

52nd IOP Annual Plasma Physics Conference

7–10 April 2026

Elphinstone Hall, University of Aberdeen, UK



Welcome

On behalf of the organising committee, we are pleased to welcome you to the annual IOP Plasma Physics Conference. This conference covers all aspects of plasma physics, including magnetic and inertial confinement fusion, astrophysical and space plasmas, low density and technological/industrial plasmas, low temperature plasmas, high energy density and laser plasmas, dusty and complex plasmas, plasma surface interactions, plasma applications including medical applications and plasma diagnostics. The programme will include invited talks, contributed talks and posters.

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Invited Speakers

Professor Lyndsay Fletcher

University of Glasgow

Solar Flares - a Chromospheric Perspective

Solar flares are rapid, unpredictable and violent episodes of intense energy release in the Sun's atmosphere. The energy source for flares is the stressed magnetic field of the Sun's outer atmosphere, or corona. The main energy sink is the radiation emitted by the Sun's lower atmosphere, particularly the thin, complex plasma layer called the chromosphere. The chromosphere provides many of the remote-sensing diagnostics for the physical processes involved - magnetic reconnection, particle acceleration, plasma heating, and mass motion - as well as for the magnetic field and its evolution. It is also a region where the plasma properties vary rapidly and by orders of magnitude, presenting many significant observational and theoretical challenges. I will discuss what we have learned about solar flares from the chromospheric standpoint and will also highlight the gaps in our understanding that are the focus of current and future satellite missions, telescopes, and modelling efforts.

Dr Bogdan Hnat

University of Warwick

Application of the magnetic field line topology in space plasmas.

Magnetic reconnection and plasma turbulence both produce complex three-dimensional magnetic configurations which can be probed with high cadence multi-spacecraft magnetic field observations. These observations allow for the local magnetic field gradient tensor reconstruction and classification of the magnetic field structures based on the eigenvalues of the tensor. We present results of two studies where the reconstruction of the magnetic field configuration provided a new insight into complex plasma dynamics and plasma heating mechanisms. First, we examine magnetopause reconnection where the MMS spacecraft encounter the Electron Diffusion Region (EDR) [1]. We found: (i) magnetic structures frozen into the electron fluid with features similar to dynamically evolving vortices in hydrodynamic turbulence, and (ii) accelerated electrons in the EDR edge where two-dimensional sheet-like structures are observed. This is consistent with sub-ion scale turbulence suppressing electron acceleration within the EDR. The second study analyses the energy transfer rate conditioned on the magnetic field line topology of the associated structures obtained from the Cluster spacecraft on scale of approximately 40 proton gyro-radii in the solar wind [2]. We determine how the global mean energy transfer rates correlate with the magnetic configuration of the turbulence.

Dr Diana Gorlova

University of York

All-optical blast-wave control of laser wakefield acceleration (LWFA) in a near-critical plasma

We propose a novel method for changing the length of laser wakefield electron acceleration in a gas jet using a cylindrical blast-wave created by a perpendicularly focused nanosecond laser pulse [1]. The shock front modifies the wake significantly and stops interaction between the laser pulse and accelerated electron bunch, allowing one to directly control the interaction length and avoid dephasing. It also improves the electron beam quality through the plasma lensing effect between the two shock fronts. We demonstrated both experimentally and numerically how this approach can be used to form a quasimonoenergetic electron bunch with controlled energy and improved divergence as well as tracking changes in the bunch parameters during acceleration.

Dr Martin Gorman

First Light Fusion

Developing an equation of state platform for studying materials at multi TPa pressures on two-stage light gas guns

Experimental access to multi-terapascal (TPa) pressures is essential for validating models of material behavior that underpin our understanding of giant-planet interiors and the performance of inertial-fusion implosions. However, such conditions can only readily be accessed at the largest high-energy-density facilities, which are highly oversubscribed and costly to operate, limiting the rate of research progress. In this talk, I will describe an experimental platform that has been developed on a two-stage light-gas gun and is capable of probing Hugoniot states of matter at multi-TPa pressures and ramp-compressing materials to several hundred gigapascals. I will present shock-compression data on quartz that extend previous Z-machine Hugoniot measurements by approximately a factor of two in pressure and directly overlap the regime accessed by the National Ignition Facility, enabling cross-platform evaluation of quartz behavior for the first time. More broadly, this approach provides a practical and significantly cheaper path to routine multi-TPa validation experiments that are central to high-energy-density physics research

Dr Matthew Streeter

Queen's University Belfast

Stable laser-acceleration of high-flux proton beams with plasma collimation

Laser-plasma acceleration offers significant potential for generating compact, ultrashort ion beams, but its broader deployment is hindered by challenges such as low shot-to-shot stability, large beam divergence, and limitations in high-repetition-rate operation. Here, I report on a promising approach to address these issues using a novel liquid-sheet target at the GEMINI TA2 laser facility (10 TW, 5 Hz). In this work, we demonstrated stable acceleration of few-MeV proton beams via target normal sheath acceleration. The resulting beams exhibited high flux and markedly reduced divergence compared to proton beams produced from conventional thin-foil targets. Supporting PIC simulations indicate that a low-density background vapour surrounding the target plays a crucial role in the observed beam collimation through the generation of azimuthal magnetic fields that act to focus the proton beam. This acceleration regime is compatible with kHz repetition rates or higher-energy laser systems, extending its applicability to a wide range of future ion-beam-driven applications.

Professor Des Gibson

University of West Scotland

Review of plasma ion assisted deposition of functional thin films and associated applications

Significant advances in functional thin films have been achieved through use of plasma ion assist in vacuum deposition of functional thin films, driven by various demanding applications. Progress depends on understanding how use of plasma ion bombardment during film deposition relates to growth mechanisms that control the film micro structure, interfaces and resulting optical, mechanical and other functional characteristics of the resulting films. This paper presents important considerations in design of plasma sources to achieve required ion energy, neutralisation, reactivity, spatial distribution and operating frequency for control of micro structure and plasma source incorporation into thin film deposition systems. An overview of the optimized properties of films prepared by plasma assisted deposition is provided, together with application examples including durable infrared optical coatings, high precision mirror coatings for gravitational wave detection, piezoelectric thin films for wearable medical devices and optical coatings for non-dispersive infrared gas sensor applications.

Dr Jordyn Polito
Oxford Instruments Plasma
Technologies

Modeling and validation of process-relevant reaction mechanisms for commercial atomic scale processing plasmas

Plasma modeling tools are used by semiconductor hardware companies to increase their understanding of plasma systems and enable rapid solutions to commercial challenges. Computational models must be timely, validated, and contain process-relevant chemistry if they are to provide advantages over traditional lab-based hardware and process development methods. However, validation of process-relevant plasma chemistry reaction mechanisms in commercial plasma systems is often challenged by lack of optical access for in-situ diagnostics. In this work, the impacts of utilizing reliable plasma modeling techniques together with process-relevant reaction mechanisms will be considered from an industrial perspective. Methods for compiling and validating these mechanisms in commercial platforms will be discussed. An example including the compilation and experimental validation of a CF₄/O₂ reaction set will be given. A 0D global model is used to predict densities of reactive ion and neutral species in the plasma region of a commercial inductively coupled plasma. Modeling results are compared to experimental measurements obtained in an Oxford Instruments Plasma PlasmaPro100 – Cobra ICP RIE Etch reactor. The mechanism is then extended to a 2D hybrid plasma model to predict species densities and fluxes that may contribute to soot formation on chamber walls during compound semiconductor etch processes. Results from the validated models can be used to predict operating conditions that lead to optimal process outcomes, ultimately leading to reduced time and cost for commercial hardware and process development.

Professor Howard Wilson
UKIFS

STEP: Designing a Plasma for Fusion Delivery

STEP – the Spherical Tokamak for Energy Production – seeks a steady state pathway to net power delivery in its fusion pilot plant: the STEP Prototype Plant (SPP). The ST has a number of beneficial properties for fusion power production, one of which is the compatibility with high fusion performance, steady state operation. Focussing on the plasma scenario requirements, we will explore how we achieve this on the SPP, consistent with a primary objective of delivering ~ 100MW of electrical power to the grid. We show how SPP is pushed into a novel fusion plasma regime. For example, the plasma turbulence that governs confinement will be dominated by electromagnetic fluctuations that display a complex relationship with plasma pressure gradient and flows, in part due to a proximity to “second-ballooning access”, which we will discuss. The compact nature of the ST poses challenges to managing the exhaust heat load but, benefitting from exciting results from MAST-U, we have a viable solution for SPP based around the Super-X divertor configuration. Demonstration of sufficient plasma control remains an open issue, and we illustrate progress with three key experimental results obtained in the past year: control of the magnetic geometry during vertical plasma oscillations on TCV; independent control of the so-called “detachment front” in the upper and lower divertors, and suppression by magnetic perturbations of the plasma eruptions called edge-localised modes (ELMs) on MAST-U – a world-first for a ST.

Professor Josefine Proll
W7-X/Greifswald

Turbulence in Wendelstein 7-X from an experimental and theoretical point of view

Stellarators have historically suffered from confining the heat of the plasma insufficiently compared with tokamaks and were therefore considered to be less promising candidates for a fusion reactor. This has changed, however, with the advent of optimised stellarators like Wendelstein 7-X (W7-X), in which the collisional transport is reduced by shaping the magnetic field accordingly. As in tokamaks, the turbulent transport remains as the now dominant transport channel. With W7-X, a well-diagnosed advanced stellarator, we can directly probe turbulence in the flexible magnetic geometry and compare against state-of-the-art gyrokinetic codes. After giving a brief introduction to stellarators and an overview over W7-X, recent findings on electrostatic and electromagnetic turbulence in W7-X will be shown, e.g. how, at much lower normalised plasma pressure than previously anticipated, kinetic ballooning modes that appear below the MHD threshold can lead to an increase in ITG-driven turbulent transport [1,2] or that heat-pulse propagation experiments confirm rather benign transport caused by electron-temperature gradient modes [3]. We will also discuss whether the density-gradient-driven trapped-electron mode (TEM) is indeed more benign in W7-X as predicted by theory [4], and whether an up to now not conclusively identified mode - possibly its sibling, the electron-temperature-gradient-driven TEM - might be the cause of a sudden change in particle and heat diffusivity observed at high plasma density [5].

Oral Presentations

Atomistic view of the Rayleigh-Taylor instability in fusion-relevant ablators under warm-dense-matter conditions using semi-classical molecular dynamics

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Inertial confinement fusion ablators are prone to hydrodynamic instability growth which results in material jetting into and contamination of the hotspot [1][2]. Instabilities can grow rapidly from perturbation seeds as small as 10 - 100 nm. These seeds grow in a warm-dense-matter environment (0.1 - 100 eV, solid density) where strong ionic correlations and quantum effects become relevant - aspects not captured by conventional continuum codes [3]. These aspects can instead be captured using semi-classical molecular dynamics simulations, with quantum-corrected [4] effective inter-particle potentials. Preliminary results are presented, demonstrating Rayleigh-Taylor instabilities growing from ~10 nm scale 'seed' features in warm-dense-matter (0.43 eV, 2.551 g/cc). Understanding the growth rate of instabilities in warm-dense-matter on an atomistic scale is vital for better describing the impact that nanometer ablator features have on overall capsule performance.

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Dephasing Mitigation in Laser Wakefield Acceleration

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Laser wakefield acceleration (LWFA) offers a route to compact electron accelerators but is typically limited by dephasing, where electrons outrun the accelerating phase of the plasma wake. In this work, we address this constraint using an active feedback controller embedded in particle-in-cell simulations to tailor the longitudinal plasma density and maintain a chosen wake phase during acceleration. The method generates experimentally realisable density ramps and is benchmarked against analytical taper prescriptions and constant-density baselines.

In this talk, I will present results across both externally guided and self-guided regimes, demonstrating that controlled density profiles approximately double the electron energy gain while also improving laser-to-beam energy transfer in representative cases. These results show how feedback-optimised density tailoring directly mitigates dephasing until the laser depletes. More broadly, this approach provides a practical framework for improving efficiency in LWFA stages, which will be important as the field moves toward application-driven systems.

Development of Novel Ion Source – Continuous Beam Laser Ion Source

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We are developing a new type of ion source using a 5 mJ/4 ps 10 kHz rep-rate laser available in the Ion Source Group of Collider-Accelerator Department at Brookhaven National Laboratory (BNL). Intense (with average current at mA scale) quasi-continuous beams of singly and multiple charged ions of any solid-state element of the periodic table can be generated by the laser with a high rep-rate. Such an ion source will find a very wide range of applications from ion implantation and medical isotope production to nuclear physics user facilities. Two immediate applications of the source will be an ion injection into the Electron Beam Ion Source (EBIS) and the realization of a compact neutron generator based on intense beam of lithium 3+ ions. The first application will allow us to improve EBIS performance as a primary ion source for the Electron Ion Collider (EIC) which will be built at BNL within the next decade. The second application will open a path to the practical realization of the Boron Neutron Capture Therapy (BNCT) technique for selective cancer treatment. The status of the development and future steps will be presented and discussed.

Work supported by Brookhaven Science Associates, LLC under Contract No. DE-SC0012704 with the U.S. Department of Energy.

Dynamo Action at low Pm via logarithmic lattices

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We consider the difficult problem of magnetic field generation at low magnetic Prandtl number Pm . This is a fundamental problem for dynamo theory, since this is the regime of interest for magnetic field generation in a wide range of situations from experiments to planets and stars. Previous numerical simulations at Pm much larger than those of stellar interiors suggest that the critical magnetic Reynolds number for dynamo action may increase as Pm gets small, whilst theory suggests that, in certain cases, it approaches an asymptote as Pm gets small. We utilise numerical computations on logarithmic lattices to access extremely high Reynolds numbers $Re \sim 1e9$ and hence extremely low magnetic Prandtl numbers. We calculate the growth-rate and the level of saturation of such dynamos

Exploring spectral energy transfer in nonlinear gyrokinetic simulations to understand zonal flow drive in tokamaks

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Zonal flows (ZFs) are large-scale sheared flows that arise spontaneously in turbulent plasmas and neutral fluids. A familiar example is the Jovian bands visible on Jupiter, which are driven by atmospheric turbulence. In tokamaks, ZFs flow in the binormal direction (perpendicular to both the magnetic field line and the flux surface normal), meaning that they provide a background of flow shear that helps to saturate turbulence. As a result, they are believed to contribute to the transition from low to high confinement mode (the L-H transition). ZFs are driven nonlinearly through the Reynolds-Maxwell stress arising from drift wave turbulence. Energy transfer into ZFs from turbulence then naturally leads to a reduction in energy in non-zonal turbulence.

Previous attempts to measure this energy transfer experimentally have been limited by the poloidal extent of typical turbulence diagnostics. To enable comparisons with experiment and probe zonal flow dynamics numerically, diagnostics have recently been added to the gyrokinetic code GS2 that resolve nonlinear energy transfer as a function of time, poloidal angle, and wavenumber.

This is distinct from an existing nonlinear kinetic energy transfer diagnostic that adopts a fluid-based approach [Schuett et al, Plasma Phys. Control. Fusion 67 115022 (2025)]. The new diagnostic adopts a kinetic approach and is fully electromagnetic and species-resolved. At high plasma pressure (high beta), nonlinear electromagnetic gyrokinetic simulations have shown that zonal flow formation can be suppressed, causing transport to saturate at much higher levels [Pueschel et al, Phys. Rev. Lett. 110 155005 (2013)]. However, recent work suggests that favourable saturation is still possible above this critical beta if persistent mesoscale zonal flow patterns can develop [Rath & Peeters, Phys. Plasmas 29 042305 (2022)]. This work investigates these dynamics further and examines how plasma shaping affects zonal flow drive at finite beta.

High-Sensitivity Spectroscopic Diagnostics and Model Validation for Oxygen Plasmas

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Advances in semiconductor etching depend on reliable plasma modelling and quantitative knowledge of near-surface behaviour of reactive species. In this research, diode laser absorption spectroscopy is utilised to determine spatially resolved number densities and gas temperatures of key species in technologically relevant inductively coupled oxygen plasmas.

Cavity ring-down spectroscopy (CRDS) is an absolute, high resolution, calibration-free experimental technique for determining number densities, and here spin forbidden $O(^1D_2) \leftarrow O(^3P)$ transitions around 630 nm are used to investigate the major reactive product, $O(^3P)$. Densities and translational temperatures are quantified as a function of height in the 20 mm region directly above a non-driven electrode. Translational temperatures are observed to decrease as the water-cooled surface is approached, whilst a modest increase in number density is observed, consistent with gas dilation. The number density of the dominant anion, O^- is also inferred via its photodetachment continuum. The spatially resolved anion densities show that O^- density decreases as the electrode surface is approached, closely following modelled trends in electron density. Trends obtained for the ground state $O(^3P)$ atoms are also contrasted to those obtained for the metastable excited species, $O(^5S)$. Differences observed illustrate the inhomogeneity of low pressure ICPs and the impact that different operating conditions can have on plasma composition.

Surface recombination is the dominant loss process for $O(^3P)$ and the lifetime of $O(^3P)$ in both the bulk plasma and near the electrode surface has been determined as a function of operating condition. Knowledge of surface loss parameters is an essential component of plasma modelling simulations and thus it is important to accurately quantify these parameters for our chamber. Spatially resolved measurements of several plasma species across a range of conditions enables careful refinement and validation of 2D plasma modelling simulations.

Inference of Plasma Parameters from Nonlinear Ion Cyclotron Emission Spectra with Time Series Extrinsic Regression

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Ion Cyclotron Emission (ICE) is an ubiquitous phenomenon in magnetically-confined hot plasmas. It shows potential to be used as a fast ion diagnostic as it can reveal spatial and velocity properties of energetic ion species, correlates with fusion reaction rate, provides coverage of both the plasma edge and core, is driven by either fusion-born or injected ions and can be detected using existing hardware such as ICRH antennae and Langmuir probes, demonstrating a high technical readiness. The magnetoacoustic cyclotron instability (MCI) is a kinetic plasma effect driven by a resonant fast Alfvén wave near energetic ion cyclotron harmonics and is considered the dominant mechanism behind ICE.

Plasma parameters including B_0 , density and fast alpha particle fraction are scanned across tokamak-relevant domains using EPOCH, a mature particle-in-cell (PIC) code, in the fully kinetic 1D3V regime. The MCI is visualised in predominantly perpendicular perturbations of the electromagnetic fields of the simulation and used to generate a rich dataset on which to perform time series extrinsic regression (TSER) using Aeon, a mature library for time-series analysis techniques.

This work details how TSER can be used to extract underlying physical plasma characteristics from experimentally-analogous ICE spectra. This information has never previously been inferred purely from observed spectra and represents a novel application for TSER. The success of the approach is in spite of the relatively small size of the training dataset, which could be generated using Tier 3 HPC resources and therefore presents a route for any device to pre-emptively model their operational ranges and infer plasma parameters in real-time diagnostics.

Information geometry analysis of EMRP effects and turbulent fluctuations in L-H and H-L transitions in the KSTAR tokamak

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We investigate the effect of edge-localised resonant magnetic perturbations (ERMPs) and turbulent fluctuations during low-to-high confinement (L-H) and high-to-low confinement (H-L) transitions. Utilizing Beam Emission Spectrometry (BES), ECE Imaging (ECEI), and Mirnov coils, we analyse time-series fluctuations of electron density (n_e), temperature (T_e), and poloidal magnetic field time derivatives ($\frac{dB_{\theta}}{dt}$). Time-dependent probability distribution functions (PDFs) are constructed from 2ms windows and analysed using information rate Γ , information length ($\mathcal{L} = \int \Gamma dt$), kurtosis κ and variance σ^2 . We find Γ successfully captures rapid transients such as ELMs and neutral beam blips. We compare shots using pre-emptive ERMPs in L-mode and those where conventional H-mode ERMPs were applied. ERMPs are found to induce greater changes in the information length at any fixed radial location in n_e and T_e profiles during L-mode than in H-mode, indicating a stronger impact on L-mode turbulence statistics. Across a density scan ($n_e = 1.5 - 3.57 \times 10^{19} \text{m}^{-3}$), \mathcal{L} demonstrates that L-H transitions strengthen the radial correlation of edge n_e and T_e profiles. At the highest density, these profiles align closely; however, at the slightly lower $3.2 \times 10^{19} \text{m}^{-3}$, the behaviour diverges due to an $n=2$ coherent mode. This highlights the important role of hidden variables and magnetic topology in turbulence reorganization. Additionally, L-H transitions transiently reduce σ^2 , whereas H-L transitions increase it. Typically, the highest fractional change in \mathcal{L} across transitions is near the pedestal shoulder. These results establish information geometry as a useful complimentary diagnostic for tracking statistical reorganization in non-equilibrium plasma.

Investigating the nonlinear Bohm-Chodura condition with ExB transport to the wall

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The Bohm-Chodura condition is routinely used in fluid codes to impose the boundary condition on the ion flow velocity at a solid target. In a magnetised plasma, the condition prescribes a sonic ion outflow parallel to the magnetic field. In reality, the condition holds at the entrance of the magnetic presheath, a boundary region forming next to the target which is treated as infinitesimally thin (a boundary layer), together with the even thinner Debye sheath.

When the magnetic field is at a very shallow angle with the target, such as in fusion devices, the transport towards the wall from (ExB and diamagnetic) drifts caused by gradients (of electrostatic potential and pressure) can compete with the transport towards the wall from a sonic parallel flow. Modifications to the Bohm-Chodura condition that include the effect of these drifts have been derived. However, drift corrections are always treated perturbatively. Here, we challenge this treatment and study the fully nonlinear Bohm-Chodura condition [1][2]. This is a Riccati equation in the flow velocity: a first order differential equation with a quadratic nonlinearity.

For given pressure and electrostatic potential profiles tangential to the wall, we find that as the magnetic field angle is decreased the perturbative Bohm-Chodura condition becomes increasingly inaccurate compared to the nonlinear condition obtained by solving the Riccati equation. This is evidence that perturbative drift corrections to the Bohm-Chodura condition are inaccurate. Eventually the Riccati solution becomes unstable at a sufficiently shallow magnetic field angle, giving flow velocities that become negative and blow up. This suggests that imposing the parallel flow velocity in the presence of significant tangential gradients is inconsistent. Two possible (non-trivial) alternative approaches to consider are: imposing the electrostatic potential variation tangential to the wall as a part of the boundary conditions; extending the drift-reduced fluid equations to model the strong gradients occurring in the magnetic presheath.

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Lessons Learned from 5 Years of PlasmaFAIR: Improving Sustainability of Plasma Software

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Software underpins modern research. It is therefore vital that we ensure that we have the best tools for the job, which means ensuring that our research software is maintainable, well tested, well documented, and is developed in a sustainable way so that it continues to be usable by researchers into the future. PlasmaFAIR started in 2021 with a mission to reach out and work with researchers to directly improve the quality and sustainability of plasma science software, and to date we have worked on more than 30 projects. In this talk we reflect on five years of work, discussing the practices that have improved codes, along with some of the tools and libraries we have developed to help researchers and developers.

Some of the highlights of the projects we have worked on as part of PlasmaFAIR include: Pyrokinetics, a new community library that helps researchers compare results from multiple gyrokinetic solvers, automatically handling things such as different normalisations, which often trip up new users; sdf-xarray, which allows users of the EPOCH code to use the powerful Python xarray ecosystem; and a major refactoring of Scotty, a beam-tracing code for Doppler Backscattering diagnostics, taking it from a student code to a full research software package used internationally.

PlasmaFAIR has also created new libraries and tools for developers to make maintaining research software easier, such as snaptol, a Python library for quickly getting tests onto numerical codes, and Fortitude, a Fortran linter that helps developers catch bugprone code, obsolete constructs, and style violations, 100x faster than other tools.

Lastly, we discuss our methodology in assessing projects for sustainability, and common, easy interventions that developers can take to improve the maintainability of their software.

This work is supported by EPSRC Grant EP/V051822/1.

Microplasma-assisted synthesis of AuNPs/Keratin nanocomposites

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Microplasma operates at room temperature and atmospheric pressure. When interacting with water, it generates microplasma induced liquid chemistry (MiLC) which contains high reactive species (such as OH·, O·, H·, H₂O₂) that can enable nanomaterial synthesis and surface modification without the use of high temperature or harsh chemicals. To date, MiLC has been successfully deployed to synthesize various nanomaterials and nanocomposites such as Au nanoparticles (AuNPs), chitosan/Au, povidone/Au [1-3]. Keratin protein is a sustainable biopolymer which can be extracted from renewable Agri-waste resource (such as poultry feathers, wool and human hair). Although keratin has found applications in plastics, biosorbent, and biomedical domains, limited research has explored its combination with nanoscale functional materials like AuNPs for advanced applications. Furthermore, the use of MiLC for synthesizing protein-based nanocomposites remains largely unexplored. In this work, we present the first study on synthesizing AuNPs/keratin nanocomposites using MiLC.

Keratin/gold salt mixture with appropriate ratio/concentration was treated by MiLC (helium gas flow 25SCCM) for 10 min. The resulting samples were then dried, and the resulting composites were characterized in detail using transmission electron microscope & energy dispersive X-ray spectroscopy (TEM&EDX), X-ray photoelectron spectroscopy (XPS), fourier-transform infrared spectroscopy (FTIR), and ultraviolet-visible spectroscopy (UV-vis). Results show that the plasma has dual functions: 1) modifies the keratin structures and 2) induces the in-situ formation of uniformly dispersed spherical AuNPs (5-8.5 nm). EDX and XPS results show the AuNPs has strong interaction with keratin through Au-S covalent bonds [4]. The resulting nanocomposite has also been demonstrated for applications such as SERS sensing.

Keywords: Microplasma, Gold nanoparticles, Keratin, Composites

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Molecular Propellants For Radio-Frequency Plasma Micro-Propulsion

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Recently, there has been a growing interest in alternative propellants for electric propulsion systems. For 'off-the-shelf', academic, and commercial satellites the search for alternative propellants includes many molecular substitutes such as ammonia, water, peroxide, ethanol, nitrous oxide, and carbon dioxide. Ammonia in particular has not been well studied, despite presenting a storage-dense, cheap, abundant (both terrestrially and in-situ), propellant solution for satellite operations. Here, we present 2D hybrid fluid/Monte-Carlo simulations of an inductively coupled Radio Frequency (RF) electrothermal micro-propulsion source (the "Pocket Rocket") operated in ammonia. Simulations were run employing the Hybrid Plasma Equipment Model (HPEM). How and where ammonia is broken down within the thruster, where power is coupled, and the predominant neutral gas heating mechanisms are discussed with respect to varying input power, flowrate, and frequency. An analysis of the discrete inductive and capacitive spatio-temporal power coupling mechanisms is presented. Finally, we present our findings on the thrust and efficiency characteristics that we expect from the thruster operating in ammonia. Beyond propulsive applications, an enhanced understanding of the production and dissociation pathways of ammonia within radio-frequency driven plasmas is of direct interest to hydrogen storage and sustainable fuel production.

We gratefully acknowledge funding from the United States Air Force European Office of Research and Development, grant number FA8655-24-1-7055, for enabling and supporting this research project.

Optical diagnostics of arc discharge plasma ion sources

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High-current negative hydrogen (H⁻) and proton (H⁺) ion sources are used for accelerator-based research and applications, e.g. for spallation neutron and medical isotope production. At ISIS, which is the UK's flagship neutron science facility, the world-record H⁻ beam current densities of 10 mA/cm² are produced with a pulsed DC Penning discharge where biased electrodes are in direct contact with the plasma resulting in limited lifetime of the ion source. We have developed time-resolved optical diagnostics system to monitor the stability and elemental composition of the ISIS ion source plasma, and to conduct plasma physics experiments on the high-density ($n_e > 10^{13}$ electrons/cm³) caesium-hydrogen discharge. The optical diagnostics system couples the plasma emitted light into a CCD spectrometer and several high-sensitivity multi-pixel photon counters through wavelength filtering, which allows simultaneous recording of the emission spectrum and monitoring of the hydrogen Balmer-series and caesium emission lines with microsecond time resolution. We present the design of this novel optical diagnostics setup applicable to a variety of technological low-temperature plasmas and showcase examples where the system is used for parametric studies of the ion source plasma. We discuss the effect of discharge power, magnetic field strength and caesium-hydrogen balance on the intensities and temporal dynamics of the optical signals. We demonstrate that the time resolution of the diagnostics is sufficient to explore the caesium dynamics during the discharge pulse, study plasma instabilities and reveal new information on the physics of the plasma-beam boundary formation with pulsed ion beam extraction. Finally, we describe the technology transfer of the optical plasma diagnostics developed at ISIS to iThemba LABS in South Africa where the setup will be used for studying positive ion source plasmas of electron cyclotron resonance and Penning discharges supporting the experimental nuclear physics programme and medical isotope production.

Quasi CW Cherenkov sources using 2-dimensional waveguide corrugations.

Strachan W

Cherenkov devices using cylindrical interaction cavities with periodic axial corrugations modify EM dispersion with spatial harmonics, allowing coupling between an electron beam and an EM wave with a reduced phase speed. Meeting demand for kW+ mm to sub-mm wavelength coherent free-electron oscillators and amplifiers with such devices is challenging, as a large transverse size capable of handling the power is often over-moded, risking oscillation in undesired modes; devices targeting mode $TM_{0,1}$ must have diameter D similar to the free-space radiation wavelength λ ($D/\lambda \sim 1$).

A novel Cherenkov device using 2-dimensional (axial and azimuthal) sinusoidal corrugations is considered. A high-order $TM_{0,N}$ volume- and $HE_{m,1}$ surface-mode pair can be selected, particularly by the number of azimuthal corrugation periods m , as the complex boundary conditions imposed by the 2D corrugations limit the number of eigenmodes capable of interacting with the hollow annular electron beam. This prevents oscillations in undesired modes, allowing coherent output with $D/\lambda \gg 1$.

Parameters for a $D/\lambda = 4.45$ quasi-CW Cherenkov slow-wave oscillator have been chosen based on analytical studies. Particle-in-cell (PiC) simulations have been undertaken for an oscillator, with $m = 13$, targeting the $TM_{0,5}$ - $HE_{13,1}$ mode pair with a 90 A, ~ 115 keV electron beam. Interaction efficiency of 25+% is predicted for output frequency 454 GHz, with up to 99% of power in the $TE_{13,1}$ mode at the smooth cylindrical output.

Modification of the boundary between the interaction region and smooth output waveguide is found to substantially affect the interaction growth and output mode-spectrum, with some geometries (optimised for minimal reflection) resulting in no oscillation. Preliminary simulations seeding these geometries with a weak signal predict significant amplification of seed power, indicating potential in the amplification regime. Extending this study to consider higher values of D/λ could lead to the development of new quasi-CW sub mm-wave sources.

Quasi-continuous exhaust regime in strongly shaped MAST Upgrade plasma

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Pilot fusion power plants based on the magnetic confinement concept, such as tokamaks, will likely maintain reactor-relevant conditions in high confinement modes (H-modes), in which the core pressure profile is elevated by the formation of a "pedestal" near the plasma edge. However, the steep radial pressure gradient across the pedestal often causes short and periodic outbursts of particles and heat, known as edge localised modes (ELMs). Large Type-I ELMs with their high peak thermal load can substantially degrade the core confinement and cause serious damages to plasma facing components. The future tokamak reactors must therefore operate in advanced H-mode regimes free of detrimental Type-I ELMs.

One example of such an advanced H-mode is the quasi-continuous exhaust (QCE) regime, characterised by Type-II ELMs that are much smaller in amplitude but higher in frequency compared to the Type-I counterparts. Observations in ASDEX Upgrade have shown that the QCE regimes can be accessed by increasing plasma elongation and triangularity. Because of the reduced transient thermal load on the plasma facing components, especially on divertor targets, the QCE regime is a potential candidate scenario for pilot fusion reactors.

Recent experiments at MAST Upgrade have observed such QCE periods in strongly shaped plasmas; in particular, high squareness. Peeling-ballooning stability analysis using the ELITE code shows these pedestals are close to the ideal ballooning limit, even though Type-I ELMs are suppressed. The Doppler Back-Scattering data show increased density fluctuation amplitudes in the pedestal region, indicative of increased turbulence; a possible explanation for the Type-I ELM suppression. Moreover, the IR thermography data show that the peak thermal load onto the divertor targets are substantially reduced. If these QCE regimes are found to be scalable to reactor-relevant conditions, then our results will have significant impact on the operational design of spherical tokamak pilot power plants, such as STEP.

Review of plasma ion assisted deposition of functional thin films and associated applications

Gibson D

Significant advances in functional thin films have been achieved through use of plasma ion assist in vacuum deposition of functional thin films, driven by various demanding applications. Progress depends on understanding how use of plasma ion bombardment during film deposition relates to growth mechanisms that control the film micro structure, interfaces and resulting optical, mechanical and other functional characteristics of the resulting films. This paper presents important considerations in design of plasma sources to achieve required ion energy, neutralisation, reactivity, spatial distribution and operating frequency for control of micro structure and plasma source incorporation into thin film deposition systems. An overview of the optimized properties of films prepared by plasma assisted deposition is provided, together with application examples including durable infrared optical coatings, high precision mirror coatings for gravitational wave detection, piezoelectric thin films for wearable medical devices and optical coatings for non-dispersive infrared gas sensor applications.

Space Charge Compensation in Positive and Negative Hydrogen Beams: A Comparative Particle-in-Cell Study

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Hydrogen ion sources have applications across domains, from high-energy physics (e.g. CERN) to spallation sources (e.g. ISIS Neutron and Muon Source), and neutral beam injectors used in fusion contexts. In the transport of these low-energy, high-intensity beams, a common problem encountered is beam divergence and transport losses caused by space charge fields. Space charge compensation (SCC) [1] is a crucial process in minimising these losses, whereby the beam interacts with a neutral background gas, primarily through ionising reactions, to produce a low-density “compensating” plasma of oppositely charged particles, reducing the net field.

Despite similarities in the cross-sections and kinetic properties of positive and negative hydrogen beams, remarkable differences in their SCC processes arise from the differing properties of their compensating plasmas, notably the particle mobilities, energy distributions, and available loss mechanisms [2]. High degrees of compensation are more easily achieved in negative beams where the slow, heavy compensating molecular ions are easily confined by the beam potential, whereas the lighter, more energetic compensating electrons in positive beams require additional confinement measures such as suppressing electrodes.

This work is a collaborative effort which aims to combine high-fidelity simulations and experimental diagnostics to study SCC. The particle-in-cell code PICLas [3] has been used to perform multi-reaction framework simulations of SCC in hydrogen beams, allowing for exploration of how key parameters such as external magnetic fields [4], secondary electron emission, and boundary conditions including invasive diagnostics [2,5] can impact the SCC process. Simulation results will be compared to diagnostic data from ISIS and the Front-End Test Stand (FETS).

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Stable laser-acceleration of high-flux proton beams with plasma collimation

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Laser-plasma acceleration offers significant potential for generating compact, ultrashort ion beams, but its broader deployment is hindered by challenges such as low shot-to-shot stability, large beam divergence, and limitations in high-repetition-rate operation. Here, I report on a promising approach to address these issues using a novel liquid-sheet target at the GEMINI TA2 laser facility (10 TW, 5 Hz). In this work, we demonstrated stable acceleration of few-MeV proton beams via target normal sheath acceleration. The resulting beams exhibited high flux and markedly reduced divergence compared to proton beams produced from conventional thin-foil targets. Supporting PIC simulations indicate that a low-density background vapour surrounding the target plays a crucial role in the observed beam collimation through the generation of azimuthal magnetic fields that act to focus the proton beam. This acceleration regime is compatible with kHz repetition rates or higher-energy laser systems, extending its applicability to a wide range of future ion-beam-driven applications.

Triple Synergy in Waste Plastic Upcycling: Enhanced BTEX Production via Plasma-Assisted Catalysis over Ga-Modified β -Zeolites

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The accumulation of waste polypropylene (PP) presents a critical environmental challenge but also offers a significant opportunity to produce high-value petrochemical feedstocks. This study investigates a novel two-stage upcycling process integrating pyrolysis with non-thermal plasma (NTP) catalysis to maximize the yield of single-ring aromatic hydrocarbons (BTEX). We systematically evaluated the catalytic performance of microporous Y-zeolite versus shape-selective β -zeolite, followed by an optimization of β -zeolite supported metal promoters (Ni, Ga, Mo, Zn).

Experimental results demonstrate that β -zeolite outperforms Y-zeolite due to its unique pore topology, which favors the diffusion of aromatic intermediates while suppressing coke formation. The introduction of NTP (40 W) at 500 °C significantly enhanced reaction efficiency. Among the metal-modified catalysts, the Ga/ β -zeolite exhibited superior performance, achieving a record BTEX yield of 45.6%. This enhancement is attributed to a "triple synergy": (1) high-energy plasma species activate stable alkane intermediates; (2) Ga species (likely GaO) specifically promote the rate-determining dehydrogenation-cyclization steps; and (3) the β -zeolite pore structure provides shape-selective confinement for aromatization. Additionally, Ga and Zn promoters were found to maintain substantial gas yields alongside high aromatic conversion, indicating a balanced product distribution. This work provides a mechanistic understanding of plasma-catalyst interactions and proposes a highly efficient route for circular plastic economy.

TV/m-level Surface plasmon excitation on smooth surface for coherent synchrotron radiation

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Recent research into the high-intensity laser-driven surface plasmon excitation has revealed the significant potential of generating extremely strong (\sim TV/m) fields for particle acceleration and radiation production [1-3]. This new approach has emerged by overcoming several challenges in laser-solid interactions. It therefore holds great promise for reshaping the research direction of large-scale facilities that pursue the energy frontier and micro-scale facilities that require great flexibility. At the same time, this research can provide new insights into the extremely complex nonlinear dynamics of surface plasmons (SPs) in strong fields and a new, unexplored regime of plasma-based particle acceleration.

In this study, I will present our recent theoretical and numerical studies of relativistic surface plasmon excitation driven by ultra-intense lasers on microscale curved surfaces in structured nanomaterials, with a particular focus on vertically aligned carbon nanotube (VACNT) forests. We show that these systems can sustain coherent surface-bound modes that generate TV/m-level cylindrical electric fields, enabling efficient acceleration and helical modulation of the electron beam. By analysing surface-plasmon mode selection on cylindrical geometries, we propose a new mechanism for coherent radiation emission that is fundamentally distinct from traditional superradiance, offering a scalable route to compact, high-field radiation sources[4].

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Posters

A New Size-Selected Metal Cluster Source for Catalyst Research at Diamond Light Source

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Size-selected metal clusters composed of tens to thousands of atoms, supported on metal oxide thin films, provide a powerful model platform for probing size-dependent effects in heterogeneous catalysis and related surface processes. Precise control over cluster size, composition, and deposition conditions is essential for establishing reliable structure–property relationships at the nanoscale. At Beamline B07, Diamond Light Source, a fully integrated size-selected cluster deposition platform has been developed and commissioned, combining plasma sputtering, a gas-phase aggregation zone, in-line mass filtering, and an ultra-high vacuum (UHV) deposition chamber. Metal vapours are generated via inert-gas plasma sputtering of solid targets, followed by controlled nucleation and growth within the aggregation region. The system enables simultaneous sputtering from three targets, allowing accurate compositional tuning and alloy cluster synthesis. In-situ plasma spectroscopy provides real-time monitoring of sputtered atoms and plasma species, while automated sample handling and control systems regulate cluster coverage and kinetic energy to ensure stable and reproducible deposition.

A central technical challenge arises from the simultaneous formation of charged and neutral clusters within the plasma. Although an in-line quadrupole mass filter (QMF) enables precise mass selection and monitoring of charged cluster current and kinetic energy, neutral clusters remain unaffected and may compromise size selectivity. To overcome this limitation, the finite element method (COMSOL Multiphysics) was used to simulate charged particle trajectories and optimise electric field configurations within the deposition chamber. These results guided the design of a deflection system enabling the separation of charged from neutral clusters. As practical examples, size-selected Pd, Fe, and Cu clusters have been synthesised and deposited on oxide supports for model catalytic and surface studies. The size selectivity and narrow size distribution of the deposited clusters were confirmed by atomic force microscopy (AFM), verifying that cluster dimensions are consistent with the selected mass range.

Advancing Circular Waste Management: A Comprehensive Modeling and Experimental Investigation of Argon-CO₂ Thermal Plasma Gasification for MSW

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The escalating crisis of municipal solid waste (MSW) accumulation poses a critical environmental challenge globally, necessitating a paradigm shift from conventional disposal methods toward advanced thermal treatment technologies. Thermal Plasma gasification stands out as a transformative solution, offering superior waste volume reduction and the generation of clean, high-energy syngas. This study investigates the efficacy of graphite electrode-based plasma-assisted gasification through a dual-scale experimental approach, utilizing both a laboratory-scale (5 kg/h) and a pilot-scale (50 kg/h) reactor. A distinct feature of this investigation is the implementation of an Argon-Carbon Dioxide (Ar-CO₂) carrier gas mixture supplied at 10 LPM Argon and 5 LPM CO₂ selected to simultaneously enhance thermal plasma arc stability and improve syngas quality. A comprehensive steady-state model was developed using Aspen Plus V14.0 software to elucidate complex thermodynamic behaviors and optimize process performance. The computational model simulates intricate physicochemical transformations within the plasma zone, accounting for critical phenomena such as in-situ moisture gasification and heat recovery integration. Rigorous validation against experimental data demonstrated exceptional predictive accuracy with minimal error in syngas composition and yield profiles. Furthermore, a detailed parametric modeling study was conducted to evaluate syngas composition dependency on varying plasma conditions and distinct gasification agents, specifically Air, Steam, and CO₂. This analysis quantifies the impact of each agent on H₂ and CO production, offering critical insights for process tuning. This study successfully bridges the gap between experimental observation and theoretical modeling, confirming the reliability of equilibrium modeling for system upscaling. The findings underscore the immense potential of this optimized plasma gasification process as a robust technology, establishing a pathway for sustainable, circular waste-to-energy practices.

Assessment of fully non-inductive start-up techniques for spherical tokamak power plants

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Fully non-inductive plasma start-up is a key requirement for steady-state operation of spherical tokamak (ST) power plants, where limited central solenoid space and high neutron loads strongly constrain inductive flux swing [1]. Electron cyclotron (EC) and mode-converted electron Bernstein wave (EBW) techniques offer a promising route to robust solenoid-free plasma initiation and current formation in high-density, high-beta ST configurations [2].

This contribution introduces the physics of solenoid-free, microwave-driven start-up in spherical tokamaks. Key aspects of the start-up process are discussed, including the ionisation of neutral gas to form a plasma, the confinement of low temperature plasmas during the earliest phases of discharge, the role of plasma current in establishing closed magnetic flux surfaces, and the basic mechanisms by which microwaves can drive current non-inductively. While current drive physics is naturally complex, a focus is placed on developing a clear physical picture of the start-up sequence and the underlying constraints.

In addition, microwave-driven start-up is compared to alternative start-up approaches, including purely inductive solenoid start-up, solenoid-assisted EC/EBW schemes, and non-inductive methods such as merging compression and helicity injection, with a view to assessing their relative advantages and limitations for power plant operation. The discussion is motivated by ongoing and planned work on devices such as MAST Upgrade [3], which provide an important experimental platform for investigating start-up physics relevant to future spherical tokamak reactors.

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Computational Studies of 3D and Rotational Effects on Tokamak Edge-Instabilities

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Typical tokamak H-mode plasmas exhibit large, quasi-periodic bursts of heat and particles over the separatrix, being deposited onto plasma-facing components (Type 1 ELMs). For reactor-scale devices, the heat flux associated with these events is unacceptable. Therefore, more advanced H-mode schemes which do not exhibit ELMs are required for operation. This includes suppression of ELMs with resonant magnetic perturbations (RMPs) or the quiescent H-mode regime (QH-mode), where RMPs can be used to enhance edge harmonic oscillations. [1]

The primary driver of Type 1 ELMs is the coupled peeling-ballooning mode instability. The main focus of the project is the influence of plasma rotation and 3D magnetic perturbations on the manifestation of the peeling-ballooning instability. Modifications of the typical axisymmetric plasma equilibrium are required to study these effects. Modelling RMPs requires a non-axisymmetric equilibrium, and plasma rotation introduces a toroidal velocity to the equilibrium, which causes flux surfaces to no longer be isobaric.

The project will involve theoretical study and computational work based on the MHD (magnetohydrodynamics) code, ELITE, which is specialised for edge-localised instabilities, and is undergoing work to include rotational and 3D effects separately. There is potential for comparison and benchmarking with VENUS MHD (EPFL) [2].

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Creation of plasma-activated water and effects on *Serratia* sp. bacteria and *Chlorella vulgaris* microalgae

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The gliding arc discharge (GAD) plasma and spark arc discharge systems were used to generate plasma-activated water (PAW). The air and air-nitrogen plasmas were used to produce PAW using the GAD plasma. The flame-emission spectrometer was used to investigate the composition of air-nitrogen and air plasmas. The N₂, N₂⁺, N⁺, NO_y, and O* particles were the main species in both plasmas. The control of the GAD plasma voltage, frequency, or gas flow rate allowed the control of the composition and concentration of nitrogen oxides in plasmas. It was found that the increase in discharge power enhanced the concentrations of NO and NO₂. The spark discharge was realized in water at atmospheric pressure over various distances between the electrodes. The physicochemical properties of PAW were investigated at various treatment durations and plasma discharge parameters. It was observed that the specific electrical conductivity, pH values, concentration of nitrates and hydrogen peroxide in the produced PAW depended on the type of water used, treatment duration, and the plasma discharge parameters used. The increase in treatment duration results in higher concentrations of NO₃⁻ and H₂O₂. The biological effects of PAW were determined using *Serratia* sp. Bacterial performance was assessed by measuring growth (OD₆₀₀), phosphate solubilization index, and nitrogen fixation ability on Ashby's nitrogen-free medium. It was found that plasma-activated water enhanced the plant-beneficial functional activities of *Serratia* sp., while reducing its growth under nutrient-limited conditions. Additionally, the effect of plasma-activated BG-11 media on the growth of *Chlorella vulgaris* microalgae was investigated.

Acknowledgement: „This work was carried out in the framework of the interinstitutional RTO Lithuania (The Association of Research and Technology Organizations) research programme“.

Development of Diamagnetic Cavities in Pre-Magnetized Laser-Produced Plasmas

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With increasing interest in magnetized ICF schemes to reach higher gains, the development of plasma shocks in a pre-magnetized environment must be thoroughly understood. We present preliminary results using UCLA's Phoenix laser facility that indicate the compression of Biermann battery fields at the shock front and the development of diamagnetic cavities trailing the front in a plasma shock wave generated from ablating a carbon target with a high-repetition rate laser. A Helmholtz coil was used to apply an external magnetic field of varying strengths up to 5,400 Gauss. In the unmagnetized case, the asymmetrical shocks generated Biermann fields of modest magnetic field strength (750 Gauss at 8mm from the target normal) when measured with 3-axis magnetic field probe. In the presence of an external magnetic field, the magnetic fields at the shock front compressed to nearly twice the strength (1200 Gauss at 8mm from the target normal for applied field of 5,400 Gauss) and were followed by a large cavity (amplitude 1500 Gauss for applied field of 5,400 Gauss). Optical Thomson scattering measurements additionally indicate higher densities and temperatures at the shock front in the pre-magnetized environments. The development of these diamagnetic cavities was characterized for 12 different external magnetic fields strengths.

Dynamic Control of Chaotic Attractors in Maxwell-Consistent Field-Constrained Plasmas

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This work proposes a theoretical framework for controlling chaotic behavior in systems governed by electromagnetic fields consistent with Maxwell's equations. By introducing tunable perturbations into the field structure, the model generates localized regions of controlled chaotic motion while maintaining global stability. The framework is formulated using a kinematic velocity field embedded in divergence-free magnetic and electrostatic configurations, and the corresponding charge and current distributions are derived analytically. Numerical simulations quantify dynamical behavior through Lyapunov exponents and trajectory evolution, demonstrating that the level and location of chaoticity are adjustable through field parameters. Although motivated by plasma confinement problems, the formulation is general and may apply to other nonlinear field systems involving transport, stability, or self-organization. The results indicate that chaos can be engineered as a stabilizing mechanism rather than treated solely as a source of instability, suggesting new pathways for field-based confinement design.

Effect of ECH on Turbulence dynamics During ETB formation

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H-mode offers a promising method for reducing turbulent losses in future magnetic confinement fusion devices; however, the mechanisms that trigger the formation of the edge transport barrier (ETB), marking the L-H transition, remain poorly understood [1]. This study investigates how the inclusion of electron cyclotron heating (ECH) modifies turbulence dynamics during ETB formation in NBI-heated plasmas.

Analysis is performed on two sharp L-H transitions and two transitions exhibiting a dithering phase on the DIII-D tokamak. Direct comparisons are made within each pair, while broader trends between the two transition types are identified. All shots have an upper single null magnetic configuration with the outer strike point in the SAS divertor, plasma current of $I_P \sim 0.98$ MA and toroidal magnetic field of $B_T \sim 2$ T. At the L-H transition, sharp transitions occurred at an X-point height $Z \sim 16$ cm, line-integrated density $n_e, \text{int} \sim 2.4 \times 10^{19} \text{ m}^{-3}$, and separatrix power $P_{\text{sep}} \sim 1.4 \times 10^6$ W, whereas dithering transitions occurred at $Z \sim 13$ cm, $n_e, \text{int} \sim 1.8 \times 10^{19} \text{ m}^{-3}$ and $P_{\text{sep}} \sim 1.0 \times 10^6$ W.

Turbulence dynamics at the transition are characterised using edge plasma density fluctuations in the frequency range $f \sim 20$ – 200 kHz, measured with the beam emission spectroscopy (BES) diagnostic. BES provides spatially localized, two-dimensional time series of light intensity fluctuations, from which density fluctuations and turbulence advection velocities are inferred [2].

Time-dependent probability density function (PDF) analysis is applied to the density fluctuations and the poloidal velocity component. Measurements are segmented into 0.5ms time windows, from which PDFs are constructed. The mean, standard deviation, skewness, and kurtosis are subsequently calculated, together with information rate and length, derived using techniques from information geometry [3]. These quantities are contrasted within each pair across the L-H transition and suggest the rate of transition is reduced when ECH is applied.

Work supported by US DOE under DE-FC02-04ER54698

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Electronic collisions with molecular cations: relevant for fusion plasma

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The impetus behind this abstract comes in relation to with studies in experimental nuclear reactors with walls made up of materials containing simple atoms (e.g., Be, C, N), referred to as PFPs or plasma-facing materials, that may react with the fuel atoms (H, D, T), producing BeH (and BeH₂), CH, NH, and their cations, all this related to the long-time elusive quest for controlled nuclear fusion energy employing magnetic-field confinement, particularly related to ITER. Generally, for kinetic modeling of low-temperature plasmas, it is not only essential to know all the constituent species present in the plasma, but also the reaction rate coefficients (which can be obtained from cross sections) for dominant collision processes that are pathways to final products. Molecular ions are a constituent of many low-temperature plasmas, where collisions of these ions with electrons play an important role in governing their chemistry. Many Nitrogen plasmas contain NH⁺ and therefore the kinetic modeling of these plasmas requires cross sections for different electron-induced processes in NH⁺. NH⁺ is also to be observed in a fusion plasma (or indeed any other sort of plasma, for example, ammonia plasmas) and it will be via emissions from its electronically excited states.

The excellent thermal conductivity and low erosion of Beryllium (Be) makes it a good choice for the Divertor walls, and its reliability is being actively tested in the JET fusion experiment with a view to using Beryllium as the walls in the ITER. Since the plasma would contain H⁺ ions, the use of Be as a wall material indicates that the plasma would interact with the wall to form Beryllium hydrides and BeH₂⁺ in particular, as one of the components. The competitive model of quantum mechanics can be used to describe Feshbach resonances, which are extremely excited bound states superposed with the continuum. Because they generate dissociation at low energy, these bound states are essential for explaining the dissociative recombination of the molecule that often occurs in this plasma environment. One effective theory that yields quantitative findings for identifying the interaction indicated by potential energy curves is the R-Matrix technique. The contribution of Feshbach resonances to the dissociation of molecules, as indicated by the dissociative rates, will be discussed in this presentation. The illustrations are based on NH⁺ and BeH₂⁺[Communicated] cations and corresponding to NH and BeH₂ molecules.

Examination of carbon sputtering and transport in CF₄/O₂ plasma processing reactors using HPEM

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Silicon carbide is a third-generation semiconductor material, vital for the automotive and renewable energy sectors. While it is advantageous due to its wide bandgap and high breakdown voltage, the processing of SiC introduces novel design considerations, including the sputtering of carbon dust and soot. The use of plasma modelling tools, such as Hybrid Plasma Equipment Model (HPEM), facilitates both a fundamental understanding of these processes and reduction in the cost to deploy commercial tools and processes. Here we present a numerical model of a SiC plasma processing reactor, using a CF₄/O₂ gas mixture in an industrially relevant reactor geometry (Oxford Instruments). Simulations employing realistic conditions (~1.4kW ICP, 200W CCP) at pressures between 5-50 mTorr are discussed. A discrete analysis of the ICP and CCP power deposition and local CF₄ dissociative mechanisms is given. Of specific interest, we provide insights into carbon dust formation, transport, and deposition from both dissociative and wafer sputtering sources. Polishing and etching of SiC wafers poses significant challenges for both equipment manufacturers and consumers, here we demonstrate that numerical simulations open the path to enhanced understanding, and minimised future reactor downtime.

Experimental investigations of Raman scattering of beat microwaves in inductively coupled cool plasma

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Parametric instabilities of electromagnetic (EM) waves in plasma are non-linear processes which involve coupling between an incident EM wave, an electrostatic plasma wave and a scattered EM wave. These interactions are known to occur in magnetic and inertial confinement fusion, laser-plasma interactions, and in radio wave interactions with the ionosphere. An understanding of these phenomena may inform the development of new energy injection methods into plasma, for use in spherical tokamaks for example; or used to avoid plasma conditions which give rise to these instabilities, where they lead to undesirable effects.

One such interaction is Raman Scattering (RS), in which energy is exchanged between incident and scattered EM waves and an electron plasma (Langmuir) wave. The dynamics of RS are investigated using the linear plasma apparatus at the University of Strathclyde. This apparatus operates in the inductive mode driven by an RF antenna at 14 MHz, producing He or Ar plasma with density $10^{15} \text{ m}^{-3} < n_e < 10^{16} \text{ m}^{-3}$ with bulk temperature $< 1 \text{ eV}$ at pressure 6.4 Pa. Plasma conditions are diagnosed using an RF-compensated Langmuir probe. For these plasma parameters, RS can be driven by powerful microwave sources. This experiment makes use of a travelling wave tube amplifier and a magnetron oscillator to launch counter propagating microwaves via Satoh horns into the plasma, with the microwave sources tuned such that the beat frequency is similar to the plasma frequency. Theoretical analysis suggests that the interaction between the counter propagating beams will generate a Langmuir wave propagating in the direction of the higher frequency EM wave. This wave can then interact with the incident waves to produce electromagnetic sidebands - evidence for which has been seen in some preliminary experiments. We will present the results of further experiments and comparison with theoretical predictions.

Gaussian-process active learning for exploration of volume-ignited targets for inertial fusion energy

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Volume-ignition remains comparatively understudied relative to central-hotspot ignition which has received greater emphasis due to higher gain under present driver constraints. Volume-ignited targets typically exhibit lower gain for equivalent drive conditions, but offer the prospect of reduced sensitivity to hydrodynamic instabilities.

These targets introduce significant architectural complexity motivating systematic exploration across broad design spaces using reduced simulation models. High-fidelity 3-D radiation-hydrodynamics is prohibitively expensive for broad design studies and so large parameter scans typically rely on 1-D modelling despite its limitations. The combinatorial scale of materials, geometries, and drive conditions nevertheless remains limiting in optimisation studies.

This poster presents an exploration methodology using Gaussian-process surrogate modelling within an active-learning framework. Design parameters are mapped to fusion yield, in order to guide acquisition and optimisation of volume-ignited target performance.

Generation of Sub-THz Super Pulses in Overmoded Two-Dimensional Periodic Surface Lattice Cherenkov Masers

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Cherenkov sources based on cylindrical, two-dimensional (2D) periodic surface lattice (PSL) interaction cavities with diameters D much larger than the free space wavelength (λ) are the topic of ongoing research. While these studies have predominantly focused on the stationary, steady-state regime, recent results demonstrate that these sources can be driven into the highly non-linear transient regime, with the potential to produce highly controllable signals delivering hundreds of megawatts of peak output power.

A key feature is a soliton-like microwave pulse which drifts through the electron beam, spatially decoupling from the electrons before conventional saturation can arise, and compressing the free energy in all the electrons into a short duration, powerful output pulse.

We present numerical results of superradiant Cherenkov masers based on highly overmoded ($D/\lambda \gg 1$) 2D PSL interaction structures designed to operate in the sub-THz range. Compared to devices based on one-dimensional interaction structures, the azimuthal corrugation provides additional control of the wave dispersion, and therefore the slippage of the beam with respect to the wave.

Particle-in-cell simulations show the potential to produce short-duration “super pulses” comprised of coupled azimuthally symmetric, transverse magnetic waves. The lattice parameters are chosen to mediate rapid slippage of an energetic electron beam through strongly subluminal surface waves, targeting a forward wave interaction close to the pi-point of the electromagnetic dispersion.

The ability to scale D/λ while maintaining the spectral purity at any chosen frequency, in both the steady-state and transient regimes, indicates the strong potential of these sources to address the long-standing THz gap with important applications in plasma science.

Growth of additional zirconium oxide layers by reactive magnetron sputtering on capacitive sensor electrodes

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The issue of increasing contaminated water is highly relevant, as it directly affects the environment, human health, and drinking water resources. Industrial, agricultural, and urban activities increase pollutant levels, while climate change further complicates water management. Inefficient water treatment can lead to ecosystem degradation, disease spread, and water scarcity, highlighting the need for advanced and sustainable treatment technologies.

Capacitive sensors are used to monitor contaminated water because they respond to changes in the dielectric properties caused by dissolved salts, ions, and other pollutants. They enable rapid and continuous real-time monitoring of water quality. Due to their simple design, low energy consumption, and potential for miniaturization, capacitive sensors are a promising technology for wastewater and environmental monitoring systems.

Electrodes coated with thin zirconium oxide (ZrO_2) layers are especially promising due to their chemical stability, corrosion resistance, and high dielectric constant. Such coatings enhance sensor sensitivity and longevity, particularly in aggressive environments, such as contaminated water. The ability to form very thin, uniform layers makes this approach suitable for miniaturized and integrated sensors.

ZrO_2 thin films were deposited on stainless steel electrodes using reactive magnetron sputtering. A glow discharge was generated above a 3-inch disk-shaped zirconium target in a vacuum chamber with argon and oxygen. Argon and oxygen ions sputter zirconium atoms from the target, which react with oxygen during transport to the substrate, forming a uniform ZrO_2 layer. This method provides precise control over layer thickness, composition, and structure, ensuring good adhesion, chemical stability, and high dielectric performance. Consequently, ZrO_2 -coated stainless steel electrodes are widely used in capacitive sensors for water quality monitoring.

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High-k electron-scale turbulence diagnostic and synthetic diagnostic development for MAST-U

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Plasma turbulence on disparate spatial and temporal scales plays a key role in defining the level of confinement achievable in tokamaks, with the development of reduced numerical models for cross-scale turbulence essential for understanding and maximising confinement. Such models require experimental turbulence data at both electron and ion scales to inform development. In this paper, we propose a novel, mm-wave collective scattering diagnostic for measuring normal and binormal high-k (electron-scale) turbulence in the core and edge plasma of MAST-U. This will complement the existing ion-scale BES (beam emission spectroscopy) diagnostic, yielding core and edge measurements at both electron and ion scales whilst providing full spatial coverage under all operating conditions. We present detailed hardware specifications along with beam-tracing calculations predicting the spatial and wavenumber resolution of measurement. We also perform analysis of the instrument selectivity function computing the localisation and sensitivity of measurement accounting for magnetic pitch rotation with radius and spatial overlap of the incident and scattered Gaussian beams. A synthetic diagnostic framework is presented combining CGYRO predictions of plasma turbulence with beam tracing data for a sample equilibrium, mapping the instrumental wavenumbers to field-aligned coordinates and predicting the scattered power spectrum. All optics and mm-wave electronics will be mounted ex-vessel, with low-loss fused silica windows used for injection and egress of the probe and scattered beams. Precision measurements have been conducted on the dielectric properties of suitable fused silica glasses from 140 – 750GHz, using a novel Mason’s gain formulation to compute the Fabry-Perot transmission characteristics and minimise losses from the probe and scattered beams. Baseline specifications of the diagnostic include an operating frequency of 376GHz, a source power of ~100mW and a normalised turbulence wavenumber measurement range of $k_{\perp} \rho_e = 0.1 - 0.6$ where k_{\perp} is the binormal turbulence wavenumber and ρ_e the electron gyroradius.

Improved Neutral Beam Injection source region modelling via self-consistent Virtual Cathode evolution

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In negative ion neutral beam injection (NBI), H^-/D^- ions are produced in the source region and subsequently neutralised to form the neutral beam. The dominant production mechanism is the conversion of H atoms to H^-/D^- ions on a caesiated plasma grid (PG). To date, fully kinetic particle-in-cell (PIC) simulations have struggled to self-consistently reproduce the H^-/D^- ion density observed in the bulk plasma, typically underpredicting experimental values. This discrepancy arises from the common assumption of a uniform background H atom density, imposed for computational efficiency, which leads to premature H^-/D^- emission and the formation of an artificially deep virtual cathode near the PG. The resulting negative space-charge potential suppresses ion transport into the bulk plasma. In this work, two modifications were explored to achieve a more self-consistent treatment of virtual cathode formation and evolution: (i) modelling emitted H^-/D^- ions with a truncated Maxwellian distribution, and (ii) introducing an artificial proton drift toward the PG to offset early ion emission. For a plasma density of $2 \times 10^{17} m^{-3}$, these approaches yield an H^- density of $4.3 \times 10^{16} m^{-3}$ in the bulk plasma, representing an 89% increase relative to the baseline model. While experiments report a corresponding density of $6 \times 10^{16} m^{-3}$, simulations employing only the proton drift while retaining a Maxwellian emission model produce an H^- density of $4.8 \times 10^{16} m^{-3}$, substantially closer to experimental observations than previously achieved. These results indicate that the artificial early formation of the virtual cathode in simulations is the main reason for the bulk plasma H^-/D^- ion density discrepancy between simulations and experiments.

Impurity Transport using tracer particles and the Hasegawa-Wakatani model

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Anomalous cross-field transport in the edge and scrape-off layer of magnetically confined plasmas remains a critical challenge for achieving efficient confinement in fusion devices [1]. This region hosts hydrogenic ions, helium ash, injected impurities (e.g. neon, argon), and eroded wall materials, all of which interact with turbulent structures to drive complex, non-diffusive transport behaviour [1] [2]. Coherent vortices and shear flows - particularly ExB shear and zonal flows - are known to regulate transport in fluid and plasma systems [3, 4], yet their precise role in governing impurity dynamics in the plasma edge remains an open question [2]. In this work, we develop a versatile particle-tracer framework coupled to a two-field Hasegawa-Wakatani (HW) turbulence model [5], implemented within BOUT++ [6]. Tracer particles, advanced via the Lorentz force in a Python-based pusher, sample self-consistent drift-wave turbulence across regimes ranging from vortex-dominated to shear-dominated by varying the adiabaticity parameter.

To investigate impurity transport, we first identify coherent structures and their boundaries using three diagnostics: (i) contours of the electric potential field, which reveal the large-scale organisation of vortical structures; (ii) the Okubo-Weiss parameter, which distinguishes vorticity dominated regions from strain dominated shear layers; and (iii) the Lagrangian Averaged Vorticity Deviation (LAVD), which captures coherence from the particle perspective. Together, these measures enable identification of coherent vortices and surrounding shear regions. Once the coherent structures and their boundaries are determined, we identify tracer particles trapped within these regions and track their evolution. This allows us to quantify how particle motion changes when interacting with coherent vortices and shear layers, including trapping, detrapping, and enhanced radial excursions. By analysing particle displacement statistics as functions of adiabaticity and charge-to-mass ratio, we can characterise how coherent structures regulate impurity transport and contribute to convective, non-Fickian transport in drift-wave turbulence.

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Influence of Tsallis q-entropy on fusion reaction in a non-extensive plasma

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The effect of Tsallis q-entropy on the fusion reaction process is investigated in a non-extensive plasma. The closed expression of the classical turning point for the Gamow fusion penetration factor in a non-extensive plasma is obtained in terms of the Lambert W-function. The closed expressions of the Gamow penetration factor and the reaction cross section for the nuclear fusion reaction in a non-extensive plasma are obtained as functions of the Tsallis q-entropy and the relative kinetic energy by using the Gougam-Tribeche interaction potential with the WKB analysis. It is shown that the influence of Tsallis q-entropy enhances the fusion reaction in a non-extensive plasma. Hence, it is found that the fusion penetration factor in a non-extensive plasma with high q-entropy is always greater than in a Maxwellian plasma. It is also found that the influence of Tsallis q-entropy on fusion penetration factor decreases with an increase of the electron-to-ion temperature ratio. In addition, it is shown that the q-entropy effect on the fusion reaction is more significant in higher density plasmas.

Mass spectrometry of atmospheric pressure plasma for air sanitation

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Atmospheric pressure dielectric barrier discharges (DBD) generate strongly non-equilibrium plasmas which are characterized by high electron energies and with near ambient gas temperatures, making them efficient sources of reactive oxygen and nitrogen species (RONS) for air treatment applications. In this work, a double mesh DBD reactor consisting of two metallic grid electrodes separated by a glass or quartz dielectric barrier was investigated using a mass spectrometer. The discharge was operated in ambient air under high voltage AC, producing a plasma with transient microdischarges. Particular attention was given to identifying gas-phase species relevant for air sanitation including neutral molecules like (O₃, NO₂, NO, N₂O), positive ions (O₂⁺, N₂⁺, NO⁺) and short lived radicals and metastable states. Species were sampled directly from the atmospheric pressure reactor into a differentially pumped quadrupole mass spectrometer via 200 μm orifice interface. Threshold ionisation analysis was used to discriminate between parent species and fragmentation products which allowed improved selectivity in complex air plasma chemistry. The mass spectrometer enables direct detection of plasma generated ions as well as selective ionisation of neutrals using controlled electron impact energy. Correlation between discharge conditions and species intensities were examined. This study demonstrates the capability of atmospheric pressure plasma with mass spectrometry to provide quantitative insight into plasma induced air chemistry, linking discharge physics to gas phase species dynamics. This approach establishes a diagnostic framework for real time characterisation of DBD driven reactive species relevant to plasma based air sanitation technologies.

Plasma-Based Post-Growth Purification for Metal FEBID Nanoprinting

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Focused electron beam induced deposition (FEBID) is an emerging direct-write nanofabrication technique enabling the additive manufacturing of complex nanoarchitectures with applications in nanoelectronics, nanomagnetism, and spintronic devices[1]. However, carbonaceous originating from organometallic precursors significantly reduces the metallic purity and functional performance of deposited the printed nanostructures.

In this work, we demonstrate a plasma-based post-growth purification strategy for FEBID nanostructures achieving high structural fidelity with feature sizes down to ~60 nm. Following deposition, reactive plasma treatment was applied using an O₂/Ar mixture to selectively remove carbon-rich shell and enhance the metallic composition of the printed structures.

Electron energy loss spectroscopy (EELS) for studied as-deposited structures revealed a metal-rich core surrounded by a big carbonaceous shell. After plasma purification the carbon shell was substantially reduced, increasing the metal purity overall from 10% to ~ 80% at printed complex structures, while maintaining the integrity.

This combined approach of high-fidelity FEBID growth assisted by modelling [2], followed by plasma-based purification step provides a scalable pathway toward high-purity functional metallic nanostructures for next-generation nanomanufacturing and advanced device applications.

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Pressure-Driven Pellet Dynamics Arising from Asymmetric Ablation in Fusion Plasmas

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Pellet injection is a key technique for fueling, profile control, and disruption mitigation in magnetic confinement fusion devices. However, experiments have consistently shown that pellets do not follow simple straight-line trajectories, instead experiencing strong lateral deflection and acceleration. In this work, we present a humanized conference-level summary of recent advances in understanding the pellet rocket effect, where asymmetric heating of the pellet ablation cloud generates a net pressure imbalance that accelerates the pellet, analogous to rocket propulsion. The study employs a semianalytical perturbative approach built upon the classical neutral gas shielding (NGS) ablation model. By treating heat-flux asymmetry as a first-order perturbation to an otherwise spherically symmetric ablation cloud, the model self-consistently links asymmetric electron heating to pressure gradients at the pellet surface. The resulting formulation demonstrates that pressure asymmetry is the dominant contributor to pellet acceleration, while momentum transport plays a secondary role. Model predictions yield pellet accelerations of order 10^5 m s^{-2} in present-day tokamaks and up to 10^6 m s^{-2} in ITER-relevant H-mode plasmas. Trajectory calculations indicate that this effect can substantially reduce pellet penetration, particularly for larger or slower pellets, with important consequences for fueling efficiency and disruption mitigation strategies. These results highlight the necessity of incorporating the pellet rocket effect into predictive pellet modeling for next-generation fusion devices.

Pulsars as Plasmas: the collective plasma influence on ultra-high energy QED processes in pulsar radiation

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QED effects in high B-field environments (10^9 T) are vital in understanding the possible source(s) of radio emissions from observed pulsars. Rotating Radio Transients (RRATs), a subclass of radio pulsars, exhibit intermittent radio emissions whereby a pulsar is capable of temporary radio emission cessation over tens/hundreds of expected emission measurements.

In this paper the pulsar radiation process is modelled holistically for the first time, showing how the pair-plasma environment created by photon absorption influences the synchrotron radiation process that gives rise to those very photons. We propose that these processes – photon production, and pair production, are connected by a feedback loop that underpins the radiation output from pulsars via fluctuations of the magnetic field caused by the plasma response to pair augmentation.

The currents produced by pair production cause magnetic field perturbations, which in turn affect the synchrotron emission from ultra-energetic electrons which is the source of the pair-creating photons. Modelling this feedback loop requires incorporating the QED cross-sections for each process within an overall plasma description. At Landau resonances, $j=k=1$, pair densities of 10^{31} are capable of 10^2 order changes in the photon absorption coefficients indicating a central role for plasma modes in emission mechanisms from pulsar sources.

Quasi CW Cherenkov sources using 2-dimensional waveguide corrugations.

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Cherenkov devices using cylindrical interaction cavities with periodic axial corrugations modify EM dispersion with spatial harmonics, allowing coupling between an electron beam and an EM wave with a reduced phase speed. Meeting demand for kW+ mm to sub-mm wavelength coherent free-electron oscillators and amplifiers with such devices is challenging, as a large transverse size capable of handling the power is often over-moded, risking oscillation in undesired modes; devices targeting mode TM_{0,1} must have diameter D similar to the free-space radiation wavelength λ ($D/\lambda \sim 1$).

A novel Cherenkov device using 2-dimensional (axial and azimuthal) sinusoidal corrugations is considered. A high-order TM_{0,N} volume- and HEm_{,1} surface-mode pair can be selected, particularly by the number of azimuthal corrugation periods m , as the complex boundary conditions imposed by the 2D corrugations limit the number of eigenmodes capable of interacting with the hollow annular electron beam. This prevents oscillations in undesired modes, allowing coherent output with $D/\lambda \gg 1$.

Parameters for a $D/\lambda = 4.45$ quasi-CW Cherenkov slow-wave oscillator have been chosen based on analytical studies. Particle-in-cell (PiC) simulations have been undertaken for an oscillator, with $m = 13$, targeting the TM_{0,5} - HE_{13,1} mode pair with a 90 A, ~ 115 keV electron beam. Interaction efficiency of 25+% is predicted for output frequency 454 GHz, with up to 99% of power in the TE_{13,1} mode at the smooth cylindrical output.

Modification of the boundary between the interaction region and smooth output waveguide is found to substantially affect the interaction growth and output mode-spectrum, with some geometries (optimised for minimal reflection) resulting in no oscillation. Preliminary simulations seeding these geometries with a weak signal predict significant amplification of seed power, indicating potential in the amplification regime. Extending this study to consider higher values of D/λ could lead to the development of new quasi-CW sub mm-wave sources.

Rapid Single Step Atmospheric Pressure Plasma Jet Deposition of Cobalt Oxide

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Recently, cobalt oxide nanostructures are regarded as promising electrode materials for a range of electrochemical applications, particularly in batteries, supercapacitors, and electrocatalysis, due to their high theoretical capacity, excellent catalytic activity, and superior thermal and chemical stability. It is worth noting that spinel Co_3O_4 exhibits a high theoretical capacity of up to 890 mAh g^{-1} in lithium-ion batteries and delivers an excellent capacitance exceeding 3000 F g^{-1} in supercapacitors. Furthermore, studies have confirmed that spinel cobalt oxide is a highly promising non-noble electrocatalyst for metal–oxygen batteries. Atmospheric pressure plasma jets (APPJs) operate by driving inert gas through a high-voltage electric field where sufficient field strength induces gas ionization and plasma formation. The plasma is then ejected from an orifice, forming an atmospheric-pressure jet discharge. This single step process aerosolizes aqueous cobalt chloride into the plasma gas, oxidized by oxygen, and then deposited on the substrate. This technology stands out for its ability to quickly function at atmospheric pressure on geometrically complex substrates and is readily scalable for industry, thereby offering a highly sustainable route for the preparation of cobalt oxide materials.

Toroidal Transformer-Coupled Plasma (TTCP) Discharges in Ar/H₂O Mixtures for Hydrogen Generation

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The decarbonisation of hydrogen production is central to the UK's net-zero strategy, with a 5 GW low-carbon hydrogen target by 2030. Over 140 countries have net-zero pledges, with hydrogen central to 80% of national roadmaps. Plasma-assisted water vapour dissociation offers an electrically driven, emission-free alternative, yet industrially electrodeless scalable of operating at high temperatures remain under-explored. This numerically-lead PhD project investigates plasma-assisted electrolysis of water vapour as an innovative route to sustainable hydrogen production. Toroidal transformer-coupled plasma (TTCP) sources present an attractive configuration for hydrogen splitting due to their electrodeless configuration and high power densities. Analogous to a tokamak, an external primary coil antenna, driven by an RF current, is wrapped around a ferrite loop, which subsequently directs and focuses power, via an intermediate magnetic field, into the plasma chamber. The resulting oscillating toroidal electric field, initiates and maintains the plasma discharge, facilitating high alternating electron fluxes and driving high levels of molecular dissociation. Here, a computational investigation is conducted using the Hybrid Plasma Equipment Model for a dual-core, 0.5 MHz TTCP sustained in 1 Torr Ar/H₂O (90/10%) at 1.0 kW. The introduction of H₂O significantly depletes the upstream electron density by dissociative electron attachment, breaking the continuous plasma loop and resulting in a low-density (10^{18} m^{-3}) upstream H⁻/O₂⁻/O₂⁺ dominated ion-ion plasma, and a high density (10^{19} m^{-3}) downstream electron-dominated plasma. This operation is similar to other electronegative gas admixtures, where transformer current continuity in the azimuthal direction is maintained by toroidally varying regions of conduction and displacement currents. Operation of the source is numerically demonstrated up-to-and-including 100% water vapor operation. Initial simulations demonstrate significant (> 50%) H₂O dissociation for operation employing 1.0 kW and an inlet flow rate of 1 slm, with a strong dependence upon argon admixture. This work establishes toroidal transformer-coupled plasmas as a potential highly-scalable technology for decarbonised hydrogen production, aligned with the UK's clean energy strategy.

Acknowledgements

We acknowledge the generous support of alumni and friends in establishing the University of Aberdeen's Interdisciplinary Institute, which enabled this research, including Dr Jane Hellman Caseley (MBChB 1956), Professor Patrick Meares (DSc 1959), Nancy Miller (MA 1942), Norman Robertson, Dr Ian Slessor (MBChB 1956) and Anne Young (MA 1957).

Vulcan 20-20 laser upgrade overview

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The Central Laser Facility (CLF) at the UKRI STFC Rutherford Appleton Laboratory (Harwell Campus, UK) provides world-leading high-power and high-energy laser beam time to the UK research community and international collaborators.

CLF is currently delivering major capability upgrades including the Vulcan 20-20 program. Vulcan 20-20 will combine an ultra-high-intensity short-pulse capability — a flagship 20 PW beam (400 J, 20 fs) — with a high-energy long-pulse suite targeting an initial ~ 10 kJ distributed across six beams. A dedicated PW-class beamline will also support short-pulse x-ray and particle probes, including laser-accelerated electron and proton beams, enabling advanced radiography and pump-probe platforms. These capabilities will underpin a broad high-energy-density (HED) and fusion-relevant research program and will open access to plasma regimes at extreme energy density and intensity.

The facility will operate with two target areas and multiple experimental configurations to support a diverse user programme, spanning warm dense matter, laboratory astrophysics, fusion-relevant physics, and strong-field QED studies.

This presentation provides an overview of the Vulcan 20-20 capabilities and the current status of the program.

**52nd IOP Annual Plasma
Physics Conference**
7-10 April 2026
Elphinstone Hall,
University of Aberdeen, UK