher pressures to the fuel capsule than otherwise possible with the projectile approach.

This talk will outline the fundamental physics basis of the projectile approach using our in-house drivers: BFG, a 32 mm bore, 2-stage gas-gun, and Machine 3, a 14 MA, 2 us pulsed-power electromagnetic launcher. The experimental data is used to validate our numerical simulations tools: Hytrac, an AMR, multi-material hydrodynamics code, and B2, a parallel multi-material MHD code. I will also present the design of our gain demonstrator, Machine 4, together with present and future opportunities for collaborations.

Instabilities driven by fast particles in the JET DT campaign

James Oliver
UK Atomic Energy Authority (UKAEA), United Kingdom

Invited Speaker X, March 29, 2023, 15:50 - 16:30

The Joint European Torus (JET) team recently conducted an experimental campaign using plasmas consisting of both deuterium (D) and tritium (T) instead of the D plasmas typically used in present-day experiments. This provided a unique opportunity to study fusion-born alphas, which are present in appreciable amounts in DT plasmas, and to assess the differences between D and DT plasmas. During our DT experiment, we varied the power of the beam injection system used to heat the plasma. During the steady state stage of our experiment, we observed high-frequency modes using two separate diagnostics. 21 toroidal Alfvén eigenmodes (TAEs) that match experimental observations were found using the linear MHD code, MISHKA. To understand why TAEs were excited in this plasma, we computed the fast particle distribution functions. Beam ions and fusion-born alpha particles were modelled using the full orbit particle tracking code LOCUST. High-resolution distribution functions produced by LOCUST were used as input for the stability code HALO. Stability calculations show that TAEs with sufficiently high toroidal mode numbers can be driven unstable by beam ions, while TAEs with small toroidal mode numbers are damped by the beam ions. Alpha particles drive all modes with significantly smaller growth rates than the beam ions. Comparing the drive from energetic particles to damping from thermal particles, all but one of the candidate modes are damped. The surviving mode with net drive fits experimental observation well. Further analysis of this mode can help us avoid dangerous instabilities in the burning plasmas that will exist in future reactors.

Contributed Talks

4 Effect of magnetic field stochastic layer formation in microtearing mode gyrokinetic nonlinear simulations

Maurizio Giacomin[1], David Dickinson[1]
[1]University of York, York, United Kingdom

6 Measurement of the H2O2 density distribution in the effluent of cold atmospheric-pressure plasma jets using cavity ring-down spectroscopy: Comparison between COST-Jet and kINPen

Benjamin Harris[1], Levin Krös[2], Andy Nave[2], Erik Wagenaars[1], Jean-Pierre van Helden[2]
[1]University Of York, York, United Kingdom, [2]Leibniz Institute for Plasma Science and Technology (INP), Greifswald, Germany

9 Parametric dependence of microwave beam broadening by plasma density turbulence

Lou Holland[1], Alf Köhn-Seeman[2], Roddy Vann[1]
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12 Using Solar Orbiter data to investigate kinetic instabilities in the Solar Wind

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13 Global gyrokinetic simulations of electrostatic microturbulent transport in LHD stellarator

Mr Tajinder Singh[1], Dr Javier H. Nicolau[2], Dr Federico Nespoli[3], Prof Zhihong Lin[2], Prof Abhijit Sen[4,5], Dr Sarveshwar Sharma[4,5], Dr Animesh Kuley[1]
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16 Studies of fast ion redistribution and loss from MAST-U plasmas using a Solid-State Neutral-Particle Analyser (ssNPA)

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26 Synchrotron-based radiography of electrical wire explosion and its hydrodynamic applications

Jergus Strucka[1], Bratislav Lukic[2], Marlene Koerner[1], Jack Halliday[1], Yifan Yao[1], Kassim Mughal[1], Daniel Maler[3], Sergey Efimov[3], Jonathan Skidmore[4], Alexander Rack[2], Yakov Krasik[3], Jeremy Chittenden[1], Simon Bland[1]
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29 Measuring the principal Hugoniot of ICF-relevant TMPTA foam

Robert Paddock[1], Matthew Oliver[2], Daniel Eakins[3], David Chapman[3], John Pasley[4], Mattia Cipriani[5], Fabrizio Consoli[5], Bruno Albertazzi[6], Michel Koenig[6], Artem Martynenko[7], Leonard Wegert[7], Paul Neumayer[7], Przemysław Tchórz[8], Piotr Rączka[8], Paul Mabey[9], Robbie Scott[2], Rob Clarke[2], Margaret Notley[2], Chris Baird[2], Nicola Booth[2], Christopher Spindloe[2], David Haddock[2], Samuel Irving[2], Warren Garbett[10], Ramy Aboushelbaya[1], Marko von der Leyen[1], Rati Goshadze[11], Valentin Karasiev[11], Suxing Hu[11], Peter Norreys[1]
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31 Observation of monoenergetic electrons from two-pulse ionization injection in quasilinear laser-wakefields

Marko Von Der Leyen[1], J Holloway[1], Y Ma[2], P Campbell[2], R Aboushelbaya[1], Q Qian[2], A Antoine[2], M Balcazar[2], J Cardarelli[2], Q Feng[1], R Fitzgarrald[2], B Hou[2], G Kalinchenko[2], J Latham[2], A Maksimchuk[2], A McKelvey[2], J Nees[2], I Ouatu[1], R Paddock[1], B Spiers[2], A Thomas[2], R Timmis[1], K Krushelnick[2], P Norreys[1]
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32 Diagnosing Non-Thermal Ion Heating in Magnetic Reconnection Experiments Using Optical Thomson Scattering

Dr Jack Halliday[1], Dr Lee Suttle[1], Dr Colin Bruulsema[1], Dr Sam Totorica[1], Prof Wojciech Rozmus[1], Dr Frederico Fiuza, Dr Danny Russell[1], Dr Vicente Valenzuela-Villaseca[1], Prof Sergey Lebedev[1]
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34 Characterising x-ray emission from laser-solid interactions and QED plasmas

Christina Ingleby[1], Dr Kate Lancaster[1], Professor Christopher Ridgers[1]
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36 New set of 4D drift kinetic equations to study the astrophysical plasma turbulence

Evgeny Gorbunov[1], Dr. Bogdan Teaca[2]
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44 Power coupling in negative hydrogen plasma ion sources

Dr Olli Tarvainen[1], Dr Dan Faircloth, Dr Scott Lawrie
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47 The failure of Chapman-Enskog theory in high-beta collisional plasmas

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48 Gyrofluid and gyrokinetic approaches for non-collisional plasmoid instability with finite beta_e

Camille Granier[1], Dario Borgogno[2], Daniela Grasso[2], Emanuele Tassi[1], Ryusuke Numata[3]
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53 Investigate Electron Density Perturbations in Magnetised HED Plasmas using an Imaging Refractometer

Stefano Merlini[1], J. D. Hare[2], G. C. Burdiak[3], J. W. D. Halliday[1], L. G. Suttle[1], A. J. Crilly[1], D. R. Russell[1], K. Marrow[1], J. P. Chittenden[1], S. V. Lebedev[1]
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54 Shear viscosity of complex plasmas in biaxial AC electric field

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55 Shock-cloud interaction experiments using a 2-stage light-gas gun

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81 SpK - A fast atomic physics code for generating tabulated EoS and opacity data for use in HEDP simulations

Mr Adam Fraser[1], Dr Nicolas-Pierre Niasse[2], Dr Aidan Crilly[1], Dr James Pecover[2], Dr Dave Chapman[2], Professor Jeremy Chittenden[1]
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91 Investigating the effects of bombarding hydrogen ion isotopes on the sputtering yield and ion penetration depth in beryllium PFCs using molecular dynamics methods

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4

Effect of magnetic field stochastic layer formation in microtearing mode gyrokinetic nonlinear simulations

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Contributed Talk X, March 29, 2023, 12:40 - 13:00

Significant progress has been achieved in magnetic confinement fusion over the past decays, paving the way for the design of the first demonstration fusion power plants based on the tokamak concept. The accurate design of future tokamaks requires predicting some key quantities, such as the energy confinement time, which strongly depends on turbulent transport. Complex gyrokinetic simulations are often used to identify and characterise the main instabilities that drive most of the particle and heat transport in the tokamak core.

Among the several instabilities that have been found in past experimental, theoretical and numerical investigations, an important role is played by the microtearing mode (MTM), which can significantly contribute to the electron heat flux in the core of high β spherical tokamaks. The MTM instability is a tearing instability at high mode numbers, characterised by magnetic perturbations that can reconnect at resonant surfaces, thus forming magnetic islands. If the magnetic islands at different resonant surfaces are sufficiently wide, they can overlap and increase the electron heat flux associated with stochastic magnetic diffusivity.

In this work, linear and nonlinear local gyrokinetic simulations are performed in experimentally relevant cases built from a MAST discharge. A collisional MTM instability is found to dominate at wavelengths comparable to the ion Larmor radius. The driving mechanism of this instability is investigated, showing the importance of the electron collision frequency, whose value is often affected by large experimental uncertainty. This motivates a nonlinear simulation scan, where the electron collision frequency is varied. While the effect of this parameter is modest in linear simulations, a strong dependence of the saturated heat flux value on the electron collision frequency is observed in nonlinear simulations.

The effect of magnetic islands generated by MTMs and their interaction is analysed, showing that an increase of the radial extension of the stochastic region caused by magnetic islands overlapping is consistent with the larger saturated heat flux value driven by the MTM instability observed in nonlinear simulations at low electron collision frequency. The effect of magnetic shear on the stochastic layer formation is also investigated, highlighting the important relation among island width, resonant surface separation and heat flux.
The important relation between heat flux and stochastic layer formation may be used to extend current quasi-linear theories and guide the development of high β spherical tokamaks.

6

Measurement of the H2O2 density distribution in the effluent of cold atmospheric-pressure plasma jets using cavity ring-down spectroscopy: Comparison between COST-Jet and kINPen

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Contributed Talk XVII, March 30, 2023, 10:00 - 10:20

Cold atmospheric-pressure plasma jets (CAPJs) are efficient sources of reactive oxygen species when supplied with a feed gas containing water vapour, making them well-suited to numerous roles in biomedicine. H2O2, the reactive oxygen species of focus in this study, plays a key role in plasma-assisted wound healing by promoting wound contraction and inactivating bacteria [1]. The presence of H2O2 has previously been investigated in the plasma afterglow, plasma-treated liquids, and biological media [2-4]. However, spatially resolved data is scarce. The distribution of H2O2 dispersing into ambient air from the plasma effluent is largely unknown, making it difficult to quantify the exposure of a substrate. To this end, this work presents the fully spatially resolved density distribution of H2O2 in the effluent of two CAPJs supplied with a helium and water vapour feed gas. These are the COST-Jet, originally designed as a reference standard, and the kINPen, a commercially available plasma source [5,6].
The plasma effluent is measured with continuous wave cavity ring-down spectroscopy, with a CAPJ being mounted in an optical cavity to characterise absorption along the line of sight of a mid-infrared laser at various axial and radial positions. The absorption spectra obtained from this are processed to isolate H2O2 absorption, allowing the line-of-sight integrated density of H2O2 to be extracted. The distribution of this parameter allows radial Abel inversions to be performed and the subsequent trends to be characterised in the axial direction, with the result of the Abel inversions giving the fully spatially resolved H2O2 density throughout the plasma effluent.
It is found that the H2O2 density profile along the axis of the COST-Jet is highly laminar up to 20 mm from the jet nozzle, at which point the density drops sharply as the H2O2 disperses more widely into the open air. In contrast, the H2O2 density profile of the kINPen is initially less laminar, however the density is more consistent further into the effluent and the same sharp drop is not observed. For both CAPJs, the bulk of H2O2 formation appears to happen either within the plasma channel or the first few millimetres of the effluent.

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9

Parametric dependence of microwave beam broadening by plasma density turbulence

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Contributed Talk XVIII, March 30, 2023, 12:00 - 12:20

High-power microwave beams can be used to inject power into magnetically confined fusion plasmas for the purpose of heating and current drive. These beams must traverse the turbulent layer of plasma at the edge of the tokamak. The density fluctuations there scatter incident microwaves, resulting in an overall broadening of the beams which can significantly impact the efficiency of the device. In fusion plasmas, the density fluctuation level can reach 100 % of the background density, and the plasma fluctuates on length scales similar to that of the wavelength used for power injection. This parameter regime is often not analytically tractable, so requires full-wave simulations in order to predict this effect. However, full-wave simulations are computationally expensive so are impractical for optimisation studies where a wide range of scenarios need to be simulated. We are therefore seeking to develop a predictive capability of this broadening for current and future tokamaks which is applicable in regimes that are not analytically tractable, but can be calculated in a fraction of a second rather than requiring expensive simulations.

To this end, we simulated a microwave beam propagating through a turbulent layer of plasma using the 2D full-wave cold plasma code EMIT-2D. We conducted a series of pairwise parameter scans to determine whether the dependence on each parameter is separable from the others. The parameters we considered were background plasma density, fluctuation amplitude, turbulence correlation lengths in the radial and poloidal direction, thickness of the turbulence layer, and microwave beam waist. We found two pairs of parameters that are not separable: the radial and poloidal correlations lengths, and the fluctuation level and background density. All other dependencies were found to be separable. We then performed a pointwise fit to the whole dataset in order to find an empirical formula for the beam broadening, making predictions of the effect possible in microseconds of processing time, instead of the hours required for full-wave simulation.

12

Using Solar Orbiter data to investigate kinetic instabilities in the Solar Wind

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Contributed Talk, March 27, 2023, 14:40 - 15:00

Solar Orbiter was successfully launched in February 2020. The goal of this ESA/NASA joint mission is to investigate the physics of solar processes at close radial distances to the Sun and eventually, at high solar latitudes out of the ecliptic plane. The spacecraft carries a suite of 4 in situ and 6 remote sensing instruments that will produce coordinated observations of unprecedentedly high resolution. We use the in situ instruments to study the solar wind, a continuous flow of high-beta plasma that is ejected from the Sun and fills the heliosphere. Specifically, we use statistical analysis to evaluate the conditions in the turbulent solar wind and how they impact the proton-scale stability of the plasma. Linear theory proposes that microinstabilities emerging from temperature anisotropy in the solar wind are responsible for restoring the plasma towards thermal equilibrium. However, the real solar wind does not provide the simple homogeneous background for microinstabilities assumed by classical linear theory. In fact, we see an interaction between background turbulence and kinetic instabilities that constrains non-equilibrium conditions in the plasma. We quantify the drivers of this interaction and derive some important limiting conditions under which ion-scale instabilities occur and act effectively to regulate the energetics of the solar wind.

13

Global gyrokinetic simulations of electrostatic microturbulent transport in LHD stellarator

Mr Tajinder Singh[1], Dr Javier H. Nicolau[2], Dr Federico Nespoli[3], Prof Zhihong Lin[2], Prof Abhijit Sen[4,5], Dr Sarveshwar Sharma[4,5], Dr Animesh Kuley[1]

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Contributed Talk V, March 28, 2023, 12:15 - 12:35

Our very recent work, "Nuclear Fusion 62, 126006 (2022)" presents the global gyrokinetic simulations of electrostatic microturbulent transport by the ion temperature gradient (ITG) and trapped electron mode (TEM) driven microturbulence in LHD using the monotonic smooth numerical profiles using the state-of-the-art gyrokinetic toroidal code (GTC) where the role of self-generated zonal flow in regulating the turbulent transport is also discussed. Here, we have analyzed a realistic discharge shot #166256 at t=5.2s with realistic geometry and experimental profile of LHD by taking into account the neoclassical radial electric field. A comparison of the simulation results with the experiment has been made. In line with the experiment, linear simulations depict the co-existence of ITG and TEM turbulence. The core turbulence is dominated by ITG turbulence, and the edge turbulence is dominated by TEM. The linear frequency and the perpendicular wave number corresponding to the ITG and TEM turbulence match well with the experimental findings. Further, the nonlinear transport of heat conductivity follows the trend found in the experiments. The simulations also investigate the role of zonal flow on ITG and TEM turbulence. The zonal flow plays a vital role in regulating the ITG turbulent transport. However, it is weak for TEM turbulence, which re-affirms our earlier investigations using numerical profiles. This study shows the robustness of gyrokinetic simulations to validate realistic experiments. It would be interesting to investigate the role of impurities on turbulence and transport in this direction.

16

Studies of fast ion redistribution and loss from MAST-U plasmas using a Solid-State Neutral-Particle Analyser (ssNPA)

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Contributed Talk II, March 27, 2023, 16:10 - 16:30

Plasmas produced in the Mega Amp Spherical Tokamak Upgrade (MAST-U) often contain supra-thermal ("fast") ion populations resulting from the ionisation of injected neutral beams. The study of these fast ions is a key element of gauging the performance of these plasmas, since they play an essential role in auxiliary heating and, in some devices, current drive. One of the tools that can be used to study fast ions is neutral-particle analysis, which relies on charge exchange with beam or thermal neutrals to measure the fast ion populations via neutrals fluxes, giving distributions as functions of radial position, energy, pitch and time. In this contribution results obtained using a Solid-State Neutral-Particle Analyser (ssNPA) will be presented from the first two MAST-U experimental campaigns. Fast ions are often redistributed or lost from tokamak plasmas due to instabilities, many of which are excited by the fast ions themselves. Measurements obtained using the ssNPA will be discussed for both stable and unstable plasmas, with strong evidence of fast ion redistribution being shown in the latter case. Modelling of ssNPA signals carried out for classically-confined fast ions will be compared with measurements in the case of stable plasmas.

26

Synchrotron-based radiography of electrical wire explosion and its hydrodynamic applications

Jergus Strucka[1], Bratislav Lukic[2], Marlene Koerner[1], Jack Halliday[1], Yifan Yao[1], Kassim Mughal[1], Daniel Maler[3], Sergey Efimov[3], Jonathan Skidmore[4], Alexander Rack[2], Yakov Krasik[3], Jeremy Chittenden[1], Simon Bland[1]
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Contributed Talk XIV, March 29, 2023, 16:50 - 17:10

The dynamics of many plasmas are dominated by the formation of different types of instabilities. These effects can be readily seen on the astrophysical scale – in the structure of proto-stellar jets and nebulae, as well as on planetary scale potentially driving mixing during the formation of the Moon via the Giant Impact Hypothesis. On Earth, these govern the success of inertial confinement fusion experiments, by mixing cold, dense, high Z plasma into fusion fuel during compression. Measuring how the hydrodynamic instabilities evolve is crucial to providing quantitative comparison to theory and simulations, yet many experiments are limited to exploring relatively small region of parameter space in Mach and Atwood numbers, or provide only a few measurements per experiment, requiring a strong control of the initial conditions.

In this presentation, we describe a novel technique to obtain time-resolved measurements (256 radiographs, 176ns interframe time, 3um resolution, 100ps exposure) of hydrodynamic interactions in arbitrary geometries. The technique utilises a compact pulsed power generator (35kA, 1000ns rise time) to resistively explode underwater metallic assemblies and drive convergent, divergent, or planar shocks in water at multi-km/s speeds. The pulsed power platform is coupled to the x-ray phase-contrast imaging capability (polychromatic beam E~30keV) of the European Synchrotron Radiation Facility ID19.

Initial experiments studied the effects of the axial density striations induced by the electrothermal instability (ETI) in exploding wires. Here we measured the interaction of a cylindrically convergent shockwave travelling from the dense surrounding water into low density plasma of an exploding wire (large negative Atwood number), revealing the frequency spectrum of the density perturbations frozen within the plasma column. The ETI dynamics were exploited to control the strength of the density perturbations within the plasma by changing the exploding wire material (Al, Ag, Cu, Mo, W). The results of the experiments agree with the ETI strength predictions for these materials by the linear theory and provide a direct test for the conductivity and equation-of-state models used in MHD simulations.

We will also discuss the design and results of the upcoming convergent Richtmyer-Meshkov instability measurements, future scaling of the experiments, and results from numerical simulations performed in the GORGON MHD code.

Measuring the principal Hugoniot of ICF-relevant TMPTA foam

Robert Paddock[1], Matthew Oliver[2], Daniel Eakins[3], David Chapman[3], John Pasley[4], Mattia Cipriani[5], Fabrizio Consoli[5], Bruno Albertazzi[6], Michel Koenig[6], Artem Martynenko[7], Leonard Wegert[7], Paul Neumayer[7], Przemysław Tchórz[8], Piotr Rączka[8], Paul Mabey[9], Robbie Scott[2], Rob Clarke[2], Margaret Notley[2], Chris Baird[2], Nicola Booth[2], Christopher Spindloe[2], David Haddock[2], Samuel Irving[2], Warren Garbett[10], Ramy Aboushelbaya[1], Marko von der Leyen[1], Rati Goshadze[11], Valentin Karasiev[11], Suxing Hu[11], Peter Norreys[1]
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Contributed Talk XIX, March 30, 2023, 12:20 - 12:40

Wetted-foam layers are of significant interest for ICF capsules, due to the unprecedented control they provide over the convergence ratio of the implosion, and the opportunity this affords to minimize hydrodynamic instability growth. However, the equation of state (EOS) for fusion relevant foams is not well characterized, and many simulations therefore rely on modelling such foams as a homogeneous medium of the foam average density. The accuracy of this hypothesis is not known with great confidence. To address this question, an experiment was performed in January 2022 using the VULCAN Laser at the Central Laser Facility. The aim was to measure the EOS of TMPTA foams at 260 mg/cc, corresponding to the density of DT-wetted-foam layers relevant to ICF research. Such a foam would be also be directly relevant for recently proposed ‘hydrodynamic equivalent’ capsules. VISAR was used to measure the shock velocity of both the foam and a quartz reference layer, while streaked optical pyrometry was used to measure the temperature of the shocked material. Preliminary results suggest that, for the 20 – 120 GPa pressure range accessed, this material can indeed be well described using the equation of state of the homogeneous medium at the foam density.

31

Observation of monoenergetic electrons from two-pulse ionization injection in quasilinear laser-wakefields

Marko Von Der Leyen[1], J Holloway[1], Y Ma[2], P Campbell[2], R Aboushelbaya[1], Q Qian[2], A Antoine[2], M Balcazar[2], J Cardarelli[2], Q Feng[1], R Fitzgarrald[2], B Hou[2], G Kalinchenko[2], J Latham[2], A Maksimchuk[2], A McKelvey[2], J Nees[2], I Ouatu[1], R Paddock[1], B Spiers[2], A Thomas[2], R Timmis[1], K Krushelnick[2], P Norreys[1]
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Contributed Talk XX, March 30, 2023, 12:40 - 13:00

The generation of low-emittance electron beams from laser-driven wakefields is crucial for the development of compact X-ray sources. Here, we show new results for the injection and acceleration of quasi-monoenergetic electron beams in low amplitude wakefields, both experimentally and using simulations. This is achieved by using two laser pulses which decouples the wakefield generation from the electron trapping via ionization injection in addition with temporally limited constructive interference of the driven wakefields. By changing the polarization of the injector pulse, reducing the ionization volume, the electron spectra of the accelerated electron bunches are improved.
The possibility of using a two-pulse approach [1] to inject electrons allows reaching higher electron energies by using a linear drive pulse which is compatible with propagation in a pre-formed channel [2].

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32

Diagnosing Non-Thermal Ion Heating in Magnetic Reconnection Experiments Using Optical Thomson Scattering

Dr Jack Halliday[1], Dr Lee Suttle[1], Dr Colin Bruulsema[1], Dr Sam Totorica[1], Prof Wojciech Rozmus[1], Dr Frederico Fiuza, Dr Danny Russell[1], Dr Vicente Valenzuela-Villaseca[1], Prof Sergey Lebedev[1]
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Contributed Talk III, March 28, 2023, 09:40 - 10:00

Magnetic reconnection is a dissipation mechanism relevant to magnetised plasma flows – it involves a rearrangement of the magnetic field topology and a conversion of magnetic energy to plasma kinetic energy, plasma thermal energy, and the generation of fast particles. In space physics and astrophysics, magnetic reconnection is often proposed as a candidate to explain observations of non-thermal particle acceleration [1,2].

Laboratory experiments, including studies driven with pulsed power using a platform pioneered on the MAGPIE facility at Imperial College [3], provide a laboratory testbed to explore energy transfer during the reconnection process. These laboratory observations are useful in the sense they can provide global measurements of energy partition within the reconnection process.

In this presentation we describe direct observations of non-thermal ion heating in pulsed power driven magnetic reconnection experiments with super Alfvenic inflows. To make this observation we used an optical Thomson scattering diagnostic. The experiments were in the collective Thomson scattering regime, and ion-acoustic scattering spectra were obtained. The diagnostic provided spatially resolved, time gated spectra, with scattering vectors aligned both parallel and orthogonal to the reconnecting electric field.

We found that the intensity of the ion-acoustic fluctuations, measured in the experiment, were enhanced by a factor of approximately five above the thermal level in the case where the scattering vector was aligned parallel to the reconnecting electric field. The observations were not consistent with turbulent dissipation driven by the ion-acoustic instability and could not be explained by a consideration of magnetised fluctuations within the plasma.

Collisional simulations of the experiment were performed in a two-dimensional geometry using the particle in cell (PIC) code OSIRIS. These demonstrated that the field-topology in the reconnection layer produced a hot-tail in the ion distribution, with a greater density of fast particles moving parallel to the reconnecting electric field. The simulated ion distribution functions were used to calculate synthetic Thomson scattering spectra. These synthetic spectra exhibited a similar level of intensity enhancement to those seen in the experimental data – suggesting that the experimental observation is consistent with the presence of a non-thermal ion population within the reconnection layer.

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Characterising x-ray emission from laser-solid interactions and QED plasmas

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Contributed Talk VI, March 29, 2023, 09:40 - 10:00

Laser-matter interactions are well established with current PW lasers, but with the commission of new multi-PW laser facilities, laser intensities beyond 10^{21} W/cm^2 are now achievable. The intense electromagnetic fields produced by these lasers can accelerate ions and electrons in solid targets to ultra-relativistic energies and both relativistic and quantum effects must be considered. This leads to the production of QED plasmas where relativistic and quantum effects influence plasma processes. QED plasmas produce a wealth of particles including hard x-rays through nonlinear Compton scattering (NCS), GeV ions, and electron-positron pairs. All are relevant to other areas of physics, including radiography of dense inertial confinement fusion cores, fast ignition fusion schemes, and the generation of antimatter and electron-positron plasmas.
However, at current achievable laser intensities of 10^{20} -10^{21} W/cm^2, the additional process of inverse bremsstrahlung emission is also present and generates x-rays that are not distinguishable from NCS x-rays in an experimental capacity. For experiments at current facilities, bremsstrahlung emission must be minimised to observe the production of NCS x-rays. NCS emission is key to the onset of the QED plasma regime; a bright-ray flash has been observed in simulations as we transition into the QED regime. Maximising the NCS emission is important if we want to observe the x-ray flash in a laboratory.
Simulations can be conducted to investigate optimal parameters that simultaneously enhance NCS emission and minimise bremsstrahlung emission including laser intensity, target shape, and target density. The work presented includes simulations conducted using EPOCH, and in particular the hybrid-PIC EPOCH extension. 2D EPOCH simulations are used to investigate the NCS emission and 3D hybrid-PIC simulations are used to investigate the bremsstrahlung emission. Separating the simulations allows us to exploit the different emission timescales and capture the full emission from both processes. A direct comparison of the two indicates that at lower intensities bremsstrahlung emission dominates, and NCS emission dominates at higher intensities. NCS emission is enhanced when using targets composed of a lower-Z material.

36

New set of 4D drift kinetic equations to study the astrophysical plasma turbulence

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Contributed Talk IX, March 29, 2023, 12:20 - 12:40

Turbulence is a phenomenon which occurs in a wide range of astrophysical plasma settings. Observations of solar wind, a highly turbulent plasma system, has shown the existence of the so-called knee-break of the spectra of different quantities at the scales equal to approximately ion gyration radius. This knee break can be seen as marking the transition from fluid to kinetic turbulent regimes in a plasma, with the exact mechanism responsible for such a sharp transition still needing further investigations. The nature of such transition is particularly perplexing as it is observed at the distance of 1 AU, where plasma remains practically collisionless, and thus the plasma shouldn't exhibit a fluid behavior.
To examine this transition region, while accounting for the collisionless regime, a gyrokinetic formalism can be used. It is able to successfully capture relevant effects, such as kinetic Alfven Waves, Landau damping and linear and nonlinear phase-space mixing. However, it is still too cumbersome to use to study fluid-kinetic transitions. By considering the ion gyroradius small compared to scales of perpendicular perturbations, we can further simplify the gyrokinetic system, reducing the dimensionality of the problem from 5D to 4D. This is done by applying the Laguerre transform in the spatial perpendicular direction to the straight background magnetic guide field, and keeping only the dominant finite Larmor radius effects. The resulting set of equations is then represented in Fourier-Hermite space, allowing to study kinetic (spatial and parallel velocity) cascades.
The resulting set of equations we have derived is solved using the new pseudo-spectral code ALLIANCE, designed for HPC. Initial results are presented.

44

Power coupling in negative hydrogen plasma ion sources

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Contributed Talk IV, March 28, 2023, 11:55 - 12:15

Negative hydrogen ions (H-/D-) play an integral role in accelerator based research and applications (H-) as well as fusion experiments utilizing neutral beam injection (D-) for plasma heating. Modern H- plasma ion sources rely on two ion formation processes, resonant-tunneling ionisation on low work function surfaces [1] and volumetric ionisation occurring in the plasma discharge [2]. We discuss the fundamental physics of each process and demonstrate that their relative importance depends on the power coupling scheme applied for sustaining the discharge. We review the results of RF power coupling and vacuum-ultraviolet (VUV) spectroscopy experiments conducted on hydrogen ion sources at ISIS and other accelerator facilities [3-7], concluding that DC discharges are more efficient in optimising the volume production pathway of H- while RF and microwave discharges are better suited for caesium-enhanced surface production. This is because the electron energy distribution in DC discharges favours molecular ionisation and vibrational excitation over the dissociation of the H_2 molecules via excitation to repulsive triplet states, whereas the opposite is true for RF discharges. The work supports benchmarking of hydrogen ion source plasma simulations and guides the development of their technology for accelerator applications.

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47

The failure of Chapman-Enskog theory in high-beta collisional plasmas

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Contributed Talk XII, March 29, 2023, 15:00 - 15:20

In this research, we consider the validity of the classical theory of transport processes in collisional plasmas. Fluid equations are typically used to describe such plasmas, since their distribution functions are close to being Maxwellian. The small deviations from the Maxwellian distribution are calculated via the Chapman-Enskog (CE) expansion, and determine macroscopic momentum and heat transport in the plasma. Such a calculation is only valid if the underlying CE distribution function is kinetically stable at collisionless scales. We demonstrate that at sufficiently high plasma β, the CE distribution function can be subject to numerous microinstabilities across a wide range of scales, the most significant of which are characterized. Of specific note is the discovery of several previously uncharacterised microinstabilities, including one at sub-electron-Larmor scales (the `whisper instability') whose growth rate in certain parameter regimes is large compared to other instabilities. Our approach enables us to construct a kinetic stability map of classical, two-species collisional plasma in terms of the mean free path λ, the electron skin depth and plasma β. This work highlights that collisional plasmas can be kinetically unstable; in strongly magnetised CE plasmas, this occurs whenever $\beta \geq L/\lambda$, where L is the length scale over which fields and bulk motions in the plasma vary macroscopically. If kinetic instability does arise, the determination of transport coefficients with the standard CE expansion is not necessarily valid. This conclusion has significant ramifications for describing correctly various astrophysical and laser-plasma environments, including inertial-confinement-fusion plasmas. Evidence for discrepancies from classical models of collisional plasma transport arising in recent laser-plasma experiments on the National Ignition Facility will also be discussed.

48

Gyrofluid and gyrokinetic approaches for non-collisional plasmoid instability with finite beta_e

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Contributed Talk XVI, March 30, 2023, 09:40 - 10:00

Non-collisional current sheets that form during the nonlinear development of spontaneous magnetic reconnection are characterized by a small thickness, of the order of the electron skin depth. They can become unstable to the formation of plasmoids, which allows the magnetic reconnection process to reach high reconnection rates. In this work we carry out a detailed study of the impact of a finite \beta_e, the latter being a parameter corresponding to the ratio between equilibrium electron kinetic pressure and magnetic pressure, on the collisionless plasmoid instability, in the case of a strong guide field. We consider inertial reconnection, and finite electron FLR effects arise from the combination of the presence of electron inertia with a finite \beta_e parameter. This study is conducted through a comparison of gyrofluid and gyrokinetic simulations.
We analyze the geometry that characterizes the reconnecting current sheet, and what promotes its elongation. Once the reconnecting current sheet is formed, we identify the regimes for which it is plasmoid unstable. Our study shows that plasmoids can be obtained, in this context, from current sheets with an aspect ratio much smaller than in the collisional regime, and that the plasma flow channel of the marginally stable current layers maintains an inverse aspect ratio of 0.1.

53

Investigate Electron Density Perturbations in Magnetised HED Plasmas using an Imaging Refractometer

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Contributed Talk VII, March 29, 2023, 10:00 - 10:20

Radiative cooling and magnetic fields significantly affect the structure of shocks formed when supersonic plasma flows stagnate against conducting obstacles, which can lead to unstable shocks and the formation of turbulence. Under these conditions, experimental measurements of plasma parameters are very difficult to perform using conventional laser-based diagnostics, such as shadowgraphy, schlieren and interferometry. Here, we present experimental data from a novel technique, called Imaging Refractometer [2], applied to stagnated magnetised plasmas on planar obstacles. Experiments were conducted at the MAGPIE Pulsed-Power Generator facility (1.4MA, 240ns rise-time) using an inverse Z-Pinch array loaded with thin metallic wires (Al and W). In aluminium plasma flows, we observe a well-defined stand-off shock at ~ 4mm from the obstacle boundary, while electron density perturbations were instead formed in tungsten flows, despite similar upstream plasma parameters ($n_e \sim 10^{19}$ 1/cm^3, V ~ 50 km/s) [3].
Electron density gradients and characteristic spatial scales of the turbulent region were successfully measured from the refractometer data. The recorded angular deflections were between 0.1 mrad and 20 mrad, which corresponds to a dynamic range of over 200, demonstrating the enhanced sensitivity of this diagnostic relative to conventional techniques.

54

Shear viscosity of complex plasmas in biaxial AC electric field

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Contributed Talk XV, March 29, 2023, 17:10 - 17:30

Molecular dynamics computer simulations have been performed to investigate the shear viscosity of three-dimensional complex plasmas (CPs). The Green-Kubo method has been employed with molecular dynamics simulation to compute the shear viscosity behavior in an external electric field. The coefficients of shear viscosity are computed for numerous values of plasma coupling (Γ), screening length (κ) and external biaxial AC electric field intensities (M). The obtained simulation results in the absence and equilibrium strength of M (= 0, 0.007) are compared and discussed with known theoretical, numerical and experimental results. The changes in the shear viscosity for three-dimensional CPs under the influence of M are observed. Three different regimes of CPs are obtained; the shear viscosity slightly decreases for small values of M, significantly increased for intermediate M and again remained constant for higher M intensities. New employed simulation algorithm with Green-Kubo relation is safe, reliable and accurate to estimate the effects of electric field on shear viscosity of CPs. The reported work explained the anisotropic shear viscosity and electrorheological characteristics of CPs. These investigations may help to understand structural transition and thermophysical properties of CPs for anisotropic interparticle potential.
Key words: molecular dynamics simulation, Green-Kubo relation, shear viscosity, electric field

55

Shock-cloud interaction experiments using a 2-stage light-gas gun

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Contributed Talk VIII, March 29, 2023, 10:20 - 10:40

Turbulent mixing induced by three classes of hydrodynamic instabilities: Rayleigh-Taylor, Richtmyer-Meshkov, and Kelvin-Helmholtz instabilities, play important roles in a vast range of systems extending from inertial confinement fusion to star formation triggered by compression from interstellar wind or supernova-driven shock waves that sweep over the dense interstellar cloud. Hydrodynamic processes of these larger scale systems, which can extend for parsecs and thousands of years, can be replicated at the sub-millimetre and tens of nanosecond or millimetre and microsecond scales in the laboratory through dimensionless matching of hydrodynamic and magnetohydrodynamic models. These matches require the use of a high-energy-density experimental environment. High-power laser facilities are commonly used to create such an environment to perform scaled experiments.

In this talk, the results of a pilot investigation into the use of a 7.5m 2-stage light-gas gun at First Light Fusion (FLF) as a shock tube are presented. This enabled 'shock-cloud' interaction experiments, a laboratory
analogy of astrophysical shocks sweeping across interstellar clouds. These experiments were successful and drove planar Mach 3 shocks in a 100-mbar nitrogen gas and across 4-mm diameter cylindrical targets. The drive was sustained for approximately 3 microseconds enabling the observation of the collapse of the cylinder over a cloud-crushing time. These results are compared to experiments possible on high-power laser-driven shock-tube experiments which used 1 mm diameter foam-filled shock-tubes. The foams are of density 100 mg/cm^3 and can include an embedded 0.1 mm diameter plastic sphere. Comparisons between the gas gun and laser-drive shock-tube experiments inform the designs for the next experiment at FLF which will push forwards laboratory shock-cloud experiments to stronger shocks with improved diagnostic systems.

81

SpK - A fast atomic physics code for generating tabulated EoS and opacity data for use in HEDP simulations

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Contributed Talk XIII, March 29, 2023, 16:30 - 16:50

SpK is a fast atomic physics code developed to produce tabulated self-consistent Equation of State (EoS) and opacity data for use in High-Energy-Density Physics (HEDP) simulations. Shell structure is captured by solving the Saha equation, with energy levels obtained from the NIST database or the Screened Hydrogenic Model with ℓ-splitting [1], allowing distributions of ionisation states and level populations to be obtained for a wide range of densities and temperatures. Extending to the TF model in strongly coupled conditions and using semi-empirical bonding corrections to reproduce the correct conditions at solid density and atmospheric pressure, a full capability has been developed to model the full transition from a solid material into the plasma state.

Following the recent submission of our paper on the opacity capabilities within SpK [2], this work focuses on the developments made to calculate EoS data, including some examples of validation and benchmarking of its predictions. Following this, the importance of accurate material properties data is demonstrated in the integrated modelling of conically convergent shock tube experiments [3], with SpK providing the best agreement to the validation data.

Fig. 1. The principal Hugoniot curve for diamond. Comparisons are made between FEOS [4] (red), SpK (pink), DFT-MD data [5] (orange), and experimental data (crosses).

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91

Investigating the effects of bombarding hydrogen ion isotopes on the sputtering yield and ion penetration depth in beryllium PFCs using molecular dynamics methods

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Contributed Talk XI, March 29, 2023, 14:40 - 15:00

Due to its unique physical properties, beryllium has been identified as the material of choice for the plasma-facing components (PFCs) of many operational and planned future nuclear fusion reactors, whether as a bulk material or as a coating. The interaction between PFCs and fusion plasma results in the sputtering of atomic or molecular species, as well as the
implantation of plasma species in the bulk of the PFC. Accordingly, determining accurate sputtering yields and implantation rates as well as penetration depths is vital for understanding PFC damage in fusion reactors. Utilising experimentally validated molecular dynamics (MD) simulations, this work reports on the sputtering yield and penetration depth
studies for deuterium and tritium ions impinging on beryllium surfaces with temperatures up to 1100K.

Poster Presentations

3 Photoionized plasmas in the laboratory using keV line radiation

Professor David Riley[1], Dr Raj Singh[1,2], Dr Steven White[1], Mr Matthew Charlwood[1], Dr David Bailie[1], Dr Cormac Hyland[1], Dr Thomas Audet[1], Professor Gianluca Sarri[1], Dr Brendan Kettle[3], Professor Gleb Gribakin[1], Professor Steven Rose[3,4], Dr Edward Hill[3], Professor Francis Keenan[1]

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5 On the transport of tracer particles in two-dimensional turbulent systems

Theo Gheorghiu[1,2], Fulvio Militello[1], Jens Rasmussen[3]

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7 Impact of higher order corrections to gyrokinetics in tokamak plasmas

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8 Impact of plasma physics model on design space of compact tokamak fusion reactor

Bong Guen Hong[1]

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10 Effect of Current Density Profiles on a Direct Current Non-Transferred Thermal Plasma Torch

Mr. Akash Yadav[1], Dr. Mayank Kumar[1], Dr. Satyananda Kar[1]

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11 On the impact of electron anisotropies on proton cyclotron and mirror instabilities

Stuart O'Neill[1], Elisabetta Boella[1,3], Maria Elena Innocenti[2], Alfredo Micera[2]

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14 Improving Wafer-level Uniformity of Dry Etching Selectivity and Profile by Modifying Chamber Design for High Aspect Ratio Contact Etch

Taehee Han[1], Yunchang Jang[1], Jiwon Kim[1], Yongseob Kim[1], Deuksoo Choi[1], Taeyeon Hwang[1], Pyungho Kim[1], Seokhyun Lim[1], Young-Won Shin[1], Hosung Seo[1], Heechul Lee[1], Yejin Shon[1], Solji Choi[1], Sun-Taek Lim[1], Seungmin Lee[1], Doowhan Choi[1]

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15 Exploring the influence of rear surface plasma on sheath accelerated proton beam divergence

Peter Parsons[1], B Loughran[1], H Ahmed[7], C Armstrong[7], S Astbury[7], M Balcazar[3], M Borghesi[1], N Bourgeois[7], G Casati[4], C Curry[2], S Dann[7], S DiIorio[3], N Dover[4], T Dzelzainis[7], O Ettlinger[4], T Frazer[6], M Gauthier[2], L Giuffrida[5], G Glenn[2], S Glenzer[2], R Gray[6], J Green[7], T Hall[7], G Hicks[4], V Istokskaia[5], M King[6], K Lancaster[8], D Margarone[5], O McCusker[1], P McKenna[6], Z Najmudin[4], R Nayli[6], M Oliver[7], C Parisuaña[2], C Ridgers[8], N Smith[8], C Spindloe[7], M Streeter[1], D Symes[7], A Thomas[3], B Torrance[6], F Treffert[2], N Xu[4], C Palmer[1]
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17 Moment Tracking to Improve Macroparticles

Alexander Warwick[1,2], Jonathan Gratus[1,2]
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18 Intense Ion Beam Propagation in Dense Plasmas : Range Enhancement via Drag Heating

Dr Alex Robinson[1]
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20 Experimental facilities at First Light Fusion and their use developing a TPa shock amplification system

Miss Rosie Barker[1], Dr Guy Burdiak[1], Dr Nicholas Hawker[1]
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21 Spin Radiation contributions in highly-quantum laser-electron beam collisions

Louis Ingle[1], Chris Arran[1], Tom Blackburn[2], Chris Murphy[1], Christopher Ridgers[1]
[1]University Of York, York, United Kingdom, [2]University of Gothenburg, Gothenburg, Sweden

25 Laser harmonic generation with tuneable orbital angular momentum using a structured plasma target

Dr Raoul Trines, Dr Holger Schmitz, Prof Robert Bingham
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27 Evolution of spheroidal dust in electrically active sub-stellar atmospheres

Declan Diver[1], Dr Craig Stark[2]
[1]University of Glasgow, Glasgow , United Kingdom, [2]University of Abertay, Dundee, United Kingdom

28 Exploration of mitigation systems for disruption generated Runaway Electrons in a STEP concept

Lars Henden[1], Alexander Fil[1], Sarah Newton[1], Mathias Hoppe[2], Tim Hender[1]
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37 Effects of plasma density fluctuations in laser wakefield accelerators

Claudia Cobo[1], Eva Los[2], Christopher Arran[1], Cary Colgan[2], Matthew Streeter[3], Robbie Watt[2], Nicolas Bourgeois[4], Luke Calvin[3], Jason Carderelli[5], Niall Cavanagh[3], Stephen Dann[4], Rebecca Fitzgarrald[5], Elias

Gerstmayr[2], Brendan Kettle[2], Paul McKenna[6], Christopher Murphy[1], Zulfikar Najmudin[2], Pattathil Rajeev[4], Christpher Ridgers[1], Dan Symes[4], Alexander Thomas[5], Gianluca Sarri[3], Stuart Mangles[2]
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38 Nonlinear Energy Transfer in Confinement Transitions of Tokamak Plasmas

Tobias Schuett[1], Dr Simon Freethy[2], Dr Istvan Cziegler[1]
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39 A novel ionisation method to diagnose the peak

intensity of ultra-intense laser pulses

Iustin Ouatu[1], Mr. Rusko Ruskov[1], Dr. Qingsong Feng[1], Professor Peter Norreys[2]
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40 Development of Yttrium Oxide Film Deposition using Microwave Excited Atmospheric Pressure Plasma Jet with a Mist Addition

Mr. Bat-Orgil Erdenezaya[1], Mr. Hirochika Uratani[1], Mr. Ryosuke Shimizu[2], Mr. Ruka Yazawa[2], Dr. Yusuke Nakano[1], Prof. Yasunori Tanaka[1], Dr. Md. Shahiduzzaman[2], Prof. Tetsuya Taima[2], Prof. Tatsuo Ishijima[1]
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43 Progress toward using Coherence Imaging Spectroscopy for

direct density measurements in the MAST-U divertor

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49 Self-focusing of pure radial mode of LG beam (LG_1^0) in an underdense, cold and collisionless plasma

Mr. Subhajit Bhaskar[1], Prof. Hitendra K. Malik
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50 Investigating radiatively driven, counter-propagating plasma flows

Katherine Marrow[1], Thomas Mundy[1], Jack W. D. Halliday[1], Aidan Crilly[1], Jeremy Chittenden[1], Roberto C. Mancini[2], Stefano Merlini[1], Steven Rose[1], Danny R. Russell[1], Jergus Strucka[1], Lee G. Suttle[1], Vicente Valenzuela-Villaseca[1], Simon N. Bland[1], Sergey V. Lebedev[1]
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51 Role of Non-extensivity on Double Sheath and Virtual Cathode Formation in Collisional-less Plasma

Mr. Yetendra Jha[1], Dr. MAYANK KUMAR[1], Dr. HITENDRA MALIK[1]
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52 Nonlinear saturation of the beam-plasma instability in inertial confinement fusion

Rusko Ruskov[1]
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56 Influence of divertor magnetic geometry on H-mode transitions

Yasmin Andrew[1], Jamie Dunsmore[1,2], Hiro Farre-Kaga[1,3], Eun-jin Kim[4], Terry Rhodes[5], Lothar Schmitz[5], Zheng Yan[6]
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57 Time-dependent probability density function analysis of H-mode transitions

Hiro Farre-Kaga[1,2], Yasmin Andrew[1], Jamie Dunsmore[1,3], Eun-jin Kim[4], Terry Rhodes[5], Lothar Schmitz[5], Zheng Yan[6]
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58 Advancements to an Integrated Data Analysis system for Bayesian inference of two-dimensional electron temperature and density fields in the MAST-U divertor.

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59 Singularity Conditions of Rayleigh-Taylor Instability in a Hall Thruster Plasma under Increased Ionic Charge

Mr. Dhananjay Verma[1], Prof. Hitendra Kumar Malik[1]
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60 Study of Magnetic Field Evolution in Counterstreaming Electron Positron Flow in One Dimension

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62 Pulsed power produced cylindrically convergent shockwaves in water at the Multi-Mega-Ampere Level

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63 PORTABLE X-PINCH DRIVER DEVELOPMENT FOR DENSE PLASMA MEASUREMENTS

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64 Initial analysis of rotational and vibrational distributions of D2 molecules in the MAST-U divertor

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65 Constraints on the ion velocity distribution from fusion product spectroscopy

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66 Characterisation of inductive plasma for microwave-plasma interaction experiments

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67 Collective High-k Adjustable-radius Scattering Instrument (CHASI) for measuring electron scale turbulence on MAST-U

Dr David Speirs[1], Prof. Kevin Ronald[1], Prof. Alan D. R. Phelps[1], Prof. Roddy Vann[2], Prof. Peter Huggard[3], Dr. Hui Wang[3], Dr. Valerian H. Hall-Chen[4], Dr. Anthony Field[5]
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68 Framework for optimizing free parameters in ICF hydrodynamic simulations using Gaussian Process surrogate models.

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72 Novel Hairpin Geometries for High-Field Low-Density Plasma Ablation Experiments

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74 Investigating the role of vibrationally resolved H2 on
detachment evolution in SOLPS-ITER MAST-U simulations

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77 Plasma Water Activation with an Inductive Plasma Torch at Atmospheric Pressure

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78 Review of Exhaust experiments in MAST Upgrade's second campaign

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80 Implementation and application of a simple radiation loss model for tamped volume ignition ICF targets

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83 Thermodynamics and collisionless relaxation of a Lynden Bell plasma

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84 3D Stability Analysis of ELM Control using Resonant Magnetic Perturbations in Tokamak Plasma

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85 Long-Time Fully Kinetic Simulations of Electromagnetic Ion Beam Instabilities in the Terrestrial Foreshock

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86 Modelling and Design of a Hard X-Ray Spectrometer for TCV

Dr Luke Simons[1], Dr Umar Sheikh[1], Dr Joan Decker[1], Dr Basil Duval[1], Dr Mathias Hoppe[1], Mrs Eva Tomesova[2], Mr Ondrej Ficker[2,3], Mr Jaroslav Cerovsky[2,3]
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87 Diamond nucleation & growth in high pressure hydrocarbons

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89 First detailed beam emission spectroscopy measurements on spatial structure of beam driven TAEs in MAST-U

Henry H. Wong[1], N.A. Crocker[1], C.A. Michael[1], K.G. McClements[2], S.E. Sharapov[2], M. Fitzgerald[2], R. Scannell[2], D. Dunai[4], S. Thomas[6], A.R. Field[2], B. Patel[2], S. Gibson[2], M. Cecconello[5], A.R. Jackson[5], E. Parr[2], G. Prechel[3], Z. Lin[3], M. Podesta[7], T. Carter[1]
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90 Operation of an X-band Self-Insulating Backward Wave Oscillator

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3

Photoionized plasmas in the laboratory using keV line radiation

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

In this paper we describe an experiment to generate x-ray photoionized plasmas in the laboratory, which has made some significant improvements over similar previous experiments. One of the key parameters of interest is the photo-ionisation parameter, $\xi=4\pi F/Ne$ where the flux, F is in ergs/cm^2/s and the electron density, Ne is in cm^{-3}. We show that we can achieve values of ξ >100 erg-cm/s, using laser-plasma x-ray sources, which is in the regime of interest for several astrophysical scenarios. In addition to this, we show that the use of a keV line source has allowed us to generate the same ratio of inner-shell to outer-shell photoionization expected from a blackbody source with ~keV spectral temperature, which is also a key factor in allowing experiments to be compared to codes relevant to astrophysical objects.

5

On the transport of tracer particles in two-dimensional turbulent systems

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

Anomalous diffusion has been observed in the SOL of MCF devices, and has made analytical modelling of this region challenging.
We have developed an ‘observational’ random walk concept based on the classical and continuous random walk formalism with the aim of examining and describing the transport properties of particles in turbulent systems. The concept is first validated on a synthetic field, in which it provides a description consistent with classical diffusion theory. It is then applied to the classical and modified Hasegawa-Wakatani system, as this has been previously considered as a system with analogous features to the tokamak scrape-off-layer. The concept applied to this system appears to demonstrate that particle transport can be modelled with a linear combination of normal and fractional transport terms.

7

Impact of higher order corrections to gyrokinetics in tokamak plasmas

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High pressure gradients in the pedestal region of tokamak plasmas provide a large bootstrap current. This bootstrap current, in turn, arises from finite Larmor radius corrections to the Maxwellian equilibrium distribution function that are not typically retained in conventional gyrokinetics or captured only in certain simplified cases, e.g. [1]. To accommodate large bootstrap current effects, relevant to the tokamak pedestal region or high beta, spherical tokamak core plasmas, gyrokinetic theory has been extended [2]. The theory of [2] is nonlinear and electromagnetic; it allows for arbitrary magnetic field configurations and finite orbit width effects, while ensuring consistent ordering. To quantify the importance of these corrections, a nonlinear local gyrokinetic code GS2 has been coupled to NEO [4], a multi-species drift kinetic solver [3]. In the limit that the poloidal component of the magnetic field is small compared to the total confining magnetic field (e.g. relevant to the pedestal of conventional tokamaks), it is found that the regions where microinstabilities are significantly influenced by higher order equilibrium effects are in the pedestal plasma and a spherical tokamak core plasma. In particular, it is found that there are three main factors that determine the importance of the higher order corrections to conventional gyrokinetics: (1) the particle Larmor radius, (2) equilibrium density and temperature gradient length scales and (3) beta. Therefore, the conditions in these regions make kinetic-ballooning modes (see Figure 1) and micro-tearing modes more influenced by higher order physics.

Figure 1 caption: (a) The growth rate, γ, (V_t is the particle thermal speed and a is the tokamak minor radius) of the GS2 most unstable mode plotted as a function of beta, β, at the flux surface of interest shown in (b). "conventional GS2" denotes the solution of the conventional, Maxwellian-based gyrokinetics, while "NEO GS2" corresponds to the solution of the extended gyrokinetic-Maxwell system of [3] with incorporated neoclassical equilibrium corrections. The vertical line in (a) shows the value of beta consistent with the rest of the equilibrium parameters.

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8

Impact of plasma physics model on design space of compact tokamak fusion reactor

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

Once plasma performance is specified, the minimum major radius, R_0, and resulting maximum magnetic field at plasma center, BT are uniquely determined by using a novel computational algorithm and a tokamak systems analysis coupled with a neutron transport calculation. They enabled determination of the optimum radial build and the reactor parameters, which simultaneously meet all the physics, engineering and neutronics requirements. By using a super computer, KAIROS, plasma performance was varied by scanning over a wide range of physics, technology, and system parameters to draw the optimal design parameters required for a compact tokamak fusion reactor. With the design goals of a fusion gain, Q > 20.0, a net electric power > 100 MW, a neutron wall loading < 2.0 MW/m2, an indicator of divertor power handling, PSOL/R_0 < 25 MW/m, and steady-state operation, a prospective design space according to the level of the physics and technology was drawn. Advanced engineering features such as the maximum allowable magnetic field at the TF coil, Bmax = 23 T by adopting high temperature superconducting (HTS) magnet technology, the usage of an advanced shield material like tungsten carbide (WC), and a plug-bucked toroidal field (TF) magnet support structure, no central solenoid, etc., were implemented. Sensitivity studies on energy confinement scaling laws such as IPB98y2, ITPA20, and β-independent were also performed.
For a conventional tokamak, βN > 3.0, H > 1.7, bootstrap current fraction, fBS > 0.6, BT > 4.0 T, Pfusion > 550 MW, and aspect ratio, A < 3.4 were required to access a design space, R0 < 4.0 m with the confinement scaling laws of IPB98y2. There are significant sensitivities associated with the energy confinement scaling laws; with the ITPA20, more strict conditions of H > 1.8, BT > 6.5 T, Pfusion > 700 MW, and A < 3.3 were required while with the β-independent, mitigated conditions of H > 1.2, bootstrap current fraction, fBS > 0.5, BT > 4.5 T, Pfusion > 500 MW, and A < 3.5 were requiered.
For a spherical tokamak, inboard blanket can be replaced by appropriate reflector material to satisfy tritium self-sufficiency. It was found that βN > 4.0, H > 1.5, bootstrap current fraction, fBS > 0.7, Pfusion > 500 MW, and aspect ratio, A > 1.7 were required to access a design space, R0 < 4.0 m with the confinement scaling laws of IPB98y2. With the ITPA20, more strict conditions of βN > 5.0, H > 1.8, Pfusion > 600 MW, and A > 1.8 were required while with the β-independent, mitigated conditions of βN > 3.5, H > 1.2, Pfusion > 500 MW, and A > 1.6 were required.
Thus, with improved physics such as large confinement enhancement factor, H, large βN, large bootstrap current fraction, etc. and advanced engineering features in HTS magnet and materials, there might be feasible design solutions for compact tokamak fusion reactor.

Effect of Current Density Profiles on a Direct Current Non-Transferred Thermal Plasma Torch

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

A laminar, steady-state, and 2D axisymmetric DC thermal plasma torch model is used to investigate the properties of a torch with different current density profiles. This is done by using the magnetohydrodynamic (MHD) method. The model takes the plasma gas injection, the torch's interior space, the cathode, and the anode wall into account when describing the torch region. On the cathode of the torch, a parabolic, exponential, and step profile are imposed, each of which provides the same current input. In order to evaluate and compare the performance of the torch in terms of torch efficiency and the temperature at the arc-root attachment at the anode, temperature and velocity profiles created using these profiles are analyzed. The maximum temperature and axial velocity of the torch are at their highest values for an exponential curve, whereas these values are at their lowest for a parabolic profile. Out of the three profiles, the step profile has the torch's lowest power input, while the exponential profile has the most. For all of the current density profiles, the anode temperature distribution and torch efficiency have also been investigated. The temperature is at its highest in the arc-root attachment when the exponential profile is used, which indicates that the anode will degrade more quickly and that the electrode will have a shorter lifespan.

11

On the impact of electron anisotropies on proton cyclotron and mirror instabilities

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

Variation in the plasma density and magnetic field strength in solar wind and magnetospheric plasmas leads to temperature anisotropies in the component species. Sufficiently large anisotropy of electrons and protons in the direction perpendicular to the ambient magnetic field may drive the whistler, cyclotron and/or mirror instabilities. In regions of plasma with low beta, it is expected that the proton cyclotron mode would dominate. That is not what is seen for plasma in the Earth's magnetosheath where unstable mirror modes are observed instead (Kaufmann et al., 1970), akin to observations of mirror modes in the solar wind at lower heliocentric radii (Zhang et al., 2009). It has been suggested that the electron temperature anisotropy may help drive the proton mirror modes as electrons become trapped and resonate with the wave (Ahmadi et al., 2016). By leveraging multidimensional kinetic simulations, in this work we explore the competition and the impact of electron perpendicular anisotropies on the proton cyclotron and mirror instabilities. These simulations are particularly challenging due to the large disparity of scales involved. The use of the innovative semi-implicit energy conserving Particle-In-Cell code ECsim (Gonzalez-Herrero et al., 2018) allows us to investigate in detail the interplay between plasma species, the non-linear phase of the instabilities and the interaction between waves and particles and build a parameter space map to identify where the different instabilities dominate.

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Improving Wafer-level Uniformity of Dry Etching Selectivity and Profile by Modifying Chamber Design for High Aspect Ratio Contact Etch

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

We have studied about methods of improving etch rate uniformity over a 300mm wafer with a high power capacitively coupled plasma etcher for a high aspect ratio contact (HARC) etch process in manufacturing recent DRAM devices. Although more than 7% of total chips are fabricated in the outermost periphery of a wafer, the etching selectivity and profile are usually worse than in the inner part of the wafer due to higher etch rate in the edge region (Lieberman et al., 2002). It is because the chamber is designed to confine plasma in the edge region to have an enough radical density, and the sheath voltage is relatively low on the edge rings due to difference in the electrical property (Figure 1). Therefore, it is difficult but crucial to achieve a uniform etch rate over all the wafer area, especially the outermost edge zone to improve the mass production yield.

Since etch rate in a plasma etcher is proportional to the product of the plasma density and the ion energy ($ER \propto n_e \sqrt{V_{ion}}$), we have focused on modulating plasma density distribution using the particle and power balance relations (Lieberman & Lichtenberg, 2005), and ion energy distribution with adjusting RF power coupling ratio between the lower electrode and the edge rings.

We have adjusted gap between the upper electrode and the lower parts of the chamber. In the assumption of a simple cylindrical discharge model, we can derive a relation from the particle and power balance equations in a recursive way that the plasma density is inversely proportional to the gap. A flat upper electrode with a high RF power usually results in a plasma density distribution with the peak value in the edge as shown in Figure 1. We have applied several modifications to the upper electrode to improve radial plasma density distribution, and found a most optimized form with a few radial thickness variations in the edge as illustrated in Figure 2. Results from computational calculations and tests on blanket oxide wafers show the modified upper electrode is advantageous to improve the plasma density uniformity, especially in the edge region (Figure 2).

The ion energy distribution in the chamber, another factor determining the etch rate, has been modulated by changing the sheath voltage ratio of the edge to the central part over the wafer from approximately 0.5 to 1. It has been implemented by combining two kinds of ring materials, quartz (SiO_2) and silicon carbide (SiC) to adjust the RF power coupling ratio between the lower electrode and the edge rings as represented as an equivalent circuit in Figure 3. We are working on computational calculations for each combination, and the result will be provided. An etch rate result on an oxide blanket wafer with one of the best configurations is provided in Figure 4, which also shows an improvement in the etch rate uniformity.

We will try to merge those two approaches and conduct tests to obtain the best possible etch rate uniformity as a further work.

15

Exploring the influence of rear surface plasma on sheath accelerated proton beam divergence

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

MeV protons can be accelerated from the surface of a thin foil by TV/m fields of the electrostatic sheath established by the expansion of laser-heated electrons. These proton beams typically have a high divergence, often greater than 10 degrees. However, for many potential applications of laser accelerated protons, in particular capturing of the proton beam within a beam transport system, a beam with lower divergence is beneficial. Here, we will present results from experiments using tailored targets to explore the influence of low density plasma on proton acceleration and proton beam divergence. These targets include a novel liquid sheet target, developed at SLAC National Accelerator Laboratory [1], and a combined thin foil and gas-jet target. Preliminary results indicate that the presence of an extended low-density plasma at the target surface resulted in a lower divergence proton beam, with minimal reduction in beam energy.

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17

Moment Tracking to Improve Macroparticles

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

In particle-in-cell codes, particles are often grouped together into 'macroparticles' but this loses detail about small-scale distributions within a macroparticle. This work proposes adding additional structure to macroparticles, by tracking the moments of the group of particles represented by the macroparticle. Tracking moments provides additional information about the underlying distribution of particles, at a cost of increased computational time and memory usage. By taking moments to higher orders it may be possible to model a large section of a plasma with a single macroparticle and its moments.

The theory for moment tracking is developed through distributions (derivatives of Dirac delta-functions)*. The moment tracking equations are not closed – higher order moments can generate lower order moments. This means the moment tracking method is only valid in situations where higher order moments can be considered negligible.

By using the theory of distributions, the coordinate transformation rule for the moments can be found, which cannot be done by other methods for moment tracking. This is particularly useful for astrophysical plasmas, where there is a choice in the coordinate system used. Numerical validation of the model is performed by modelling the accretion disc around a black hole in Schwarzschild and Kruskal-Szekeres spacetimes.

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18

Intense Ion Beam Propagation in Dense Plasmas : Range Enhancement via Drag Heating

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

Since the emergence of CPA lasers, there has been intense interest in both ion acceleration, and the possibility of producing nuclear reactions from laser-accelerated ions. During this time there have been many experiments where it has been challenging to reconcile the observed reaction yield with theoretical expectations, with the observed yields being larger than expected in many cases.

This suggests that ions may have ranges that are longer than expected. This could be the case if the electron temperature is elevated, but that in turn requires explanation.

In the work presented here we have analysed the possibility that the heating associated with the electron drag on the ions become strong enough to produce such heating, and we present our estimates of the conditions that have to be satisfied to enter this regime where the ion beam and background electrons alone provide the required heating.

20

Experimental facilities at First Light Fusion and their use developing a TPa shock amplification system

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

First Light Fusion uses one sided projectile impact on a target fuel cavity to produce fusion. The company has multiple experimental facilities at its site in Oxfordshire, including two-stage light-gas guns and electromagnetic pulsed-power drivers. We will present an overview of these facilities and their diagnostics which are available for collaborative work with the wider research community. For instance, our two stage light-gas gun, the BFG, is capable of accelerating a 38 mm, 100 g projectile to 6.5 km/s delivering 2.1 MJ of kinetic energy on impact, whereas our 8 MA, 2us pulsed-power driver, Machine 3, is capable of launching a cm square, 1 mm deep projectile faster than 12 km/s. These facilities and their diagnostics have been used for impact experiments, HED research, radiative shock and warm dense matter experiments and pulsed power launcher development.   Diagnostics available include ultrafast optical imaging and spectroscopy, VISAR velocity measurements, x-ray probing, and neutron diagnostics.

To produce fusion in the target cavity, the impact pressure from the projectile must be increased. First Light Fusion has developed a shock amplification system which increases the impact pressure provided by the projectile by ~20 times. We present spatially and temporally resolved optical emission data from experiments measuring the output velocity and profile of the shock exiting the amplifier on the BFG. Nanosecond time resolution is required to capture the event lasting < 10 ns. The amplifier produces TPa pressures over several mm spatial scales.

21

Spin Radiation contributions in highly-quantum laser-electron beam collisions

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With the advent of new laser intensities comes an opportunity to explore quantum electrodynamics effects. One such quantum effect is the radiation reaction, the recoil exhibited by a particle due to its emission. Said emission in extreme intensity must be corrected for these quantum phenomena, specifically spin effects. These spin effects have been examined before in environments such as crystals, however due to the small quantum parameter of said systems, the effect spin has on the emission was also said to be small. However, it is possible to use an intense laser pulse and a counter-propagating relativistic electron bunch to reach these highly quantum regimes and thus such effects become more dominant. Here, we perform novel simulations of such a set-up where we compare the photon emission and the radiation reaction with and without spin effects. We find substantial differences in both the photon distribution function and in the average moments of gamma, demonstrating the importance of including spin effects. Understanding these quantum effects will be important for informing experiments at next-generation facilities and astrophysical environments with strong fields such as magnetars.

25

Laser harmonic generation with tuneable orbital angular momentum using a structured plasma target

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In previous studies of spin-to-orbital angular momentum (AM) conversion in laser high harmonic generation (HHG) using a plasma target, one unit of spin AM is always converted into precisely one unit of OAM [1,2]. Here we show, through analytic theory and numerical simulations, that we can exchange one unit of SAM for a tuneable amount of OAM per harmonic step, via the use of a structured plasma target. The target absorbs the difference in total AM between that of n fundamental photons and the outgoing n-th harmonic photon. We introduce a novel way to analyse the frequency, spin and OAM content of the harmonic radiation which provides enhanced insight into this process. The prospects of structured targets for HHG with high-order transverse modes will be discussed.

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27

Evolution of spheroidal dust in electrically active sub-stellar atmospheres

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

This paper (Stark, Diver A&A 644 2020 A131) addresses the problem of the spheroidal growth of dust grains in electrically activated sub-stellar atmospheres. It presents the novel application of a mechanism whereby non-spherical, elongated dust grains can be grown via plasma deposition as a consequence of the surface electric field effects of charged dust grains.
Differential scattering from a population of aligned, non-spherical dust grains is a potential source of polarization that could be used to determine geometric properties of the dust clouds.
Numerical solutions show that e ≈ 0.94 defines a watershed eccentricity, where the eccentricity of grains with an initial eccentricity less than (greater than) this value decreases (increases) and spherical (spheroidal) growth occurs. This produces a characteristic bimodal eccentricity distribution function yielding a fractional change in the observed linear polarization of up to ≈0.1 corresponding to dust grains of maximal eccentricity at wavelengths of ≈1 µm, consistent with the near infrared observational window. Order of magnitude calculations indicate that a population of aligned, spheroidal dust grains can produce degrees of polarization P ≈ $\mathcal{O}$(10^-2 − 1%) consistent with observed polarization signatures.

Conclusions. The results presented here are relevant to the growth of non-spherical, irregularly shaped dust grains of general geometry where non-uniform surface electric field effects of charged dust grains are significant. The model described in this paper may also be applicable to polarization from galactic dust and dust growth in magnetically confined plasmas.

Exploration of mitigation systems for disruption generated Runaway Electrons in a STEP concept

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

STEP, the Spherical Tokamak for Energy Production, is a project currently under development by UKAEA. During operation, plasma disruption events can lead to a significant generation of Runaway Electrons (RE) which have the potential to critically damage PFCs and the reactor. STEP planned operating plasma current of > 20MA increases the potential danger posed by a high Mega-Ampere Runaway beam and yields a necessity for an extensive and reliable Disruption Mitigation System (DMS). This has been corroborated using the advanced DREAM code [1], which model RE generation and evolution in addition to several other key plasma parameters, and where STEP unmitigated disruptions produce a Runaway Beam of current greater than 10MA which far exceeds acceptable limits [2]. For mitigated disruptions, idealized impurity injections have been extensively scanned over varying densities of Argon and D2 & Neon and D2. No scenario has been found where a RE beam of current less than 8MA can be created, while also satisfying other DMS targets such as keeping the radiation fraction above 90%, current quench times greater than 20 ms but less than 120 ms, and a Heat Impact Factor lower than 60 $MJ.m^{-2}.s^{-0.5}$ to avoid W melting during the radiation flash. It was also found that Neon provided a marginally lower RE formation and a wider operational window compared to Argon. Subsequently, additional systems must be investigated, in particular higher-fidelity modelling of pure D2 RE mitigation Shattered Pellet Injection (SPI) [3] which is currently the
primary RE mitigation strategy for both ITER and STEP. Another alternative is the use of a passive Runaway Electron Mitigation Coil (REMC) which is planned for DIII-D and is the primary RE DMS in the under construction SPARC tokamak [4]. Initial simulations with simplified magnetic stochasticity assumptions have seen outstanding success in reducing the runaway
generation, however, a more detailed study is needed to assess the viability of a REMC in STEP.

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37

Effects of plasma density fluctuations in laser wakefield accelerators

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

Laser wakefield accelerators are promising candidates for compact sources of relativistic electron beams and bright x-rays. Highly stable accelerator performance is required for applications of these electrons, but this is difficult to achieve due to the sensitivity of the injection and acceleration dynamics to initial conditions, resulting from the non-linear underlying physics. A key parameter in determining the quality of the accelerated electrons is the plasma density, often taken as a constant and controlled by the backing pressure of the gas target. By tailoring the density profile, such as introducing a sharp longitudinal density transition in the target, it may be possible to improve the shot-to-shot stability of the accelerator.

We present the results of particle-in-cell simulations of electron beams generated by a laser wakefield accelerator in a plasma target with a density transition. The plasma density profile is varied in a manner consistent with interferometry measurements of the shot-to-shot density fluctuations in a laser wakefield acceleration experiment and these density variations are correlated to the characteristics of the accelerated electrons. The results suggest that fluctuations of the density profile caused by motion of the blade in the gas are more significant than fluctuations caused by variations in gas pressure.

Nonlinear Energy Transfer in Confinement Transitions of Tokamak Plasmas

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

The turbulent transport of heat and particles is limiting the confinement of tokamak plasmas. However, the existence of different confinement modes such as the high-confinement mode (H-mode) show that phase transitions to plasma states of reduced transport are possible. The quenching of turbulence associated with the transition into H-mode is believed to be caused by the self-organisation of turbulence into zonal flows. Zonal flows do not contribute to radial transport and break up turbulent structures through radial flow shear. This self-organisation is driven by the nonlinear energy transfer between drift-wave turbulence and zonal flows (DW-ZF interaction). Measurements of this transfer can serve as a path towards a better physical understanding of confinement transitions [1].

In this project we investigate the DW-ZF interaction in the upgraded Mega-Amp spherical tokamak (MAST-U) as well as in gyrokinetic simulations. The aim is to both investigate whether the DW-ZF interaction remains a valid predictor of the H-mode transition for MAST-U's new super-X divertor, and to study the implications of this new divertor system for the accessibility of H-mode. Gyrokinetic simulations complement the localised experimental turbulence measurements of the beam emission spectroscopy system [2] by simulating the nonlinear plasma dynamics on a full flux tube. Here we use the local δf gyrokinetic code GS2 [3] to investigate the poloidal distribution of the DW-ZF interaction. Whereas prior work has investigated this distribution for a simple circular flux tube (Cyclone base case) [4], this project will take this investigation towards realistic plasma geometry. Current work focuses on the comparison of fluid kinetic energy transfer and gyrokinetic entropy transfer for ion-temperature gradient mode driven turbulence in GS2, aiming to shed light on the connection between two commonly used paradigms of DW-ZF interaction analysis [1, 5].

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A novel ionisation method to diagnose the peak intensity of ultra-intense laser pulses

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

A paradigm shift in the physics of laser-plasma interactions is approaching with the commissioning of multipetawatt laser facilities worldwide. Radiation reaction processes will result in the onset of electron-positron pair cascades and,
with that, the absorption and partitioning of the incident laser energy, as well as the energy transport throughout the irradiated targets. To accurately quantify these effects, one must know the focused intensity on target in-situ.
In this paper, the recently proposed method to diagnose the peak intensity at focus [1] is extended by careful consideration of the laser-field ionisation mechanism on which it is based. The laser-atom interaction is analyzed at its most fundamental level by numerically solving the time-dependent Schrodinger equation [2, 3, 4] and the set of time-dependent Kohn-Sham equations [5, 6, 7, 8, 9] to most accurately predict the ionisation probabilities after the passage of the laser pulse. Even though it is computationally demanding, the equations are fully solved in three dimensions (3D). This approach is facilitated by the use of a state-of-the-art non-uniform discretisation scheme for the radial coordinate: the Generalised-Pseudospectral-Grids method [5, 10, 11, 12, 13]. A high performance parallelised numerical solver has been implemented. This is used with a novel Hamiltonian formulation suited to be propagated in the length gauge [4], which takes into account non-dipole corrections up to first order in the electron velocity over the speed of light: O(v_e/c) [14]. The photoelectron momentum distribution is studied by means of analytical Volkov propagation [15] including non-dipole corrections.
We acknowledge very useful discussions with Professor Dmitry A. Telnov (St. Petersburg State University, Russia), Dr. Mitsuko Murakami Korobkin (Roswell Park Cancer Institute, Department of Biostatistics and Bioinformatics, Buffalo, United States of America), as well as the other members of Professor Peter Norreys' research group. The simulations were run on the ARCHER2 UK National Supercomputing Service (https://www.archer2.ac.uk) under UKRIEPSRC grant EP/R029148/1.

40

Development of Yttrium Oxide Film Deposition using Microwave Excited Atmospheric Pressure Plasma Jet with a Mist Addition

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1. Introduction
As integrated circuits continue to miniaturize, several challenges are being addressed such as high-speed and vertical etching process of wafers using corrosive gas. The high-density plasmas including corrosive gas potentially damage components such as chamber walls, monitor windows, and holders during the etching process. To address these challenges, Yttrium oxide (Y_2O_3) is used as a plasma-resistant material. This material exhibits thermodynamic stability and a high melting point compared to conventional ceramics like alumina. It is necessary to utilize a Y_2O_3 film with a thick and high density in order to meet the requirements of the complex structure inside the chamber for this application. In this study, we have developed a method to deposit Y_2O_3 using a Microwave-excited Atmospheric Pressure Plasma Jet (MW-APPJ) by Plasma-Enhanced Chemical Vapor Deposition (PE-CVD) and investigate the deposited film characteristics.

2. Experimental apparatus
The experimental apparatus MW-APPJ for PE-CVD is shown in Fig. 1. Microwave of 2.45 GHz was modulated using a 10 kHz square wave. The peak power was 80 W. The on-time duty factor was 30%. The APPJ reactor consisted of a cylindrical container with a gas inlet port and a quartz nozzle placed at the lower end of the central axis. Argon (Ar) was used as a working gas at a flow rate of 223 sccm. A Y_2O_3 precursor mist was introduced into the APPJ reactor via a solvent tank, bubbling Y_2O_3 precursor solution using a carrier Ar gas at a flow rate of 153 sccm. $Y(CH_3COO)_3\ 4H_2O$ was used as a base material for the Y_2O_3 precursor solution. The deposited film thickness was measured using a step-profiler (Surfcoder-ET200). The chemical composition of the deposited film is analyzed by X-ray Photoelectron Spectroscopy (XPS). The deposited film surface and its cross-section was observed by Scanning Electron Microscopy (SEM).

3. Results and Discussions
Quartz glass substrate (25 x 25 mm^2) was located under the quartz nozzle. The distance between the quartz nozzle and the substrate was 5.5 mm. Deposition time was fixed at 20 min. The clear white-colored film was deposited on the substrate. The microscope image was shown in Fig. 2. The deposited film width was approximately 1 mm in Fig. 3. The maximum height was about 16 µm on the quartz glass. Figure 4 (a) illustrates the O1s spectrum, which can be deconvoluted into two oxygen peaks with binding energies of approximately 530.7 eV and 532.9 eV. These peaks are attributed to O-H surface bonds and to oxygen trapping within the material during oxide growth. Figure 4 (b) displays the Y 3d3/2 and Y 3d5/2 spectra, respectively. The Y 3d5/2 spectrum reveals that the main component consists of yttrium hydroxide species, indicating that the precursor solution of Y_2O_3 is decomposed and deposited components are partially present in the deposited film. This study demonstrates that Y_2O_3 films deposited onto a quartz substrate at a rate of 0.8 µm/min using the MW-APPJ with CVD mist addition. XPS measurements reveal the formation of Y_2O_3 film in the deposited film. The influence of operating parameters on the deposited film characteristics and deposition rate will be discussed.

43

Progress toward using Coherence Imaging Spectroscopy for

direct density measurements in the MAST-U divertor

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

The spherical tokamak MAST-U can operate in a variety of magnetic divertor configurations, such as the Super-X divertor, facilitating a comparison of their performance. A Multi-delay Coherence Imaging Spectroscopy (CIS) camera view of the MAST-U lower divertor has been added to the Multi-Wavelength-Imaging (MWI) diagnostic [1][2] with the goal of the CIS camera providing direct electron density measurements across the poloidal cross-section of the divertor. The decrease in the contrast of the fringes making up the CIS interference pattern, due to the Stark broadening of the imaged Dγ Balmer line, allows the determination of the emissivity-weighted chordal-averaged density for each pixel of the camera [3]. This should allow measuring the density in the entire emitting region of the divertor with greater spatial resolution than previously possible. The Multi-delay CIS channel can measure the contrast at three different interferometric delays, as shown in figure for the conventional divertor phase of experiment #46663, to help distinguish between different broadening mechanisms. The separatrix outer strike point is visible as the region of lowest contrast (dark), indicating a higher line-averaged electron density.

A non-linear inversion technique, applied to the chordal-average density, is being developed to determine 2D density profiles under the assumption of toroidal symmetry. The technique is being developed and assessed using predicted plasma conditions from SOLPS simulations and will be validated against other diagnostics. In the future, the new CIS channel will be analysed synergistically with the other divertor imaging cameras in an integrated way enabling more consistent and comprehensive physics studies.

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49

Self-focusing of pure radial mode of LG beam (LG_1^0) in an underdense, cold and collisionless plasma

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

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Abstract: The growing demand for high-intensity lasers has prompted researchers to have precise knowledge of shaping the laser pulse. Focusing is one of the techniques to achieve an ultra-intense laser pulse where the electromagnetic energies are focused down to a smaller diameter. It is well known that when a highly intense laser propagates through a plasma medium, the plasma electrons experience a nonlinear ponderomotive force and are expelled out from higher intensity to lower intensity region generating a density cavity in the plasma. This changes the refractive index of the beam and the medium then acts as a converging lens. This leads to the focusing of the beam and enhancement of the beam intensity. This enhancement of intensity exerts more force on the electrons and may lead to the complete evacuation of the electrons.
In this article, we have considered the propagation of Laguerre-Gaussian beam in an underdense, cold, and collisionless plasma to investigate the self-focusing phenomenon. The simultaneous presence of the ponderomotive and relativistic nonlinearities have been taken into consideration in the study, as the relativistic effect introduces a change in the mass of electrons and helps in ponderomotive self-focusing. The Laguerre-Gaussian beams consist of two indices l and p, with l as the orbital angular momentum and p as the radial index of the beam. LG beams are multi-ringed optical angular momentum beams like Bessel beams and Bessel-Gaussian beams and have shown their importance in different applications like particle trapping, particle acceleration, higher harmonic generations, etc. [1] Since most of the studies in LG beams were strictly on OAM modes, the radial index is mentioned as the “forgotten quantum number” in the literature [2]. Hence, our work focuses on the propagation properties of the pure radial mode of LG beams with l = 0. We have used the WKB approach under paraxial approximation and derived a nonlinear differential equation of the beam width parameter. The results show that the initial laser intensity has an important effect on the dielectric constant of the medium and hence on the self-focusing of the beam. The critical condition for which the diffraction effect is canceled out by the nonlinearities is found to be smaller than that of the Gaussian beam. [3]

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Investigating radiatively driven, counter-propagating plasma flows

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

We summarise existing results and future avenues of research from a novel experimental platform [1] fielded on the MAGPIE pulsed-power generator (1.4 MA, 240 ns rise time). This platform uses the x-ray pulse emitted from a wire array z-pinch to drive plasma ablation from a target. The radiatively driven outflow has a uniform (quasi-1D) structure and expands into the ambient magnetic field produced by the z-pinch.
The x-ray pulse produced by the z-pinch carries a total energy of 15 kJ over 30 ns. The resulting plasma expands into a ~10 T magnetic field supported by the current flowing through the pinch. Spatially resolved diagnostics including interferometry, Thomson scattering, and Faraday rotation are used to measure plasma conditions such as electron density, temperature, and magnetic field.
Our initial work with this platform has focussed on characterising the flow of plasma produced by a single silicon target. This work demonstrated that the morphology of the expanding plasma had a simple morphology, and that we were able to access physics topics relevant to fields including inertial confinement fusion, various topics in atomic physics, and laboratory astrophysics.
In this poster, we describe an experimental configuration in which two targets facing each other are both irradiated by the x-ray pulse, resulting in two, radiatively driven, counterpropagating flows. The dense layer of plasma, formed when these flows collide, is subject to strong radiative cooling. Due to the highly uniform nature of the flows, perturbations in the stagnation layer can be clearly identified. The plasma parameters in this layer can be controlled by varying the target material and separation, making this platform a versatile solution for studying radiative instabilities.

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Role of Non-extensivity on Double Sheath and Virtual Cathode Formation in Collisional-less Plasma

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

When plasma comes in contact with the hot electrode (cathode wall) that acts as electron beam emitting source inside the sheath, then the positive ion space charge gets partially neutralized, and the electrical property of the sheath gets altered. This type of sheath formed is called a double sheath, which was first observed by Langmuir [1]. Amemyia [2] analysed the effect of negative ions on the double sheath. Considering the inertia and the temperature of species the criterion for the presence of stationary sheath containing both charges has been formulated by Shiraishi and Takamura [3] where it was shown that a double-layer structure is formed inside the sheath in which there is ion-depleted sublayers adjacent to plasma and electron-depleted sublayers adjacent to the charged body. The use of ordinary Maxwellian distribution in Boltzmann-Gibbs statistics is valid till the system is in equilibrium. While for a system in non-equilibrium stationary state, the long-range interaction occurs just like in the plasma and in gravitational system the Tsallis or Non-extensive statistics gives the more correct explanation of the phenomenon occurring in the system. Hence, the concept of non-extensivity should be revisited to have a balance condition required for sustaining of the plasma in the system where electron emission also takes place from the wall. Here, we have purposed a basic model to understand the role of non-extensivity on double sheath and virtual cathode formation in collisional-less plasma. The variation of velocity of positive ions inside the sheath and the sheath edge, the electric potential, space charge density and sheath thickness are analysed for the cases of different non-extensivity q. The electric field at cathode becomes zero at lower value of electron beam current density and hence the formation of the virtual cathode takes place earlier for the case of super-extensive distributed electrons as compared to that of the Boltzmann-distributed electrons. By replacing the beam electrons emitted from the cathode with negative ions in our model, the transport of the negative ions across the double sheath can also be understood, which has application in negative ion source and is a suitable candidate for neutral beam injector (NBI) for a fusion reactor such as ITER.

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52

Nonlinear saturation of the beam-plasma instability in inertial confinement fusion

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

In a recent study Ratan et al. [Physical Review E 95, 013211 (2017)] studied the collisionless heating of inertial confinement fusion hot-spots by crossing relativistic electron beams. Energy is extracted from those beams due to the beam-plasma instability leading to exponentially growing Langmuir waves. Through Vlasov-Maxwell simulations of the process, we find that the instability is saturated by trapping of the beam electrons inside the potential of the dominant Langmuir mode. We compare the predictions of models of the trapping mechanism such as the saturation amplitude and the coupling efficiency with the simulations, and find reasonable agreement. Further, we observe two distinct stages of the heating process – heating before saturation of the instability, and heating after saturation. The secondary stage of heating is due to the relaxation of the energy built up in the electric field during the linear stage of the instability.

56

Influence of divertor magnetic geometry on H-mode transitions

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

Results are presented from an experiment to study the effect of divertor closure and X-point height variation on the L-H and H-L transitions in DIII-D. The experiment compared two different divertor set-ups: the small angle slot (SAS) divertor that strongly baffles neutral particles, and the conventional horizontal target divertor. The plasma line-averaged electron density, $\bar{n}_e$, was varied over a range $\bar{n}_e = 1.5 - 4 \times 10^{19} m^{-3}$ during the experiment. Otherwise, conditions were kept similar for all shots, with Ip /Bt ~ 1MA/2T and little net neutral beam torque injected into the plasma. Scanning the vertical distance between the plasma X-point and the divertor surface plate from 0.10m to 0.19m is found to increase the L-H power threshold, Pth, by 30% with the SAS divertor. For the horizontal target configuration, the X-point height was scanned from 0.17m to 0.21m resulting in a 30% reduction in Pth. These dependencies are only observed in plasmas with line-averaged electron density $\bar{n}_e > 2 \times 10^{19} m^{-3}$. A similar trend of two distinct regimes is seen for the H-L transition, with the power threshold increasing as the X-point height is raised from 0.07m to 0.13m then decreasing as the X-point height is raised further from 0.13m to 0.18m. The effect of X-point height on other key variables of the L-H transition, including the ion pedestal temperature and the radial electric field, is also discussed.

57

Time-dependent probability density function analysis of H-mode transitions

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

The first application of time-dependent probability density function (PDF) analysis to the L-H transition in fusion plasmas is presented. PDFs have been constructed using Doppler Backscattering data of fluctuation velocity, $u_\perp$, and turbulence from the edge region of the DIII-D tokamak. This raw time-series data has been sliced into millisecond-long sliding time-windows to create the PDFs. Analysing key variables like turbulence and $u_\perp$ using PDFs allows many subtle, but important, features of their evolution to be studied - helping to shed light on causal processes in the L-H transition. For example, the $u_\perp$ PDFs develop strong right tails during the transition, which are indicative of turbulence-suppressing shear zonal flows in the plasma edge region. The effect of the zonal flows can be seen in the turbulence PDFs, which show a two-step suppression of turbulence in H-mode. Large-amplitude turbulent structures are suppressed first, followed by a more general suppression of turbulence. Other PDF features observed and analysed during the transition include non-Gaussian distributions, bi-modality and oscillatory behaviour. The power of PDF analysis to predict the onset of L-H transitions and support theories of predator-prey self-regulation between turbulence and shear flows is demonstrated.

Advancements to an Integrated Data Analysis system for Bayesian inference of two-dimensional electron temperature and density fields in the MAST-U divertor.

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

In most tokamaks for developing nuclear fusion, the divertor plays a key role in the management of heat flux from the core plasma to the tokamak walls. The control of this heat flux represents an essential step toward the development of power-station reactors. To aid the understanding of processes occurring in the divertor, an Integrated Data Analysis (IDA) system based on Bayesian Inference is being directed toward experimental data at MAST-U.

Inference of two-dimensional, poloidal cross sections of electron temperature (T_e), electron density (n_e) and neutral density (n_0) fields has been performed on synthetic data of the MAST-U divertor via the IDA system of analysis [1]. The treatment of the plasma fields jointly as a large array of parameters evaluated at grid points throughout the divertor, coupled with the usage of a grid aligned with the poloidal magnetic flux surfaces, has enabled the natural inclusion of known physics, or priors', in the inference. For example the monotonic reduction in electron pressure along flux tubes to surfaces. The usage of such known physics has been found to enable inference of synthetic data across the relevant divertor region of 4.7%, 2.7% and 8.7% mean absolute percentage error (MAPE) for T_e, n_e and n_0 respectively.

The IDA analysis works by generating a probability distribution over different combinations of plasma conditions (parameters, θ) for a given set of diagnostic measurements (data, D). This posterior distribution is found through Bayes' theorem,

$$P(\theta|D) \propto P(D|\theta)P(\theta). \qquad (1)$$

P(θ) is the prior probability. The likelihood, P(D|θ), calculation demands faithful, synthetic models of the diagnostics in order to accurately predict their response for a certain parameter combination. For adequate resolution, T_e, n_e and n_0 parameters are desired at many points throughout the divertor region causing the posterior distribution to be over a very highly dimensional total parameter space. This generates an ill-posed problem (for the same data, multiple parameter combinations are plausible) creating an extremely complex probability distribution. Consequently, finding regions of high probability in the distribution (for efficient sampling) is challenging and constitutes a hurdle for the inferring ability of the IDA.

The use of the known physics that follow from the poloidal flux surface-aligned grid have been found to address this impasse through their inclusion as the prior of equation 1. This reduces the number of regions of high probability in the posterior distribution. Doing so enables the inclusion of additional parameters in the IDA and thus permits more complicated, faithful models. Such model enhancements include molecular contributions to Balmer emission lines which have been shown at recent experiments at MAST-U to be significant [2]. Consequently, the careful inclusion of known physics as priors (enabled by a poloidal magnetic flux surface-aligned grid) to allow more complicated models is crucial for the IDA to be applied to experimental data.

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Singularity Conditions of Rayleigh-Taylor Instability in a Hall Thruster Plasma under Increased Ionic Charge

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

Hall thrusters are ionic propulsion devices that are being used across the globe in governments and commercial satellites for orbital adjustments due to their high specific impulse and no limit of maximum current density. Hall thrusters provide a thrust of a few mN to 1 N, thus needing to operate continuously for a very long period. Hall thrusters use a magnetic field to trap the electrons, which are used to ionize the fuel (Xenon gas). These ionized gas atoms are accelerated using an axial electric field to produce the desired thrust [1]. Hall thrusters are among the best space propulsion technologies in use, although their effectiveness and longevity are decreased by several plasma instabilities and persistent wall erosion [2]. Since ions provide the restoring force to the electrons, the increased ionic charge will modify the properties of these unstable waves and electron transport.
The Rayleigh-Taylor instability in the Hall thruster plasma is caused by the magnetic trapping of the electrons in the thruster channel [3]. The current article studies this Rayleigh-Taylor instability using a three-fluid model under the effect of increased-ionic charge. A singularity in this Rayleigh-Taylor instability is observed, and the condition that causes it as well as the frequency at which it happens are investigated under the effect of increased ionic charge for different thruster plasma parameters. The local electric field in the thruster channel is also affected by the plasma turbulence in the Hall thrusters' channel, which further affects the wall erosion rate, shortens the thruster's life span, and causes more energy to be lost on the wall, further lowering efficiency [4]. The propagating frequency and growth rate of these instabilities can be manipulated by controlling various parameters [5]. The plasma parameters can be modified with the aid of the current study for optimal effectiveness and a longer thruster life.

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60

Study of Magnetic Field Evolution in Counterstreaming Electron Positron Flow in One Dimension

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

The magnetic field is omnipresent in the universe, which makes it an exciting topic for various research fields. The Weibel instability [1] is one of the prominent candidates behind this magnetic field. Various theoretical and simulation studies have been performed to study this Weibel instability and the reason behind its origin. Here 1D simulations are carried out by the particle in cell (PIC) EPOCH code for the unmagnetized counterstreaming electron-positron (e-/e+) plasma beams in two different cases. A weak relativistic case is considered for the drift velocity of 0.5c for the two counterstreaming (e-/e+) plasma beams [2]. The wave vector of growing mode is parallel to the x-direction. The simulations show that the electric and magnetic field energy for homogeneous and non-homogeneous plasma distribution grows linearly with time in the initial stage and reaches its saturation for the rest of the simulation time. The cause of these electrostatic field is magnetic pressure gradient, and the redistribution of plasma particles takes place in space.

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62

Pulsed power produced cylindrically convergent shockwaves in water at the Multi-Mega-Ampere Level

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

The pulsed power driven explosion of cylindrical arrays of wires in water has been used for the past decade to produce high speed, convergent shockwaves. On axis, the pressures that these shockwaves are expected to produce, which regularly stretch into the Mbar regime, should result in warm dense matter conditions being created, even with relatively small pulsed power drivers.

We report on the first experiments, exploring how this technique scales to multi-Mega-ampere currents. Our research was performed on the Cepage generator at First Light Fusion with array diameters of 13mm consisting of up to 100 x 200µm copper wires. Currents between 1.2 and 2.3MA were driven through the arrays – more than four times that of any previous experiments - and the energy deposited into the exploding wires reached a maximum ~50kJ. Extremely symmetric shockwaves were launched through the water, and reached velocities ~5km/s at 1mm radius. The shockwaves then appeared to accelerate to > 12km/s due to convergence, creating multi-Mbar pressures in the vicinity of implosion axis. With the high level of current available on Cepage we were able to field simple, easy to field, cylindrical foil liners instead of wire arrays - these also showed a highly symmetric, high velocity implosions resulting from explosion of the foil.

Future plans for experiments on the 14MA M3 generator will be presented, along with configurations to use the shockwaves to drive pressures in separate targets, and the results of the first experiments producing spherical implosions to reach more extreme conditions.

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63

PORTABLE X-PINCH DRIVER DEVELOPMENT FOR DENSE PLASMA MEASUREMENTS

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

Determining the properties of Warm Dense Matter (WDM) necessitates the use of advanced X-ray based diagnostics including diffraction and absorption spectrometry. As many experiments that produce WDM do so for only a few ns, the probing X-rays must be short pulsed, ideally with a high enough yield to produce data on a single experiment. They must also have the correct spectral characteristics – e.g. a smooth continuum for absorption spectrometry. Such requirements often restrict experiments to large scale facilities like 3rd generation Synchrotrons and XFELs, which have a very limited time available for individual users.

At Imperial College we have been developing several X-pinch based X-ray sources to provide a complementary capability to large facilities, with the aim of promoting 'in house' WDM research at universities. This would encourage new researchers in the field and provide a method to optimize experiments prior to their use elsewhere. In an X-pinch two or more crossed fine metallic wires are driven by a fast-rising current pulse. The magnetically driven implosion of the crossing point emits a short pulse of X-rays that can be utilized for diagnostics - however, at present, X-pinches are relatively unknown outside the pulsed power community with the complexity of their drivers and lack of portability hampering wide-spread use.

We report on new, portable X-pinch systems presently under development at Imperial College for probing dense plasmas that are extremely portable (~50kg) and designed to be easy to use. The X-pinches are driven by >100kA currents and emit ~100mJ of >10KeV radiation on ns timescales, from a spot size of a few microns. The emission spectra depend on wire material, typically with strong emission in the K- and L-lines, along with a broadband continuum stretching to many 10s of keV.

By selecting the appropriate wire material to form the X-pinch, different emission characteristics can be obtained. Typically, higher Z materials yield continuous emission spectra, whereas discrete lines are more dominant in lower Z materials. The focus of this work is to use the X-rays emitted by an X-pinch source for diffraction measurements of WDM. For this purpose, lower Z materials such as Cu and Ag, with strong line emissions, are used in combination with X-ray optics to obtain sufficient photon flux and localized focal point; The current design uses a focusing polycapillary lens to achieve this goal; however, recent studies also showing that Fresnel Zone Plates (FZP) can offers high resolutions (~1.5 microns) at a significantly lower cost.

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64

Initial analysis of rotational and vibrational distributions of D2 molecules in the MAST-U divertor

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

Plasma detachment will be an essential feature of large-scale fusion devices (such as DEMO) in order to ensure that the divertor target heat flux does not cause intolerable damage. During detachment, the particle flux reaching the divertor plates is reduced by particle, momentum and energy sinks [1] and it is now evident that molecules have an important role to play in this process [2, 3].

Electronically excited D2 molecules can be observed directly via the Fulcher band (a band of visible lines between 590 nm and 650 nm) and a careful analysis of Fulcher band emission can reveal information about the rotational and vibrational distributions of the molecules [4-6]. It is known that these distributions can have a high impact on plasma-molecule reaction rates.

Such emission can be observed in the MAST-U divertor. High resolution Fulcher band divertor spectroscopy from the first experimental campaign indicates an increasing rotational temperature in the MAST-U divertor during a density ramp in the Super-X configuration. It also contains possible evidence for populations of molecules at different temperatures; and vibrational-vibrational energy exchange between molecules.

Further Fulcher band analysis is planned for new data from various divertor conditions and configurations currently being investigated in the second experimental campaign.

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65

Constraints on the ion velocity distribution from fusion product spectroscopy

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

Fusion product spectroscopy is a common diagnostic technique used in both magnetically and inertially confined fusion plasmas to infer properties of the fusing plasma. This includes neutron spectroscopy from DT and DD reactions as well as proton spectra from D3He fusion. Previous analyses based on the assumption of Maxwellian ion velocity distributions show that the energy moments of the spectrum can be related to the fluid velocity and temperature of the plasma. However, if the distributions are non-Maxwellian, forward models are typically used to compute the spectrum requiring knowledge of the form of the ion velocity distributions. In this work, we derive the relationship between the spectral moments and properties of the ion velocity distribution for the most general case of a 3D, spatially and temporally varying, kinetic plasma [1]. This allows the inference of properties of the ion velocity distributions without evoking a model for their velocity dependence. It is found that distributions which are isotropic in velocity space only produce spectra in a restricted space of spectral moments. Predictions of this theoretical analysis are compared to recent results from ICF experiments which potentially show the presence of kinetic effects in burning plasmas [2].

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Characterisation of inductive plasma for microwave-plasma interaction experiments

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

Non-linear interaction between electromagnetic waves and plasmas can result in exchange of energy. This can particularly arise if the electromagnetic waves meet some resonance condition with a natural plasma oscillation. For example, Raman and Brillouin scattering can be excited between two injected electromagnetic signals and an electrostatic plasma wave, the Langmuir and ion-acoustic oscillations respectively. These are each important in laser plasma interactions. In a magnetised plasma beat-waves can excite the upper hybrid and electron cyclotron resonances. This would be of interest for driving current in overdense (with respect to the cyclotron frequency) magnetically confined fusion plasma.

Progress is reported in the construction of an apparatus and characterisation of a plasma, including supporting numerical simulations, for fundamental experiments in microwave-plasma coupling. A helium or argon plasma is formed in a vacuum vessel 1m in diameter and 3m long, using a flat spiral antenna driven by a high frequency RF source at 14 MHz. The experiment can produce both unmagnetised plasma (inductive mode), or magnetised plasma (helicon mode [1]) using a Helmholtz pair of magnet coils, 1.6m in diameter. RF compensated Langmuir probes and microwave interferometry indicate a cool, Te~ few eV, stable plasma with ne < 2x1015 m-3 in inductive mode with 200W of drive power.

Using microwave beams to study parametric interactions in a cool tenuous plasma allow for greater active control of injected waves and diagnostic accessibility. By combining measurement, simulation, and theoretical analysis a greater understanding of these interactions is sought. Pulsed high power microwaves in the range 9-10 GHz are being launched across the vessel using horn antennae [2]. The antennae have been designed to convert the fundamental mode of a cylindrical waveguide into a Gaussian beam at its aperture. Lenses have also been designed to focus the beam into the centre of the plasma. The high power microwaves are currently generated by a magnetron at 9.4GHz, but will soon exploit frequency flexible TWT amplifiers. To excite a chosen plasma resonance, the amplifiers allow for tuning of the microwave frequencies.

The project builds on previous research in magnetospheric cyclotron instabilities [3-5]. The authors gratefully acknowledge support from the UK EPSRC through grants EP/R004773/1 and EP/R034737/1.

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67

Collective High-k Adjustable-radius Scattering Instrument (CHASI) for measuring electron scale turbulence on MAST-U

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

Plasma turbulence on disparate spatial and temporal scales and associated cross-field particle / heat transport plays a key role in limiting the level of confinement achievable in magnetic confinement fusion experiments (tokamaks) [1]. The development of reduced numerical models that accurately predict the wavenumber spectrum of cross-scale turbulence is essential for understanding and maximising confinement. Such models require the experimental measurement of core and edge turbulence at both electron and ion scales to inform development. MAST-U is a well-equipped experimental facility having instruments to measure ion and electron scale turbulence at the plasma edge. However, measurement of turbulence at electron scales in the core is problematic, especially in H mode. Electron scale turbulence is expected to be most significant in the binormal direction with scale ranges of order k_perp ρ_e ~ 0.1 -> 0.4 (where k_perp is the binormal turbulence wavenumber and ρ_e the electron gyroradius) in the confinement region of the core plasma (0.5 < r/a < 1). In this paper, we therefore propose a novel, mm-wave based scattering diagnostic for measuring binormal oriented high-k (electron scale) turbulence in the MAST-U core and edge plasma.

We present detailed hardware specifications for the diagnostic along with the results of Gaussian wave optics and beam-tracing calculations [2] that demonstrate the predicted spatial and wavenumber resolution. Using the k_perp data from the beam tracing simulations of the scattered spectrum, we conducted an analysis of the instrument selectivity function using a methodology similar to that presented by Mazzucato et al. [3, 4], yielding estimates for the localisation and sensitivity of measurement. Primary specifications of the diagnostic include an operating frequency of 376GHz, a source power of ~100mW, a normalised turbulence wavenumber measurement range of k_perp ρ_e = 0.1 -> 0.43, a turbulence wavenumber resolution of Δk_perp = 1cm^-1, a minimum spatial localisation of ~5cm along the primary beam path and a minimum signal to noise power ratio of 16.

Framework for optimizing free parameters in ICF hydrodynamic simulations using Gaussian Process surrogate models.

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

To design and interpret inertial confinement fusion (ICF) experiments, accurate and predictive calculations with well-defined uncertainties are required. Additionally, the physical models used in these hydrodynamic codes need to be benchmarked and validated against experimental data. Free parameters within these codes can be optimized through large ensemble parameter scans to maximize the fit to experimental data. Given the high dimensionality of parameter space for a full laser driven ICF simulation, this can become very computationally expensive, particularly for 2D and 3D calculations. Similarly, it may be necessary to perform ensemble simulations to characterize the uncertainty in, and robustness of, the permanence of future experimental work.

To speed up the ensemble simulations and optimizations, a Gaussian Process (GP) model can be trained to produce an inexpensive surrogate model to be used in place of the code itself. This surrogate model allows for a more thorough sampling of parameter space, allowing for a converged distribution and more accurate bound on errors, as well as allowing the user to optimize a quantity of interest (QoI). Optimized parameter values can then be benchmarked against the original numerical method. Sensitivity analysis can be extracted from, or inferred using, the surrogate model and potentially reduce the dimensionality of the problem. GPs encompass uncertainty in both the underlying physical models and the surrogate model itself, with the latter being reduced by convergence testing.

The work presented here details the development of a framework which implements a GP model to speed up parameter optimization used in ICF ensemble parameter simulations. The method has been applied to experimental data from the OMEGA Laser facility, and an example application from planar [1] shock-timing data will be presented. These shock-timing experiments are simulated using the 1D hydrodynamics code Freyja, but the method is equally applicable to multidimensional codes where the computational speed-up of using a GP becomes more apparent. As the propagation of shocks in the early stages of an ICF implosion is sensitive to the equation of state (EoS) model used, this framework has also been applied to a variety of different EoS models to assess the ability of each fit to experimental data. The GP surrogate model will be trained on the resulting shock-merger time and the resulting fit to the experimental shock-velocity profile will be accessed.

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72

Novel Hairpin Geometries for High-Field Low-Density Plasma Ablation Experiments

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

On university-scale pulsed power drivers (of typically ~1 MA peak current), it is difficult to produce stripline experiments with current densities and magnetic fields relevant to the design of the next generation pulsed power machines. In this poster, we present a novel approach that is being tested on the MAGPIE driver at Imperial College. This approach, called the "hairpin", uses small wires of circular cross-section bent into slightly inductive loops; it is advantageous for several reasons. First, it is far easier to work with small-diameter wires than very thin planar foils, so manufacturing costs are dramatically reduced. Second, the curvature of the wire cross-section provides significant field enhancement at the apex of the curve, allowing access to even higher magnetic and electric field strengths at larger A-K gap widths. Lastly, the size (and, correspondingly, the inductance) of the loop can easily be varied, allowing precise control over the electric field strength at similar current levels when fired on a stiff driver like MAGPIE. Several simulations of different hairpin designs are presented using the COMSOL multiphysics software, and recommendations are made for a future experimental campaign on MAGPIE.

Investigating the role of vibrationally resolved H2 on detachment evolution in SOLPS-ITER MAST-U simulations

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

Contemporary work suggests that the vibrational distribution of H2 may have a strong impact on detachment evolution. SOLPS-ITER simulations mainly utilise the AMJUEL database for its rate data. AMJUEL contains effective rates for H2 that average over an assumed distribution of vibrational states. H2VIBR contains individual rates for each of the vibrational states of H2. Simulations utilising H2VIBR and tracking individual vibrational states will be compared with standard simulations utilising AMJUEL and tracking the ground state only, as well as with MAST-U experimental data.

Verhaegh defines detachment in four phases [1]. The first is the detachment of the ionisation front from the target, increasing the molecular density in this region. This increases plasma-molecular interactions (PMI) in the region such as molecular-activated recombination (MAR) and molecular-activated dissociation (MAD), resulting in excited atoms and greater Balmer emissions. In the second phase the MAR region detaches from the target leaving a cold region behind. Thirdly, strong emission via eletron-ion recombination (EIR) occurs. Finally resulting in a decay of the ne near the target. The creation of molecular ions below Te = 5eV requires the presence of H2 excited to high vibrational levels [2]. Therefore, the vibrational distribution of H2 has a strong impact on PMI, and subsequently on MAR. This increased neutral density may lead to further plasma-neutral interactions, enhancing detachment further [3].

Work by Holm utilises a 0D EIRENE setup to explore the differences between AMJUEL and H2VIBR [4]. Holm observes a 25-65% decrease in the dissociation rate from the AMJUEL case to the H2VIBR case. This indicates a reduction of momentum losses from plasma-neutral
friction and radiative losses. From the nature of the simulation setup, transport effects and plasma-neutral interactions were excluded from Holm's investigation. Modifying this approach for this investigation in SOLPS-ITER will include these effects, in addition to providing a
route to compare detachment evolution between H2VIBR and AMJUEL simulations.
MAST-U's diagnostics can be utilised to compare with these simulations. Verhaegh utilises a synthetic diagnostic of MAST-U's DMS to compare SOLPS-ITER simulations with experiment [1], this can be used in this investigation. Synthetic diagnostics for MAST-U's MWI, bolometry systems, and langmuir probes will be made for verification.

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Plasma Water Activation with an Inductive Plasma Torch at Atmospheric Pressure

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

The production of reactive oxygen species (ROS) and reactive nitrogen species (RNS), collectively referred to as RONS, has been of increasing interest in recent years. This is based on the wide range of applications for the components mentioned. Examples include the food industry and agriculture or biological applications [1 – 3]. The generation of RONS by plasma-liquid interaction in plasma-activated water is a widely used method. Due to the plasma properties, such as high electron temperatures at low gas temperatures, mainly cold or non-equilibrium plasmas are used [4 – 5]. Plasmas in thermal equilibrium at atmospheric pressure have so far played a subordinate role in PAW generation due to their moderate electron temperatures and high thermal losses. This leads to a lack of publications in this field.
In our work, we have developed an inductively driven plasma (ICP) torch, which was used for plasma water activation. An atmospheric pressure inductive Argon plasma was generated with a power of 1.2 kW at a frequency of 3 MHz. The used setup is shown in Figure 1. The plasma was pointed to distilled water in a distance of 1 cm. During a one-hour treatment, the concentration of hydrogen peroxide (H2 O2), nitrite (NO2 −), nitrate (NO−3) and the pH value was measured every 10 minutes by using Quantofix test strips (Peroxide 100, Nitrite, Nitrate 100, pH-Fix 0-14, Machery-Nagel, Düren, Germany).
Furthermore, a simulation model of the lab setup used was created. The FEM software COMSOL multiphysics was used to simulate the plasma behaviour and to determine the electron temperature at the atmosphere and the water impact region [6]. With the results, the formation rate of the components mentioned were approximated and compared with other methods for PAW generation.

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Review of Exhaust experiments in MAST Upgrade's second campaign

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

Review of Exhaust experiments in MAST Upgrade's second campaign

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One of the biggest challenges facing tokamak fusion power is safely exhausting the heat and particles from the fusion core. The exhaust plasma is effectively confined within a region of narrow radial width (typically mm-cm), the Scrape-off layer (SOL), and the power leaving the plasma core can be several 10's of MW in large current and future tokamaks, which can result in heat fluxes large enough to damage plasma-facing surfaces in the tokamak divertor. One possible solution to this challenge is alternative divertor configurations, which are intended to enhance the dissipation of power and particles in the divertor region before they reach material surfaces and to increase the area over which power and particles are deposited on these material surfaces.

The MAST Upgrade tokamak is equipped with an extensive array of coils to manipulate the magnetic geometry in two up-down symmetric and tightly baffled divertor chambers. The second experimental campaign on MAST-U has exploited the extensive array of exhaust diagnostics to conduct studies of alternative divertor configurations, filamentary transport and divertor detachment experiments.

In this contribution a summary of these experimental findings and plans for the next campaign, which begins in spring 2023, will be presented, including the operating space currently explorable on MAST-U. The first measurements from the reciprocating probe will be presented along with detachment studies in three distinct divertor configurations which provide valuable input for the viability of alternative configurations and tightly baffled divertors for reactor designs. Initial studies for preparation for real time detachment control will also be presented.

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80

Implementation and application of a simple radiation loss model for tamped volume ignition ICF targets

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An important element of a reduced volume ignition model is accurately capturing the trapping of radiation by the high-Z pusher surrounding the fuel capsule of a typical inertial confinement fusion (ICF) target, as radiation loss represents one of the most significant energy sinks. As fuel temperatures rapidly start increasing during the burn stage, the enhanced bremsstrahlung emission absorbed by the inner wall of the pusher drives a supersonic diffusive radiation (Marshak) wave. The result is a drop in radiation recycling efficiency of the system and thus, may be a substantial barrier to ignition. A consistent set of analytical solutions to this phenomenon were first derived by Hammer and Rosen [1] assuming analytical forms for the material properties. This theory was later extended by Dodd [2] to derive a set of rate equations describing the evolution of both the radiation temperature and the heat front position as a function of the radiation flux incident on the pusher surface.
As part of First Light Fusion's effort to develop a computationally inexpensive reduced volume ignition model for optimisation purposes, Dodd's model has been implemented and verified. The implementation of the spherical ignition model uses operator splitting for the different physical processes involved and an adaptive time stepping method determined by the adiabatic compression of the capsule. An underlying assumption of Hammer and Rosen's work is that the material properties follow an analytic power-law, thus a surface fitting calculator was developed to determine coefficients from transport and EOS tables. Instabilities of the differential equations at t=0 were overcome by using a semi-implicit, predictor-corrector scheme with a ramped-up time step increasing to the hydrodynamic scale. Verification tests were implemented following Dodd and extended solving for a range of simple analytic profiles describing the temperature profile at the boundary. The model was compared to a simple radiation trapping model often used in Hohlraum physics, where the fuel-pusher interface is equated to a reflective wall with constant albedo. Both models were implemented in the reduced ignition model and their effects studied and compared using a single-shell ICF capsule setup. Results show that the evolution of the wall temperature can hugely affect both the time of ignition and the maximum fuel temperatures reached during burn, thus playing an important part in the reduced model.

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Thermodynamics and collisionless relaxation of a Lynden Bell plasma

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

The relaxation to non-Maxwellian quasi-equilibria on timescales much shorter than the the timescale of coulomb collisions is frequently observed in nature. It is thought that this relaxation may be sufficiently fast to preserve the conservation laws of the collisionless Vlasov equation, namely phase-volume conservation, which necessarily implies different equilibrium distributions. These equilibria were derived by Lynden-Bell (1967) on the grounds of entropy-maximisation subject to the constraints of evolution governed by the collisionless Vlasov equation. We show that these equilibria can be reached dynamically by a 'collisionless collision integral' and discuss its implications for collisionless relaxation. We further discuss the equilibria themselves in detail, showing that, despite the seemingly strong additional constraints of phase-volume conservation, the equilibria possesses power-law tails with remarkable generality.

3D Stability Analysis of ELM Control using Resonant Magnetic Perturbations in Tokamak Plasma

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

Next generation magnetic confinement tokamak fusion reactors will operate in a regime with high particle and heat confinement (H-mode). H-mode is characterised by the existence of periodic transient eruptions occurring in the edge of the plasma, driven by unstable peeling ballooning modes and known as Edge Localised Modes (ELMs) [1][2].

Next generation tokamak plasmas cannot operate in a standard ELMy H-mode state, due to the erosion that results from ELMs. As such, it is vital that ELM control (or avoidance) is achieved or else large scale high energy tokamak plants (such as ITER and STEP) will suffer extreme degradation of the internal walls, accelerating the rate at which they will need to be maintained.

One method of controlling ELMs is to apply small non-axisymmetric (3D) resonant magnetic perturbations (RMP) to the plasma, produced by external coils, with the objective of relaxing the pressure gradient at the edge of the plasma, and so mitigating or even suppressing ELMs [3].

These RMP enhance the transport [4][5] in the plasma edge region by perturbing the magnetic field on the scale of typically 3-4 orders of magnitude lower than the plasma equilibrium magnetic field. An important physics question to address is how the presence of applied 3D fields impact ELM dynamics.

ELITE [6] is a spectral eigenvalue linear stability code used to analyse ideal MHD modes in tokamak plasmas, that has been extended to model the effect of RMPs on stability, and hence quantify their impact on ELMs. Thus, ELITE can now be used to calculate the fixed boundary linear ideal MHD plasma response (the 3D part of an equilibrium field) to 3D RMP, and then to compute ideal MHD eigenmodes for these non-axisymmetric tokamak plasmas.

This upgraded code, called ELITE-3D [7], uses eigenfunctions for the toroidally symmetric plasma peeling-ballooning stability as basis functions in a 3D energy principle stability analysis for the resulting equilibrium. This analysis is bolstered by rigorous ballooning theory of 3D MHD equilbria. This capability is particularly relevant for the investigation of RMP-induced ELM suppression which can help uncover ELM free operating regimes on ITER or STEP, for example.

Progress in further extending the theoretical basis for the ELITE-3D code will be presented, providing a more accurate description of how the two components of plasma displacement normal to the magnetic field are related. First results from applying ELITE-3D to realistic tokamak equilibria will also be described.

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85

Long-Time Fully Kinetic Simulations of Electromagnetic Ion Beam Instabilities in the Terrestrial Foreshock

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

Suprathermal ions and accompanying large-amplitude MHD-like waves are common and important features of Earth's foreshock. Backstreaming field-aligned beams, formed by solar wind proton reflection at the quasi-perpendicular bowshock, provide the robust free energy source needed to excite the predominantly fast-magnetosonic fluctuations observed in-situ.

For cool beams, linear Vlasov theory yields two instabilities with maximum growth at parallel/antiparallel propagation: (1) a right-hand-polarised beam cyclotron resonant mode (dominant for tenuous beams), and (2) a nonresonant firehose-like instability (excited preferentially by fast and/or dense beams). Although best suited to ion-scale physics, kinetic-hybrid simulations of these instabilities have revealed a wealth of multi-scale behaviour, such as: pulsation steepening due to beam spatial and gyrophase bunching, and the fully-developed turbulence that results from bifurcations of these structures; shear Alfvén wave dominance at long times, and nonlinear whistler generation. Kinetic studies capable of spanning the full range of relevant spatiotemporal scales present an important next step in understanding the consequences of ion beam instabilities upstream of Earth's bowshock.

We present results from local 1D- and 2D-3V initial value PIC simulations of the nonlinear post-saturation evolution of the ion foreshock beam-plasma interaction. Motivated in particular by recent results suggesting a correlation between elevated solar wind core temperatures and anisotropy-driven instabilities in the foreshock, we give principal focus to the action of secondary instabilities on the plasma evolution.

Modelling and Design of a Hard X-Ray Spectrometer for TCV

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

Fast electron populations in tokamak plasmas are vulnerable to runaway acceleration up to relativistic energies as the collisional drag decreases with increasing velocity. These Runaway Electrons (REs) are anticipated to pose a threat to ITER in post-disruption scenarios [1], as they have the potential to cause significant damage that may halt operation [1, 2]. A path to benign termination of RE beams has recently been developed [3, 4] and preliminary experimental findings suggest that it may be related to changes in RE energy [5]. It is therefore necessary to measure these energy distributions to investigate the underlying physics.

In this work, the design and modelling of a Hard X-Ray spectrometer for the Tokamak à Configuration Variable (TCV) is presented. The optimisation of the design for an ITER relevant, LaBr3 scintillator based, Hard X-Ray spectrometer is evaluated under constraints related to calibration, shielding, collimation, signal processing and modelling with the aim of recovering information about the initial energy distribution. This scheme is informed in part by recent measurements made using CeBr3 scintillator detectors on loan from the GOLEM tokamak [6] as well as by simulations performed using Geant4 [7] that are used to build synthetic detector response functions. In this work, favorable shielding and collimation geometries are demonstrated that attenuate the photon flux without adversely affecting the reconstructed spectrum. The inversion of the simulated, detector response to reconstruct the photon energy spectrum is successfully validated using calibration data and test exponential distributions by regularization with Minimimum Fisher Information. This detection method is therefore demonstrated to provide useful reconstructions of the photon energy distribution from measured spectra that may constrain physical models of the electron velocity distribution function.

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Diamond nucleation & growth in high pressure hydrocarbons

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Understanding the nucleation of carbon into diamond is important to many physical disciplines. We are particularly interested in the behavior under intense pressures similar to those found in the atmosphere of giant planets or within the ablator of a target undergoing laser compression. Within the methane rich atmosphere of the ice giant planets, Neptune and Uranus, diamond nucleation is theorized to occur [1]. In inertial confinement fusion experiments, diamond nucleation within the ablator may seed instabilities that would prevent ignition. In particular the formation of density in-homogeneity may seed Rayleigh-Taylor instability. However laser compression of hydrocarbons may potentially be a new way to create nano-diamonds for medical and technological purposes.

Recent experiments have shown that conditions equivalent to those in planetary interiors, P ~ 150 GPa and T ~ 5000 K, approximately 50% of the carbon in a polystyrene sample was converted to diamond [2,3]. Upper and lower limits on the diamond size were measured to be 4nm and 100nm respectively.

We have developed a model to track the rate of nucleation at high pressure conditions. The model splits diamond formation into nucleation and growth phases. We have included the effect of carbon depletion on both phases and the effect of surface area coupling in the growth phase. We use experimental outcomes as boundary conditions to set the coefficients in the model.

Our results shown in Fig.1 predict nucleation rates higher than expected in classical nucleation theory and calculated growth rates far exceed those achieved by methods such as carbon vapor deposition (CVD). Within dense systems diamond nucleation occurs too rapidly to allow any growth beyond the nano-scale, ultimately capping their size through carbon depletion.

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Figure 1: Nucleation rates (left) and growth rates (right) predicted for various size boundary conditions and 50% carbon conversion to diamond. The nucleation rate is calculated from the first derivative of the number density of unique diamonds as a function of time. The growth rate is calculated from the first derivative of the one dimensional size of the first seeded diamond group.

89

First detailed beam emission spectroscopy measurements on spatial structure of beam driven TAEs in MAST-U

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Drinks Reception and Poster Session, March 27, 2023, 16:50 - 18:30

The viability of magnetic confinement fusion reactors will depend on fast (suprathermal) ions being adequately confined to ensure that they provide the heating (and possibly current drive) needed to sustain burning plasma conditions. Fast ion confinement can be degraded by instabilities driven by the fast ions themselves. We have obtained mode structures of fast-ion driven toroidicity-induced Alfvén eigenmodes (TAEs) using beam emission spectroscopy (BES) in the second physics campaign of the Mega Amp Spherical Tokamak Upgrade (MAST-U). The upgraded BES provides a 2D poloidal viewing window adjustable in radial locations, covering approximately 13cm radially (about one-third of the minor radius) and 15cm poloidally. The experiments reported here carried out in similar or nearly identical conditions such as minimum safety factor (qmin) values well above 1, energy of neutral beam injection induced fast ion at about 60keV, toroidal magnetic field at about 0.4T, core electron densities and temperatures at about $3x10^{19}$ m^{-3} and 1keV, and plasma current at about 750 kA at the times of appearances of TAEs. BES data from these shots show that density fluctuations associated with TAEs with toroidal mode number n = 1 are consistently peaked at or near the locations with safety factor (q) of about 3.5. Efforts are underway to improve the equilibrium profile reconstructions with constraints imposed by motional Stark effect (MSE) measurements of the magnetic field pitch to identify the exact q surface at which the TAEs are located.

The TAE mode structure measurements are compared with fast ion loss measurements. MAST-U is equipped with a suite of powerful new or upgraded fast ion diagnostics such as a fast ion loss detector (FILD), a fast ion D-alpha (FIDA) spectrometer, a solid state neutral particle analyzer (ssNPA), and a neutron camera (NC), all of which either capture or can be used to assess the TAE associated fast ion redistribution and losses. The gyroradii and pitch angles of fast ions ejected by TAEs inferred from FILD data show the losses primarily came from the off-axis beam injection. Analyses on FIDA, ssNPA and NC data are also in progress. These measurements, along with the measured mode structures, could be compared with results from various simulations in future work to advance the study of TAE and the associated fast ion losses.

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90

Operation of an X-band Self-Insulating Backward Wave Oscillator

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The Self-Insulating Backward Wave Oscillator (SIBWO) is a novel variant of the relativistic BWO (≳500keV), replacing the conventional annular electron-beam (e-beam) and externally-applied magnetic confining field [1 – 2] with a solid e-beam propagating purely under the influence of its own self-forces. Such e-beams are naturally divergent, with the net imbalance in the Lorentz force resulting in an expanding beam envelope as it propagates through the interaction region, however electronic efficiencies of 20 – 30% have been predicted [3], making the SIBWO comparable in performance to the conventional state of the art.
Efficient operation is obtained in two general steps; the first being optimisation of the electron gun optics to maximise the uniformity of the particle momenta at the entry to the interaction region, providing the majority of the electron energy expressed as axial momentum. This is key, as the operational mode of the SIBWO (and indeed the BWO) is intended to be the TM01, possessing a well-defined Ez field component that peaks radially on axis, with a secondary (Ez) maximum induced by bending of the Er field lines close to a corrugation of the drift-tube wall. Expression of the particle energy in the axial momentum allows for optimal modulation by (and coupling of energy to) said Ez field component.
The second step involves careful tuning of the interaction region. In contrast to the conventional BWO, the SIBWO interaction is dominated by modulation induced near the central axis, with the e-beam essentially spanning the cross-section of the drift-space. The SWS lead-in operates as a quasi-modulation cavity, increasing the density and uniformity of the electron beam, with the SWS corrugation depth exaggerated in comparison to the conventional BWO. This provides stronger coupling between the e-beam and the Ez field close to the axis, whilst also reducing the frequency sensitivity to spread in the electron energy.
We present the first experimental output from this source, resulting from a collaborative research programme involving the University of Strathclyde (UoS) and the US Naval Research Laboratory (NRL).

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