ID	Posternumber	Title	Topic	Pesenter first name	Presenter last name
32	P2b.101	Scenarios for physics experiments in the COMPASS Upgrade tokamak	Magnetic Confinement Fusion	Fabien	Jaulmes
37	P2b.102	Gyrokinetic simulation of electrostatic microturbulence transport in ADITYA-U tokamak	Magnetic Confinement Fusion	Tajinder	Singh
80	P2b.104	Optimisation of Resistive Wall Mode Control in STEP	Magnetic Confinement Fusion	Guoliang	Xia
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163	P2b.107	Data-driven model discovery from fusion plasma turbulence simulations	Magnetic Confinement Fusion	Ivana	Abramovic
177	P2b.108	Energetic particle confinement and stability in the Spherical Tokamak for Energy Production	Magnetic Confinement Fusion	Ken	McClements
234	P2b.110	Physics based design of a multi-purpose non-axisymmetric active coil system for the Divertor Test Tokamak	Magnetic Confinement Fusion	Tommaso	Bolzonella
238	P2b.111	Microtearing Modes in high-β Spherical Tokamaks	Magnetic Confinement Fusion	Daniel	Kennedy
250	P2b.112	Confinement and transport studies of high-Z impurities injected by Laser Blow-Off technique in electron and ion-root TJ-II stellarator plasmas	Magnetic Confinement Fusion	Belén	López Miranda
259	P2b.113	New insights into cryogenic and TESPEL pellet physics in TJ-II	Magnetic Confinement Fusion	Daniel	Medina Roque
261	P2b.114	Transport analysis of a DTT negative triangularity scenario	Magnetic Confinement Fusion	Alberto	Mariani
263	P2b.115	Formation studies of field-reversed configurations on the HFRC-F device	Magnetic Confinement Fusion	Yue	Peng
303	P2b.116	Modelling of the Neutral Gas and Plasma Transport in the Scrape- off Layer and Divertor of ST40-Tokamak	Magnetic Confinement Fusion	Albert	Nicolai
318	P2b.117	Improving the Performance of a Fusion Neutron Science Facility	Magnetic Confinement Fusion	Luca	Guazzotto
329	P2b.118	Calorimetry probe measurements of runaway electron impact energy on plasma facing components at COMPASS tokamak	Magnetic Confinement Fusion	Jakub	Čaloud
365	P2b.119	The first experimental campaign results of plasmas heated by a new 1 MW neutral beam injector on the COMPASS tokamak	Magnetic Confinement Fusion	Klara	Bogar
379	P2b.120	Study of GAM-Turbulence intermittency in the FT-2 tokamak using GENE simulations	Magnetic Confinement Fusion	Francis Clinton Prasant	Albert Devasagayam
423	P2b.121	Modeling of Alfven cascades in the TJ-II stellarator with STELLGAP and AE3D codes	Magnetic Confinement Fusion	Adriana	Ghiozzi
451	P2b.122	Whistler wave destabilization by a runaway electron beam in COMPASS	Magnetic Confinement Fusion	Andrea	Casolari
453	P2b.123	Using Genetic Algorithms to Optimise Current Drive in STEP	Magnetic Confinement Fusion	Stephen	Marsden
86	P2b.201	Laser ion acceleration from tailored solid targets with micron-scale channels	Beam Plasmas and Inertial Fusion	Kirill	Lezhnin
196	P2b.202	Influence of the laser pulse steep rising front on ion acceleration	Beam Plasmas and Inertial Fusion	Martin	Matys
335	P2b.203	Target characteristics used in laser-plasma acceleration of protons based on the TNSA mechanism	Beam Plasmas and Inertial Fusion	Alexandru	Magureanu
348	P2b.204	Low proton bunch divergence from double-layer target driven by twisted light	Beam Plasmas and Inertial Fusion	Camilla	Willim
357	P2b.205	Drive-laser-wavelength dependence of the power partitioning in a laser-produced tin plasma with relevance to EUV nanolithography	Beam Plasmas and Inertial Fusion	Diko	Hemminga
380	P2b.206	Effect of density ramp on electron acceleration driven by tightly focused ultrashort laser pulses	Beam Plasmas and Inertial Fusion	Zsolt	Lécz
424	P2b.208	Optical shaping of high-pressure gas-jet targets for proton acceleration experiments in the near-critical density regime	Beam Plasmas and Inertial Fusion	Ioannis	Tazes
430	P2b.209	Study of chromatic focusing, post-acceleration and bunching of protonsaccelerated by Target Normal Sheath Acceleration in helical targets	Beam Plasmas and Inertial Fusion	Arthur	HIRSCH
498	P2b.210	The design and performance of an asymmetrical nozzle in Laser Wake Field electron acceleration	Beam Plasmas and Inertial Fusion	Georgia	Andrianaki
601	P2b.211	High-repetition rate neutron source by few-cycle intense laser pulse	Beam Plasmas and Inertial Fusion	Prashant	Singh
394	P2b.301	Investigation on O3 and NOx Production in a Surface DBD	Low Temperature and Dusty Plasmas	Cecilia	Piferi
403	P2b.302	Studying the onset of turbulence in flowing complex plasmas	Low Temperature and Dusty Plasmas	Eshita	Joshi
406	P2b.303	Fractal polymeric surfaces by plasma processing	Low Temperature and Dusty Plasmas	Cecilia	Piferi
611	P2b.304	Modeling of the nanoparticle size segregation in magnetron discharge	Low Temperature and Dusty Plasmas	Cecile	Arnas
40	P2b.401	Dynamical study of chaotic magnetic fields in magnetohydrodynamic plasmas	Basic, Space and Astrophysical Plasmas	Siba Prasad	Acharya
140	P2b.402	Quantum Computing Approach to Electromagnetic Wave Propagation in Plasma	Basic, Space and Astrophysical Plasmas	Efstratios	Koukoutsis
207	P2b.403	Qubit Lattice Algorithms for 2D Scattering of Electromagnetic Waves from Scalar Dielectric Objects	Basic, Space and Astrophysical Plasmas	George	Vahala
510	P2b.404	Numerical simulations modelling the interaction of ultra-relativistic neutral fireball beams with magnetised plasmas	Basic, Space and Astrophysical Plasmas	Cinzia	Chiappetta
540	P2b.406	Impact of Suprathermal and Beam Electrons on Nonlinear Electrostatic Waves in an Electron-Positron Plasma	Basic, Space and Astrophysical Plasmas	Ashkbiz	Danehkar

Scenarios for physics experiments in the COMPASS Upgrade tokamak

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The COMPASS Upgrade tokamak [1] will be a tokamak of major radius R_0 = 0.894 m with the possibility to reach high field (Bt ~ 5 T), high current (Ip ~ 2 MA) along with high shaping capabilities (κ=1.8, δ=0.6). The main auxiliary heating system used to access H-mode will be 4 MW of Neutral Beam Injection (NBI) power, assisted with 2 MW of ECRH. The baseline scenario of COMPASS Upgrade will mimic the expected high triangularity plasma shape of ITER (δ_u=0.43, δ_l=0.58, κ=1.8).

The new tokamak should have access to two types of H-mode observed in C-Mod [2]: the usual ELMy H-mode at lower densities and the stationary, ELM-suppressed Enhanced Dα (EDA) regime, seen at high densities and higher values of q_{95}. Furthermore, thanks to the large toroidal field, the window of operation of I-mode [3] will be significant, especially at reversed field or Upper Single Null operation. We introduce also plausible access to more advanced confinement regimes such as Super H-mode [4] and QH-mode [5].

The three main distinct confinement regimes (ELMy H-mode, EDA H-mode and I-mode) occur at significantly different values of the pedestal top density and collisionality. Based on existing scaling laws as obtained from Alcator C-mod [2], we can described the pedestal for various sets of achievable engineering parameters using the METIS code [6]. The ELMy pedestals are compared against the results of the more detailed MHD stability code EPED [7]. We make predictions for plasma performance for several scenarios and discuss plasma density and temperature profiles, NBI power density, separatrix parameters and their relation to SOL and divertor conditions. We demonstrate the relevance of the COMPASS Upgrade project as an exploratory device for the edge physics dimensionless parameter space and estimation of subsequent power exhaust in view of a fusion reactor.

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Gyrokinetic simulation of electrostatic microturbulence transport in ADITYA-U tokamak

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It is highly accepted in the fusion plasma community that the low-frequency drift waves (DW) are responsible for anomalous turbulent transport in tokamaks [1]. In this work, we have presented the global gyrokinetic simulations of electrostatic microturbulence for the realistic geometry and experimental profile of ADITYA-U [2] tokamak using the state-of-the-art gyrokinetic toroidal code (GTC) [3]. The collisions have been retained in the simulations and a direct comparison of simulations with the experimental observations has been done [4]. The simulations show that the linear eigenmode is dominated by the trapped electron mode (TEM) driven turbulence that propagates in the electron diamagnetic drift direction [5,6]. The ion diffusivity obtained from the nonlinear simulation matches well with the experimentally measured value of $\sim 0.2\text{m}^2$/sec. The experimentally obtained spectrogram shows the broadband from 0 to $\sim$ 50kHz, which agrees well with the spectrum of electrostatic fluctuations from the simulations. These findings assure that the TEM turbulence acts as one of the dominant channels for the microturbulence transport in ADITYA-U. The knowledge gained from the gyrokinetic simulations could be insightful to set up future ADITYA-U experiments.

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Optimisation of Resistive Wall Mode Control in STEP

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The Spherical Tokamak for Energy Production (STEP) is a UKAEA program that aims to deliver a prototype fusion energy plant and a path to commercial viability of fusion [1]. The low aspect ratio spherical tokamak is attractive because of its potential to achieve high normalized beta β_N operation, and fusion power ~ β_N^2 . To fully exploit this, and to maximise economic attractiveness, operation above the no-wall β-limit is desirable, where the resistive wall mode (RWM) must be controlled either by passive or active control, since otherwise this may lead to major disruption.

Previously, it was found that passive stabilization of the RWM in STEP gives a relatively small increase in β_N above the no-wall limit, relying on toroidal plasma flow and drift kinetic resonance damping (from both thermal and energetic particles) [2]. In order to optimise performance in STEP from an MHD viewpoint, active control of the unstable RWM appears to be a necessity. In this work, the MARS-F code [3] is utilized to model feedback schemes for controlling the n=1 RWM in STEP, assuming a set of active coils located near the outboard mid-plane of the torus. Results show that, with the flux-to-voltage control scheme which is the basic choice, a proportional controller alone does not yield complete stabilization of the mode. Adding a modest derivative action, and assuming an ideal situation without any noise in the closed loop, the RWM in STEP can be fully stabilized in the presence of plasma flow.

With more realistic control assumptions, i.e. the presence of sensor signal noise in this study, the RWM feedback is found to be of a more subtle issue in STEP. This is partially due to the fact that the derivative action tends to amplify the sensor noise, and partially related to the statistic nature of the problem leading to difficulties e.g. in judging the success of mode suppression in certain cases. To model the sensor signal noise, random perturbations with a normal distribution, with zero mean and standard deviation of σ<0.1 G, are injected into the magnetic field measured by pickup coils during initial value closed loop simulations. A criterion, based on the total perturbed magnetic energy of the system, is proposed to judge the control loop success. To obtain reliable results, 100 initial value closed loop simulations are performed for the same feedback configuration, with statistics drawn in terms of the success rate for the RWM suppression. As a key finding, success rates exceeding 90% are achieved, and generally increase with the proportional feedback gain. On the other hand, the required control coil voltage also increases with feedback gain and with the sensor signal noise.

Further studies, to be reported at the conference, will investigate alternative criteria (e.g. that based on the n=1 locked mode amplitude to trigger a disruption [4]) for the closed loop stability in the presence of noise, as well as schemes of sensor noise filtering to improve the control performance.

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The Atomic Beam Probe Synthetic Diagnostic

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The Edge Localised Modes (ELMs) are repetitive instabilities of fusion plasmas. A significant particle and heat flux leave the confined region by ELM events. The ELMs are caused by the large pressure gradient and the edge current in the pedestal region. It is important to understand the edge current dynamics, however, the high temporal resolution edge current measurements are limited.

The Atomic Beam Probe (ABP) was a novel diagnostic tool installed on COMPASS tokamak [1]. A 40–100 keV light neutral alkali beam was injected into the plasma and ionised close to the last closed flux surface [2]. The primary ions were collected by a Faraday cup detector matrix, and their current was measured with high temporal resolution [1, 3]. The ion beam position and distribution at the detector are related with the magnetic field along the ions' trajectories [2, 3]. This work presents a synthetic diagnostic to support the understanding of the measurements.

The synthetic diagnostic is a machine independent tool which combines the relevant physical processes of beam diagnostics in tokamaks: magnetic and electric field, primary [4] and secondary ionisation, GPGPU ion trajectory simulation [5]. The fast changes of the magnetic field are parametrised by simplified models and added to the numerical solver. The output of the synthetic diagnostic is the current distribution of the Faraday cup matrix.

We will present synthetic cases with the variation of plasma parameters and compare with the COMPASS ABP measurements [6].

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Novel high speed spectrally resolved imaging system for simultaneous 2-D Te and ne edge plasma measurements with temporal resolution up to 100 kHz

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The coupling between the electron density n_e and temperature T_e is crucial for understanding turbulent transport in the edge plasma of fusion devices. Measuring this coupling is one of the main objectives of the novel system presented here that combines high speed imaging with the well-established *He* line-ratio spectroscopic technique. It allows simultaneous 2-Dimensional (2D) measurements of turbulent T_e and n_e structures at sampling rates of up to 100 kHz. The new system is an upgrade of an older setup [1] that monitored 2 lines yielding 1 ratio. The new system images the emission of 3 characteristic He I lines, which allows deducing both T_e and n_e simultaneously. The atomic line emission is collected from a plasma region into which Helium is puffed. The precise alignment of the system was designed to minimize the angle between the line of sight of the lenses and magnetic field lines within the emission volume. This setup provides maximum spatial resolution, as the line-integrated light intensity will closely approximate the poloidal cross-sectional distribution of the emission. This work reviews the system design in detail and presents its final layout. Additionally, first results are presented and the possibility to study the coupling of plasma turbulence with neutrals will be discussed.

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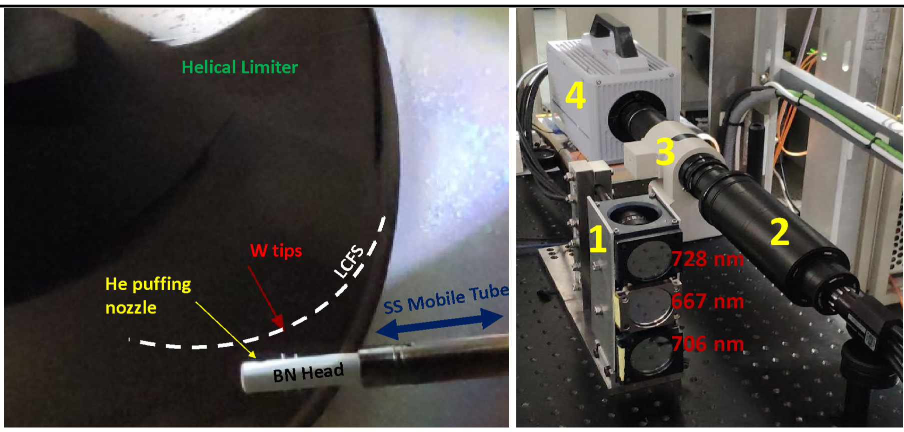
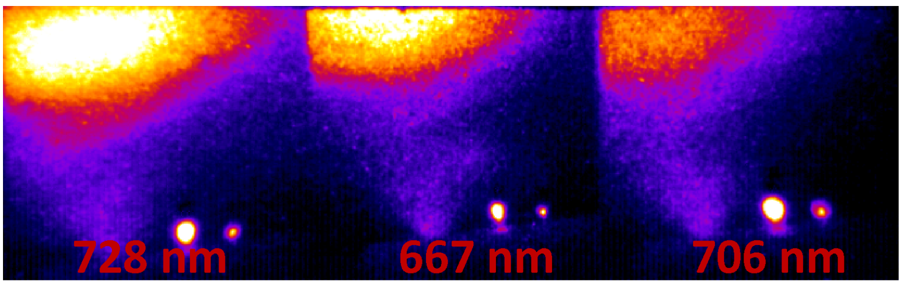


Left: *Mobile Helium Gas puffing injector in the vacuum vessel of TJ-II*

Right: *Triple fiber-bundle lens assembly with interference filters (1), Relay optics (2), Image intensifier (3) and Fast camera (4).*



Spectrally resolved image (15 μs exposure time)

Data-driven model discovery from fusion plasma turbulence simulations

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A machine learning method has shown the ability to extract the underlying physics equations using only the data from fusion plasma turbulence simulations. This can potentially be applied for derivations of reduced models and validation against experimental data. Turbulence, being a highly non-linear process, is challenging to theoretically describe and computationally model. High-fidelity computational models come at a high computational cost and cannot be applied for routine simulation of plasma turbulence. Reduced models based on artificial neural networks could fill the need for affordable simulations. However, the training requires very large volumes of data and the obtained models lack interpretability, making it difficult to understand the physics being learned and whether it can be extrapolated to scenarios not encountered previously during training. This is especially problematic for predictions in future machines which will operate in unexplored parameter ranges. In particular, we explore parameter ranges foreseen for MIT's high field tokamak SPARC [1]. SPARC will feature high temperature superconducting magnets enabling it to have a field of 12 T on axis and demonstrate a fusion net energy gain. To circumvent the problem of extrapolability and data-inefficiency, we explore a data-driven model discovery approach based on sparse regression and infer governing partial differential equations from the data [2, 3]. Our data is generated by simulations of drift-wave turbulence according to Hasegawa-Wakatani model [4]. Balancing model accuracy and complexity enables the reconstruction of the governing equations, accurately describing the dynamics from the input data sets. The methodology is further applied to more complex synthetic data produced by the Global Drift Ballooning code [5]. The findings show that the methodology is promising for development of reduced and computationally cheap models as well as for existing model validation.

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Energetic particle confinement and stability in the Spherical Tokamak for Energy Production

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The UK has launched a programme to build a prototype fusion power plant, the Spherical Tokamak for Energy Production (STEP), generating fusion power ~1 GW and net electrical power ~100 MW. Good confinement and low redistribution of fusion α-particles will be required to ensure acceptable first wall power loads and to realize the target plasma scenario. Waves in the electron cyclotron range will be used for external current drive, and therefore α-particles will be the only significant fast ion species. We will report on modelling of α-particle confinement and of toroidal Alfvén eigenmodes (TAEs) driven by these particles in the target scenario. Results have been obtained so far for two scenarios: STEP Prototype Reactor (SPR)-008 with major radius R_0 = 3.6m, toroidal field on-axis B_0 = 2.3T, plasma current I_p = 23MA and volume-averaged beta β = 0.22; and SPR-014, with R_0 = 4.7m, B_0 = 4T, I_p = 23MA and β = 0.07. Prompt and toroidal field (TF) ripple-induced losses of α-particles and associated power loads on plasma-facing components have been calculated using the LOCUST code for a range of ripple parameters (the number of TF coils N_{coil} and the major radii of their outer limbs R_{coil}). In both SPR-008 and SPR-014 the peak power fluxes due to prompt alpha-particle losses occur in the upper divertor whereas those due to ripple occur in the main chamber, where the maximum tolerable fluxes are relatively low (~0.5MWm^{-2}). For SPR-008 acceptable power loads are achieved with N_{coil} =12 and R_{coil} = 8.0m. For SPR-014 R_{coil} would need to be as high as 11m if 12 coils were used, but a 10m coil radius would be acceptable if N_{coil} = 14. TAE stability calculations for STEP performed using the HAGIS and HALO codes will also be presented. Due to the presence of high magnetic shear in the plasma edge, many TAEs exist in STEP plasmas, some of which have intrinsic growth rates as high as γ/ω ~ 0.2. However bulk ion damping of these modes in flat-top conditions is generally even stronger due to high β (meaning that the Alfvén and ion thermal speeds are not widely-separated) and TAEs are therefore unlikely to be driven unstable during this phase. Net damping of TAEs is found even in the case of SPR-014 despite lower β. Further stability analysis remains to be carried out, in particular of finite temperature effects, TAE excitation during plasma ramp-up, and higher order (ellipticity-induced and noncircular triangularity-induced) Alfvén eigenmodes.

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Physics based design of a multi-purpose non-axisymmetric active coil system for the Divertor Test Tokamak

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Edge-Localized-Modes (ELMs) are local Magneto-Hydro-Dynamic instabilities that appear in fusion relevant plasmas during the so-called H-mode operation. Type-I ELMs in particular are large bursts that can damage the plasma facing components causing large heat and particle fluxes. Applying 3D resonant magnetic perturbations (RMPs) with non-axisymmetric coils is a promising method to mitigate or suppress type-I ELMs [1][2]. Controlling these instabilities is a crucial task in particular for the upcoming DTT device [3], whose construction is starting in Frascati (Italy) with the main mission of developing reactor-relevant power exhaust solutions. A set of in-vessel non-axisymmetric coils is being developed for DTT, with the main purpose of ELM mitigation and Error Field (EF) control. The present design of that system is described, taking into account geometrical and technical constraints, requirements driven by both ELM and EF control, integration with other in-vessel components. From the point of view of ELM control, a first requirement assessment has been carried out using linear plasma response modelling to evaluate the effect of vacuum RMPs on edge stability. As an output of this study the coil current requirement can be inferred. A set of different metrics is exploited for the purpose. Given a target scenario obtained from integrated modelling of the full power phase [4], plasma response calculations are carried out by the MARS-F code for n=1,2,3 toroidal mode numbers. Depending on the perturbation periodicity and adopted metric, the total coil current required for ELM control ranges from 20 kAt to 30 kAt.

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Microtearing Modes in high-β Spherical Tokamaks

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Microinstabilities often result in turbulence that influences energy confinement in tokamak discharges. One such microinstability, of particular importance to the design of next-generation spherical tokamaks (STs) such as STEP [1], is the microtearing mode (MTM), a tearing-parity mode centred on high-order rational surfaces. MTMs are short-wavelength ion scale (low $k_y\rho_s$) electromagnetic instabilities that are primarily driven unstable by the electron temperature gradient. In plasmas where β_e (the ratio of electron thermal pressure to magnetic pressure) is sufficiently high, MTMs can become the dominant instability contributing to electron transport in the plasma core, and local linear gyrokinetic (GK) simulations find that this is likely to be the case for STEP [2]. Thus, to predict the evolution of next-generation ST discharges, we must improve our capability to predict electron thermal transport driven by MTMs. A key focus for STEP is designing a reduced model for use in whole device predictive modelling codes to assist in making intelligent design choices. The first focus of this contribution will explore one promising existing model [3] and our attempts at both (i) benchmarking this model using GK simulations and (ii) generating new tools for modelling turbulence in next-generation STs. Whilst GK simulations have thus far proven to be a very accurate tool in modelling turbulent transport, obtaining saturated nonlinear MTM simulations has proven computationally challenging. Local simulations suffer from the so-called high β runaway [4], where turbulent amplitudes and transport levels grow to tremendous values once a certain β_e is exceeded. It has been a source of considerable confusion as to whether this runaway effect resulted from shortcomings of the available GK codes or due to the failure of local GK at low $k_y\rho_s$. In recent studies, global physics has been found to play a prominent role in obtaining saturated MTM simulations (e.g., [5]). In the second thrust of this contribution, we will also exploit the unique additional capabilities of the gyrokinetic code GENE [6] in our attempts to obtain the first saturated nonlinear simulations relevant to a conceptual design of a burning ST plasma.

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Confinement and transport studies of high-Z impurities injected by Laser Blow-Off technique in electron and ion-root TJ-II stellarator plasmas

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The avoidance of impurity accumulation in present day stellarator devices is a key challenge for the development of steady-state operation scenarios in reactors based on this concept [1]. In the TJ-II stellarator, impurity transport was investigated previously in low-density regimes (≤ 6×10^{18} m^{-3}) [2, 3], where the radial electric field is positive across the minor radius and the plasma is in the electron-root. However, some limitations were found for heavy impurity (Fe, W) injections into high-density microwave heated plasma regimes in this device, due to the intrinsic limitation of the TJ-II cut-off density (1.3×10^{19} m^{-3}) and to the difficulties in achieving a true density plateau at high densities. These limitations have been partially solved with a better conditioning and more operational control. Here, the behaviour of heavy impurities (Fe, W) injected, using the Laser Blow-Off (LBO) technique, into both electron and ion-root regimes in TJ-II plasmas is investigated. For this, the confinement times of the high-Z impurities are deduced from the decay-times of different radiation signals. In parallel, the radial and temporal evolution of the total radiation is analysed using the STRAHL code [4] to deduce transport coefficients. Finally, since neoclassical transport simulations predict differences in transport for different regimes [5], we compare experimental results with simulations obtained using the `EUTERPE` [6] code used to estimate neoclassical transport, and the `stella` [7] code, which predicts the turbulent counter-part. This is done in order to identify the mechanisms involved in these processes.

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New insights into cryogenic and TESPEL pellet physics in TJ-II

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Pellet injectors (PI) are operated on many medium- and large-sized magnetic confinement devices. For instance, cryogenic PI is essential to achieving efficient plasma fuelling, in particular in large fusion devices. In contrast, tracer PI is used to investigate impurity transport and confinement, *e.g*., TESPEL [1]. Both types are used on W7-X, LHD and TJ-II as tools to study scenarios to achieve efficient core fuelling and avoid impurity accumulation in stellarators. Despite much progress, a complete comprehension of the physics involved in pellet ablation, particle drift and diffusion, as well as efficient fuelling remains outstanding. However, given the shared physics, comparative experiments using both pellet types can provide new insights and understanding into physics processes and plasma response.

A cryogenic PI is operated on TJ-II, a heliac-type stellarator. In parallel, a TESPEL system is piggybacked to its up-stream end to create a unique tool for pellet research in plasmas [2]. TJ-II is also fitted with a wide variety of diagnostics that can provide unique insights into pellet physics and post-injection plasma response, *e.g*., a dual HIBP system, magnetic-coil arrays, a 2-channel Doppler reflectometer, and a high-resolution Thomson scattering system [3]. Here, novel comparative experiments reveal strong plasmoid deceleration close to rational surfaces (inducing short-lived magnetic instabilities during ablation), show that post-injection reductions in broadband magnetic fluctuations can be associated with temperature gradient changes, and indicate that post-injection frequency jumps in NBI-driven Alfvén eigenmodes are dominated by plasma mass density changes. The analysis of density and potential fluctuations, measured simultaneously at 2 toroidal positions by the HIBP system, provides additional insights. Details of the experiments and findings, plus their implications for pellet injection physics, are presented and discussed.

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Transport analysis of a DTT negative triangularity scenario

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Plasmas with cross section featuring positive triangularity (PT) have historically been preferred to those with negative triangularity (NT), due to their better magnetohydrodynamic stability properties [1]. Recently, the NT option has gained more interest, since it could allow to achieve H-mode levels of confinement in L-mode, avoiding detrimental edge localised modes (ELMs). As long as experimental evidences add up (TCV: [2], DIII-D: [3], AUG: [4]), the NT option is now studied as a possible viable option for a future fusion reactor [5]. Within this framework, a NT scenario is under investigation for the divertor tokamak test (DTT) facility [6]. Here, the results of the transport analysis of the DTT reference full power scenario with Ne seeding are presented, comparing a NT option with the PT reference one. The analysis consists of transport simulations, gyrokinetic and quasi-linear runs. The transport runs are carried out with the ASTRA code [7], coupled with the quasi-linear model TGLF SAT2 [8]. Larger temperature gradients are predicted by ASTRA for NT, but not sufficient to recover the loss due to the lack of pedestal in NT L-mode. The difference of PT and NT profiles is mainly due to the different boundary conditions rather than to the geometry itself. Flux-tube gyrokinetic runs are performed with the GENE code [9] at fixed radius to characterise the turbulence and to evaluate the associated flux levels. The variation of the temperature stiffness, i.e. the degree to which the temperature profiles respond to changes in the applied heat fluxes, is also investigated when going from PT to NT. The GENE results indicate ITG dominant turbulence at larger radii. A strong (>50%) stabilising effect is observed when the triangularity is reversed, both on linear growth rates and nonlinear heat fluxes. This effect is partially compensated by the high temperature stiffness, that limits its impact on logarithmic gradients. TGLF stand-alone runs are ongoing, to be compared with GENE. This work is performed within the TSVV-02 EUROfusion task.

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Formation studies of field-reversed configurations on the HFRC-F device

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Abstract

Collisional-merging is a way to form high-performance field-reversed configuration (FRC) plasma after decades of research. In order to improve the properties of the merged plasma, one feasible way is to optimize the formation process and enhance the parameters of the initial plasma before translation.

An experimental device named HFRC-F has been constructed in Huazhong University of Science and Technology, which is used to investigate the field-reversed theta-pinch (FRTP) formation process of FRCs. The formation region of HFRC-F device has a large size with a radius of 0.3 m and length of 2.6 m. The coil system consists of 12 theta-pinch coils and 4 quasi-steady state coils, which can generate a max bias field of -0.1T, a max pre-ionization field of 0.15T with a frequency of 150kHz and a max main field of 0.5T in quartz tube, and can achieve various changes such as alterable magnetic field configuration between cusp and mirror. As for now, magnetic diagnostics and CO_2 interferometry are installed to measure the density, magnetic flux and calculate other parameters of the plasma.

Initial HFEC-F experiments obtain typical parameters with plasma density of 1×10^{20} m^{-3} and lifetime of dozens of microseconds with B_{bias} = -0.02 T, B_{PI} = -0.015 T and B_{main} = -0.05 T. The results also show that, 1) the greater the bias magnetic field, the longer the lifetime of FRC. 2) the larger the main magnetic field, the higher the density of formed plasma. 3) the PI magnetic field should not be too large relative to the bias field, otherwise ionization will occur near the zero crossing of the total magnetic field, leading to a small initial frozen flux.

In addition, a magnetohydrodynamics (MHD) simulation software called USim is used to study the effect of the initial density of plasma, the amplitude of the bias and main magnetic field, the configuration of the bias field, the rise time of the main field on the plasma parameters. It is hoped that these works can improve the parameters of the formed plasma.

Modelling of the Neutral Gas and Plasma Transport in the Scrape- off Layer and Divertor of ST40-Tokamak

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In ST40 (design parameters: R/a=0.4/0.25m, B_t=3T, I_{pl}=2MA flat top duration up to 1 sec, NBI-power 2MW, NBI-energy E_b=25-50 keV, ECRH - power 1-2 MW/1/) a double null poloidal divertor configuration is under investigation.

To compute the density and ionization rate of the neutral gas in the divertor of ST40, the pseudo-collision technique was applied /2/. A two-dimensional grid with radial and poloidal resolution is used to calculate the neutral gas density n_c, the temperature T_c and the deposition (absorption) profile d_c of the ionized neutrals. As neutral particles atoms and molecules arising from reflection and dissociation are considered. The backscattering model accounts for the correlation according the Behrisch matrix /2/ and a smooth transition between specular and diffuse reflection as in /2/. The potential sheath in front of the plate enforces a zero total charge flux of the incoming electrons, the released secondary electrons, and the incoming ions. The secondary electrons reduce the potential step thus the acceleration of the ions and therefore the sputter yield at the plate, an important input for the impurity module.

The description of the plasma transport /3/ accounts for parallel and perpendicular heat conduction, perpendicular particle diffusion, parallel convection, recycling of the neutral particles. The boundary conditions account for the symmetry with respect to the equatorial plane and for the temperture and density values at the separatrix (T_{es}=T_{is}=100eV, n_{ic}= 3 10^{12}/cm^3).

The main results are:

The deposition of the ionized neutrals d_c has a strong maximum at the separatrix, the density n_c has the opposite behaviour since n_c~d_c/n_e, similar as in /2/. The maximum density is n_{cmax}=2 10^{12}/cm^3 and falls off rapidly in the parallel direction. n_{cmax} is consistent with continuity at the plate.

The simulation of the plasma transport shows a radial T_e(T_i)-e-folding length of ~ 4 cm. The velocity has the maximum at the separatrix v_{max}=9 10^6 cm/sec.

Due to recycling, the density has a weak maximum in the vicinity of the divertor plate and the ion temperature has a minimum at the plate due to the cooling by the neutrals.

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Improving the Performance of a Fusion Neutron Science Facility

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Two major modifications to the existing steady state Fusion Neutron Science Facility (FNSF) [1] concept are investigated with the aim of determining whether or not the predicted performance can be substantially improved. The modifications are high magnetic field and pulsed operation. We find that high field leads to major improvements in a steady state FNSF, although at the expense of lowering the engineering gain. Pulsed operation replaces the problems associated with low current drive efficiency, with hopefully more manageable engineering problems. Here, however, high field is not helpful, and low field is more desirable. Pulsed FNSFs also have a reduced engineering gain. Further modifications lead to FNSF designs satisfying the additional constraint of engineering gain equal to unity. For these designs there is a large cost penalty for the steady state FNSF but only a modest penalty for the pulsed FNSF. All of our modified designs show modest to large potential improvements over the existing design. Overall, our conclusion is that it may be desirable to carry out a more detailed analysis of one of our improved designs, the choice depending upon which issue in the existing design is most important.

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Calorimetry probe measurements of runaway electron impact energy on plasma facing components at COMPASS tokamak

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Runaway electrons (RE), accelerated during a tokamak discharge to relativistic energies in the order of MeV, can cause high heat loads on the plasma facing components. This can lead to a serious damage of a tokamak device [1]. Therefore, it is important to study the heat loads as a reaction to mitigation techniques. For this reason, a new diagnostic - the calorimetry probe, was developed at the COMPASS tokamak [2] to measure the deposited energy by the RE beam on the low field side (LFS) protruded protection limiter - one of the most affected components.

Runaway electrons were generated mainly during low density discharges using a special experimental scenario [3], which allowed to study various mitigation strategies and RE control techniques. The highest deposited energy measured on the calorimetry head was (15 ± 1) kJ during a discharge with an additional acceleration of the RE beam by keeping a constant ramp of the current in the central solenoid. Thanks to the complementary surface temperature measurements by the IR camera [4], it was also possible to estimate an incident power on the calorimeter front surface. The most notable effect on decreasing the RE impact energy was measured after an injection of Ne into the plasma. A similar effect was observed after an additional injection of deuterium into the RE beam. It was found, that the deposited energy scales with the atomic number of the injected gas. The active radial position control also leads to the lowering of heat loads on the calorimeter surface. A detailed analysis of the calorimetry probe measurements and a comparison of the studied effects on the RE beam energy will be given in this contribution.

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The first experimental campaign results of plasmas heated by a new 1 MW neutral beam injector on the COMPASS tokamak

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The COMPASS tokamak had been equipped with two identical neutral beam injectors with a nominal energy 40 keV and power 2×400 kW since its re-installation at IPP Prague. During 2021 a new neutral beam injector (NBI) with nominal energy of 80 keV and auxiliary heating power up to 1 MW was installed and connected to the COMPASS vacuum chamber. Such a high total possible heating power allowed to significantly extend the operating space of COMPASS, in particular in the high confinement mode.

This contribution presents experience with the new NBI operation, mainly the beam properties, which were characterised during an extensive experimental campaign in summer of 2021. Although the beam nominal energy is 80 keV, the NBI was operated only at energies up to 70 keV due to temporary operational limits. Despite that, the nominal power of 1 MW was achieved by operating at higher neutral beam current, which was slightly above the optimum for beam divergence.

Second part of the contribution focuses on the plasma parameters, which were achieved thanks to the new NBI. New COMPASS record plasma parameters were obtained, for example the beta reached 2.95 or the total stored plasma energy 16.7 kJ. As the first COMPASS campaign with all three available neutral beam injector was simultaneously the last campaign before the final COMPASS shut-down at IPP Prague, the obtained operational experiences are important mainly for the future COMPASS-Upgrade operations, as all COMPASS neutral beams will be re-used and the auxiliary heating systems will be extended by few almost identical 1 MW units.

Study of GAM-Turbulence intermittency in the FT-2 tokamak using GENE simulations

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In recent experiments in the FT-2 tokamak, intermittencies in GAM and turbulence amplitudes over a period of 13 ms were observed while the changes in the density and temperature profiles are insignificant [1]. The amplitude of turbulence fluctuations measured by two reflectometers recorded a 21% suppression during the GAM period in the radial region r/a = 0.4 to 0.8. In this project, we ran two local simulations $\rho_{tor} = 0.55$ and 0.60 and one global simulation using the gyrokinetic code GENE [2] covering ρ_{tor} from 0.475 to 0.725.

Simulation results are analysed to study the interplay between GAM and turbulence in the FT2 tokamak to better understand the mechanisms behind the energy transfer between GAMs and turbulences and damping of the GAM's and differences between global and local simulations are identified. Both, local and global simulations show intermittency in GAM activity. The Reynold's stress is calculated via the cross bispectrum between radial and poloidal velocities in the wave vector space to study the energy transfer between turbulent fluctuations and GAM flows. The future work will be concentrated on developing synthetic diagnostic for comparing results from simulation with Enhanced Scattering (ES) Doppler measurements of rotation velocity and its fluctuations, in the experiment.

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Modeling of Alfven cascades in the TJ-II stellarator with *STELLGAP* and *AE3D* codes

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Alfvenic instabilities driven by energetic particles pose a challenge to the efficient operation of magnetic confinement fusion devices. These modes can dispel fast ions leading to the introduction of significant heat loads onto plasma facing components and degradation of overall plasma confinement. One class of Alfvenic instabilities known as reversed shear Alfven eigenmodes (RSAEs) are of particular risk in devices with reversed shear rotational transform profiles. Reversed shear configurations have recently been of interest because of their enhancement to confinement quality; with this in mind, further study of RSAEs is necessary.

RSAEs, also called Alfven cascades, were observed in the TJ-II flexible heliac in hydrogen plasma discharges with varying magnetic configurations [1]. In this work, we simulate the cascade events using the STELLGAP [2] and AE3D [3] codes and study the relationship between the frequency of the modes that form the cascade and the minimum value of the rotational transform profile. The simulations predict the appearance of a cascade sweeping downward in frequency formed by a set of modes with m (poloidal mode number) = 6, and n (toroidal mode number) = 9 when the minimum value of the iota profile is varied between approximately 1.48 < i_{min} < 1.50, which is corroborated by experiment. The results presented support the utility of MHD spectroscopy, a diagnostic tool whereby the temporal gradient of the frequency of an Alfven cascade can be used to determine the variation in time of the plasma's rotational transform profile.

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Whistler wave destabilization by a runaway electron beam in COMPASS

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Runaway electrons (RE) are typically generated during plasma disruptions in tokamaks and they represent a serious issue for the integrity of the device [1]. Several strategies have been proposed to control and suppress RE beams in tokamak plasmas, such as the use of massive gas injection, pellet injection or use of resonant magnetic perturbations [2]. An alternative strategy to control the RE beam energy was proposed, which relies on the resonant interaction between high energy electrons and whistler waves [3]. The mechanism of destabilization of electromagnetic waves by a RE beam was proposed in 2006 [4], but a first direct observation of RE-driven whistler waves in a tokamak plasma was performed only in 2018 in DIII-D [5] and a detailed study of radiofrequency emissions in presence of a RE beam was carried out more recently in FTU [6]. Here a model for the description of plasma waves destabilization in presence of a RE beam in COMPASS is proposed. Two different situations are considered: the one in which the waves are spontaneously generated inside the RE beam and the one in which the waves are injected from the outside by an antenna. Wave propagation is calculated using the ray-tracing method [7]; the linear growth rate of the wave is calculated using analytical formulas [8] . Multiple reflections of the wave inside the plasma are followed and the positions of maximum wave amplification are identified. Considerations on the optimal wave injection strategy are made.

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Using Genetic Algorithms to Optimise Current Drive in STEP

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The Spherical Tokamak for Energy Production (STEP) programme aims to deliver a commercially viable fusion energy plant. The reactor will be fully non-inductive, utilising microwave heating in the Electron Cyclotron Radio Heating (ECRH) range to drive current.

The Electron Cyclotron Current Drive (ECCD) has a large impact on the shape of the safety factor, q, which in turn is important for plasma stability. The ECRH can thus be used to create an optimal q profile. Finding the optimal ECRH profile is a highly non-linear problem as changing the power deposition affects the local temperature and density, which in turn affect the current drive efficiency and bootstrap current.

Simulations were performed using JETTO to calculate the current driven and the fully diffused self consistent current profile for a given ECRH power deposition. The time required for each of these simulations inhibits the use of traditional optimisation techniques that rely on taking many sequential steps in parameter space.

A Genetic Algorithm (GA) is an optimisation method inspired by natural selection. A population of points in parameter space are considered in parallel. Those which are judged by the algorithm to have perform the best are combined to create the next generation. The process is iterated until a sufficiently optimal solution is found. This allows the parameter space to be explored in parallel, minimising the time needed to converge on a solution.

Presented here is the development and performance of a GA which has been shown to be effective at generating populations of JETTO simulations and making a judgement on which simulations performed best, often converging on a suitably optimised current drive in under ten generations. Typical input ECRH and resulting q profiles after eight generations are shown in figures 1 and 2.

The GA's success is leading towards additional design parameters being considered such as the shape and size of the plasma, and the net fusion power.

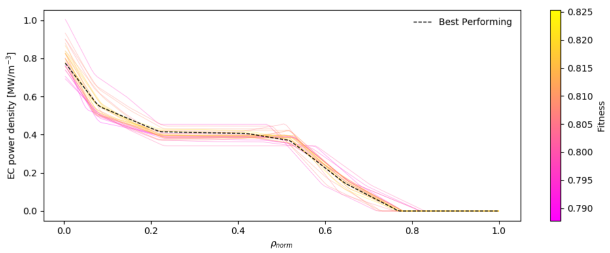

Figure 1: Input ECRH profiles.

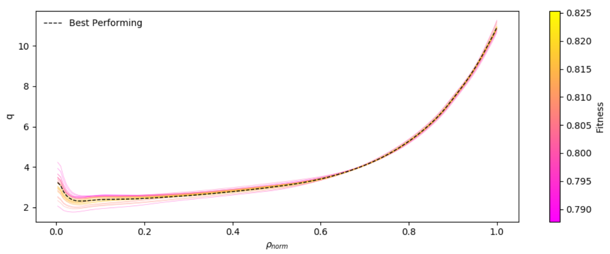

Figure 2: Output safety factor, q.

Laser ion acceleration from tailored solid targets with micron-scale channels

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Laser ion acceleration is a promising concept for generation of fast ions using a compact laser-solid interaction setup. In this study, we theoretically investigate the feasibility of ion acceleration from the interaction of petawatt-scale laser pulses with a structured target that embodies a micron-scale channel filled with relativistically transparent plasma. Using 2D and 3D Particle-In-Cell (PIC) simulations and theoretical estimates, we show that it is possible to generate GeV protons with high volumetric charge and quasi-monoenergetic feature in the energy spectrum. We interpret the acceleration mechanism as a combination of Target Normal Sheath Acceleration and Radiation Pressure Acceleration. Optimal parameters of the target are formulated theoretically and verified using 2D PIC simulations. 3D PIC simulations and realistic preplasma profile runs with 2D PIC show the feasibility of the presented laser ion acceleration scheme for the experimental implementation at the currently available petawatt laser facilities.

Influence of the laser pulse steep rising front on ion acceleration

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The shaping of a time profile of the high-intensity laser pulse can substantially influence electron and ion dynamics in the irradiated target. It was shown that a steep time profile could mitigate the development of transverse short-wavelength instabilities with Rayleigh-Taylor-like features to use long-wavelength corrugation of the target for quasi-monoenergetic ion acceleration [1]. The steep rising front of the laser pulse can also enhance photon emission from under-dense targets [2].

One of the ways to produce the steep rising front is the use of the plasma shutter [3, 4, 5], a thin solid foil placed in front of the target. This approach is also beneficial for the mitigation of the prepulses accompanying the main laser pulse. Moreover, the intensity of the laser pulse can locally increase after burning through the plasma shutter [6]. The combination of these effects can increase the energy of ions accelerated from the target [7].

In this work, we study the effect of the steep rising front generated by the plasma shutter on ion acceleration from the target. We used 3D and 2D particle-in-cell simulations using code EPOCH [8]. In our simulations, we demonstrate an increase in the quality of accelerated ions. Namely, a substantial decrease in their divergence is observed when the steep-front laser pulse is used.

Our work is supported by High Field Initiative (CZ.02.1.01/0.0/0.0/15_003/0000449).

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Target characteristics used in laser-plasma acceleration of protons based on the TNSA mechanism

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The target normal sheath acceleration is a robust mechanism for proton and ion acceleration from solid targets when irradiated by a high power laser. Since its discovery extensive studies have been carried out to enhance the acceleration process either by optimizing the laser pulse delivered onto the target or by utilizing targets with particular features. Targets with different morphologies such as the geometrical shape (thin foil, cone, spherical, foam-like, etc.), with different structures (multi-layer, nano- or microstructured with periodic striations, rods, pillars, holes, etc.) and made of different materials (metals, plastics, etc.) have been proposed and utilized. Here we review some recent experiments and characterize from the target point of view the generation of protons with the highest energy [1].

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Low proton bunch divergence from double-layer target driven by twisted light

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The study of ultrashort (ps) multi-MeV proton bunches generated during high-intensity laser-plasma interactions is motivated by a wide range of applications such as the modification of material parameters or 'fast ignition' of inertial confinement fusion [1]. Plasma-accelerated multi-10-MeV protons are already in use [2], but applications such as radiation therapy require an improvement of the proton bunch properties, e.g. collimated bunches with energies in excess of 200 MeV [3]. While lasers with orbital angular momentum (OAM) [4] can lead to a reduction in beam divergence [5], double-layer targets can support enhanced proton energies in comparison to single foil targets due to an improved laser energy coupling [6].

Here, we study how to exploit the benefits of both, lasers with OAM and double-layer targets, by combining them. The self-consistent laser–plasma dynamics is investigated analytically and by relying on three-dimensional particle-in-cell simulations in OSIRIS.

The work was devoted to examining the effects of relativistic self-focusing of Gaussian and OAM laser drivers in the near-critical plasma part of the target. The results demonstrate that by utilizing the cylindrical symmetry and the more stable self-focusing properties of an OAM laser, the laser can drive high-energetic proton bunches with a significantly reduced divergence, in comparison to a Gaussian driver containing the same energy. We identified a simplified relation between the laser pulse energy and the target composition which always leads to high-quality proton bunches, accelerated by the same mechanism, for a range of laser pulse energies under experimentally feasible conditions.

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Drive-laser-wavelength dependence of the power partitioning in a laser-produced tin plasma with relevance to EUV nanolithography

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New-generation nanolithography machines employ extreme ultraviolet (EUV) light to pattern nanometre-scale features on silicon wafers in the production of new-generation integrated circuits. EUV light is efficiently produced in a laser-produced plasma formed on tin microdroplet targets [1]. One of the principal parameters governing the plasma characteristics is the drive laser wavelength.

In current EUV lithography machines, CO_2 lasers (operating at a wavelength of 10.6 µm) drive the EUV-emitting plasma. Researchers are now investigating the feasibility of using solid-state lasers systems, such as those operating at 1.064 (Nd:YAG) [2] and 1.88 µm (Th) [3,4], to drive the plasma emission. Such laser systems exhibit many favourable features, such as an ease of scalability to higher output powers, higher wall-plug efficiencies as well as excellent pulse shaping capabilities.

In this theoretical study, we consider a tin plasma driven by laser wavelengths between (and including) 1.064 µm and 10.6 µm. We take the simplified case of a single-pulse illumination of a spherical droplet target to explore the influence of drive laser wavelength on the plasma expansion dynamics [5] and radiative properties. To investigate these plasma properties, we consider the subdivision of instantaneous power. We quantify the fraction of laser power that is absorbed and how this absorbed power is channelled into plasma expansion kinetics and radiative emission, including the desired in-band EUV radiation. Our aim is to supplement the search for an optimum drive laser wavelength and substantiate the necessity of target pre-shaping at long drive laser wavelengths.

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Effect of density ramp on electron acceleration driven by tightly focused ultrashort laser pulses

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In the present work we investigate the optimization of electron acceleration in high density plasma, where the scale length of the density ramp is similar to the Rayleigh length of a tightly focused laser pulse. By changing the focus position relative to the density ramp at the front side of the gas target the pulse envelope can evolve very differently, which results in different electron spectra (see Fig. 1). The counter-acting relativistic self-focusing and pulse diffraction decide the evolution of the peak intensity, which in turn influences the electron injection and wakefield amplitude. Up to now only several relevant works have been published and they show different results, depending on the focusing optics or other setup parameters [1].

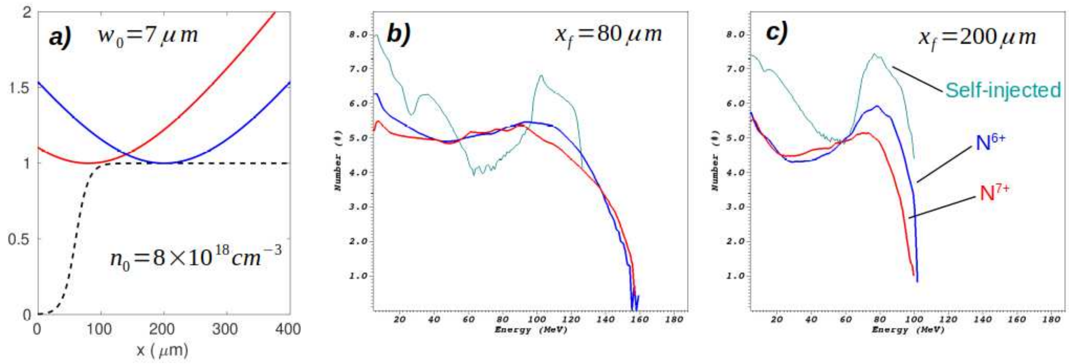

Figure 1: *(a) Simulation setup: dashed lines shows the plasma density profile and the full lines present the laser waist size agains propagation distance in vacuum. Resulting electron spectra (log_{10}) are shown for two focus positions: at the end of the density up-ramp (b) and much deeper inside the plasma (c).*

In Fig. 1 the 3D simulation was performed with a grid resolution of 500x300x300, which is used to resolve a domain size of 24x32x32 μm^3. The pulse duration is 8 fs, contains 80 mJ energy, $w_0 = 7\,\mu$m and the density profile is described as: $n_e = n_0[1+\tanh(x/\sigma-3)]/2$, where $\sigma = 20\,\mu$m. We consider to use Gaussian density profiles as well in future simulations. The target gas was composed of He and 1 % Nitrogen, but self injection is dominant.

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Optical shaping of high-pressure gas-jet targets for proton acceleration experiments in the near-critical density regime

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Laser-induced proton acceleration is a subject of great interest due to its numerous potential applications, among others in energy production through Inertial Confinement Fusion (ICF), or in medical applications such as hadron therapy. Extreme pressure gas-jet targets, able to reach the near-critical density regime, can be used as high repetition rate (HRR), debris-free proton sources. In the near-critical regime, Magnetic Vortex Acceleration (MVA) is one of the most promising proton acceleration mechanisms. While state-of-the-art simulations predict hundreds of MeV of protons by super-intense, short wavelength, femtosecond laser pulses, MVA remains experimentally challenging due to the extremely steep density gradient plasma profiles required as implied by simulations. Here, we present Magnetohydrodynamic (MHD) simulation results on the capability of delivering optically shaped targets through the interaction of nanosecond laser pulses with high-density gas-jet profiles. Multiple laser-generated Blastwave schemes capable to compress the gas target into near-critical steep density gradient slabs of few microns thickness are reported. In addition, experimental findings of the optically shaped gas-jet targets, delivered by a solenoid valve along with an air-driven hydrogen gas booster, able to support 1000 bar of backing pressure are presented [1]. Additionally, the capability of proton acceleration by the interaction of the compressed, steep gradient, near-critical density developed targets, with the fs laser pulse of the ZEUS 45TW laser system of IPPL, is demonstrated by 3D Particle-In-Cell (PIC) simulations.

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Study of chromatic focusing, post-acceleration and bunching of protons accelerated by Target Normal Sheath Acceleration in helical targets

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Helical coils (HC) [1] allow focusing and post-acceleration of protons accelerated by Target Normal Sheath Acceleration (TNSA). This scheme uses the discharge current, generated by the charge expulsion from the laser-plasma interaction, as it flows through a conducting helix. The current's propagation produces an electromagnetic pulse (EMP) inside the helix that focuses, post-accelerates and bunches part of the proton beam. This device has been validated, for constant pitch and diameter helixes, by several experiments [1, 2]. This technique is promising for several applications requiring high maximum proton energies and very collimated beams..

Experimental results have been compared to large-scale Particle-In-Cell (PIC) simulation with the SOPHIE code. The good agreement between experimental results and simulated data gives us a better understanding of the phenomenology behind the processes inside the device and allows us to use PIC simulations for the design of future experiments.

New experimental campaigns, lead on the LULI2000 installation with high energy laser pulses (50J, 1ps) irradiating helical coils, allowed us to deepen the study of focusing, bunching and post-acceleration of proton beams. We have observed the efficiency of micro-coils in modulating the TNSA proton beam, the influence of the coil geometry on the output proton beam as well as the current limitations of the device, such as the low yield in charge.

We have also developed a numerical model based on the traveling wave tubes theory and validated by comparaison to PIC simulations. It will be used for optimisation work in the design of the next experimental campaigns, as it is more adapted than PIC codes for this purpose.

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The design and performance of an asymmetrical nozzle in Laser Wake Field electron acceleration

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Laser Wakefield is a method for the acceleration of electrons up to the GeV level, with important applications[1]. Experimentally, the acceleration is realized by focusing an ultra-intense ($I>10^{18}$ W/cm^2), ultra-short ($t<50$ fs) laser pulse on an under-dense gaseous target. The parameters that interplay and lead to the tunability of the acceleration process are the laser pulse characteristics (e.g energy, pulse duration) as well as the gas density profile.

The gas density profile is defined by the gas itself, the backing pressure, and the nozzle geometry. The importance of the gas density profile has been examined by many groups experimentally and numerically. One of the significant ideas is the plasma density down-ramp, which is reported to enhance the control over the electron beam quality[2,3]. To achieve such a profile either a complex target is needed (multiple jets[2], blade[3]), or the design of a specific asymmetric nozzle[4].

We are working on the development of an asymmetric nozzle by conducting 3D computational Fluid Dynamic (CFD) simulations. We have conducted studies for conical nozzles using 2D simulations. Based on the results of these simulation studies, nozzles were 3D printed and used in our experiments[5,6]. Based on 3D simulations we now examine an advanced, asymmetrical nozzle design. This nozzle, producing a high-density peak, followed by a lower density plateau, is expected to improve electron beam quality. The nozzle's profile characterization and its performance in our experiments will be presented.

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High-repetition rate neutron source by few-cycle intense laser pulse

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We present an experimental demonstration of fusion neutron generation with sub-12 fs, 25 mJ laser pulses [1]. The inherent high-temporal contrast of the laser architecture [1] allowed irradiating a few nm of ultra-thin foils with a peak intensity of 10^{19} W/cm^2, without employing contrast enhancement methods such as frequency-doubling or plasma mirrors. The proton beams of maximum 1 MeV energy were observed leaving both sides of the target foil, namely, along forward and backward directions. The point-projection imaging measurement [2] carried out with these proton beams demonstrated two unique features – i) collimated particle beam with divergence as low as 5-degree and ii) the effective source size being as small as a few µm. The combined effect of these two features can help in minimizing the transverse emittance of the beam, which defines the merit of beam transport and ultimate focal spot.

For fusion neutrons, the deuterium ions were accelerated by irradiating homemade 200nm thin deuterated polyethene foils. The calibrated Thomson spectrometer suggests that during the acceleration process deuterium ion carry significant flux and have similar maximum energy (~ 0.8 MeV) as protons (Fig. 1d and 1f). The accelerated deuterons hits a deuterated catcher. The products of DD reaction were characterised by various plastic scintillators connected to fast PMTs. In the time-of-flight signals collected over 300 single shots (Fig. 1e), the initial strong gamma peak clearly separates from the neutrons (after 90 ns). From the captured neutron events and their multiplication, we have concluded, that an average of 2500 neutrons was generated in a shot. With development of high repetition rate primary target system, the neutron yield/second would reach the flux achieved with present PW class lasers.

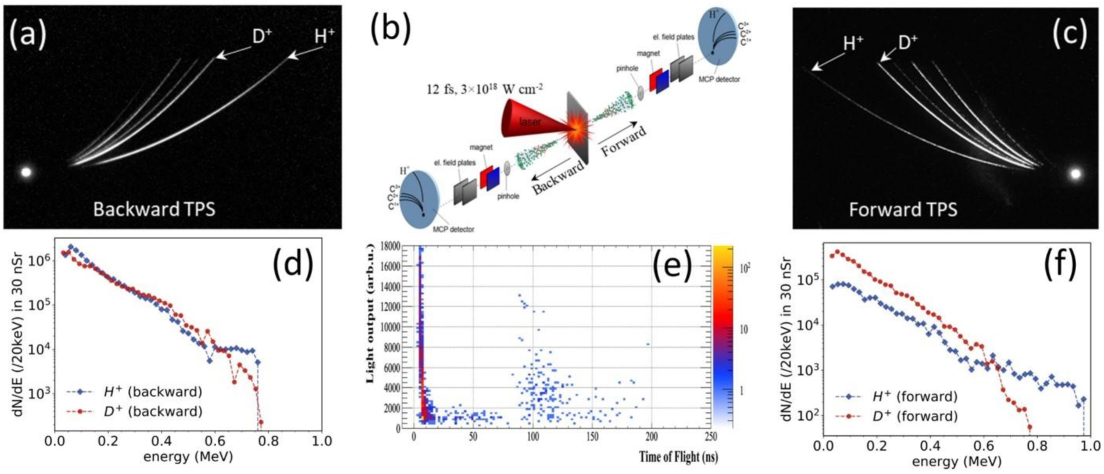

Figure 1. a) and c) simultaneously recorded backward and forward TPS traces. d) and f) respective evaluated spectrum for deuterium and protons along both directions. b) Experimental set up. e) Neutron time-of-flight.

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Investigation on O_3 and NO_x Production in a Surface DBD

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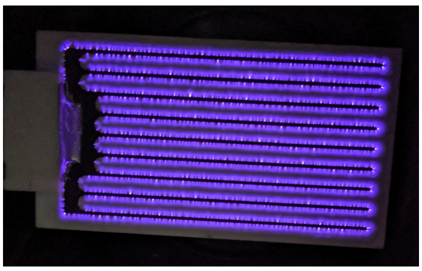
The usage of Surface Barrier Dielectric Discharges (SDBD) is increasing in different application fields, such as the removal of volatile organic compounds or pathogenic organisms from air. However, the composition of the reactive species in the plasma and their role in treatments are not well understood.

The aim of this work is to evaluate the production of O_3, NO_2 and NO_3 in a static condition by a SDBD [1] as well as their correlation with the temperature.

Absorption spectroscopy is used to determine the reactive species densities n. We placed the SDBD (Fig. 1 Left) in a vacuum box sealed at two opposite sides by quartz windows and at the other two ends by open-close valves. In front of one of the quartz window we placed the lamps, while at other side the radiometric detectors. We estimated the species' production according to the Lambert-Beer law: $n = -\frac{\frac{I}{I_{\text{no plasma}}}}{Lc}$ where I is the intensity when the plasma is on, $I_{\text{no plasma}}$ is the intensity when the plasma is off, L is the distance between the lamps and the probe, and c is the absorption coefficient.

A simplified 0D kinetic model has been implemented to study the time-evolution of the main neutral species produced by the discharge. The results are compared with the performed measurements, as in Fig. 1 Right.



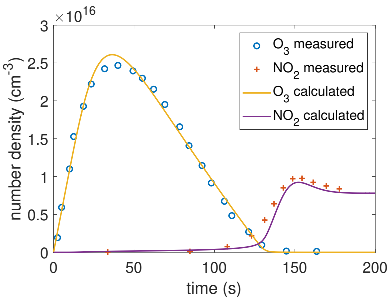


Figure 1: *Image of the used plasma device (Left); measured and computed number densities of O_3 and NO_2 (Right).*

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Studying the onset of turbulence in flowing complex plasmas

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Turbulence remains one of the oldest unsolved problems in physics. Studying how a flow can transition from laminar to turbulent can deepen our understanding of how and when turbulence emerges. Complex plasmas are ionised gasses with micrometre sized "dust" particles immersed in them, and they are valuable in studying turbulence as the highly charged microparticles are big enough to be imaged directly when their flow becomes turbulent. We investigate the onset of turbulence by studying complex plasmas flowing past a disturbance. We perform molecular dynamics (MD) simulations of the experiment performed using the Plasmakristall-4 (PK-4) laboratory on board the International Space Station at low pressures to study the emergence and decay of turbulence

Fractal polymeric surfaces by plasma processing

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The aim of this project is to show the use of a low pressure plasma to modify the surfaces morphology of a plastic material, yielding different physical and chemical properties. The surface modification is extremely important for different applications, such as sensor devices, tissue colouring, anti-fouling and antibacterial properties. Recently, nano-structures have been studied exploiting roughness at the micro and nano-scales produced by a competition of plasma etching and deposition processes. Specifically, for PET films an analysis of the distribution function of the rugosity showed they are distributed in space with a fractal index between 2 and 3 [1]. This work is devoted to the plasma treatment of Teflon films. An oxygen capacitive plasma is used in order to promote the chemical etching of samples. We analyse the plasma treated samples by means of SEM microscopy and by evaluating the contact and roll-off angles. Different statistical tools are employed in order to study the morphological descriptors as a function of the main plasma parameters, such as power, treatment time and vacuum pressure. Finally microbiological analyses are performed in order to evaluate the fouling and anti-fouling properties of the samples.

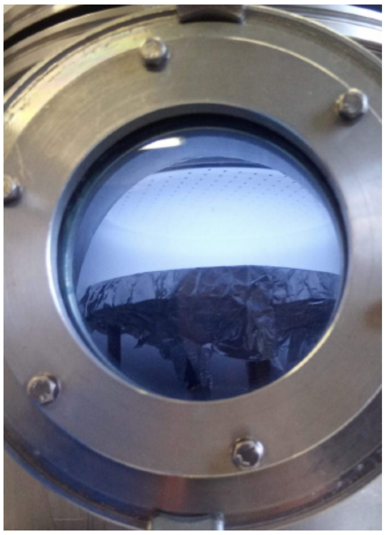

Figure 1: *Image of the used plasma device.*

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Modeling of the nanoparticle size segregation in magnetron discharges

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The charge and forces applied on an isolate NP in conventional magnetron discharges were established using basic models. In the field of nanoparticle production where the control of sizes is a sensitive issue, the goal was to explain why for a given plasma, there is a size segregation in NP depositions inside the device. First, 2D measurements of the plasma parameters were performed and correlations with the magnetic field lines and strengths were shown. The plasma parameters were then used to calculate the 2D variations of the negative charge of an isolated NP and the resulting electric and ion drag forces applied on it. The termophoretic force due to the discharge gas temperature gradients, induced by the sputtered atom thermalization was also established. The force balance was studied for the average size measured on the grounded guard ring i.e. the anode located around the cathode. It is shown that only the electric and thermophoretic forces have an influence. Near the guard ring, the particle is mainly pushed by the electric force towards the guard ring. In the lower mid-plane of the plasma, the thermophoretic force due to large temperature gradients is always dominant and pushes the particle towards the coldest regions in particular, towards the anode plate parallel to the cathode. Therefore, in the plasma region separating both electrodes, the particle can have enough space and time to grow by accretion, this reinforcing the role of the thermophoretic force proportional to the NP square radius. In magnetron discharges, this can also explain why the average size of NPs deposited on the anode plate where the collection of NPs is usually made is larger than on the guard ring located around the sputtering source.

Dynamical study of chaotic magnetic fields in magnetohydrodynamic plasmas

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We consider nonlinear evolution of chaotic magnetic fields in flowing magnetohydrodynamic (MHD) plasmas. The evolution is described by a set of coupled nonlinear equations with the assumption that all quantities vary only in one direction. Chaotic oscillations of the magnetic fields have been analysed numerically in a general sense considering all the parameters and oscillations of lower hybrid and cyclotron types are also seen for some specific cases. The fixed points accompanied with their stability analysis corresponding to the nonlinear evolution equations are performed. The behaviours of Lyapunov exponent and correlation dimension in the parameter space are explored; in addition, the long range correlations and anticorrelations of the oscillations using the Hurst exponent estimated by the method of the rescaled range (R/S) statistics have been analysed. Our results can have implications in laboratory as well as space and astrophysical plasmas.

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Quantum Computing Approach to Electromagnetic Wave Propagation in Plasma

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Quantum computing (QC) has shown enormous promise for solving classes of problems for which a quantum algorithm can obtain a speedup (advantage) over the classical counterpart [1]. As a result, many contemporary studies exploit the QC techniques in order to apply them to plasma physics [2, 3, 4]. Our studies are on an appropriate formulation of Maxwell equations in a plasma, suitable for implementing on quantum computers. It was recognized early by Oppenheimer [5] that Maxwell equations in vacuum can be cast in a form similar to the Dirac equation. This approach was extended to Maxwell equations for a space-time varying scalar dielectric [6] using the Reimann-Silberstein-Weber (RSW) vectors [7]. Based on this procedure, a quantum lattice algorithm has been developed for wave propagation in scalar dielectrics [3, 8]. For wave propagation in dispersive, magnetized plasmas, we are developing a formalism based on the Schrödinger representation, ensuring unitary time evolution which is crucial for quantum algorithm implementation. We show that the RSW representation of the electromagnetic fields is not ideally suited for time varying media. Therefore, an alternate approach, pertaining to pseudo-Hermitian and non-Hermitian quantum dynamics [9], is adopted which allows us to construct an electromagnetic Schrödinger equation for studying wave propagation in an anisotropic plasma medium under the scope of QC.

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Qubit Lattice Algorithms for 2D Scattering of Electromagnetic Waves from Scalar Dielectric Objects

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Qubit lattice algorithms (QLA) are developed as initial value solvers for both the full Maxwell equations in a scalar dielectric and the curl-curl subset commonly used in the modeling of wave propagation in a plasma The QLA consists of an interleaved sequence of unitary collision-streaming operators in which the collision operators entangle the local on-site qubits, while this entanglement is spread throughout the lattice by the streaming operators. For scalar dielectric media, the Riemann-Silberstein-Weber representation of the electromagnetic fields permits Maxwell equations to be expressed in a form similar to the Dirac equation. For a minimal set of qubits, the QLA involve potential operators that are not unitary, although embedding in higher qubit dimensions could resolve this. For an electromagnetic wave propagation in 1D, incident normally on a dielectric interface, the QLA initial value results are in full agreement with the standard boundary value Fresnel results, except that the ratio of the amplitude of the transmitted to the incident electric fields is augmented by the square root of the ratio of the two refractive indices. In 2D scattering from scalar dielectric objects we observe internal sloshing of the electromagnetic fields inside the dielectric. This leads to re-emission of waves into the background medium resulting in intricate field structures. The QLA representation of the two curl-curl Maxwell equations requires fewer qubits/lattice site than that for the full Maxwell system. (For x-y dependence one requires 6 vs. 8 qubits/lattice site). From our current QLA runs, the curl-curl subset seems to be a good representation of the full Maxwell system, although there are non-trivial differences.

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Numerical simulations modelling the interaction of ultra-relativistic neutral fireball beams with magnetised plasmas

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Energetic astrophysical objects, such as gamma-ray bursts, neutron stars and active galactic nuclei are powered by relativistic electron-positron jets. These jets interact with the surrounding medium and may cause a variety of phenomena including magnetic field amplification, particle acceleration and radiation emission [1].

In this work, we explore the microphysics of the interaction between a neutral ultra-relativistic electron-positron beam and a magnetised plasma. By using Particle-In-Cell simulations [2], we investigate how a pre-existing magnetic field in the direction parallel to the beam propagation modifies the growth and saturation of kinetic instabilities. While in the absence of a magnetic field, the dominating instability is the current filamentation instability (CFI) which causes modes perpendicular to the direction of the beam [3], by increasing the strength of the magnetic field, we observe the transition towards progressively more oblique modes. The growth rate of these modes is smaller than the growth rate of the CFI. In all cases, these instabilities generate a magnetic field in the direction perpendicular to both the beam velocity and the wavenumber. Our simulations indicate that the instability-driven field reaches higher values at saturation in the presence of higher degrees of magnetisation. Finally, with the aim of probing the physics underpinning the interaction in the laboratory, we examine the impact of beam length and density on the development of the oblique instability.

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Impact of Suprathermal and Beam Electrons on Nonlinear Electrostatic Waves in an Electron-Positron Plasma

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Electrostatic waves are commonly generated in high-energy astrophysical plasmas such as pulsars and microquasars having electron populations with distinct temperatures, which may also contain a fraction of positrons and magnetic field-aligned beam electrons, while background hot electrons seem to follow a suprathermal κ-distribution. We therefore consider the nonlinear formation of electrostatic acoustic solitary waves in an electron-positron plasma that consists of an electron fluid, a suprathermal hot electron background, an electron beam, and a positron fluid. We explore how the nonlinear properties and existence domain of electrostatic solitary waves are altered by the electron suprathermality and the physical conditions of beam electrons and positrons. Our results will help us understand better the formation and propagation of electrostatic acoustic waves in astrophysical electron-positron plasmas, where field-aligned beam and suprathermal electrons exist.

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