Summary of the theory and modelling contributions at the 30th IAEA Fusion Energy Conference (FEC 2025)

S.E. Sharapov[1] and M. Romanelli[2]

[1]UKAEA, Culham Campus, Abingdon, Oxfordshire OX14 3DB, UK

[2]NEXT STEP FUSION Ltd, Culham Campus, Abingdon, Oxfordshire, OX14 3DB, UK

E-mail: Sergei.Sharapov@ukaea.uk , mr@nextfusion.org

Abstract

The contributions in magnetic fusion theory presented at the 30th IAEA Fusion Energy Conference (FEC 2025) are summarized. This summary provides information on novel ideas and briefly reviews the most recent advances along the main avenues of the research, such as plasma integrated modelling, computational physics and application of artificial intelligence, fast ion instabilities, runaway electrons, disruptions, pellets, and amongst others. Given the current interest in bringing the magnetic fusion to the burning plasma state, the focus of the theory presentations was on burning plasma physics.

Keywords: tokamak, stellarator, turbulence, energetic particles, divertor, pedestal, control, disruptions, modelling

1. Introduction

The 30th IAEA Fusion Energy Conference had a very large number of submissions in theory and modelling of magnetically confined plasma covering both Tokamaks and Stellarators. The theoretical and computational landscape presented at the 30th IAEA Fusion Energy Conference (FEC 2025) reflects a pivot from fundamental discovery toward predictive validation for next-generation devices and highlights the synergy between private companies and public institutions on advancing modelling capabilities. Contributions emphasized the physics of the ITER re-baseline strategy, high-fidelity transport simulations, and the global modelling of fusion integration. Integrated Scenarios and Transport Physics represented a central theme involving the refinement of Integrated Modelling (IM) suites to account for the transition to tungsten-wall environments. Significant updates to SOLPS ITER and the SOLEDGE3X-EIRENE transport codes allowed for more robust predictions of impurity transport and pedestal stability under metallic wall conditions. Theoretical efforts in turbulent-transport focused on the non-linear coupling between disparate scales, utilizing high-performance computing to map phase-space transport in alpha-particle dominated regimes. In the realm of 3D magnetic configurations, new methodologies for Stellarator optimization were unveiled. Researchers introduced "piecewise omnigenous" magnetic fields, significantly

reducing neoclassical transport while maintaining engineering feasibility. Concurrently, modelling of MHD instabilities focused on vertical displacement events (VDEs), with JOREK simulations providing 3D thermal load distributions critical for guarantying the structural integrity of the ITER vacuum vessel. Theory-driven models for tungsten armour degradation advanced via the integration of stochastic topography metrics. By employing Gaussian distribution functions to model surface roughness, researchers achieved higher accuracy in predicting sputter yields and tritium retention compared to traditional "flat-wall" approximations. This summary is organised around the following topics.

- Integrated modelling and global plasma simulations;
- Machine learning approach to plasma modelling;
- Tokamak Disruptions and runaway electrons;
- Fast ion-driven instabilities;
- Plasma turbulence in Tokamaks and Stellarators;
- Plasma-wall interaction;
- Novel ideas and research trends in fusion theory.

2. Integrated modelling and Global plasma simulations

The approaching deuterium-tritium (DT) burning plasma experiments are going to increase significantly the cost of every magnetic fusion discharge up to, e.g., in excess of $\$10^6$ on ITER. Such increase in the price tag, along with machine integrity and safety issues, will require a solid justification for experimental study, discharge predictive modelling would be the key element in such justification. This desirable progress in the modelling is resulting in developing digital twins and whole device facility frameworks that integrate physics and engineering.

Achievements of the E-TASC (EUROfusion Theory and Advanced Simulation Coordination) initiative that was launched in Europe in 2021 was summarised in an overview talk by F. Jenko [1]. This initiative includes 15 Theory, Simulation, Verification, and Validation projects supported by 5 Advanced Computing Hubs. The idea is to combine all the available numerical tools for modelling in the following key areas: core performance in burning plasmas, MHD transients, L-H transitions and ELM-free regimes, plasma exhaust, and plasma-wall interactions – with applications to both tokamaks and stellarators.

Burning plasma with strong nonlinear coupling between its confinement, electromagnetic turbulence, and Alfvén waves destabilized by energetic particles was the focus of the study. While a low-beta plasma has dominant ITG turbulence, a high-beta plasma exhibits turbulence dominated by Kinetic Ballooning Modes identified with the ORB5 model.

The nonlinear MHD code JOREK (presented also in more detail by M. Hoelzl et al. [2]) has advanced the modelling of transient MHD instabilities in plasma edge including disruptions and runaway electrons generation. A novel 3D kinetic RE model in JOREK (presented also in detail by H. Bergstrom et al. [3] and Shi-Jie Liu et al. [4]), coupled to MHD, represents a significant step forward. Impressive results were achieved in the JOREK modelling of flux pumping for mitigating vertical displacement events.

In the area of gyrokinetic turbulence modelling, successful reproduction of eight perturbation characteristics measured experimentally was achieved. The code predictions for L-H transitions, plasma exhaust, negative and positive triangularity were compared against experimental data on many machines. Optimising the stellarator geometry and confinement was one more important avenue of the studies.

The Virtual KSTAR (V-KSTAR) project in Korea, aims at developing digital twin technology for fusion along with the applications of V-KSTAR for KSTAR experiments [5]. This V-KSTAR development efforts have successfully demonstrated that high fidelity fusion simulations can be combined with CAD models of tokamak device with engineering level details.

Since the original project design was focused on the KSTAR tokamak, there have been KSTAR specific features in the original design. Realizing limitations stemming from these features, the authors now draw a new design by removing those KSTAR specific features and develop a general platform to virtualize any tokamak device.

Recent progress is described in the development of such virtual tokamak platform called WILL (Versatile Virtual platform for Integrated fusion simuLation and anaLysis), which integrates various data from tokamak machine operation, experiment, and simulation in flexible and seamless ways. WILL inherits most of enabling technologies and software developed for the original V-KSTAR project. For better abstraction and modularization the components constituting the original V-KSTAR were refactored with newly developed interfaces.

The operation of future fusion reactors requires nonlinear and multivariate control of fusion plasma behaviour under conditions of limited measurements. However, a predictive model (digital twin) essential for such complex control generally involves large uncertainties. This challenge was addressed by developing an analysis and control system, ASTI, based on a data analysis (DA) framework that integrates model adaptation and control estimate [6]. The ASTI-centered control system was implemented in the Large Helical Device (LHD) and successfully applied to control the plasma temperature and density. The control experiments demonstrate the effectiveness of the DA-based approach, which enables the synergistic interaction of measurement, heating, fuelling, and simulation. This approach provides a flexible platform for digital twin control of future fusion reactors.

A Fusion Twin platform has been developed by private company Next Step Fusion with the prospect of simulating both tokamak and stellarator design and operation [7]. The presentation described the Fusion Twin Platform (FTP), a free web-based tool (see https://fusiontwin.io/) designed to expand access to advanced tokamak simulations, promote collaborative research in fusion science, and enhance plasma physics education. FTP integrates pre-built digital replicas of tokamaks with a fast free-boundary equilibrium and transport solver, enabling customizable simulations, scenario development, and exploration of plasma dynamics. The platform supports full discharge evolution, including plasma control requirements, stability margins, and inverse solvers for shaping and profile fitting. It provides users with interactive visualization, integrated data management, and machine learning model integration, while ensuring data security and user privacy.

A plasma "flight simulator" in support of spherical tokamak (ST) operation has been developed by the private company Tokamak Energy [8]. The main framework for simulating plasma

operation at Tokamak Energy is SOPHIA [9], a versatile tokamak plasma simulator. It integrates models for the plasma, diagnostics, actuators and the plasma control system, providing a 'control room'-grade experience to the operator. SOPHIA has been successfully deployed on the high field spherical tokamak ST40 in the preparation of new scenarios (for both single and double-null diverted configurations), in the validation of experiments, the testing of new controllers and in the training of session leaders. The validation of SOPHIA and its physics models on ST40 enables the development of plasma scenarios in the next generation of devices, such as a spherical tokamak Fusion Pilot Plant (FPP), to be carried out with a higher level of confidence.

The ITER Team also presented their vision on how simulations of plasma discharges should be performed with high-fidelity models, including interfacing with diagnostics and engineering components, to mimic experimental operation. Several ITER groups reported on various aspects of the simulations. The tokamak simulator presented in reference [10] is designed around modern code architecture principles, and uses principles of multiscale and multi-physics modelling. Its development is guided by assessing software components, using a modified version of NASA Technical Readiness Levels, combined with a System Readiness Assessment.

An ITER high-fidelity plasma simulator is currently being developed also by combining a core-edge-SOL transport and source modelling suite, JINTRAC, and a free-boundary plasma equilibrium evolution code, DINA, adopting the ITER Integrated Modelling & Analysis Suite (IMAS) paradigm [11]. It is required to refine and complete the development of the ITER plasma scenarios necessary for elaborating the ITER Research Plan and preparing the experimental campaigns. It will also be used to support the analysis of ITER plasmas, including in the burning regime, by enabling the application of a wide range of physics models for interpretative integrated modelling analyses. The ability to perform integrated modelling including additional physics components is now being extended by adopting the actor framework, MUSCLE3, which enables a new co-simulation type of coupling between different physics codes.

The presentation by M. Schneider [12] gave a more specific insight into the modelling tools and analyses which support the new re-baseline design of ITER associated with the change of first wall material from beryllium (Be) to tungsten (W). Such change implies an adjustment of the plant system configuration and of the various phases of the ITER Research Plan that has largely been guided by modelling activities supported by the Integrated Modelling and Analysis Suite (IMAS). The new baseline will stage the installation of some components (first wall, heating systems, etc.) and adapt the wall conditioning techniques, heating mix, and operation scenarios, to overcome the increase of W source and the constraints related to the ITER neutron budget.

3. Machine learning approach to plasma modelling

Apart from the global plasma simulation tools being developed, a machine learning approach to plasma modelling has become possible now based on the wealth of accumulated experimental and simulation data. While such approaches may not necessarily provide an insight on what physics effects cause some specific aspects of the plasma evolution, this approach delivers an answer on much shorter time sale. The short time scale is more relevant to a "forecast"-type predictive modelling similar to the weather prediction for next day, not for

whole month ahead. The heart of the machine learning is a neural network and a data base involving the parameters relevant for a particular nonlinear system. With the data base sufficiently large, the neural network could be trained to achieve an adequate output result (e.g. a disruption condition in a tokamak) based on the numerous input samples from the existing data base (previously observed disruptions in the same tokamak). Note, that such a simulation tool, strictly speaking, is valid only for interpolations within the known set of the output results, not for an extrapolation outside the data base. However, the learning algorithm developed for a neural network could indicate on how a similar network for another similar system could be trained by providing the information on the number of samples needed and on the most important input parameters.

To optimize tritium consumption and limit neutron activation, a support function is considered for the plasma control system called a "dud detector" that triggers an alarm if the plasma fails to achieve expected fusion performance [13]. This function has been developed and routinely employed at JET during DT campaigns. This study presents advanced dud detectors that build upon experience from JET DT operations, and it incorporates machine learning methods reproducing the neutron rate in JET DTE1 and DT-TFTR plasmas The portability and the inherent limitations of these new detectors are investigated towards DT operations on BEST, ITER and SPARC.

Traditional control systems in tokamaks rely on complex, model-based algorithms that are computationally intensive and depend on accurate plasma state reconstructions. An alternative approach to plasma shape and position control is to utilize deep reinforcement learning (RL) [14]. An RL-based controller for the DIII-D tokamak that directly maps magnetic sensor data to actuator commands, bypassing the need for explicit state reconstruction has been successfully developed and experimentally validated. The controller demonstrates robust and precise control over plasma shape and position, maintaining stability even in the presence of significant plasma perturbations.

Data-driven disruption prediction has been increasingly investigated and promoted due to its outstanding performance. However, most data-driven models are based on machine learning, which leads to a lack of interpretability. Investigating the interpretability of disruption prediction models not only validates the reliability of the models but also helps researchers understand the disruption rules that the models have learned, and implement disruption avoidance strategies targeting the disruption causes. A model is being developed designed to predict density-limit disruptions, other disruptions, and non-disruptive discharges by excluding empirical scaling parameters and instead incorporating physics-guided features such as MARFE-related radiation asymmetries, density fluctuations, MHD activity, and plasma control system parameters [15]. Evaluation on 1,099 discharges from J-TEXT shows that the model achieves an overall accuracy of 96.0% for the discharges in test set.

4. Disruptions and runaway electrons

One of the most important subjects considered at this Conference was the problem of disruptions and runaway electrons. Apart from the runaway electrons modelling progress with the JOREK code described in the overview talk by F. Jenko (see above), the runaway presentations considered three very different mechanisms of possible runaway mitigation.

The effect of electron-cyclotron (EC) waves on post-disruption plasma with runaway electrons has been investigated by P. Aleynikov and co-authors [16]. The O- and X-mode EC waves that are routinely used for plasma heating and current drive, do not interact directly with relativistic electrons and cannot be injected into plasma with a density above the cutoff density. It is shown that the internal slow X-mode is capable of the resonant interaction with runaway electrons. The paper reports on experiments conducted on the DIII-D tokamak, where the internal slow X-mode was generated via the so-called OX (Ordinary to eXtraordinary) mode conversion, a process previously explored in space plasmas to understand planetary radio emissions, auroral kilometric radiation, and particle acceleration. In this experiment, the application of ECH during the runaway electron plateau resulted in a significant increase in background plasma density, along with a doubling of the loop voltage and runaway electron synchrotron emission. These observations indicate effective mitigation of the runaway electron beam.

A passive coil method for runaway (RE) mitigation has been tested in the J-TEXT tokamak, achieving complete suppression of the RE current plateau [17]. In this work, the authors present a self-consistent simulation of this RE suppression using the M3D-C1 code. The results align with experimental findings, including plasma and coil current evolution and RE current suppression. Analysis of the simulation indicates that RE current generated near the magnetic axis plays a crucial role in sustaining peak current profile and maintaining the q=2 rational surface, which is essential for MHD instability excitation and magnetic field stochastization. The passive coil plays a supporting role by providing seed magnetic perturbations and facilitating the MHD mode growth.

Results of numerical simulations of a temporal evolution of plasma and RE currents during a discharge disruption in an ITER-scale tokamak have been discussed in [18]. The injection of tungsten "collectors" of runaways can significantly reduce the runaway current. The requirements for the collector parameters and characteristics of its injection are to ensure a safe operation of the tokamak. The simulation results show that the most promising scenario for preventing the consequences of a discharge disruption is a simultaneous injection into the plasma of several 80-gram tungsten "collectors" at a velocity of 250 m/s right after the thermal quench.

The experimental results on the density limit and core-localized kinetic MHD instabilities on HL-2A have been presented by W. Chen et al in [19]. They found that there are multiple MHD instabilities in the core plasmas while plasma approaches the Greenwald limit, $n_e/n_e(G) \sim 1$. To clarify the types of core instabilities in high-density plasmas, simulations were conducted on the parameters of one of the discharges. The modelling and the interpretative analysis suggest that the core localized MHD activities belong to Alfvenic ion temperature gradient (AITG) modes or kinetic ballooning modes (KBMs), and it is found that they trigger a minor or major disruption of bulk plasmas if the density is peaked.

Disruptions caused by resistive wall tearing modes (RWTMs) have been investigated by H.R. Strauss [20]. With a resistive wall, a RWTM can grow to a large amplitude, causing a complete thermal quench. With an ideally conducting wall, tearing modes produce only minor disruptions. Feedback and rotating wall boundary conditions act like an ideal wall. A signature of RWTM is that the rational surface is sufficiently close to the wall to interact with it. This implies that the mode can be stabilized by feedback. For $(m,n) = (2,1)$ modes, with a resistive wall at normalized radius $\rho(w) = 1.2$, the required normalized $q = 2$ radius is $\rho(q2) \geq 0.75$. This

can also be expressed as q(75) ≤ 2. The q(75) criterion applies to DIII-D, NSTX, and the MST-based model discussed in the presentation. For ITER, the requirement is ρ(q2) ≥ 0.78.

The integral vertical disruption force acting on the tokamak vacuum vessel wall was analytically calculated [21]. With axial symmetry, transformations are possible of the integral to the expression explicitly showing the key parameters in the problem. It is confirmed, in particular, that the toroidal current density in the plasma fully determines the plasma contribution into the force, while the knowledge of the poloidal halo current is not needed. Another finding is that, for the wall current description, two modes with different decay rates are required. The force is examined with emphasis on the post-disruption stage in [21].

5. Fast ion-driven instabilities

Significant number of theory and modelling results on fast ion-driven instabilities were presented at the Conference. An interaction of these instabilities with thermal plasma turbulence was quite remarkable new trend that revitalise the interest to modelling of the instabilities.

Importantly, the unification of energetic particle (EP) descriptions coming from various models, to the same form that could provide both EP distribution and its derivatives on the IMAS platform at ITER has been advanced [22]. An accurate characterization of EP distributions is essential for quantitative predictions of burning plasma stability, as gradients in EP phase space govern the drive and damping of instabilities that impact confinement and fusion performance. The EPCoM tool enables transformation of EP distributions between common numerical representations and a Constants-of-the-Motion (CoM) form, utilizing the invariants energy, magnetic moment, and toroidal canonical angular momentum in axisymmetric plasmas, with pitch-angle sign included to resolve orbit degeneracy. Representation in CoM space ensures true steady-state solutions of the Fokker–Planck equation, reduces dimensionality, and suppresses numerical noise. Validation on distributions for DIII-D, JET, and ITER demonstrates accurate transformations and low mean errors, with discrepancies attributed to non-stationary initial conditions.

G. J. Choi and co-authors [23] presented an analytic theory of a fast ion population effect, namely thermal ion dilution effect, to the drift wave turbulence-zonal flow system in magnetized plasmas, which results in probably the simplest self-consistent dynamical model that captures the favourable roles of the fast ions to the enhancement of tokamak confinement. A simple 0D predator-prey model shows that the fast ion population can lead to a significant nonlinear suppression of turbulent transport in tokamak core, due to its strong dependence on the dilution factors originating from the fast ion population. Further analytic work on the longer-term evolution of the saturated turbulence-zonal flow system in the context of the E×B staircase reveals that the initial saturated E×B flow shear level should be strong enough to maintain its saturated structure,

A comprehensive simulation of ICRF-heated tokamak plasmas on the slowing-down timescale using the kinetic MHD hybrid code MEGA was also presented [24]. The fast-ion transport caused by shear Alfven waves in this simulation is self-consistently included during the high-energy tail formation. Bursting TAEs are observed in both multi-n and single-n simulations of plasmas with a relatively low magnetic field (B= 1.5 T) and an ICRF resonance layer located

at the magnetic axis or on the inboard side of the torus, while outboard ICRF-heating always leads to non-bursting TAEs.

A comprehensive study of TAE- and EPM-induced fast ion transport and losses at the Globus-M/M2 spherical tokamaks was carried out by O.M. Skrekel and co-authors [25]. The results demonstrate that the dominant transport mechanism is convective resonant transport, leading to significant fast ion losses across a wide energy range. A key finding is the identification of two distinct components in the heat flux to the wall: a coherent part, synchronous with the mode and resulting from direct ion orbit losses, and an incoherent part, attributed to enhanced charge-exchange losses of ions transported to the plasma periphery. Both components exhibit a linear threshold-like dependence on the TAE amplitude. This dependence is successfully explained by a full-orbit Monte Carlo simulation. The model demonstrates that the instability must reach a critical amplitude to expel ions from the high-density plasma core. At lower amplitudes, wave-induced transport is limited to the low-density periphery, resulting in negligible losses.

Hybrid simulations for multiple fast ion species interacting with plasma described by MHD were conducted using the MEGA code to investigate the synergetic effect of multiple fast ion species on the instability and the fast-ion transport in the Large Helical Device (LHD) experiments with the fast protons and fast deuterons [26]. In the MEGA simulations, the Alfvén eigenmode (AE) amplitude burst after approaching the steady state of fast ion stored energy is larger than that before the steady state. Then, there is a significant increase in the fast-ion loss rate. Through comparison with simulations in the case of AEs driven by single fast ion species, the additional AEs are destabilized by multiple fast ion redistributions in the case of multiple fast ions. The synergetic effect of multiple fast ions is shown to increase the fast ion transport and loss in the LHD.

Simulations to model the transport of fusion-born alpha particles in the spherical tokamak for energy production (STEP, UK) were presented by A. Snicker and co-authors [27]. The work is carried out by two Monte Carlo codes ASCOT and LOCUST. In this contribution, ASCOT results are compared against earlier LOCUST simulation results for toroidal field ripple and resonant magnetic perturbations. The magnetic field studied in this work has a dominant contribution from the axisymmetric equilibrium using a common EQDSK file, but in addition, a cylindrical perturbation is implemented to model the toroidal field ripple and external coils used for ELM mitigation further perturb the equilibrium field. The plasma response is calculated using the MARS-F model, and the only MHD perturbation considered in this work is the resistive wall mode (RWM) implemented using the MARS-F. For a quantitative estimate of the effect of fast ions to the tungsten sourcing, fast ion losses are recorded as a function of the incidence angle and energy for the sputtering yield calculations. These results show that the current design point of the STEP is stable in terms of basic fast ion transport calculations, and no major showstoppers have been identified during the work.

An eigenvalue code, MAS, has been developed by J. Bao and co-authors [28] that non-perturbatively couples drift-MHD model for bulk plasmas and gyrokinetic model for energetic particles, which captures the important kinetic effects describing drift-Alfvén waves (DAW). Building on the kinetic physics capability and attractive efficiency in computation, MAS has the advantages of fast calculation of dispersion relation and global mode structure for various

DAW instabilities in general experimental geometry, which helps to interpret the experimental observations.

Reactor-relevant burning plasmas will be complex, self-organized systems in which energetic particles (EPs) play a crucial role in processes underlying cross-scale couplings. A detailed study by F. Zonca [29] reviews the concept of phase space zonal structures and their significance in transport analyses in burning plasmas. The results validate the ATEP code for simulating distribution function evolution in realistic tokamak conditions, including sources and collisions. The presented work demonstrates the existence of an overarching and unified theoretical framework for the self-consistent description of fluctuation spectra and corresponding transport in reactor-relevant fusion plasmas. The integration of the ATEP workflow into the ITER IMAS system is complete, and applications to realistic cases of practical interest are in progress.

Understanding fast-ion and turbulence interactions is critical for future burning plasma scenarios, where MeV range alpha particles dominate the core dynamics, and such improved confinement may be reached by exploiting fast-ion-triggered beneficial mechanism. Since high pressure plasma core (and thereby high β) is frequently obtained in current tokamaks, the same type of plasmas is envisaged for the next-generation tokamaks, and hence it is of paramount importance to determine the physical properties of the deep-core under high-performance plasma conditions. Due to the difficulties in reaching these internal positions of the plasma through routinely used diagnostics, advanced numerical simulations represent a crucial tool to explore the deep-core of the high-performance plasmas. In these conditions, kinetic ballooning modes (KBMs) have been found unstable, possibly determining the pressure profile shapes. Presentation [30] is focusing on two tightly intertwined aspects: (i) the confinement properties regulation by MeV range ions destabilizing AEs and couple to zonal structures, and (ii) the destabilization of KBMs at high β. These two aspects cannot be separated into a linear chain of causes and effects, but instead form a nonlinear set of interactions, where fast-ion-driven instabilities, turbulence, and electromagnetic fluctuations coexist and evolve consistently. The interplay between these two mechanisms is of particular importance for next-generation fusion reactors, such as ITER, SPARC, and DEMO [30].

Recent progress on the theory, numerical simulations, and experimental observations of Vertical Displacement Oscillatory Modes (VDOM) in tokamak experiments was reported by F. Porcelli [31]. VDOM are driven unstable by energetic particles and can have an impact on plasma disruptions, plasma edge stability and confinement. These modes are a candidate to explain Alfvén frequency n=0 modes recently observed on JET, TCV, and MAST-U. The specific types of fast ion distribution functions that can drive VDOM are discussed and numerical results obtained by the NIMROD code simulating the n=0 modes driven by fast ions are shown.

By employing nonlinear gyrokinetic simulations and analytical theory, L. Chen and co-authors [32] investigated the effects of zonal (electromagnetic) fields (ZFs) on the saturation dynamics of reversed-shear Alfven eigenmodes (RSAEs) driven by energetic particles (EPs) in tokamak plasmas. The key findings reveal that ZFs, generated through beat-driven RSAEs, influence mode saturation via two primary routes. One route involves the modification of EP dynamics by ZFs. Contrary to conventional expectations, simulations show that ZFs enhance the EP drive by modifying the EP phase-space zonal structure, leading to higher saturation levels. These

puzzling simulation results can be understood analytically in terms of the general fishbone-like dispersion relation with the correspondingly different formations induced by ZFs. The other route involves the nonlinear dynamics of thermal plasmas. Simulations show that beat-driven ZFs can suppress RSAEs by inducing a net downward frequency shift.

6. Plasma Turbulence in Tokamaks and Stellarators

Plasma turbulence is the dominant mechanism for transporting heat and particles out of the hot core in most magnetically confined plasma configurations, significantly limiting confinement time and reactor performance, thereby hindering net energy gain for fusion power. Along with Tokamaks, optimized stellarators, with their complex fields, also face turbulence as a key performance limiter, making its study vital for designing future fusion devices. Progress in understanding plasma turbulence has been presented at the conference with the following highlights.

The improvement of physical models and the increase of computational power have allowed for first- principles, turbulent simulations of experimentally relevant scenarios, where the plasma dynamics is self consistently simulated with the dynamics of neutral particles. The GBS code [33], which self-consistently evolves plasma and neutral species in three dimensions is an example of such type of simulation, now affordable by researchers as the computational time viable for this task became possible. Simulations for Tokamak relevant conditions at high-density reproduce detachment dynamics, revealing the importance of molecular processes and E×B drifts. Flux-driven simulations with resonant magnetic perturbations demonstrate reduced divertor heat loads, and stellarator studies highlight distinct turbulence features with respect to tokamaks. The geometrical operators appearing in the drift-reduced Braginskii equations evolved by GBS have been expanded considering the typical parameter ordering of stellarator configurations. Simulations of an island divertor stellarator show that, although the island magnetic field-lines divert the plasma towards the strike points of the walls, the islands do not seem to have a significant impact on the turbulence properties. The dominant mode, identified as interchange-driven, is field-aligned and breaks the stellarator toroidal symmetry. The radial and poloidal extensions of the mode are of the same order, in contrast to typical tokamak simulations.

Using the gyro-kinetic particle-in-cell codes ORB5 and EUTERPE which are applicable to 2D and 3D magnetic equilibria, respectively, it is possible to address the interplay of small and large scale instabilities and the zonal flow in a variety of burning plasma relevant conditions [34]. It is demonstrated that several plasma instabilities can be described using the same theoretical and numerical background even when their non-linear evolution is addressed. They have addressed phenomena ranging from electromagnetic turbulence and heat transport, tearing modes, fast particle generated zonal flows and their interaction with ITG instabilities, chirping fast particle modes, the interaction of turbulence and Alfven modes to finally the gyro-kinetic high-β stability of stellarator plasmas, and demonstrated that gyro-kinetic codes can be confidently applied to burning plasmas. More numerical and algorithmic developments need to be implemented to allow turbulence calculations to fully capture the burning plasma regime.

The nonlocal behaviour of ITG turbulence and heat pulse propagation using GYSELA simulations with poloidally localized heat sources has been investigated [35]. The analysis reveals asymmetries in turbulence spreading and heat transport depending on the heating

location. The key findings are as follows: First, the initial heat pulse propagation is governed by parallel conduction and neoclassical drift effects, with magnetic curvature drift playing a crucial role in creating poloidally inhomogeneous heat transfer. This anisotropy influences the subsequent turbulent response. Second, we observe a pronounced asymmetry in turbulence spreading between low field side and high field side heating scenarios. Low field side heating effectively excites turbulent fluctuations that propagate both toward the core and edge, accompanied by radial shifts in the $E \times B$ shear layer. This behavior is consistent with the ballooning characteristics of ITG turbulence, where longer radial correlation lengths on the low field side facilitate edge-to-core turbulence spreading. In contrast, high field side heating produces highly localized fluctuations with minimal spreading capability. This suppression is attributed to the combined effects of broader pressure perturbations on the low field side and enhanced local damping due to stronger $E \times B$ shearing rates, which effectively reduce parallel conduction of turbulent fluctuations. These results demonstrate that the poloidal location of edge heating, and potentially localized particle source, critically determines the nonlocal transport characteristics, with implications for understanding heat pulse propagation and turbulence control strategies in tokamak plasmas.

Two neural network–based reduced models for plasma turbulence have been introduced in [36], addressing both sub-grid closure and turbulence–zonal flow dynamics. For drift-wave turbulence, the Extended HW-Closure model identified by physics-informed neural networks successfully reproduced transport fluxes and spectral features of high- resolution simulations on coarse grids, achieving more than an order-of-magnitude reduction in computational cost. For turbulence–zonal flow interactions, a stochastic surrogate model learned from modified HW simulations captured predator–prey oscillations, saturation mechanisms, and stochastic variability, providing a compact but physically interpretable representation of the dynamics. Together, these results highlight the potential of machine learning in constructing reduced turbulence models that combine efficiency with physical fidelity.

An overview of recent activities in a project developing machine learning (ML) facilitated pedestal models was presented by A. Jarvinen [37]. The project is divided into three branches, consisting of surrogate modelling techniques for pedestal magnetohydrodynamics, development of reduced pedestal transport models with ML methods, as well as data-driven methods to learn corrections for the remaining gap between numerical predictions and experimental observations. A proof-of-principle model for accelerating pedestal MHD stability evaluations has been recently published, and the next step activities to go beyond this proof-of-principle are detailed. First proof-of-principle models are emerging from the part of the project developing surrogate models for local, linear pedestal gyrokinetic evaluations based on GENE simulations for JET and MAST- U. The data-driven models are proceeding from purely observations-based models to models that combine both physics models and experimental observations for a combined representation.

7. Plasma-Wall Interaction

Theory and modelling of plasma-wall interaction (PWI) in tokamaks and stellarators are critical because these interactions directly influence plasma performance, the integrity and lifespan of reactor components, and the safety and economic viability of fusion power plants. Highlight on latest progress made on the theory and modelling of plasma interaction with surrounding components are reported here.

First SOLPS-ITER plasma boundary modelling with numerical grids extending to all main chamber surfaces under Q = 10 burning plasma conditions have been performed and presented [38]. This provides the main wall fluxes of main ions and seeded (neon) impurities, key for more realistic estimates of wall power fluxes and provides a means to derive tungsten (W) influxes for assessments of impact on burning plasma performance in the recent ITER re-baseline with a full W main wall. Scans (without drifts and currents activated) have been performed over a range of radial transport coefficients in the far scrape-off layer. The choice of this range, and, in particular, the radial variation of the coefficients, is guided by estimates based on the assumption of cross-field filamentary (blobby) transport.

A hierarchy of models to describe turbulent transport has been applied to simulate the TCV-X21 L-mode attached reference plasma scenario in [39]. The standard empirical approach used in 2D transport modelling to interpret experiment is found to be very effective to reproduce a specific experimental scenario but without any predictive ability. The accuracy to reproduce experimental trend requires implementing neutral recycling but also carbon sputtering and radiation. First-principles 3D turbulent modelling also recover experimental trends, in particular scrape-off layer width λ_q. For a more quantitative agreement between turbulent simulation results and experimental measurements, it will be necessary to add carbon sputtering and radiation in the simulation as suggested by the mean-field simulation results. In between these two approaches, the reduced turbulent model is a way to keep investigating and improving to improve mean-field modelling predictability at a lower numerical cost than first-principles turbulent models. When applied to the TCV-X21 case, the current k- model implemented in SOLEDGE3X fails to recover the experimental scrape-off layer width due to the semi- empirical closure used in the model based on λ_q scaling-law (the scaling law overestimating the scrape-off layer width when applied to the TCV-X21 parameters).

Achieving high electron density is essential for tokamaks to reach energy breakeven and sustain a burning plasma. However, tokamak operation is often constrained by an upper density limit, beyond which disruptions occur. Understanding and overcoming this density limit remains a key challenge. Certain type of experiments in the EAST tokamak have achieved a line-averaged electron density in the range (1.3-1.65) Greenwald density n_G, while the usual range in EAST is (0.8-1.2) n_G. This was achieved through ECRH-assisted Ohmic start-up combined with a sufficiently high initial neutral density. This technique is consistent with predictions of a recent plasma-wall self-organization (PWSO) theory, that increasing ECRH power or pre-filled gas pressure leads to lower plasma temperatures around divertor target and higher density limits by mimicking a stellarator start-up [40]. The experiments are confirmed operating within the density-free regime predicted by the PWSO model. These results suggest a promising scheme for substantially increasing the density limit in tokamaks, a critical advancement toward achieving burning plasma conditions.

Progress regarding plasma-wall interaction modelling for EU-DEMO has been presented as part of the EUROfusion Theory and Advanced Simulation Coordination (E-TASC) activities that were established to advance the understanding and predictive capabilities for modelling of existing and future fusion devices using a modern advanced computing approach [41]. This paper presented new results on erosion and re-deposition of tungsten. These are studied with different assumptions on the far scrape- off layer plasma parameters, the dust transport and inventory evolution for various starting locations and initial conditions. Transient limiter melting during upward vertical displacement events are also considered accounting for spatial and temporal variation of the incoming heat flux.

The wall material evolution during EAST 400s long pulse discharges has been investigated by plasma-wall integrated modelling [42]. The results reveal that a lithium (Li)-enriched layer can develop underneath the surface of the tungsten (W) material in divertor. This multilayered structure significantly influences local particle recycling processes, thereby affecting the distribution of edge plasma. During EAST long pulse discharges, modelling results indicate that there exist periodic formation and diminishment of W-Li multilayers at outer strike point (OSP) of the divertor. As the plasma impinges, the surface W enriched layer gradually diminishes, leading to a transition in the dominant surface material from W to underlying Li. This evolution of the material components can significantly impact the reflection and reemission of D on plasma facing material (PFM). Although the total D recycling rate at EAST OSP is approximately 1 during the discharge, the D reflection and reemission rates fluctuate according to the evolution of material components. Unlike the D reemission, which releases D at an average energy equivalent to the wall temperature, the D reflection launches D at a much higher averaged energy even above 100 eV. 1D simulation of the SOL plasma with different recycling D^0 energy demonstrates that the D recycling energy can directly affect the plasma distribution. An iterative simulation loop between OEDGE and SDTRIM.SP is established and used to simulate the material evolution during EAST long pulse discharges. In these simulations, the plasma computational grid is extended to the first wall, which allows a global wall material migration. The particle recycling evolution on different wall locations has been investigated. Modelling advances in this work demonstrated that it is essential to consider the wall materials evolution to obtain the accurate background plasma solution, especially for long pulse discharges.

Control of divertor heat loads is a critical challenge for the safe and efficient operation of reactor-scale fusion devices. Externally applied 3D magnetic fields for edge localized mode (ELM) control induce complex plasma responses and alter heat and particle transport to divertor targets. A full orbit (FO) particle simulation approach has been developed by K. Kim and co-authors [43] to model divertor heat flux splitting by 3D field, implemented in the POCA code, enabling more physically consistent predictions compared to field line tracing (FLT) approach. The FO approach provides additional detail on peak amplitudes and hot spot formation compared to the FLT. The FO simulations are extended to realistic 3D wall and divertor geometries based on 3D CAD model by integrating a novel collision detection algorithm. Simulations with 3D CAD geometries further reveal realistic striation structures under resonant and non-resonant RMP configurations. The developed method can be an alternative for quantitative prediction of divertor heat fluxes through further improvement and integration with a digital twin.

8. Novel ideas and research trends in fusion theory

Several very interesting theory presentations were given at the Conference, in addition to the Topics above. We describe some of them here.

Electron cyclotron resonance heating (ECRH) and current drive are widely used in toroidal plasmas and are considered as the main, or significant type of auxiliary heating on ITER, STEP, and FPP. Over the recent decade and a half, various anomalous nonlinear phenomena have been found during microwave passage through the plasma volume. In particular, a convincing demonstration of anomalous ion acceleration at X2-mode ECRH under conditions where the energy exchange between the ion and electron components was negligible has been obtained on TCV and TJ-II. Such ion heating may become of significant importance for future burning plasma machines with dominant auxiliary ECRH. The nonlinear mechanisms are identified in

terms of parametric instabilities and the approximate expression for the absolute threshold dependence on the daughter waves of these instabilities are obtained in [44].

Most current gyrokinetic codes in the magnetic fusion community are based on the scalar and vector potential formulation, typically considering only the parallel component of the vector potential. These studies are generally limited to specific branches or a few types of instabilities, such as drift-wave turbulence or Alfvenic modes. In contrast, G. Meng and co-authors have developed a gauge-free drift-kinetic Vlasov–Maxwell model coupled with a fully kinetic description of ions, extending the geometric Particle-In-Cell (PIC) framework on dual grids [45]. The approach relies on a discrete action principle using only the electric and magnetic fields, avoiding the use of potentials. The resulting macroscopic Maxwell equations incorporate polarization and magnetization terms, enabling seamless coupling with a fully kinetic model for treating energetic particles and edge physics.

Recent experiments using multi-pellet injection in NBI-heated plasmas in the TJ-II stellarator have achieved record energy confinement times that surpass predictions derived from the International Scaling law ISS04 [46]. The observed profile modifications suggest a potential neoclassical transport mechanism, owing to its strong collisionality dependence, simultaneous measurements of reduced density and electrostatic potential fluctuations indicate at a turbulent transport contribution to the overall enhanced confinement. It is shown that the increased ion temperature resulting from multi-pellet injection mitigates neoclassical diffusion by transitioning the collisionality from the Pfirsch-Schluter regime to the plateau regime and partially explains the enhanced plasma performance observed under NBI heating in the TJ-II stellarator.

In the late 1970s, European physicists Owen Storey and Laurent Cairó discovered and published a novel method of plasma confinement, building on an earlier discovery by American astrophysicist Eugene Parker. They proved that when a supersonically flowing plasma is confined by a magnetic field parallel to the flow, a secondary magnetic field discovered by Parker can emerge under certain conditions, reinforcing the confinement and reducing the requirement for the external magnetic field. The resulting overall confining field is concentrated within the thin static boundary layer between the plasma and the external field, while the bulk plasma remains both field-free and current-free. They suggested that this might be applicable to fusion and proposed a conceptual device exploiting this method, which they called the Plasma Storage Ring. The paper [47] presented now revisits this work and extends it to demonstrate its advantages.

9. Conclusions

The FEC 2025 confirmed the transition of magnetic confinement fusion theory and modelling activities towards reactor design and identification of operational solutions that integrate physics and engineering. It highlighted the synergy between private fusion companies and public institutions on advancing plasma modelling along with the central role of machine learning algorithms and AI to advance the field. Advancement of gyrokinetic simulations and the extension of the theory to stellarator relevant orderings shows the new focus of the community on applications of theory and modelling across the whole magnetic fusion devices spectrum, moving away from a Tokamak centric enterprise. High fidelity representation of the three-dimensional characteristics of the plasma was central for both plasma dynamics in different magnetic configuration and of plasma wall interaction in tokamaks. The effort of

achieving full integrated modelling of plasma, actuators and reactor-wall has led to full coupling of core and edge and inclusion of kinetic physics in MHD codes, novel solutions to accelerate codes are emerging, from advanced algorithms to application of artificial intelligence to define pre-conditioners. This has led to the successful development of several plasma "digital twins" and "flight simulators". The achievement of high-performance long pulse operation on EAST has allowed to test novel theories of plasma wall self-organization. Turbulence models for the SOL have been developed and tested in codes that extend their grid towards the first wall. The framework to model plasma turbulence in burning plasmas and the interaction between fast ions and thermal plasma in the new, self-organised state is advancing and promises to be ready for when burning plasma conditions will be achieved experimentally for the first time in a magnetic confinement fusion reactor.

Overall, the theory presentations at the 2025 FEC demonstrated the very healthy and vibrant state of the field. This bodes well for the key role of theory in underpinning future reactor designs.

References

[1] Jenko F. *et al* 2025 TOWARDS DIGITAL TWINS OF FUSION SYSTEMS *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/35598/)

[2] Hoelzl M. *et al* 2025 PROGRESS ON THE UNDERSTANDING OF 3D TRANSIENT PLASMA DYNAMICS AND CONTROL MEASURES FROM FLUID AND HYBRID FLUID-KINETIC SIMULATIONS WITH THE NON-LINEAR CODE JOREK*Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/35636/)

[3] Bergström H. *et al* 2025 Hybrid kinetic-MHD studies of runaway electron beam termination events *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/35794/)

[4] Shi-Jie Liu *et al* 2025 3D hybrid fluid-kinetic simulations of large scale plasma instabilities in runaway electron beams *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/35598/)

[5] Jae-Min Kwon *et al* 2025 VIRTUAL TOKAMAK FOR INTEGRATED PHYSICS AND ENGINEERING ANALYSIS *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/36413/)

[6] Morishita Y. *et al* 2025 DEVELOPMENT OF DATA ASSIMILATION SYSTEM ASTI TOWARD DIGITAL TWIN CONTROL OF FUSION PLASMA *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/35762/)

[7] Zhurba A. *et al* 2025 FUSION TWIN PLATFORM: An Innovative Tool for Fusion Research and Education *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/36291/)

[8] Romanelli M. *et al* 2025 PLASMA PREDICTION AND SIMULATION IN SUPPORT OF REACTOR DESIGN AND OPERATION AT TOKAMAK ENERGY *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/36353/)

[9] Janky F. *et al* 2026 Fus. Eng. Design **222** 115447

[10] Poli F.M. *et al* 2025 A MULTISCALE AND MULTIPHYSICS APPROACH TO THE DEVELOPMENT OF A HIGH-FIDELITY PHYSICS PLASMA SIMULATOR FOR BURNING PLASMA *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/36336/)

[11] Kim S.H. *et al* 2025 DEVELOPMENT OF ITER HIGH-FIDELITY PLASMA SIMULATOR BASED ON JINTRAC AND DINA, AND STRATEGY FOR VALIDATION *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/36343/)

[12] Schneider M. *et al* 2025 INTEGRATED MODELLING ACTIVITIES IN SUPPORT OF THE ITER RE BASELINE *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/35675/)

[13] Piron L. *et al* 2025 MACHINE LEARNING AIDED NEUTRON YIELD FOR DUD DETECTION BASED ON JET AND TFTR DEUTERIUM-TRITIUM PLASMAS *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/36088/)

[14] Subbotin G.F. *et al* 2025 ADVANCED MAGNETIC PLASMA CONTROL ENABLED BY REINFORCEMENT LEARNING *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/35922/)

[15] Chengshuo Shen *et al* 2025 DECODING THE CAUSES OF HIGH-DENSITY DISRUPTION THROUGH INTERPRETABLE MACHINE LEARNING *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/36259/)

[16] Aleynikov P. *et al* 2025 EFFECT OF ELECTRON CYCLOTRON WAVES ON PLASMA WITH RUNAWAY ELECTRONS *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/36133/)

[17] Chang Liu *et al* 2025 ANALYSIS AND SIMULATION OF EFFECTIVE RUNAWAY ELECTRON MITIGATION USING PASSIVE COIL IN J-TEXT DISRUPTIONS *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/35709/)

[18] Kuteev B.V. *et al* 2025 THE IMPACT OF A FLYING COLLECTOR ON RUNAWAY ELECTRONS DURING CURRENT DISRUPTION IN A TOKAMAK *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/36358/)

[19] Chen W. *et al* 2025 DENSITY LIMIT DISRUPTION INDUCED BY CORE LOCALIZED ALFVENIC ION TEMPERATURE GRADIENT INSTABILITIES IN TOROIDAL PLASMA *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/35906/)

[20] Strauss H.R. *et al* 2025 ELIMINATING TOKAMAK MAJOR DISRUPTIONS WITH FEEDBACK *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/36431/)

[21] Pustovitov V.D. *et al* 2025 ANALYTICAL APPROACH TO CALCULATION OF DISRUPTION-INDUCED VERTICAL FORCE ON THE TOKAMAK WALL *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/36383/)

[22] Pinches S.D. *et al* 2025 ENERGETIC PARTICLE DISTRIBUTIONS FOR QUANTITATIVE CALCULATIONS OF BURNING PLASMA STABILITY *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/36146/)

[23] Choi G.J. *et al* 2025 THEORY OF FAST ION POPULATION EFFECT ON TURBULENCE SELF-REGULATION IN MAGNETIZED FUSION PLASMAS *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/36292/)

[24] Wang J. *et al* 2025 COMPREHENSIVE SIMULATIONS OF BURSTING AND NON-BURSTING ALFVÉN WAVES IN ICRF HEATED TOKAMAK PLASMAS *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/35783/)

[25] Skrekel O.M. *et al* 2025 STUDY OF FAST ION TRANSPORT AND LOSSES DURING ALFVÉN TYPE MHD INSTABILITIES AT GLOBUS-M2 *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/36121/)

[26] Seki R. *et al* 2025 HYBRID SIMULATION OF ALFVÉN EIGENMODES CAUSED BY MULTIPLE FAST ION SPECIES IN THE LARGE HELICAL DEVICE *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/36118/)

[27] Snicker A. *et al* 2025 FAST ION TRANSPORT SIMULATIONS FOR THE SPHERICAL TOKAMAK FOR ENERGY PRODUCTION *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/36075/)

[28] Bao J. *et al* 2025 KINETIC MODELING OF INTERACTIONS AMONG DRIFT-ALFVEN INSTABILITY, CONTINUOUS SPECTRUM AND ENERGETIC PARTICLES IN FUSION EXPERIMENTS *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/36171/)

[29] Zonca F. *et al* 2025 THEORY AND SIMULATION OF PHASE SPACE TRANSPORT IN BURNING PLASMAS *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/35776/)

[30] Mazzi S. *et al* 2025 HOW MEV-RANGE IONS AND HIGH β WILL SHAPE THE CORE PLASMA DYNAMICS OF FUSION POWER PLANTS *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/36034/)

[31] Porcelli F. *et al* 2025 n=0 VERTICAL DISPLACEMENTS, IMPACT OF MAGNETIC X-POINTS, AND VERTICAL DISPLACEMENT OSCILLATORY MODES DRIVEN BY FAST IONS IN TOKAMAK PLASMAS *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/36420/)

[32] Chen L. *et al* 2025 EFFECTS OF ZONAL FIELDS ON ENERGETIC-PARTICLE EXCITATIONS OF REVERSED-SHEAR ALFVEN EIGENMODES *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/36184/)

[33] Ricci P. *et al* 2025 PROGRESS IN FIRST-PRINCIPLES BOUNDARY SIMULATIONS OF PLASMA TURBULENCE AND NEUTRAL DYNAMICS WITH THE GBS CODE *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/35916/)

[34] Mishchenko A. *et al* 2025 TURBULENCE, ZONAL FLOWS, AND GLOBAL MODES IN BURNING PLASMAS: CODE DEVELOPMENT AND SIMULATIONS *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/35784/)

[35] Cho Y.W. *et al* 2025 NONLOCAL BEHAVIOR OF TURBULENCE IN THE PRESENCE OF POLOIDALLY LOCALIZED HEAT SOURCE *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/36301/)

[36] Qu Z.S. *et al* 2025 NEURAL NETWORK REDUCED MODELS FOR PLASMA TURBULENCE *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/36054/)

[37] JÄRVINEN A.E. *et al* 2025 DEVELOPING MACHINE LEARNING FACILITATED PEDESTAL MODELS *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/35919/)

[38] Kaveeva E. *et al* 2025 FIRST SOLPS-ITER WIDE GRID SIMULATIONS OF THE ITER BURNING PLASMA SCRAPE-OFF LAYER *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/35727/)

[39] Bufferand H. *et al* 2025 HIERARCHY OF TURBULENT TRANSPORT MODELS WITH THE SOLEDGE3X CODE *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/35666/)

[40] Liu J.X. *et al* 2025 VALIDATION OF PLASMA-WALL SELF-ORGANIZATION THEORY BY HIGH DENSITY LIMITS ACHIEVED ON EAST *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/36230/)

[41] Matveev D. *et al* 2025 PROGRESS IN PLASMA-WALL INTERACTION MODELLING FOR EU-DEMO *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/36251/

[42] Xu G.L. *et al* 2025 MODELING OF WALL MATERIAL EVOLUTION AND THE IMPACT ON EDGE PARTICLE RECYCLING FOR LONG PULSE DISCHARGES IN EAST *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/36262/)

[43] Kim K. *et al* 2025 PREDICTION OF HEAT FLUX SPLITTING BY NON-AXISYMMETRIC MAGNETIC FIELD IN THE REALISTIC TOKAMAK WALL AND DIVERTOR BASED ON 3D CAD MODEL *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/36069/)

[44] Gusakov E.Z. and Popov A.Yu. *et al* 2025 LOW-THRESHOLD ABSOLUTE PARAMETRIC DECAY INSTABILITY IN X2-MODE ECRH EXPERIMENTS AND THE MISSING POWER EFFECT *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/35971/)

[45] Meng G. *et al* 2025 DRIFT-KINETIC AND FULLY KINETIC SIMULATIONS OF PLASMA WAVES BASED ON A GEOMETRIC PARTICLE-IN-CELL DISCRETIZATION OF THE VLASOV- MAXWELL SYSTEM *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/36156/)

[46] Tribaldos V. *et al* 2025 CONFINEMENT MODELLING OF ENHANCED PLASMA PERFORMANCE AFTER MULTIPLE PELLET INJECTIONS IN THE TJ-II STELLARATOR *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/36027/)

[47] Storey M.C. *et al* 2025 INNOVATIVE AND EFFICIENT PLASMA MAGNETIC CONFINEMENT METHOD BASED ON AN OVERLOOKED HISTORICAL DISCOVERY *Preprint: 2025 IAEA Fusion Energy Conf. (Chengdu, China, 13-18 October 2025)* (available at: https://conferences.iaea.org/event/392/contributions/36340/)