P 17: Poster Session II

Time: Wednesday 16:15–18:15 Location: ZHG Foyer 1. OG

P 17.1 Wed 16:15 ZHG Foyer 1. OG

Assessing the validity of simplified models to describe the island divertor — •Nassim Maaziz, Felix Reimold, Vicoria Winters, David Bold, Sergei Makarov, Yühe Feng, and The W7-X Team — Max Planck Institute for Plasma Physics, 17491 Greifswald

In a nuclear fusion reactor power and particle exhaust is crucial. In stellarators the island divertor concept has been proposed as an exhaust solution. In essence a resonant component of the magnetic field creates a chain of magnetic islands around the core. These islands divert heat and particles towards the material interface. This concept is utilized in the W7-X stellarator and shows promising performance [1]. However, particle exhaust is less efficient in stellarators than in tokamaks. Increasing the plasma density at the target (plasma-surface-interaction zone) is required to improve it. The density in the divertor depends on the particle, energy, and momentum transport. Understanding the transport in the 3D island divertor is challenging. Hence, simplified models have been developed to describe the island divertor. This work assesses the validity of a simplified model: the stellarator two-point model [2]. Model predictions are compared to simulations of an island divertor geometry performed with the 3D self-consistent fluid code EMC3- EIRENE. Past comparisons claim that the simplified model is able to describe EMC3-EIRENE simulations [3], but our results indicate that the applied simplifications are not valid. In particular, we have identified that momentum losses are more complex, and that parallel heat convection and explicit particle sources cannot be neglected. [1]NF611060032021 [2]NF468072006 [3]PPCF530240092011

P 17.2 Wed 16:15 ZHG Foyer 1. OG

Implementation and exploitation of new bolometer electronics at ASDEX Upgrade — •Alessandro Mancini and Matthias Bernert — Max Planck Institute for Plasma Physics, Garching, Germany

Bolometry is a diagnostic technique employed in magnetic confinement nuclear fusion machines, like tokamaks and stellarators. It measures the full electromagnetic power (visible to soft X rays, without spectral information) radiated by fusion plasmas. This measure is essential for the global power balance of a fusion reactor. Foil ('resistive') bolometers are a type of bolometer which use thin metallic foils that heat up upon radiation absorption. The foils are connected to resistors, arranged as Wheatstone bridge, whose electrical resistance varies according to their temperature. The bolometer cameras are connected to an electronic system that provides an excitation voltage waveform and measures the bridges response voltage, from which the incident radiation power can be inferred. An amplitude demodulation algorithm is used to obtain the real time incident power. So far only a square waveform has been used for the ASDEX Upgrade foil bolometers. New electronics have been designed at ASDEX Upgrade, capable of driving different excitation waveforms. With this contribution an amplitude demodulation technique for sinusoidal waveforms, which is implemented on an FPGA, is presented, with the goal of improving the signal quality and time resolution of foil bolometers. The new system has been tested in the laboratory and in the current ASDEX Upgrade experimental campaign.

P 17.3 Wed 16:15 ZHG Foyer 1. OG

3D nonlinear MHD simulations with kinetic neutrals and impurities — •Mate Szucs[1], Matthias Hoelzl[1], Andrés Cathey[1], Yu-Chih Liang[1], and Sven Q. Korving[2] — [1]Max Planck Institute for Plasma Physics, Boltzmannstr. 2, 85748 Garching b. M., Germany — [2]ITER Organization, 13067 St. Paul Lez Durance Cedex, France

In reactor-scale tokamaks like ITER, both transient and stationary heat and particle fluxes pose significant threats to plasma-facing components and the safe operation of the machine. Stationary fluxes can be mitigated by "detaching" the divertor using neutral or impurity atoms, which effectively act as a neutral cushion. This detached state can be disrupted by transient heat fluxes originating from MHD edge instabilities, such as type-I or even small ELM, a phenomenon known as burn-through. Therefore, predicting such transients under realistic scrape-off layer (SOL) conditions, which enable the modeling of detachment, is crucial.

The JOREK nonlinear MHD code is routinely used to predict large and small ELM regimes, among other phenomena. The base fluid model has been coupled with kinetic neutral and impurity extensions, allowing for the simultaneous simulation of transient MHD and SOL processes. In this contribution, the first 3D simulations of small ELM burn-through and X-point Radiator Regime (XPR) are presented.

P 17.4 Wed 16:15 ZHG Foyer 1. OG

Towards Modeling Pellet-Produced Plasmoid Dynamics in Stellarators with JOREK — •Carl Wilhelm Rogge[1], Ksenia Aleynikova[1], Pavel Aleynikov[1], Rohan Ramasamy[2], Matthias Hoelzl[2], and Nikita Nikulsin[3] — [1]Max-Planck-Institut, 17491 Greifswald, Germany — [2]Max-Planck-Institut, 85748 Garching, Germany — [3]Dept. of Astrophysical Sciences, Princeton University

Pellet injection will be vital for refueling future tokamak and stellarator reactors. While pellet plasmoid physics has been extensively studied in tokamak magnetic geometries, understanding it in stellarator geometries remains less comprehensive. In particular, the non-axisymmetry of the equilibrium field in stellarators increases the complexity of numerical analysis.

However, recent advancements in the stellarator extension [Nikulsin 2022] of the JOREK non-linear 3D MHD code, which employs a reduced MHD model for stellarator geometry, show significant promise in addressing this challenge. Consequently, this project aims to leverage JOREK to deepen the understanding of pellet plasmoid dynamics, with a particular focus on perpendicular drifts in stellarators.

We benchmark computed plasmoid dynamics with the expected analytical solutions [Aleynikov 2019, 2024]. A good agreement is demonstrated when the plasmoid expands predominately along the field line using an appropriate heating model. Different heating models for the pellet-plasmoid are implemented in JOREK and compared.

P 17.5 Wed 16:15 ZHG Foyer 1. OG

A novel optimization approach for stellarator design — •Issra Ali, Alan Goodman, and Ryan Wu — Max-Planck-Institut für Plasmaphysik, Greifswald, Germany

Stellarators are a class of fusion reactor candidates which confine a hot plasma in a toroidal shape using powerful magnetic fields. One of stellarators' great strengths is their vast design space, which offers incredible flexibility in their physical properties. This flexibility is exploited via numerical optimization to carefully mold magnetic field geometries and corresponding coil designs to maximize confinement quality.

Gradient-based optimization methods are the industry standard for stellarator and coil optimization problems, and have recently proven effective in finding reactor-relevant stellarator designs. However, these problems are often multimodal and highly sensitive to initial conditions, meaning that gradient-based methods are at best unlikely to find global minima, and at worst unable to converge altogether without careful selection of initial conditions and optimizer hyperparameters. Global optimization methods, such as Bayesian Optimization, may offer a better way to explore the entire parameter space, but tend to scale poorly to high-dimensional problems such as stellarator optimization. Moreover, they do not exploit gradient information, which is a powerful tool in high-dimensional optimization spaces. In this work, we present a novel global optimization method that seeks global optima while still being guided by gradients.

P 17.6 Wed 16:15 ZHG Foyer 1. OG

Plasma termination studies in LHD and W7-X — •Hjördis Bouvain[1], Andreas Dinklage[1], Naoki Tamura[1], Hiroe Igami[2], Hiroshi Kasahara[2], Kieran McCarthy[3], Daniel Medina-Roque[3], Wendelstein 7-X Team[1], and LHD Experiment Team[2] — [1]Max Planck Institute for Plasma Physics, Greifswald, Germany — [2]National Institute for Fusion Science, Toki, Japan — [3]Laboratorio Nacional de Fusion, CIEMAT, Madrid, Spain

Control of potentially occurring plasma terminating events is crucial for safe operation of large fusion devices. In tokamaks, disruptions, caused by current driven instabilities, lead to rapid loss of stored kinetic and magnetic energy. Stellarators, however, are more resilient since the poloidal field is generated from external coils, avoiding the loss of magnetic energy. Thermal quenches, due to large impurity influxes, are barely investigated in stellarators. These can cause significant damage to the wall material if the heat loads exceed a critical threshold, making the development of mitigation measures necessary. Intentional injection of large amounts of tungsten impurities via TESPEL in LHD and W7-X plasmas to study thermal quenches in more detail are investigated. Radiative losses along propagating cold fronts may induce termination, but below a critical threshold of impurity amounts the plasma may recover to stored energies prior perturbation. Application of additional electron heating extended the plasma cooling phase; thus, different heating strategies were explored. Results suggest that, in stellarators, less efforts for mitigating termination events are needed due to their higher operational resilience.

P 17.7 Wed 16:15 ZHG Foyer 1. OG

Effect of stray magnetic fields on particles in the Wendelstein 7-X neutral beam box — •Lucas van Ham[1], Samuel Lazerson[2], Björn Hamstra[3], Paul McNeely[1], Norbert Rust[1], Dirk Hartmann[1], Sergey Bozhenkov[1], and the W7-X Team[1] — [1]Max Planck Institute for Plasma Physics — [2]Gauss Fusion GmbH, Germany — [3]Eindhoven University of Technology

A new comprehensive model for calculating ion trajectories inside the neutral beam injection (NBI) system of Wendelstein 7-X (W7-X) is presented. The model consists of two parts: First, the magnetic materials code MUMAT calculates the magnetic response of ferritic materials (including NBI shielding) to the magnetic field produced by the main W7-X coil system. This code has been verified through application to a scenario with a known magnetic field. Second, the Monte Carlo particle following code BEAMS3D follows particles through the resulting magnetic field and estimates heat loads on NBI components.

MUMAT calculations of the magnetic field inside the NBI system predict significant fields (>10 Gauss) inside the NBI neutralizer, indicating that stray magnetic fields penetrate the NBI system. Subsequent BEAMS3D simulations predict that heat loads on NBI components shift vertically due to this neutralizer field. These shifts agree qualitatively with experimental observations, and a quantitative comparison with infrared imaging and calorimetry is planned.

The NBI system is essential for achieving high performance plasmas in W7-X, and this new model can help improve NBI reliability and develop paths towards longer NBI heat pulses.

P 17.8 Wed 16:15 ZHG Foyer 1. OG

Simulations of the X-point Radiator in ASDEX Upgrade with Kinetic Neutrals and Impurities in JOREK — •Yu-Chih Liang[1,2], Andres Cathey[1], Matthias Hoelzl[1], Ulrich Stroth[1,2], Sven Korving[3], Mate Szuecs[1,2], Felix Antlitz[1,2], Daniël Maris[3], JOREK Team[1], and ASDEX Upgrade Team[1] — [1]Max Planck Institute for Plasma Physics, 85748 Garching, Germany — [2]TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [3]Eindhoven University of Technology, 5612 AZ Eindhoven, The Netherlands

The problem of power exhaust in the future thermonuclear fusion reactors, such as ITER and DEMO, necessitates operation regimes that can avoid extreme heat fluxes onto plasma-facing components. One promising regime is the X-point radiator (XPR), a cold, dense, and highly radiative plasma region that forms above the X-point of the single-null magnetic configuration in a tokamak plasma. This poster presents axisymmetric (2D) simulations of the XPR regime using the nonlinear magnetohydrodynamic (MHD) code, JOREK, extended with a kinetic particle framework for neutral deuterium particles and impurities. Three simulations are presented: one with a quasi-stationary XPR, one with the XPR moving vertically upwards and turning into an unstable solution (MARFE), and one with the XPR moving vertically downwards and being lost. These three simulations show JOREK's capability of simulating time-varying XPR, and they provide a baseline for the transition to 3D simulations, so the MHD activities and their interaction with the XPR can be studied.

P 17.9 Wed 16:15 ZHG Foyer 1. OG

Assessment of Radiation Asymmetries employing the new Imaging Bolometer diagnostic at W7-X — •Kevin Andrea Siever[1], Gabriele Partesotti[1], Felix Reimold[1], Glen Wurden[2], Fabio Federici[3], Byron Jay Peterson[4], and Kiyofumi Mukai[4] — [1]Max-Planck Institute for Plasma Physics, Greifswald, Germany — [2]Los Alamos National Lab, New Mexico, United States — [3]Oak Ridge National Lab, Tennessee, United States — [4]National Institute for Fusion Science, Toki, Japan

Estimation of the plasma radiation distribution is a key aspect in the context of power exhaust optimization. This is particularly demanding in Stellarators due to the intrinsically 3D plasma geometry. The InfraRed Video Bolometer (IRVB) diagnostic provides wide spatial coverage both in the poloidal and toroidal directions, enabling direct observation of the emission gradients in the divertor region. Here we combine its data with that from the resistive bolometry systems to quantify the emissivity asymmetries at Wendelstein 7-X. First of all, the thermal properties of the bolometer foil need to be calibrated to allow correct inference of the impinging power. Using synthetic simulations of the calibration process allows to identify the optimal procedure and settings.

Given the IRVB measurements, we then employ the 2D radiation patterns obtained from the resistive bolometers to generate reference patterns with constant emissivity along the field lines. Comparing with the latter allowed us to isolate better the features of interest and to assess the toroidal gradients in the plasma emissivity

P 17.10 Wed 16:15 ZHG Foyer 1. OG

Gyrokinetic studies of dominant instabilities in different particle transport regimes in Wendelstein 7-X — •Nico J. Guth, Josefine H. E. Proll, Sebastian Bannmann, Oliver P. Ford, and Gabriel G. Plunk — Max Planck Institute for Plasma Physics, Greifswald, Germany

One of the key aspects for ensuring efficient and stable fusion energy production in a future stellarator is to accurately predict the plasma density profiles and their time evolution. In a stellarator, ions and electrons stream freely along magnetic field lines, leading to nested toroidal surfaces of nearly constant density (and temperature). Thus, the main interest of the study of particle transport lies in the perpendicular (radial) direction, with a goal of understanding which plasma conditions lead to favourable density peaking near the magnetic axis and which conditions degrade particle confinement. Optimized stellarators, like Wendelstein 7-X (W7-X), are specifically tailored to reduce the average outward drifts of trapped particle orbits, leading to reduced neoclassical transport. Experiments have however shown that transport is larger than predicted, which can be attributed to turbulent processes in the plasma on the gyroradius scale. Recent experimental work (Bannmann et al 2024) indicates a change in turbulent particle diffusivity (and convectivity) above a critical density gradient. Using gyrokinetic simulations, this qualitative change is investigated with a focus on changes in dominant instabilities as well as simple quasilinear estimates of the corresponding fluxes.

P 17.11 Wed 16:15 ZHG Foyer 1. OG

Fluid Turbulence Modelling of Magnetic Islands in Stellarators — •Miguel Madeira, Sophia A. Henneberg, and Brendan Shanahan — Max-Planck-Institut für Plasmaphysik, Wendelsteinstr. 1, 17489 Greifswald, Germany

Understanding scrape-off layer (SOL) turbulence is crucial for advancing nuclear fusion technology, particularly in improving plasma confinement and performance. While extensive efforts have been dedicated to developing plasma fluid turbulence codes, most applications have focused on tokamak configurations. With the recent success of Wendelstein 7-X (W7-X) and the rising interest in stellarators, multiple codes have now been adapted for three-dimensional simulations and are ready to be leveraged for future physics studies.

This research aims to enhance the understanding of SOL turbulence around magnetic islands in stellarators, specifically focusing on W7-X, by utilizing two fluid turbulence codes, BSTING and GRILLIX. The flexible coil system of W7-X enables control over its magnetic islands' locations and sizes. Notably, when the 5/5 island chain is inside the last closed flux surface, a transition to improved electron transport has been observed. This state is characterized by higher plasma energy and periodic sawtooth crashes within the island region, known as island localized modes (ILMs). The frequency and amplitude of these crashes correlate with the island size.

Given the critical role of magnetic islands in improved confinement scenarios and the island divertor design for future stellarator reactors, this work explores how they influence turbulence behavior.

P 17.12 Wed 16:15 ZHG Foyer 1. OG

Improvement of impurity transport studies at Wendelstein 7-X by integration of 2D X-ray emission data — •Alice Bonciarelli[1,2], Birger Buttenschön[1], Felix Reimold[1], Christian Brandt[1], and The W7-X Team[1] — [1]Max-Planck-Institut für Plasmaphysik, Greifswald — [2]Politecnico di Milano, Italy

Impurities play an important role in fusion plasmas, since their presence and distribution have a strong influence on the plasma performance: the actual amount must be kept under control, within a suitable range defined by the need to avoid plasma dilution and radiation cooling (upper limit), and by their protective function with respect to the plasma facing materials from high power fluxes (lower limit). The impurity transport determines their distribution and it can be described by convection and diffusion coefficients. These coefficients can be determined from experiments and we use the transport code pySTRAHL to forward model the impurity density evolution for given coefficients. These can, in turn, can be used to predict synthetic line-integrated signals of various diagnostics using the atomic data available in the ADAS database. It is then possible to compare the measured and simulated data using Bayesian inference analysis to obtain more realistic transport coefficients. To increase the accuracy of transport coefficients as determined by spectroscopy alone, a fast 2D x-ray tomography system is introduced into this framework. The necessary methods of data reduction and first results of the extended set of diagnostics are shown in this contribution.

P 17.13 Wed 16:15 ZHG Foyer 1. OG

Landau Damping for Non-Maxwellian Distribution Functions — •Riccardo Stucchi[1,2] and Philipp Lauber[1] — [1]Max Planck Institute for Plasma Physics — [2]Technical University of Munich

Landau damping is one of the cornerstones of plasma physics. In the context of the mathematical framework developed by Landau in his original derivation of Landau damping, we examine the solutions of the linear Vlasov-Poisson system for different equilibrium velocity distribution functions, such as the Maxwellian distribution, kappa distributions, and cut-off distributions without and with energy diffusion. Specifically, we focus on the full set of roots that the dispersion relation of the linear Vlasov-Poisson system generally admits, and we wonder if the full structure of solutions might hint at a deeper understanding of the Landau damping phenomenon.

P 17.14 Wed 16:15 ZHG Foyer 1. OG

Frequency-sweeping calibration source for the dual-frequency CTS radiometer at W7-X — •Daniel Straus, Dmitry Moseev, Sergiy Ponomarenko, Laurent Krier, Heinrich Laqua, Stefan Marsen, and Torsten Stange — Max-Planck-Institut für Plasmaphysik, Wendelsteinstr. 1, 17491 Greifswald, Germany

The Collective Thomson Scattering (CTS) diagnostic at the Wendelstein 7-X stellarator must be calibrated. The current calibration process involves using two thermal sources, one roughly at room temperature and the other at -196 C (boiling point of nitrogen), with the black body radiation emitted by each source being significantly different. The CTS receiver works at two frequency bands: 138.5-141.5 GHz and 171-177 GHz, and it is important that the receiver is absolutely calibrated in both bands. These black body sources produce weak signals which require hours long averaging times in order to achieve an acceptable signal-to-noise ratio. With such time scales, the receiver electronics experience systematic drifts which also need to be accounted for, making the overall calibration procedure long and cumbersome. In this contribution, we will discuss the design and first results of a new sweeping calibrator that replaces the black body sources. This calibrator consists of a tunable continuous wave THz source, followed by attenuators, waveguide switches and a directional coupler, which splits the incoming signal into two distinct power levels. The THz source and other components are carefully characterized to protect receiver electronics from high power. The calibration tool is integrated with the CTS receiver and allows quick semi-automatic calibration.

P 17.15 Wed 16:15 ZHG Foyer 1. OG

Towards efficient accelerated 3D nonlinear MHD simulations with the finite element code JOREK — •Patrik Rác, Matthias Hölzl, and Ihor Holod — Max Planck Institute for Plasma Physics, Garching, Germany

Enabling next-generation simulations of realistic magnetic confinement fusion devices is crucial for understanding and controlling large-scale plasma instabilities. Current simulation codes, such as JOREK, are designed to run on traditional supercomputers but have yet to be optimized for efficient execution on modern accelerated platforms. With the increasing prevalence of accelerator architectures, like GPUs, in high-performance clusters, JOREK requires adaptation to harness the performance of these new systems. We ported the matrix construction and the iterative solver of the time-stepping loop to GPUs. Our approach aims for portability and minimal code changes, allowing scientists to continue working on the code and easily integrate future changes. We achieve this by combining OpenMP and highly optimized GPU libraries. By optimizing the code structure for GPU offloading and eliminating synchronization overhead through coloring the finite element mesh, we obtain comparable performance to the original CPU implementation, paving the way for fully integrated JOREK simulations on GPU-accelerated clusters. Future work will explore novel preconditioning methods, designed to run efficiently on accelerated hardware, with the possibility of harnessing machine learning for further acceleration.

P 17.16 Wed 16:15 ZHG Foyer 1. OG

Characteristics of the SOL ion-to-electron temperature ratio on W7-X with an island divertor configuration — •Jiankun Hua[1,2], Yunfeng Liang[1,2,3], Alexander Knieps[2], Kaixuan Ye[2,3], Carsten Killer[4], Erhui Wang[2], and Pei Ren[2] — [1]International Joint Research Laboratory of Magnetic Confinement Fusion and Plasma Physics, Huazhong University of Science and Technology, Wuhan, China — [2]Forschungszentrum Jülich GmbH, Institut für Energie- und Klimaforschung Plasmaphysik, Jülich, Germany — [3]Institute of Plasma Physics, Chinese Academy of Sciences, Hefei, China — [4]Max-Planck-Institut für Plasmaphysik, Greifswald, Germany

The ion temperature, Ti, in the scrape-off layer (SOL) plays a critical role in understanding diverter plasma transport in magnetic confined fusion research. Previous studies have shown SOL Ti is typically higher than the electron temperature, Te. Moreover, as the ion collisionality (υ) increases, the ion-to-electron temperature ratio (τ) decrease accordingly. Experiments in the W7-X device, which employs an island divertor configuration, are consistent with earlier observations made in tokamaks. However, the Ti profile is non-monotonic due to the influence of the open magnetic island structure in SOL. Ti inside the island is lower than at the island boundary. When SOL plasma transitions from an attached state to a detached state by ramping up upstream plasma density, the υ increases, and both Ti and Te decrease in the SOL. Meanwhile, the relation between τ and υ remains consistent with the attached plasma, so the τ further decrease under the detachment.

P 17.17 Wed 16:15 ZHG Foyer 1. OG

A functional perturbation theory for rapid analysis of orbits and tori in magnetic confinement fusion research — •Wenyin Wei[1,2,3], Alexander Knieps[1], Jiankun Hua[1,4], and Yunfeng Liang[1,2,4] — [1]Forschungszentrum Jülich GmbH, Institute of Fusion Energy and Nuclear Waste Management - Plasma Physics, Jülich, Germany — [2]ASIPP, Hefei, China — [3]USTC, Hefei, China — [4]HUST, Wuhan, China

This work presents a functional perturbation theory (FPT) that efficiently computes how orbits shift and tori deform under perturbation by considering the magnetic field as a function argument for these geometric objects. This approach acknowledges topological significance, inspired by the discovery from mature 3D magnetohydrodynamic simulations (e.g., EMC3-EIRENE, JOREK), which have revealed the distinctive lobe structure intertwined with stable and unstable manifolds of the outermost X-cycle (the field trajectory consists of X-points at all cross-sections). In practice, without delicate hardware acceleration, FPT completes computations in seconds for three-dimensional configurations like Wendelstein 7-X and almost instantly for tokamaks, offering near-real-time insights for device optimization and control. Based on this swift speed, FPT can guide experimental decisions by quickly predicting how coil setups or plasma responses affect magnetic topology, indicating whether flux surfaces remain intact or break into island chains. The framework is expected to support more agile, precise operations in existing fusion devices and inform the design of advanced configurations.

P 17.18 Wed 16:15 ZHG Foyer 1. OG

Deuterium Uptake and Isotope Exchange in Tungsten Displacement Damaged at High Temperature — •Laurin Hess[1,2] and Thomas Schwarz-Selinger[2] — [1]Technische Universität München, Arcisstr. 21, 80333 München — [2]Max-Planck-Institut für Plasmaphysik, Boltzmannstr. 2, 85748 Garching b. München

Retention of hydrogen fuel in tungsten is an active area of research, as it is an integral part of modelling the tritium inventory and certification of future fusion reactors. It has been shown that hydrogen retention significantly increases due to displacement damage produced by 14 MeV fusion neutrons. Over the last years, basic understanding of the behaviour of hydrogen in point defects was acquired. However, damage at high temperatures can also produce nm-sized voids. Only little research has been done to examine the behaviour of hydrogen in these voids. To improve the understanding of hydrogen in nm-sized voids, tungsten single crystals were self-damaged by irradiation with 20 MeV tungsten ions at 1370 K and decorated with different fluences of 5 eV deuterium from a low-temperature plasma. The retention of deuterium was measured via ^{3}He Nuclear Reaction Analysis as a function of D fluence. In addition, the exchange of retained deuterium with protium has been studied by exposing deuterium-decorated samples to different fluences of 5 eV protium.

P 17.19 Wed 16:15 ZHG Foyer 1. OG

Thermal-Hydraulic Modelling of Plasma Facing Components using OpenFOAM — •Ahmet KILAVUZ[1,2], Rudolf Neu[1,2], Jeong-Ha You[1,3], and Boštjan Končar[4] — [1]Max Planck Institute for Plasma Physics, Garching, Germany — [2]Technical University of Munich, Garching, Germany — [3]University of Ulm, Ulm, Germany — [4]Jožef Stefan Institute, Ljubljana, Slovenia

Plasma-facing components, like divertor targets in fusion reactors, operate under extreme thermal and hydraulic conditions, including high heat and mass fluxes and elevated pressures. Under such conditions, boiling phenomena occur in cooling channels, and boiling models are highly sensitive to flow conditions, complicating the creation of accurate models. OpenFOAM, an open-source CFD software, provides a customizable platform for developing these models. This study develops and evaluates conjugated heat transfer models in OpenFOAM for divertor-relevant conditions. Material properties were included as a function of temperature. The solver results were compared to ANSYS Fluent predictions, experimental measurements, and empirical correlations. The agreement between the two solvers was observed for temperature and velocity predictions, including armor surface and inner pipe temperatures, velocity profiles, and volume fractions. Both solvers aligned well with experimental data. Differences between single-phase model predictions and experimental data highlight the need to incorporate boiling effects for accurate thermal predictions in plasma-facing components.

P 17.20 Wed 16:15 ZHG Foyer 1. OG

Temperature-dependent grain boundary permeation in tungsten investigated by hydrogenography — •Fahrudin Delic, Armin Manhard, and Udo von Toussaint — Max Planck Institute for Plasma Physics, 85748 Garching, Germany

The temperature-dependent permeation of deuterium through grain boundaries in tungsten has been studied using a newly developed hydrogenography technique, which employs patterned films to laterally resolve hydrogen fluence density on the back side of the permeation samples. Primarily, a tungsten oxide layer was developed as a hydrogen indicator that could withstand greater temperatures than previously used yttrium, and a method for reliably quantifying the results was established. Ion-driven permeation with constant deuterium fluence was conducted using 50 μm thick recrystallized tungsten samples at various exposure temperatures. The temperature-dependent permeation indicated that the permeation fluence density of hydrogen isotopes in grain boundaries is dominant up to 660 K, with an increasing number of grain boundaries favorable for hydrogen transport as the temperature rises. At 660 K, a halo of hydrogen fluence density forms around several permeating grain boundaries, suggesting a desorption of hydrogen isotopes from grain boundaries and the initial signs of the transition towards predominant bulk permeation

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Influence of the presence of deuterium on damage evolution in tungsten — •Z Shen, T Schwarz-Selinger, M Zibrov, and A Manhard — Max-Planck-Institut für Plasmaphysik, Boltzmannstrasse 2, Garching D-85748, Germany

The influence of the presence of deuterium (D) on damage evolution at elevated temperatures was studied for self-ion irradiated tungsten (W). W samples were irradiated by 20.3 MeV W ions at room temperature to the peak damage dose of 0.23 dpa and loaded with a low-temperature D plasma at 370 K to decorate the created defects. To study the evolution of the defects with D being present, samples were heated during plasma loading to 4 different temperatures, ranging from 470 K to 770 K. The annealing time was calculated by the rate equation modelling code TESSIM-X. For comparison, annealing experiments at each temperature were carried out also in vacuum. Nuclear reaction analysis (NRA) was used to determine the D depth profile and thermal desorption spectroscopy (TDS) was used to measure the total retention and de-trapping energy of D. Decorating the samples after annealing again with the same D plasma at room temperature shows decreased D retention with increasing annealing temperature both for plasma annealing and vacuum annealing. The presence of D during annealing has only a small stabilization effect for the defects.

P 17.22 Wed 16:15 ZHG Foyer 1. OG

Expanding the physics modeling capabilities of ASTRA from core to SOL and from tokamak to stellarator towards application in a multi-device flight simulator — •Fabian Solfronk[1,2], Emiliano Fable[1], Hartmut Zohm[1,2], Roberto Bilato[1], and the ASDEX Upgrade Team[3] — [1]Max-Planck-Institut für Plasmaphysik, 85748 Garching, Germany — [2]Ludwig-Maximilians-Universität München, 80539 München, Germany — [3]see the author list of H. Zohm et al. 2024 NF 64 112001

This work aims at augmenting the ASTRA transport code capabilities of simulating magnetic confinement fusion devices. In parallel, two avenues are pursued:

First, a few options for a reduced, theory-based scrape-off-layer (SOL)/exhaust model will be explored and implemented to allow simulations of seeded discharges and discharges with both low and high-recycling regimes displaying either impurity flush-out or detachment. Application to ASDEX Upgrade and future devices like ITER and DEMO, where the FENIX flight simulator (to which ASTRA is coupled) is being deployed, is foreseen.

Second, the implementation of an equation for the current diffusion compatible with a vacuum helical field (as in a stellarator device) will be pursued. After which, the inclusion of reduced models for stellarator physics may be initiated. The goal is to develop a tool that can be used for both tokamak and stellarator-reduced modeling, paving the way for a flight simulator that can also simulate stellarators.

P 17.23 Wed 16:15 ZHG Foyer 1. OG

Gyrokinetic pedestal studies varying shaping in AUG — •Facundo Sheffield[1], Tobias Goerler[1], Lidija Radovanovic[2], Elisabeth Wolfrum[1], Frank Jenko[1], and the ASDEX Upgrade team[3] — [1]Max-Planck-Institut für Plasmaphysik — [2]Institute of Applied Physics, TU Wien — [3]See author list of H. Zohm et al, 2024 Nucl. Fusion https://doi.org/10.1088/1741-4326/ad249d

The pedestal region in tokamak plasmas plays a critical role in determining overall confinement and performance, yet the interplay between turbulence and plasma shaping within this region remains to be fully understood. In this work, we present a comprehensive characterization of pedestal instabilities and their sensitivity to plasma shaping effects using the gyrokinetic code GENE. Key turbulence modes, including kinetic ballooning modes and electron temperature gradient modes (ETG), are identified and compared in differently shaped ASDEX Upgrade equilibria to assess their impact on transport and stability. Further insights into the nature and characterization of ion-frequency ETG modes are discussed. The influence of shaping parameters, mainly triangularity and elongation, is systematically explored with linear and global nonlinear simulations. The findings presented reveal novel dependencies between pedestal turbulence properties and shaping.

P 17.24 Wed 16:15 ZHG Foyer 1. OG

Investigation of Wendelstein 7-X Scrape-Off Layer Characteristic by Helium Line Ratio Spectroscopy — •Foisal B.T. Siddiki[1,2], Oliver Schmitz[2], Maciej Krychowiak[1], Erik Flom[3], Frederik Henke[1], Dorothea Gradic[1], and W7-X team[1] — [1]Max Planck Institute for Plasma Physics, Germany — [2]University of Wisconsin-Madison, USA — [3]Thea Energy, USA

Heat and particle transport in the Wendelstein 7-X(W7-X) scrape-off layer (SOL) significantly influences the performance of its divertor, which serves as the heat and particle exhaust system. To optimize the divertor concept, it is essential to understand the transport phenomena within the SOL, which can be achieved by studying plasma parameters like electron temperature (T_e) and the density (n_e). As a way of measuring the basic plasma parameters in the W7-X SOL, the diagnostic systems used consist of a gas injection system and multiple spectrometers with different spectral resolutions. They observe one upper and one lower divertor unit (downstream position) and for the first time also in the midplane area (upstream position). Line ratio spectroscopy based on a collisional radiative model of atomic helium is used to infer n_e and T_e. The helium beam diagnostic at W7-X has been thoroughly validated and widely utilized to map plasma parameters within the island divertor. The T_e , n_e profiles presented here in this work were measured using all three systems under various conditions, including detached and impurity-seeded plasmas. A comparison of the T_e , n_e profiles obtained at the downstream and upstream positions will be presented.

P 17.25 Wed 16:15 ZHG Foyer 1. OG

Modeling of the spatial and temporal dynamics of Cs in large negative hydrogen ion sources using the CsFlow3D code — •Daniele Mussini, Adrian Heiler, Christian Wimmer, Dirk Wünderlich, and Ursel Fantz — Max-Planck-Institut für Plasmaphysik (IPP), Boltzmannstr. 2, 85748 Garching

Negative ion-based sources for ITER's neutral beam injectors (NBI) rely on the production of negative hydrogen ions on a low work function converter surface (plasma grid, PG). To reduce the work function of the PG (< 2eV), Cs is continuously evaporated into the source forming a layer on the PG. However, the plasma-surface interaction and the resulting redistribution of Cs inside the source lead to a temporally unstable and inhomogeneous layer. This is a key aspect to be investigated and understood in order to perform long pulses at ITER's requirements (several hundred s in H, 3600s in D). For this purpose, the Monte-Carlo Test-Particle code CsFlow3D is exploited. CsFlow3D models the Cs dynamics in the source, for which several input parameters (plasma parameters, electromagnetic fields, sticking coefficients, etc.) are required. The current target is to model the Cs dynamics during long pulses for the BATMAN Upgrade source in hydrogen. To validate the code, a synthetic laser absorption diagnostic (TDLAS) for the quantification of neutral Cs densities along different line-of-sights is implemented to compare to experimental results. This contribution presents the results of the code after the implementation of input parameters resulting from a fluid code and the benchmark of the code against experimental TDLAS results.

P 17.26 Wed 16:15 ZHG Foyer 1. OG

Impact of fishbone modes to core microturbulence with global gyrokinetic simulations — •davide brioschi[1], alessandro di siena[1], roberto bilato[1], alberto bottino[1], thomas hayward-schneider[1], alexey mishchenko[2], emanuele poli[1], alessandro zocco[2], and frank jenko[1] — [1]Max Planck Institute for Plasma Physics, Boltzmannstr. 2, 85748 Garching, Germany — [2]Max Planck Institute for Plasma Physics, Greifswald 17491, Germany

Fishbone instabilities (FBs) are a class of macroscopic plasma modes which develop inside tokamaks around rational surfaces. Theoretical and experimental results show a correlation between the development and/or sustainment of ITBs inside tokamak plasmas and the destabilization of FBs. These studies point out the need for a self-consistent description of the interaction of FBs with plasma microturbulence, i.e. the main driving mechanism of turbulent transport inside tokamaks detrimental for plasma confinement. Our work wants to study such an interaction through gyrokinetic simulations performed with the code GENE and ORB5, including both the n=m=1 FB (with n and m tororidal and poloidal mode number respectively) and the ion temperature gradient (ITG) mode branches inside the plasma. Multiscale interaction between turbulence, global FB structures and zonal flows is studied via dedicated nonlinear simulations, starting from results obtained through linear ones used to identify the ideal subset of the parameters space where all these modes are present at once.

P 17.27 Wed 16:15 ZHG Foyer 1. OG

First successful plasma start-up with X2 ECRH at a reduced field of 1.8T at W7-X — •Niklas Simon Polei, Torsten Stange, Heinrich Peter Laqua, Kai Jakob Brunner, Juan Fernando Guerrero Arnaiz, Georg Schlisio, and W7-X Team — Max-Planck-Institut für Plasmaphysik, 17491 Greifswald, Germany

At Wendelstein 7-X (W7-X) the nominal magnetic field strength is 2.5T, but operation at a lower magnetic field strength is desired to achieve higher plasma beta (ratio of kinetic and magnetic pressure). The electron cyclotron resonance heating (ECRH) operates at 140GHz, corresponding to third harmonic (X3) heating at 1.8T. A plasma start-up is not possible with X3-heating, but one gyrotron was successfully tuned to 101GHz for an X2 start-up with 250kW. A multi-pass scenario was developed to ensure six passes close to the magnetic axis to increase the effective power in the first few milliseconds and allow a plasma breakdown even at low power. Neutral beam injection (NBI) with a power of 3MW was expected to be able to takeover the plasma from the X2 ECRH, increasing the electron temperature up to 1keV, so that X3 ECRH can take over.

The foreseen start-up scenario was successfully demonstrated in the last operational phase OP 2.2. The X2 ECRH alone can create a central plasma with a peak temperature of several keV and line integrated densities above $5 \cdot 10^{18} m^{-2}$. The plasma can be taken over by the NBI to increase temperature and density, for subsequent X3 ECRH takeover to maintain a steady plasma. This enables the low field operation of W7-X.

P 17.28 Wed 16:15 ZHG Foyer 1. OG

First measurements of divertor conditions in the new ASDEX Upgrade upper divertor — •Felix Albrecht[1,2], Dominik Brida[1], Tilmann Lunt[1], Bernhard Sieglin[1], Ou Pan[1], and the ASDEX Upgrade team[3] — [1]Max Planck Institute for Plasma Physics, Garching, Germany — [2]Technical University of Munich, Physics Department E28, Garching, Germany — [3]see author list of H. Zohm *et al.* 2024 *Nucl. Fusion* **64** 112001

The divertor is a crucial component for any magnetic confinement fusion machine, which enables efficient pumping of impurities and fusion-produced helium, as well as density and power exhaust control. In the divertor, the magnetic field lines of the outermost part of the plasma, the so-called Scrape-Off Layer (SOL), are intersected by a wall component, the divertor target, which experiences very high power loads. The target heat flux must be limited by the seeding of impurities, which radiate power away. However, a power plant divertor could require seeding rates which would be unacceptably high for the plasma core. A possible solution are Alternative Divertor Configurations (ADCs), which can help to induce detachment at lower impurity concentrations by enhanced control of the field configuration in the divertor region.

At the tokamak ASDEX Upgrade (AUG), the upper divertor has recently been equipped with additional coils to study a variety of ADCs, for the first time in a machine with high heating power and a tungsten wall. This contribution presents the first Langmuir probe measurements in the new upper divertor of AUG, and compares the divertor conditions between different field configurations.

P 17.29 Wed 16:15 ZHG Foyer 1. OG

The avalanche source for a 3D particle in cell model of runaway electrons — •Fiona Wouters[1], Matthias Hoelzl[1], Hannes Bergstroem[1], Guido Huijsmans[2,3], and Jan van Dijk[2] — [1]Max Planck Institute for Plasma Physics, Boltzmannstraße 2, 85748 Garching, Germany — [2]Eindhoven University of Technology, Groene Loper 3, 5612 AE Eindhoven, the Netherlands — [3]CEA, IRFM, 13115 Saint-Paul-lez-Durance, France

Disruptions, i.e. major instabilities in which plasma confinement is lost, are a significant threat to tokamak operation. During a disruption the resistivity of the plasma increases as the thermal energy is quickly lost, causing the current to decrease. Due to the self-inductance of the plasma this leads to the generation of a strong parallel electric field. As the friction force experienced by fast electrons in a plasma has the peculiarity that it decreases with increasing electron velocity, this electric field can accelerate some fast electrons to relativistic velocities. These so-called runaway electrons (REs) can then exponentially multiply due to large-angle collisions with thermal electrons in what is known as the runaway avalanche. Because the avalanche is exponentially sensitive to the pre-disruption plasma current, this can lead to multi-MA RE beams in large future devices such as ITER, which may cause severe localized wall damage. Simulations including the RE sources in realistic 3D fields are needed to further the understanding of RE generation and losses and develop viable mitigation scenarios. For this purpose the avalanche source was implemented in the 3D nonlinear extended MHD code JOREK.

P 17.30 Wed 16:15 ZHG Foyer 1. OG

Turbulence imaging in the scrape-off layer of Wendelstein 7-X — •Floris Scharmer[1], Adrian von Stechow[1], Sean Ballinger[2], Seung-Gyou Baek[2], James Terry[2], Carsten Killer[1], Olaf Grulke[1,3], and the W7-X Team[1,4] — [1]Max Planck Institute for Plasma Physics, Greifswald, Germany — [2]MIT Plasma Science and Fusion Center, Cambridge, USA — [3]Department of Physics, Technical University of Denmark, Lyngby, Denmark — [4]See O. Grulke et al 2024 Nucl. Fusion 64 112002

Understanding the dynamics of the edge plasma is crucial for magnetic confinement fusion experiments, as it significantly impacts both core performance and plasma exhaust. In the Wendelstein 7-X stellarator experiment, a 2D poloidal cross section of the island scrape-off layer plasma is imaged with a gas puff imaging diagnostic. This system measures the fluctuations in H_α line emission, a proxy for plasma fluctuations, at a high spatio-temporal resolution by increasing the local light emission with an external neutral gas puff. In the latest operation phase (2024), the diagnostic capabilities were upgraded with the ability to use a high-resolution camera, which can be swapped with the existing avalanche photodiode detector array as needed. This enhancement allows for the study of turbulence statistics with higher spatial resolution and over a larger field of view, including the last closed flux surface. The turbulence statistics (e.g. skewness) have distinct features corresponding to the magnetic geometry and also depend on the operational regime. In this contribution, the results of the first measurements of the diagnostic extension are presented.

P 17.31 Wed 16:15 ZHG Foyer 1. OG

Improving the signal to noise ratio of a TALIF diagnostic applied to a hydrogen plasma for enhanced hydrogen EDF determination — •Julian Hörsch, Christian Wimmer, and Ursel Fantz — Max-Planck-Institut für Plasmaphysik, Boltzmannstraße 2, 85748 Garching bei München, Germany

Two photon Absorption Laser Induced Fluorescence (TALIF) is a plasma diagnostic technique that can be used to measure the density and energy distribution function (EDF) of atomic hydrogen. The simultaneous absorption of two photons leads to the excitation of ground state hydrogen atoms to the n=3 level and a subsequent fluorescence decay to the n=2 level. The fluorescence decay emits Balmer H-alpha radiation, which can be detected for density and EDF measurements. Since the plasma emits strong H-alpha radiation, weak fluorescence signals received from TALIF are difficult to measure. The determination of the EDF requires an accurate measurement of the line profile, particularly in the wings of the line profile. For that it is important to distinguish the signal from the background noise. To be able to measure these wings of the EDF and thus the predicted deviations from a Maxwellian EDF, optimizations of the detector and the optical setup such as laser focusing and beam compression are investigated.

P 17.32 Wed 16:15 ZHG Foyer 1. OG

Plasma dynamics analysis with the fast helium beam at W7-X — •Sebastian Hörmann[1,2], Michael Griener[1], Maciej Krychowiak[3], Dorothe Gradic[3], Erik Flom[3], Mohammad Foisal Siddiki[3], Adrian von Stechow[3], Carsten Killer[3], Felix Reimold[3], Stepan Sereda[3], Ulrich Stroth[1,2], the ASDEX Upgrade Team[1], and the W7-X Team[3] — [1]Max-Planck-Institut für Plasmaphysik, 85748 Garching, Germany — [2]Physik-Department E28, Technische Universität München, 85748 Garching, Germany — [3]Max-Planck-Institut für Plasmaphysik, Greifswald 17491, Germany

Understanding and quantifying particle and energy transport at the plasma edge region is crucial for magnetic confinement fusion devices, as it determines plasma performance and wall loads. For the thermal helium beam systems in the island divertor of the stellarator W7-X, a new polychromator system with 1 MHz time resolution was installed, which is 25000 times faster than the existing system. This allows to measure and characterise turbulent structures, such as plasma edge modes and filaments and correlate their properties with plasma parameters. The diagnostic system measures within two magnetically connected divertors, which, in combination with the multi-purpose manipulator, enables the study of long-range correlation of modes. Utilising a collisional-radiative model, the diagnostic can measure fast density and temperature variations associated with plasma modes and filaments. It also provides high temporal resolution measurements of the detachment process in the divertor. This poster presents the design and implementation of the diagnostic and discusses the first results.

P 17.33 Wed 16:15 ZHG Foyer 1. OG

Investigation of perpendicular transport effects in W7-X divertor islands using 2D plasma parameter measurements with MANTIS. — •Joey Louwe, Felix Reimold, Valeria Perseo, Victoria Winters, Henry Greve, Thomas Klinger, Michael Griener, and W7-X team — Max Planck Institute for Plasma Physics, 17491 Greifswald/85748 Garching, Germany

To enhance the performance of fusion experiments, such as Wendelstein 7-X (W7-X), the divertor concept is employed to efficiently exhaust plasma particles, impurities and heat from the plasma. Both stellarators and tokamaks employ divertors, though their designs differ. W7-X implements the Island Divertor, which utilizes magnetic islands to divert and guide particles and heat along magnetic field lines to target plates. Compared to typical tokamak divertors, the stellarator divertor field lines have a significantly lower pitch angle, making perpendicular transport effects more significant. This study aims to characterize these perpendicular transport effects utilizing the Multispectral Advanced Narrowband Tokamak Imaging System (MANTIS) being build for the W7-X reactor. By integrating MANTIS with active gas puff imaging and helium impurity injections, we can measure specific spectral lines to create 2D images of electron density and temperature of the divertor islands. Additionally, the EMC3-EIRENE simulation code is employed in the determination of optimal helium injection positions, identifying six strategic locations for effective coverage of the divertor island region.

P 17.34 Wed 16:15 ZHG Foyer 1. OG

Towards a deeper understanding of the pronounced increase in co-extracted current density in H-/D- negative ion sources for fusion — •Joey Rubin, Niek den Harder, and Ursel Fantz — Max Planck Institute for Plasma Physics

Negative ion sources for fusion face stringent operational demands. ITER's sources must achieve a current density of 329 A/m^2 for H$^-$ ions over 1000 s and 286 A/m^2 for D$^-$ ions over 3600 s. Negative ions are generated on caesiated surfaces through the conversion of precursors formed in RF-drivers. Electrons are inherently co-extracted with the negative ions and must be removed from the beam before full acceleration. Magnets embedded in the extraction grid deflect and collect these electrons. During long pulses, the co-extracted electron current density increases, particularly in deuterium operation, limiting the pulse duration. At the ELISE test facility, which hosts a half-ITER-size source, a comprehensive set of diagnostics has been used to investigate the physics behind this phenomenon, and strategies to counteract it have been developed. This contribution reviews the current understanding of the mechanism driving the growth of co-extracted electron current density, highlighting the varying growth rates seen during beam extraction. Correlations with caesium dynamics and potential variations are discussed, along with open questions.

P 17.35 Wed 16:15 ZHG Foyer 1. OG

Calibration and Operation of the Imaging Motional Stark Effect Diagnostic at ASDEX Upgrade — •Lea Hollendonner[1], Alexander Bock[1], Andreas Burckhart[1], Thomas Pütterich[1], Rainer Fischer[1], and the ASDEX Upgrade Team[2] — [1]Max Planck Institute for Plasma Physics, 85748 Garching, Germany — [2]See author list of H. Zohm et al, 2024 Nucl. Fusion

Detailed knowledge on the current density distribution in the core of the plasma is essential in many research topics in the field of magnetic confinement nuclear fusion, examples comprising the investigation of sawtooth instabilities, flux pumping, or advanced scenario development. Experimentally, the current density distribution can be reconstructed from measurements of the magnetic field pitch angle. Of all diagnostics capable of measuring the field pitch angle in the plasma core, the Imaging Motional Stark Effect (IMSE) diagnostic offers the highest resolution. Moreover, it provides a two-dimensional image instead of data from a limited amount of channels. In order to routinely operate the IMSE with high resolution, the calibration must be equally accurate. Fine-tuning of the IMSE calibration is challenging and open to optimization. This work presents the state of the IMSE diagnostic at ASDEX Upgrade and investigates possibilities to improve the calibration of the diagnostic.

P 17.36 Wed 16:15 ZHG Foyer 1. OG

The role of turbulence and radial electric field in the achievement of high-performance regimes in W7-X — •Bojana Stefanoska[1], Daniel Carralero[2], Teresa Estrada[2], Thomas Windisch[3], Emmanouil Marakoudakis[2], José Luis Velasco[2], and the W7-X team[3] — [1]Max Planck Institute for Plasma Physics, 85748 Garching, Germany — [2]Laboratorio Nacional de Fusion. CIEMAT, 28040 Madrid, Spain — [3]Max Planck Inst. for Plasma Physics, 17491 Greifswald, Germany

Prolonged operation of the NBI system during the 2023 W7-X campaign refined a high-performance scenario combining NBI and ECRH heating. The NBI+ECRH high-performance (HP) phase exhibits a substantial increase in ion temperature and plasma energy. To study this scenario, the Doppler reflectometry (DR) system was upgraded with an E-band reflectometer, enabling core measurements of density fluctuations and the radial electric field E_r in high-density discharges.

DR measurements show that density fluctuation amplitude decreases as a strong density gradient builds during the pure NBI phase. The strong dependence of turbulence amplitude on the gradient ratio η_i indicates ITG-like turbulence in the core. E_r profiles remain flat before the HP phase and form a strong negative E_r well during it, accurately predicted by neoclassical simulations. Further turbulence reduction is observed in the HP phase, correlating with regions of strong radial electric field. These findings highlight the role of high density gradients in suppressing ITG-like turbulence, enabling improved performance with additional heating.

P 17.37 Wed 16:15 ZHG Foyer 1. OG

Quantification and analysis on the formation of a secondary strike line in the Wendelstein 7-X stellarator — •Sebastian Dräger[1], Thierry Kremeyer[1], Yu Gao[1], Robert Wolf[1,2], and Felix Reimold[1] — [1]Max Planck Inst. for Plasma Physics, 17491 Greifswald, Germany — [2]Technical University of Berlin, Strasse des 17. Juni 135, 10623 Berlin, Germany

In future magnetic confinement fusion reactors, efficient particle exhaust is essential for sustained operation. Helium ash, generated during fusion reactions, and other impurities must be removed to enable steady-state fusion and maintain plasma stability. Since ionized particles are confined by magnetic fields, their removal requires neutralization. For this purpose, Wendelstein 7-X (W7-X) employs an island divertor system. Magnetic islands intersect with target plates, where particles neutralize upon contact, allowing their exhaust. These interactions form high-intensity regions known as strike lines. The divertor plates are meticulously engineered to endure the plasma's heat flux. However, unexpected shifts in heat flux topology pose a significant risk to their integrity.

Recent observations at W7-X have revealed under certain operational conditions the formation of a secondary strike line [1]. This phenomenon, identified through infrared imaging and H_α photon emission, represents a notable change in the heat flux pattern. A precise quantification of the secondary strike line and an analysis of its dependence on plasma parameters is presented.

[1] Yu Gao et al 2024 Nucl. Fusion **64** 076060

P 17.38 Wed 16:15 ZHG Foyer 1. OG

Hybrid kinetic-MHD simulations of interactions between tearing modes and runaway electrons in JOREK — •Shijie Liu[1], Hannes Bergstroem[1], Tong Liu[2], Haowei Zhang[1], and Matthias Hoelzl[1] — [1]Max Planck Institute for Plasma Physics, Garching b. M., Germany — [2]Dalian University of Technology, Dalian, China

Runaway electrons (REs) are of particularly importance to the safe operation of tokamaks. Electrons may be accelerated by the large toroidal electric field arising during a major disruption. Without adequate mitigation measures, these energetic electrons may eventually hit the first wall of the device focusing on an extremely localized area, which poses a serious threat to the safe operation of the device. To predict the runaway dynamics during a disruption and develop mitigation strategies, the mutual interaction between REs and the bulk plasma should be carefully considered.

In this work, we focus on developing a self-consistent coupling of the full-f relativistic PIC model for REs to the background plasmas with a guiding center treatment, using the nonlinear extended MHD code JOREK. The accurate representation of the radial force balance of a circular axisymmetric RE beam is verified by comparing to analytical results. Moreover, a comparison to the 3D tearing modes linear theory is done for the MHD simulation with REs. Finally, non-linear results are presented for tearing modes in the presence of runaway electrons with different Δ'.

P 17.39 Wed 16:15 ZHG Foyer 1. OG

In-situ Uptake Measurement and Modelling of Deuterium Atoms in Self Damaged Tungsten at Different Temperatures — •Abdulrahman Albarodi, Thomas Schwarz-Selinger, and Mikhail Zibrov — Max-Planck-Institute for Plasma Physics, Garching bei München

Self-damaged tungsten samples (damage dose 0.23 dpa) were exposed to low energy deuterium (D) atoms ($<$ 5 eV) at 400, 500 and 600 K to investigate D uptake and D retention at different temperatures. The time evolution of the D depth profile was observed in-situ with ^{3}He nuclear reaction analysis at different uptake times. Thermal desorption spectroscopy was performed ex-situ to determine the bulk and surface model parameters. A modified surface coverage-dependent model was used to describe the results and extended to lower temperatures in the tungsten samples. The extended model was implemented in TESSIM hydrogen transport simulations. Effects of grain boundary diffusion on D depth profile evolution were also investigated by comparison with results from a D atom exposure experiment on a tungsten single crystal at 500 K.

P 17.40 Wed 16:15 ZHG Foyer 1. OG

Validation of a Comprehensive First-Principles-Based Framework for Predicting the Performance of Future Stellarators — •Don Lawrence Carl Agapito Fernando[1], Alejandro Bañón Navarro[1], Daniel Carralero[2], Jose Luis Velasco[2], Arturo Alonso[2], Alessando Di Siena[1], Felix Wilms[1], Frank Jenko[1], and W7-X Team[3] — [1]Max-Planck-Institut für Plasmaphysik, Garching, Germany — [2]Laboratorio Nacional de Fusión, CIEMAT, Madrid, Spain — [3]Max-Planck-Institut für Plasmaphysik, Greifswald, Germany

Validation studies are necessary to ensure the accuracy of simulation predictions relative to experimental results. In this poster, we showcase the results of the successful comprehensive validation of the GENE-KNOSOS-Tango simulation framework for predicting the steady-state plasma profiles in a stellarator. This framework couples the gyrokinetic turbulence code GENE, the neoclassical transport code KNOSOS, and the transport code Tango in a multiple-timescale simulation loop.

We perform ion-scale kinetic-electron and electron-scale adiabatic-ion flux-tube simulations to evolve the density and temperature profiles for four OP1.2b W7-X scenarios. The simulated profiles show excellent quantitative agreement with experimental data, while turbulence properties, such as density fluctuations and heat diffusivities, match the trends extracted from diagnostic measurements. The validation of the GENE-KNOSOS-Tango framework enables us to make credible predictions of physical phenomena in stellarators and reactor performance.

P 17.41 Wed 16:15 ZHG Foyer 1. OG

ECRH Power deposition and Te perturbation investigations using dynamic ECE analysis — •Vaishnavi Murugesan, Matthias Hirsch, Gavin Weir, Juan Fernando Guerrero Arnaiz, Neha Chaudhary, and Robert Wolf — Max Planck Institute for Plasma Physics

At Wendelstein 7-X, the plasma electron temperature profile is derived by assuming that the Electron Cyclotron Emission (ECE) behaves like a blackbody radiation from a certain layer in the plasma. When the plasma is heated using Electron Cyclotron Resonance Heating (ECRH), the microwave beams are absorbed in a thin layer where they are in resonance with the gyration frequency of the electrons. When the ECRH beam power is modulated, perturbations in plasma temperature are initiated, that propagate away from the deposition zone. This modulation is observed as an immediate response in the ECE signals. The goal of this work is to study this zone of power deposition.

A first approach is to do a conditional averaging over the modulation periods and deriving a slope of the local dT/dt that allows the calculation of the power deposition profile. To study the temperature profile during these modulation events, the radiometers should sample at a rate that is at least twice the collision rate of the electrons during these events. For this, a high frequency-resolution radiometer backend called the ZOOM system, has been upgraded to help monitor the power deposition zones at high sampling rates.

P 17.42 Wed 16:15 ZHG Foyer 1. OG

Divertor island studies with GRILLIX — •Barnabas Csillag, Andreas Stegmeir, Christoph Pitzal, Marion Finkbeiner, and Frank Jenko — Max Planck Institute for Plasma Physics, Garching, Germany

The global, electromagnetic, drift-reduced, trans-collisional Braginskii fluid turbulence code GRILLIX has been recently adapted to stellarator geometry. However, in order to perform comprehensive simulations of the Wendelstein 7-X Scrape-Off Layer (SOL) plasma, it is necessary to reconsider the treatment of boundary conditions in the model. So far the Immersed Boundary Approach (IBA) has been applied in GRILLIX, and using that the code was able to produce high fidelity tokamak edge-SOL simulations in diverted geometry. Nevertheless, the 3D geometry of the W7-X island divertors could present an insurmountable obstacle with such approach.

To examine the effects of boundary condition treatments in GRILLIX, a simplified divertor island geometry is investigated. In this test environment a circular toroidal magnetic field is applied with helical perturbations superimposed on it, creating the magnetic islands at a rational surface. In this model the magnetic islands can be intersected with poloidal target plates that are following the helical shape of the islands, similarly to the divertor plates of Wendelstein 7-X. Such setup is suitable to test the boundary condition treating methods, like the already implemented IBA, or if it is not found sufficient, for instance the Leg Value Fill scheme.

P 17.43 Wed 16:15 ZHG Foyer 1. OG

Simulation of fully global electromagnetic turbulence in the stellarator W7-X — •Yann Narbutt[1], Ksenia Aleynikova[1], Matthias Borchardt[1], Ralf Kleiber[1], Alexey Mishchenko[1], Edilberto Sánchez[2], and Alessandro Zocco[1] — [1]Max Planck Institute for Plasma Physics, Wendelsteinstraße 1, 17489 Greifswald — [2]Laboratorio Nacional de Fusión, CIEMAT, Avda. Complutense 40, Madrid 28040

Magnetic confinement fusion needs high values of $\beta = \langle p\rangle/(B^2/2\mu_0)$, the ratio of plasma pressure to magnetic pressure, to achieve high performance. Moderate β can be beneficial for ion-temperature-gradient suppression. However, when β exceeds a certain threshold, the so-called kinetic ballooning mode (KBM) and other electromagnetic instabilities may be destabilized. These instabilities, driven by plasma pressure gradients and inherently electromagnetic, can result in strong outward-directed heat fluxes, thereby degrading plasma confinement, as has been shown by global nonlinear simulations. While KBMs have been successfully studied linearly and nonlinearly in the Wendelstein 7-X stellarator using flux-tube simulations, it has also been demonstrated that the instability tends to become most unstable as it develops a global structure on the magnetic surface. Utilizing the global gyrokinetic code EUTERPE electromagnetic instabilities and turbulence are investigated in the stellarator Wendelstein 7-X at β-values of 1%, 2.5% and 4%.

P 17.44 Wed 16:15 ZHG Foyer 1. OG

Tightest possible energetic bounds on local gyrokinetic instabilities — •Paul Costello and Gabriel Plunk — Max Planck Institute for Plasma Physics, Greifswald, Germany

The turbulence in fusion plasmas, which hampers their performance in many respects, is best understood with gyrokinetic theory. Recent work has shown that energetic upper bounds on the growth of turbulence causing gyrokinetic instabilities can be derived by seeking optimal modes, states of the gyrokinetic equation which maximise the growth of an energy norm [2]. Typically, an energy norm is chosen which is a nonlinear invariant of the gyrokinetic equation, such that the bounds are valid linearly and nonlinearly.

The growth of unstable linear eigenmodes, which are the focus of much theoretical and numerical work, is also bounded by the optimal mode growth rate. A natural question, which we seek to answer in this work, is, “How tightly can the linear eigenmode growth be bounded?” We find that using a special energy norm which is not a nonlinear invariant in most systems gives an upper bound equal to the growth of the most unstable linear eigenmode. This energy norm is a sum of projection coefficients in the linear eigenmode basis and is positive definite by the completeness of these modes [2]. Systems for which this energy norm is a nonlinear invariant are free from subcritical turbulence and may form a simple paradigm for turbulence saturation [3].

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[2] K. M. Case. Annals of Physics 1959.
[3] G. G. Plunk. Phys. Plasmas 2015.

P 17.45 Wed 16:15 ZHG Foyer 1. OG

Feedback Controlled Phase Contrast Imaging at Wendelstein 7-X — •Max Zimmermann[1], Adrian von Stechow[1], Jan-Peter Bähner[2], Søren Kjer Hansen[2], Sean Ballinger[2], Olaf Grulke[1,3], Eric Edlund[4], Miklos Porkolab[2], and The W7-X Team[1] — [1]Max Planck Institute for Plasma Physics, 17491 Greifswald, Germany — [2]MIT Plasma Science and Fusion Center, Cambridge, MA 02139, USA — [3]Technical University of Denmark, 2800 Kongens Lyngby, Denmark — [4]SUNY Cortland, Cortland, NY 13045, USA

The phase contrast imaging (PCI) diagnostic at Wendelstein 7-X (W7-X) is used for detection of core turbulence density fluctuations [E.M. Edlund et al. 2018 Rev. Sci. Instrum. 89 10E105]. This is done by imaging electron density fluctuations using a CO_2 laser. The laser is aligned using several mirrors, some of which are attached to the outer vessel of W7-X and are therefore subject to vibrations from auxiliary systems (e.g. vacuum pumps). These vibrations lead to movements of the image plane and are visible in the PCI signal as low frequency components up to 250 Hz. A reduction of these vibrations leads to increased beam position stability and a higher signal saturation limit for PCI signals. A digital RST feedback controller is designed and implemented, which together with a piezo-based fast steering mirror and a four quadrant detector forms an active vibration compensation system. The controller design is validated by frequency response measurements and its impact on plasma fluctuation signals is evaluated.

P 17.46 Wed 16:15 ZHG Foyer 1. OG

Comparision of absolute calibration techniques for the Thomson scattering diagnostic at W7-X — •Jannik Wagner, Golo Fuchert, Ekkehard Pasch, K. Jakob Brunner, Jens Knauer, Sergey A. Bozhenkov, Matthias Hirsch, Robert C. Wolf, and W7-X Team — Max Planck Insitute for Plasma Physics, Germany

Thomson scattering is a cornerstone diagnostic for determining plasma electron density and temperature in many nuclear fusion experiments, such as Wendelstein 7-X (W7-X). To reconstruct these parameters, absolute spectral calibration factors of the diagnostics' optical detection system are required. At W7-X, two calibrations are performed to determine these factors: A relative spectral calibration and an absolute calibration using Raman scattering of Nd:YAG laser pulses in Nitrogen. The relative calibration of the system is needed for electron temperature measurement, interpretation of the absolute calibration and extension of the latter into wavelength ranges inaccessible by Raman scattering. A recent study [1] proposes that Rayleigh scattering of laser pulses from a wavelength tunable optical parametric oscillator (OPO) in Argon could serve as a standalone-source for the absolute calibration. The calibration method has the potential to drastically reduce the systematic errors occurring from a strong dependence of the absolute calibration factors on the accuracy of the wavelength measurement in the spectral range of the Raman scattered signal. In this work, the conventional Raman calibration procedure is compared with the promising direct measurement using an OPO.

[1] E.R. Scott et al. JINST 14 C10033 (2019)

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Towards a standard Diagnostic for not absorbed Electron Cyclotron Resonance Heating power at Wendelstein 7-X — •Jonas Zimmermann, Torsten Stange, Heinrich Laqua, Dmitry Moseev, and Johan Oosterbeek — IPP Greifswald

Electron cyclotron resonance heating (ECRH) at 140 GHz is the primary heating method of the Wendelstein 7-X device, a magnetically confined plasma experiment with the goal to demonstrate 30 minute plasma operation. Gaussian beams, with a power of about 1 MW each, are radially injected into the plasma, propagate as plasma waves, and are absorbed at the resonance where their frequency matches the 2nd harmonic of the electron cyclotron frequency. Non-absorbed radiation leaves the plasma and hits the wall opposite to the ECRH launchers. During long pulse operation, even a small percentage of non-absorbed power is sufficient to cause critical head loads on directly hit components. Therefore, a primary objective is to deposit the power only in the plasma and to guarantee the optimal parameters for polarization and direction of the beam. The wall opposite to the ECRH launchers is equipped with an antenna array called Electron Cyclotron Absorption (ECA) diagnostic, capable of detecting the power density and sensitive to the polarization of the transmitted beams. It is planned to use this diagnostic to routinely measure the fraction of non-absorbed power caused by various plasma effects or incorrect beam parameterization. This poster presents initial results of the ECA diagnostic on absorption, refraction, and beam parameter changes, and outlines steps toward a quantitative absorption diagnostic.

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Characterisation of the assimilation of shattered pellets injected into a fusion plasma — •Ansh Patel[1], G Papp[1], A Matsuyama[2], S Jachmich[3], ASDEX Upgrade Team[4], and EUROfusion Tokamak Exploitation Team[5] — [1]Max Planck Institute for Plasma Physics, Garching, Germany — [2]Kyoto University, Uji, Kyoto, Japan — [3]ITER Organization, St. Paul-lez-Durance, France — [4]See the author list of H. Zohm et al, Nucl. Fusion 2024 — [5]See the author list of E. Joffrin et al, Nucl. Fusion 2024

A disruption mitigation system (DMS) is necessary for reactor-relevant tokamaks like ITER to ensure the preservation of machine components throughout their designated operational lifespan. To address the intense heat and electromagnetic loads during a disruption, a shattered pellet injection (SPI) system will be employed. The SPI system involves injecting material into the plasma in the form of a cryogenic pellet that is shattered on a bent tube before entering the plasma. The penetration and assimilation of the injected material is influenced by various SPI parameters, including the fragment sizes, speeds, composition and the injection scheme. In this contribution, the material assimilation during SPI in the ASDEX Upgrade tokamak is characterized. The influence of different SPI parameters and different injection schemes on assimilation is carried out to determine optimal parameters for mitigation. The spatial distribution of material ablation and assimilation was carried out. Experimental analysis is also complemented with modelling with the 1.5D INDEX code to understand the plasma dynamics and its dependence on the aforementioned SPI parameters.

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Fast Surrogate Modeling of Radio-Frequency Minority Heating at ASDEX Upgrade — •Michael Sieben, Markus Weiland, Roberto Bilato, and ASDEX - Team — Max-Planck-Institute for Plasma Physics

Auxiliary heating is essential to achieve the burning plasma conditions in fusion reactors. Radio-frequency waves in the Ion Cyclotron Range of Frequency (ICRF) are one of the possible auxiliary heating system in present devices and planned for ITER. The combined full-wave and Fokker-Planck code package TORIC-SSFPQL [1] provides accurate heating profiles for transport modeling in view of discharge analysis and design. However, long computation times pose challenges for fast transport simulations and real-time applications. We present a fast neural network (NN) surrogate model that reproduces minority heating profiles in deuterium-hydrogen plasmas at the ASDEX Upgrade (AUG) research reactor with real-time capability and high accuracy - comparable to an approach reported for NSTX and WEST [2]. We highlight possible directions for future work that could improve model accuracy - particularly by accounting for second harmonic heating and integrating equilibrium parameters into the model, which has been found to play a relevant role at AUG.

[1] M. Brambilla and R. Bilato. Nuclear Fusion, 49(8):085004, 2009.
[2] Á. Sánchez-Villar, Z. Bai, et al. Nuclear Fusion, 64(9):096039, 2024.