P 11: Poster I

Time: Wednesday 14:00–15:30 Location: HSZ EG

P 11.1 Wed 14:00 HSZ EG

Novel microwave interferometry approach for spatial plasma profile measurements — •Christos Vagkidis, Eberhard Holzhauer, Walter Kasparek, Alf Köhn-Seemann, Stefan Merli, Mirko Ramisch, and Andreas Schulz — IGVP, University of Stuttgart, Germany

Interferometry is widely used in plasma physics to obtain the line-integrated density of a plasma. Here, we present a method to obtain in addition information about the spatial profile of the plasma density from interferometry measurements with the help of accompanying full-wave simulations. For this purpose, a microwave-generated plasma torch is used, which is confined in a quartz tube. A high frequency (208 GHz) microwave beam is emitted by a horn antenna, perpendicular to the plasma, and used as a probing beam. The receiving antenna is placed behind the plasma and is aligned with the sending antenna. The reference beam is generated artificially from a network analyser, which measures the phase difference of the beams. In spite of the beam being scattered, the phase difference can still be used to calculate the line-integrated density of the plasma with reasonable accuracy. Furthermore, the intensity distribution of the probing beam, in the plane perpendicular to the plasma torch, is obtained by moving the receiving antenna with a stepping motor, which can be operated with sub-millimetre precision. Full-wave simulations (inhouse FDTD code and COMSOL Multiphysics) have been carried out with arbitrary plasma density profiles. Comparing the simulation results with experiments allows to deduce information on the actual density profile.

P 11.2 Wed 14:00 HSZ EG

Inverstigation on methanol synthesis with a microwave plasma torch — •Marc Bresser, Katharina Wiegers, Andreas Schulz, Matthias Walker, and Günter Tovar — IGVP, University of Stuttgart, Germany

Due to the increasing concentration of carbon dioxide (CO_2) in the atmosphere and the resulting impact on climate change, possibilities are being sought to remove CO_2 from air by direct air capturing and a subsequent reuse of CO_2. In addition, the chemical industry is heavily dependent on fossil fuels and is looking for new ways to generate sustainable base chemicals. A possible renewable way to form carbon-based products is to use CO_2 as a reactant for the production of the base chemical methanol. Renewable methanol synthesis could be achieved via a microwave plasma process using electricity from renewable sources and "green" hydrogen (H_2). A CO_2 plasma forms carbon monoxide (CO) and oxygen (O_2).The oxygen is extracted via ceramic hollow fibers from the plasma. The addition of H_2 to the CO_2 plasma leads to the formation of new molecules such as methanol. The methanol can be separated by condensation of the exhaust gas. In this work, the CO_2 conversion in a microwave plasma (2.45 GHz) is studied. In dependence of the gas flow and the microwave power (up to 6 kW) the exhaust gas composition is analyzed with a Fourier-transform infrared spectroscopy (FTIR). Optical emission spectroscopy (OES) in the range from UV to IR is used to investigate the influence of the added H_2 onto the plasma gas composition and the exhaust gas stream.

P 11.3 Wed 14:00 HSZ EG

Applying machine learning to the inverse scattering problem for experimental plasma profiles — •Ewout Devlaminck, Christos Vagkidis, Mirko Ramisch, and Alf Köhn-Seemann — IGVP, University of Stuttgart, Germany

This work proposes a novel method to study the spatially resolved electron density profile of experimental plasmas using machine learning. The approach, here applied to an atmospheric plasma torch, solves the so-called inverse scattering problem of recovering the plasma profile from non-invasive measurements of the scattered microwave field. The proposed multi-output neural network is trained on 1D scattered intensity profiles, obtained from full-wave FDTD simulations of a high-frequency microwave beam traversing the plasma torch setup with various plasma profile settings. As opposed to the conventional experimental diagnostic, which only provides information on the line-integrated plasma density, the neural network can use the same measurement data to predict multiple parameters describing the complete spatial density profile.

P 11.4 Wed 14:00 HSZ EG

Combining a nanosecond-pulsed DBD with an electrolytic cell to reduce CO_2 and N_2 — •Martin Leander Marxen[1], Luka Hansen[1], Gustav Sievers[2], Volker Brüser[2], and Holger Kersten[1] — [1]Plasmatechnology Group, Institute of Experimental and Applied Physics, Kiel University (CAU), Kiel, Germany — [2]Leibniz Institute for Plasma Science and Technology (INP), Greifswald, Germany

Plasma-catalytic approaches are promising for converting mixtures of CO_2 or N_2 with H_2 at mild conditions (ambient pressure and low temperatures) into higher-value gases or fuels such as syngas ($CO + H_2$), methanol (CH_3OH) or ammonia (NH_3)[1]. Activation of the strong chemical bonds in CO_2 and N_2 is achieved by collisions of the molecules with energetic electrons present in the discharge.

In a polymer electrolyte membrane (PEM) cell[2], oxygen ions (O^{2-}) and protons (H^+) are produced in the anode space. The protons permeate the membrane and adsorb on the cathode. By locating a custom nanosecond-pulsed DBD in the cathode space (as proposed in this contribution), the adsorbed hydrogen can directly be utilized for reducing activated CO_2 or N_2 species. This has two major advantages compared to other plama-catalytic approaches: First, hydrogen is produced in place. Second, the power supplied to the plasma is mainly used to activate the CO_2 or N_2 bonds instead of activating H_2 bonds as well.

[1] A. Bogaerts et al., J Phys D Appl Phys 53 (2020) 443001

[2] S. Shiva Kumar, V. Himabindu, Mater Sci Energy Technol 2 (2019) 442-454

P 11.5 Wed 14:00 HSZ EG

Investigation of OH and H2O2 distribution in aqueous solution treated by a humid atmospheric pressure plasma jet — •Steffen Schüttler, Emanuel Jess, Marc Böke, Volker Schulz-von der Gathen, and Judith Golda — Ruhr-University Bochum, Universitätsstraße 150, 44801 Bochum, Germany

Biological enzymes are suitable to convert a substrate into a valuable product in presence of H2O2 without producing heavy metal waste. Atmospheric pressure plasma jets can produce H2O2 under very good control so that a stable environment can be maintained. This work investigated the delivery of reactive species from an atmospheric pressure plasma jet into a liquid. The capillary plasma jet used is comparable to the COST reference jet and was operated in humid He. Spectrophotometric diagnostics by use of ammonium metavanadate and terephthalic acid were performed to measure the concentrations of H2O2 and OH in the liquid, respectively. The distribution of reactive species at the liquid surface was visualise by the chemiluminescence of luminol. Our work showed that a H2O2 concentration of up to 1 mM was achievable while the OH concentration was a factor of 40 lower. Both species could be controlled by the dissipated plasma power and by the humidity of the feed gas. The transport process could be used to achieve a higher selectivity towards H2O2. Pulsing the RF jet at low frequencies of up to 2 kHz increased the energy efficiency of H2O2 production while reducing the OH concentration in the liquid. This work is supported by the DFG within CRC1316 (Subproject B11, project number 327886311).

P 11.6 Wed 14:00 HSZ EG

Time-resolved characterization of a micro cavity plasma array using a multi-photomultiplier setup — •Henrik van Impel[1], David Steuer[1], Volker Schulz-von der Gathen[2], Marc Böke[2], and Judith Golda[1] — [1]Plasma Interface Physics, Ruhr-University Bochum, D-44801 Bochum, Germany — [2]Physics of Reactive Plasmas, Ruhr-University Bochum, D-44801 Bochum, Germany

Dielectric barrier discharges (DBDs) have many applications, such as ozone generation or treating volatile organic compounds (VOCs). To understand the underlying processes, fundamental knowledge about the generation of reactive species is necessary. Here we investigated atomic oxygen production as a model system in a micro cavity plasma array, a customized surface DBD confined to geometrically arranged cavities of micrometer size. We studied the behavior and the plasma chemical processes using optical emission spectroscopy methods. The discharge is operated in helium with a molecular oxygen admixture of about 0.1% at atmospheric pressure using a 15 kHz and about 600V triangular excitation voltage. With helium state enhanced actinometry (SEA) [1] high atomic oxygen densities could be observed. Using a multi-photomultiplier setup with synchronous narrow bandwidth detection of characteristic transitions and SEA, we measured the temporal evolution of the atomic oxygen density and the effective mean electron energy over the first ignitions, which are affected by a memory effect due to residual charges on the dielectric surface.

The project is funded within project A6 of the SFB 1316.

[1] David Steuer et al 2022 Plasma Sources Sci. Technol. 31 10LT01

P 11.7 Wed 14:00 HSZ EG

Development of plasma reactors for plasma-assisted catalysis — •Kerstin Sgonina, Alexander Quack, and Jan Benedikt — Institute of Experimental and Applied Physics, Kiel University, Kiel, Germany

The energy efficient and decentralized performance of catalytic reactions, such as for the production of ammonia, has become even more important nowadays. Plasma-assisted catalysis can help to achieve these goals as it is available on demand and works without enormous external heating. Non-equilibrium atmospheric pressure plasmas are used to dissociate gaseous molecules, which can then react at the surface of the catalyst to form the desired products. Plasma-assisted catalysis reactors at atmospheric pressure are often realized by packed bed reactors, in which the catalyst is packed into or deposited on millimeter-sized spheres. However, these millimeter-sized spheres are not feasible for all types of possible catalysts.

Therefore, different plasma reactors for plasma-assisted catalysis were developed and tested with and without different catalysts for in-plasma catalysis, where the catalyst is in direct contact with plasma, and post-plasma catalysis, where only reactive species from the plasma are reaching the catalyst. Dielectric barrier discharges operated at kHz- or radio-frequencies are used for ammonia synthesis using N_2 and H_2 as working gas as well as for methane formation experiments using CO_2 and H_2. Depending on the reactor-type and working gas, the gas temperature during plasma operation ranges from room temperature up to 200 °C.

P 11.8 Wed 14:00 HSZ EG

Coaxial dielectric barrier discharge for plasma catalysis in N_2 and H_2 — •Roland Friedl[1], David Rauner[1], and Ursel Fantz[1,2] — [1]AG Experimentelle Plasmaphysik, Universität Augsburg, 86135 Augsburg — [2]Max-Planck-Institut für Plasmaphysik, Boltzmannstr. 2, 85748 Garching

Dielectric barrier discharges (DBDs) are frequently utilized for plasma catalytic systems, due to their advantages regarding several crucial aspects: due to the repetitive filamented discharge, gas heating is avoided and distinctive non-equilibrium conditions are maintained at atmospheric pressure. In addition, if operated in a so-called packed-bed configuration, where the catalyst is coated on or embedded in the dielectric material, a large interaction area between the plasma and the active catalyst surface can be exploited.

In this contribution, a recently commissioned coaxial DBD setup is introduced, which is targeted towards the investigation of nitrogen and hydrogen discharges together with catalytic materials in a packed-bed configuration, e. g. in view of ammonia production. First investigations in view of an electrical and spectroscopical characterization are presented.

P 11.9 Wed 14:00 HSZ EG

Active Flux for Vlasov-Maxwell I: Application of the Linear Advection scheme to the Vlasov System — Lukas Hensel, •Gudrun Grünwald, and Rainer Grauer — Ruhr-Universität Bochum, Universitätsstraße 150, 44801 Bochum, Germany

The Vlasov-Maxwell system for the kinetic description of collisionless plasmas is numerically challenging due to its high dimensionality (3 dimensions in position and velocity space, respectively, plus the time) as well as the coupling of the particle trajectories to the EM-fields, resulting in extreme computational expense. Thus, there is an ongoing demand for efficient low-dissipation conservative schemes suitable for this system. The Active-Flux (AF) Method is a finite-volume method for hyperbolic conservation laws with additional degrees of freedom on the cell interfaces. It hereby allows achieving 3rd order while keeping a compact stencil in space and time. This can facilitate the bulk coupling. The point values on the cell interfaces are evolved independently of the conservation update, with the former step not having to be conservative. For the Vlasov equation, being a linear transport equation, this allows for the use of semi-Lagrangian techniques. We present first results on the numerical error of the method for the cases of 1 and multidimensional linear advection and the 1D electrostatic limit, considering the case of Landau-damping. AF showed lower dissipation than other 3rd order schemes and performed better particularly at low resolution, encouraging its application to the full 3D Vlasov-Maxwell problem.

P 11.10 Wed 14:00 HSZ EG

Active Flux for Vlasov-Maxwell II: Application of the Linear Advection scheme to the Vlasov System — •Lukas Hensel, Gudrun Grünwald, and Rainer Grauer — Ruhr-Universität Bochum, Universitätsstraße 150, 44801 Bochum, Germany

The Vlasov-Maxwell system for the kinetic description of collisionless plasmas is numerically challenging due to its high dimensionality (3 dimensions in position and velocity space, respectively, plus the time) as well as the coupling of the particle trajectories to the EM-fields, resulting in extreme computational expense. Thus, there is an ongoing demand for efficient low-dissipation conservative schemes suitable for this system. The Active-Flux (AF) Method is a finite-volume method for hyperbolic conservation laws with additional degrees of freedom on the cell interfaces. It hereby allows achieving 3rd order while keeping a compact stencil in space and time.

The point values on the cell interfaces are evolved independently of the conservation update. For the Vlasov equation, being a linear transport equation, this allows for the use of non-conservative semi-Lagrangian techniques. We present first results on the application of AF to the full three-dimensional Vlasov-Poisson system. Different possible strategies for directional splitting that allows the solution of the six-dimensional equation with lower dimensional substeps are discussed. The multidimensionality of AF furthermore allows for the solution of the three-dimensional velocity space in a single steps, encouraging its future application to the relativistic Vlasov-Maxwell equations.

P 11.11 Wed 14:00 HSZ EG

Efficient GPU implementation of 2D Particle-in-Cell Simulations for capacitively coupled plasmas — •Christian A. Busch and Uwe Czarnetzki — Institute for Plasma and Atomic Physics, Ruhr University Bochum, D-44780 Bochum, Germany

Particle in cell (PIC) simulations are an indispensable tool for the study of low-pressure plasmas, in which a correct description of the particle transport can only arise from kinetic theory. However, the great ability of PIC simulations to model such systems has the drawback of being extremely expensive computationally.

In recent years, the development of general purpose graphics processing units (GPGPUs), provided cards with thousands of cores for computations different from graphics processing. This highly parallel hardware allows significant speedups in PIC simulations up to around a factor of 100 compared to CPUs, enabling the simulation of large multidimensional discharges.

Presented here are details for the efficient implementation of all components of a 2d3v PIC/MCC simulation on the GPU. The focus is on data management across the different types of memory on the GPU. Since data transfer is one of the main bottlenecks for high speed computation, optimization of the data storage and processing strategy is key to a successful implementation of PIC codes on the GPU.

P 11.12 Wed 14:00 HSZ EG

Control of the angular distribution of incident ions by tailoring electromagnetic fields in the sheath region — •Elia Johannes Jüngling, Neil Unteregge, David Klute, Marc Böke, and Achim von Keudell — Experimental Physics II - Reactive Plasmas, Ruhr-University Bochum, Bochum, Germany

The angular distribution of ions impinging on a surface in contact with a plasma plays a key role in various applications like anisotropic plasma etching or glancing angle film growth for the fabrication of microstructure devices. Here, we investigate ways to influence and ultimately control the ion incident angle and the angular distribution of the impinging ions to enable a true 3d manufacturing of microstructure devices. The ion incident angle can be controlled by applying additional local electric and magnetic fields in the sheath region of a plasma. Here, the electric field is modified by including a grid system (mask) in front of the surface which can be either on the floating potential of the plasma or externally biased; a magnetic field parallel to the surface is introduced to induce an asymmetry in the angular distribution of incident ions. A combination of both methods has been tested for reactive ion etching of carbon films in an argon-oxygen plasma and for deposition of copper in a HIPIMS plasma. The resulting etching or deposition profiles have been compared with a 2d3v particle-in-cell code (PIC) to simulate the ion trajectories in the sheath region/mask region in front of the substrate surface. A very good agreement has been found.

P 11.13 Wed 14:00 HSZ EG

Studies of low temperature radio-frequency discharges using a velocity moment analysis — •Tim Bolles, Maximilian Klich, Thomas Mussenbrock, Ralf Peter Brinkmann, and Sebastian Wilczek — Ruhr University Bochum, 44780 Bochum, Germany

Plasmas are complex systems in terms of their physics and chemistry. Thus, a fundamental understanding of the underlying mechanisms is crucial. The solution of the Boltzmann equation (BE) offers insight into the full spatio-temporal dynamics of the plasma. Single particle simulations such as the kinetic particle-in-cell/Monte Carlo collisions scheme (PIC/MCC) are a feasible way to obtain this information. This work aims to generate a fundamental understanding of a low-temperature plasma by the means of an analysis of velocity moments of the electron energy distribution function. By doing so, the particle generation can, for example, be related to plasma heating. Since the PIC/MCC scheme gives a stochastic solution to BE, arbitrary moments can be calculated and interpreted without approximations and truncation. Many considerations stop the analysis after the first moment, known as momentum balance. We, however, include the energy balance equation (i.e., the second moment) in our evaluation. For our work, we run simulations at varied parameters for pressure, background gas and driving frequency. The conservation equations, especially the energy balance equation, then provides insight into energy dissipation mechanisms. Overall, this work establishes the second moment of the BE as valuable diagnostics and contributes to a fundamental understanding.

P 11.14 Wed 14:00 HSZ EG

High-efficiency machine learning approach for nanoparticle 2D size characterization via kinetic Mie polarimetry — •Alexander Schmitz, Andreas Petersen, and Franko Greiner — IEAP, Kiel University, 24118 Kiel, Germany

In a nanodusty plasma, the determination of the size of the nanoparticles is crucial to their diagnostics. In the Mie regime, in situ polarization measurements of light scattered by the particles (polarimetry), have proven to be an effective, non-invasive technique.

This method holds a number of challenges. The polarization state depends not only on the particle size, but also on its complex refractive index. Furthermore, the inverse mapping from the measured polarization state to the time dependent particle size and refractive index in a reactive plasma exhibits a strongly non-linear relationship. To resolve this, a customized kinetic fitting algorithm has been introduced in the past [1]. However, that method, based on Least-Square Fits, is highly sensitive to the time series length and requires considerable computing time.

We present a new deep-learning approach to the mapping problem via our High-Efficiency Refractive index MappIng NEural network (HERMINE). With this, the error rate of automated data evaluation, as well as computing time was significantly reduced. This paves the path for future data-intensive, real-time imaging of the particle's growth dynamics in nanodusty plasmas [2].

[1] S Groth et al, J. Phys. D: Appl. Phys., 2015.
[2] S Groth et al, Plasma Sources Sci Technol, 28 (11), 2019.

P 11.15 Wed 14:00 HSZ EG

3D machine-learning reconstruction techniques for particles in dusty plasmas — •Andre Melzer, Michael Himpel, Christina Knapek, Daniel Maier, Daniel Mohr, and Stefan Schütt — Institute of Physics, University Greifswald

Dusty plasmas provide an interesting system to study fundamental processes in many-particle systems since the particles can be imaged and followed on the kinetic individual-particle level.

We have performed experiments with dusty plasmas on parabolic flights using a stereoscopic camera system with four cameras. Under microgravity conditions the dust particles form a dense dust cloud, and a small fraction of the dust cloud is imaged by the four cameras.

In this contribution, techniques to reconstruct the three-dimensional position of the dust particles from the stereoscopic images with the help of machine-learning methods are reviewed and tested. This is important for a future application in the Compact facility planned for the ISS [1].

The work is supported by DLR under 50WM2161/50WM1962.

[1] C. Knapek et al., "COMPACT - A new complex plasma facility for the ISS", Plasma Phys. Control. Fusion 64 (2022) 12400

P 11.16 Wed 14:00 HSZ EG

What's the rheology of electro-rheological plasmas? — •Michael Kretschmer[1,2], Markus Thoma[1], Andreas Schmitz[1], Lukas Wimmer[1], Thomas Nimmerfroh[1], and Christian Schinz[1] — [1]Justus Liebig University, 1st Institute for Physics, Giessen — [2]Technische Hochschule Mittelhessen, Abt. EI, Giessen, Germany

Negatively charged micron-sized particles inside a low-temperature plasma interact with each other and form strongly coupled Coulomb systems. In such so-called complex plasmas structure formation can be observed, from crystalline states ('plasma crystal') to dynamical fluids, depending on the plasma parameters. Since gravity is a disturbing factor many experiments with complex plasmas are performed in microgravity, e.g. on parabolic flights or aboard the International Space Station ISS.

We report here on experiments on so-called electro-rheological (ER) plasmas done on parabolic flights. ER plasmas are a model system of well-known and technically used ER fluids where immersed particles form strings when an electric field is applied. This drastically changes rheological properties, such as viscosity and elasticity of the fluid.

In a setup similar to PK-4 on the ISS we use a laser to manipulate strings of microparticles inside a polarity-switched DC discharge by applying a force (light pressure) in longitudinal as well as transversal direction. The behaviour between particles in strings and unbound particles is investigated to compare their rheology and to decide whether the labeling of a complex plasma as 'ER' is justified.

P 11.17 Wed 14:00 HSZ EG

Dust acoustic wave properties in varying discharge volumes — •Christina A. Knapek[1,4], Mierk Schwabe[2,4], Victoriya Yaroshenko[3,4], Peter Huber[4], Daniel P. Mohr[1,2,4], and Uwe Konopka[5] — [1]Institute of Physics, University of Greifswald, Greifswald, Germany — [2]Institut für Physik der Atmosphäre, DLR, Oberpfaffenhofen, Germany — [3]Institut für Solar-Terrestrische Physik, DLR, Neustrelitz, Germany — [4]Institut für Materialphysik im Weltraum, DLR, Köln, Germany — [5]Physics Department, Auburn University, Auburn, Alabama, USA

An ion flow through a cloud of microparticles suspended in a low-temperature plasma can induce an ion streaming instability and lead to the formation of dust acoustic waves. The properties of such self-excited dust acoustic waves under the influence of active compression of the dust particle system were experimentally studied. Ground based laboratory experiments show clearly that wave properties can be manipulated by changing the discharge volume and thus the dust particle density. Complementary experiments under microgravity conditions (parabolic flights) were less conclusive due to residual fluctuations in the planes acceleration indicating the need for a better microgravity environment. A theoretical model, using plasma parameters obtained from PIC (particle-in-cell) simulations as input, supports the experimental findings. It shows that the waves can be described as a new observation of the dust acoustic mode which demonstrates their generic character. This work is funded by DLR/BMWi (FKZ 50WP0700, FKZ 50WM1441).

P 11.18 Wed 14:00 HSZ EG

Dichromatic Mie scattering approach for particle size measurements — •Franziska Reiser, Sören Wohlfahrt, and Dietmar Block — Institute of Experimental and Applied Physics, Kiel University, Germany

Microparticles are an essential component in complex (dusty) plasmas. These microparticles are negatively charged in the plasma and levitate in the plasma sheath due to the sheath electric field. To understand structure as well as dynamical processes in dust clouds, a precise knowledge of the particle size is indispensable, as it determines charge as well as all forces acting on a particle. Recently, a suitable diagnostic based on Mie scattering was introduced [1]. It compares measured angular and polarization resolved intensity patterns of scattered light with predictions of Mie theory. However, Mie scattering is based on interference, the intensity patterns of particles which slightly differ in size and refractive index are selfsimilar and thus an ambiguity in the resulting particle size can occur. As this ambiguity is dependent on the wavelength it can be removed using two lasers with different wavelength. This contribution presents an enhanced setup using two lasers with different wavelength and discusses evaluation concepts.

[1] S. Wohlfahrt, D. Block, 2021 Phys. Plasmas 28

P 11.19 Wed 14:00 HSZ EG

COMPACT – the future complex plasma facility for the ISS — •Daniel P. Mohr and Christina A. Knapek for the COMPACT-Collaboration — University of Greifswald, Institute of Physics, Greifswald, Germany

Complex, or dusty, plasmas consist of micrometer-sized grains injected into a low temperature noble gas discharge. The grains become charged and interact with each other via a screened Coulomb potential. On ground, gravity compresses the system and prevents the generation of larger, three-dimensional particle clouds.

The future complex plasma facility COMPACT will allow the investigation of large three-dimensional complex plasmas under microgravity conditions on the International Space Station (ISS). Its technology is mainly based on pre-studies (Ekoplasma, PlasmaLab), including a novel plasma chamber with adaptive internal geometry, a four-electrode radio-frequency system for plasma generation, and a stereoscopic particle diagnostic that allows to record 3D particle dynamics in real-time.

We will present the scientific goals of COMPACT, scientific and technology results from the pre-studies, technologies currently under discussion, and the project status.

This work is funded by DLR/BMWi (FKZ 50WM2161).

P 11.20 Wed 14:00 HSZ EG

Comparison of HERMES-2 and EMC3 for the SOL transport of Wendelstein 7-X — •David Bold[1], Brendan Shanahan[1], Felix Reimold[1], and Benjamin Dudson[2] — [1]Max-Planck-Institut für Plasmaphysik, Greifswald, Germany — [2]Lawrence Livermore National Laboratory, Livermore, California, USA

The EMC3-EIRENE code is a well established tool for modelling of the scrape-off layer (SOL) of stellerator devices like Wendelstein 7-X. However EMC3 does not include drifts, which are expected to play a significant contribution to the transport in the SOL.

HERMES-2 is a hot-ion drift reduced SOL-model using the BOUT++ framework. A recent addition to BOUT++ is the inclusion of the flux coordinate independent (FCI) scheme for fully 3D geometries. The HERMES-2 model is currently modified to be able to handle the geometry of a stellerator using the FCI method. As a first step the results of the two codes are compared when solving the geometry of Wendelstein 7-X. For a direct comparison, only the terms in Hermes-2 which are similar to those found in EMC3 are used.

P 11.21 Wed 14:00 HSZ EG

Overview of MHD mode observations during the recent operational phase at the Wendelstein 7-X stellarator — •Kian Rahbarnia, Sara Vaz Mendes, Charlotte Bueschel, Christian Brandt, Henning Thomsen, Adrian von Stechow, Jan-Peter Baehner, Ralf Kleiber, Christoph Slaby, Axel Koenies, and Wendelstein 7-X Team — Max-Planck Institute for Plasma Physics, Wendelsteinstr. 1, 17491 Greifswald, Germany

In November 2022 the second operational phase (OP2) at Wendelstein 7-X (W7-X) started. Amongst many technical and diagnostic upgrades W7-X has been equipped with a fully water cooled high heat flux divertor, which in principle allows to operate high energy regimes for several minutes up to the envisaged half hour pulse. During the first part of the recent phase, OP2.1, a number of experiments have been conducted, specifically to investigate the role of magnetohydrodynamic (MHD) mode activity in high power heating scenarios involving neutral beam injection and electron cyclotron resonance heating. The obervation of various fluctuation diagnostics (Mirnov coils, soft X-ray tomography, phase contrast imaging, electron cyclotron emmission) are investigated and closely compared to findings of past operational campaigns. This contribution will mainly focus on Alfvén eigenmode activity, new insight concerning their driving mechanism and impact on high performance experiments.

P 11.22 Wed 14:00 HSZ EG

Neural Networks for the analysis of Langmuir probe characteristics — •Jasmin Joshi-Thompson and Mirko Ramisch — IGVP, University of Stuttgart, Germany

Developed in the early 1920s, Langmuir probes continue to be one of the most widely used plasma diagnostic tools. Theoretical curves are fitted to measured current-voltage (I-V) characteristics in order to obtain parameters such as electron density (n_e) and temperature (T_e). For extensive discharge conditions and comprehensive spatial profiles, measuring plasma parameters becomes more challenging and would best be addressed via automation, with manual checks for specific samples. In this work, deep neural networks are used for associating I-V characteristics to plasma parameters and are tested for robustness. Data is collected from the stellarator TJ-K for training and testing the networks, covering magnetized low-temperature plasmas in a broad parameter space. These networks are assessed as an adaptable, automated plasma characterisation method without the need for further control processes.

P 11.23 Wed 14:00 HSZ EG

Mode analysis of high performance discharges at Wendelstein 7-X during OP 1.2 — •Charlotte Büschel, Kian Rahbarnia, Sara Vaz Mendes, Henning Thomsen, Christian Brandt, Ralf Kleiber, Axel Könies, and Wendelstein 7-X Team — Max Planck Institute for Plasma Physics, Wendelsteinstr. 1, 17491 Greifswald, Germany

During the last operational phase, the optimized stellarator Wendelstein 7-X achieved so-called high performance up to 1.1 MJ of diamagnetic energy. In most experiments the high energy phase only lasted for about 200 ms following a series of pellet injections. During the discharges Alfvén Eigenmodes (AEs) were recognized which show dynamic behaviour throughout the pulse. The AE activity is investigated in detail to determine the type of the AEs and their possible impact on the often abrupt ending of the high energy phase. To identify relevant frequencies with high precision the parametric model stochastic system identification is used. Additionally poloidal mode number spectra are calculated with the use of a nonuniform Fourier Transformation. Experimental findings are compared to theoretical predictions of Alfvén continua calculated by the 3D ideal MHD code CONTI.

P 11.24 Wed 14:00 HSZ EG

ITG simulations with a fully-kinetic Semi-Lagrangian code — •Aleksandr Mustonen[1], Felipe Nathan de Oliveira[2], Ken Hagiwara[2], Sreenivasa Thatikonda[2], Daniel Told[2], and Rainer Grauer[1] — [1]The Ruhr Univeristy Bochum — [2]Max Planck Institute for Plasma Physics

Gyrokinetic framewrok has become a standart tool to research the phenomena occuring in the nuclear fusion devices. However, steep gradients in the edge region of tokamaks violate the the assumptions used to derive the gyrokinetic theory. Thus, we want to investigate the practical limits of the gyrokinetic theory with a model containing complete physics of the system. We develop a fully kinetic code employing semi-Lagrangian schemes to simulate the slab ion temperature gradient (ITG) mode with various setups, in order to learn the new physical effects that could be present only in the 6D model. Adiabatic electron approximation used to both verify the results with the analytical linear solution and to perform simulations. However, due to the smalness of the electron Larmor radius with comparison to the ion one, we can employ driftkinetic model for electrons to obtain a hybrid electrostatic description for the ITG simulations.

P 11.25 Wed 14:00 HSZ EG

Investigation of the influence of nanosecond pulsed plasmas in water on surfaces and on nanoparticle formation — •Pia-Victoria Pottkämper, Katharina Laake, Elia Jüngling, Oliver Krettek, and Achim von Keudell — Ruhr-Universität Bochum

One application of in-liquid plasmas is the formation of nanoparticles both in the treated liquid and on a surface in contact with the liquid. Plasmas in liquids ignited by voltage pulses with fast rise times and nanosecond pulse lengths applied to an electrode cause a dissociation of the molecules in the liquid. The reactive species created by the in-liquid plasma can propagate through the liquid and are able to modify surfaces in direkt contact with it. For instance it is possible to initiate surface growth of nanoparticles. In this project the modification of copper surfaces by in-liquid plasma treatment is investigated. On copper surfaces nanoparticles can be found in the shape of CuxO nanocubes which can act as catalysts e.g. in the reduction of CO2. The activity of these catalysts decreases over time. The plasma in water causes the formation of reactive oxygen species from the water molecules which can react with the surface to re-oxidize the material, leading to the formation of new CuxO nanocubes. It is postulated that by an in-situ in-liquid plasma treatment a re-activation of the surface could be achieved, thereby extending the lifetime of the catalytic surface. Furthermore the in-liquid plasmas can also yield particles through erosion of the electrode material itself. These particles dissolved in the liquid and their production is also investigated in this project.

P 11.26 Wed 14:00 HSZ EG

Influence of atmospheric microplasma jet treatment on self-organised sub-micrometer surface structures generated by short pulsed laser irradiation — •S. Chur[1], L. Kulik[1], R. Labenski[1], V. Schulz-von der Gathen[2], M. Böke[2], and J. Golda[1] — [1]Plasma Interface Physics, Ruhr-University Bochum, D-44801 Bochum, Germany — [2]Physics of Reactive Plasmas, Ruhr-University Bochum, D-44801 Bochum, Germany

Catalyst efficiency is strongly dependent on catalytic surface characteristics. Key features are the morphology and chemical composition. The combination of reactive species provided by an atmospheric pressure microplasma jet and energy input by laser irradiation can lead to very effective functionalisation of surfaces.
Self-organising surface structures were generated on copper (Cu) layers deposited through High Power Impuls Magnetron Sputtering (HiPIMS) on silicon wafers via the Pulsed Laser-Induced Dewetting (PLID) effect. The nanoparticles were investigated using a Scanning Electron microscope (SEM). Cu samples were treated simultaneously with the effluent of a micro atmospheric plasma jet (He/O2 admixture) and laser irradiation in a controlled atmosphere. Treated surfaces were investigated using Xray Photon Emission Spectroscopy (XPS).
A trade-off between high atomic oxygen fluxes and nanoparticle formation was found. Preliminary XPS measurements showed that plasma treatment can influence the oxidation state of copper, namely increase the percentage of CuO compared to an untreated surface.
Supported by the SFB 1316 within project B2

P 11.27 Wed 14:00 HSZ EG

Electric probe measurements inside and outside of magnetic islands in the SOL of Wendelstein 7-X. — •Dario Cipciar[1], Carsten Killer[1], Olaf Grulke[1], Jiri Adamek[2], and W7-X Team[1] — [1]Max Planck Institute, Greifswald, Germany — [2]IPP of the CAS, Prague, Czech Republic

We report on electric probe measurements in the Scrape-Off Layer (SOL) plasma of the W7-X stellarator. In this device, the SOL is formed by a chain of magnetic islands that separate the SOL into different topological regions and furthermore contain regions of closed magnetic field lines around the island centers ("O-points"). Measurements inside and outside of magnetic islands are performed using the multipurpose manipulator equipped with a probe head carrying 27 Langmuir and 2 ball-pen probes (BPPs). One of the BPPs is floating and measures the electron temperature and plasma potential and is used to cross-validate of the newly installed BPPs against triple probe measurements. The second BPP is in a swept regime for ion temperature measurements and will be compared to RFA results from similar discharges. The probe head also features poloidal and radial measurements of key fluctuating parameters (floating potential V_{fl} and ion saturation current I_{sat}) and, inferred from these are the turbulent radial particle fluxes, radial and poloidal electric fields. With these measurements we aim to assess the SOL plasma profiles and turbulence.

P 11.28 Wed 14:00 HSZ EG

Study of fast electrons population in the TJ-K stellarator. — •EdgardO Villalobos Granados and Alf Köhn-Seemann — IGVP, University of Stuttgart, Germany

Microwaves provide one of the most widely used methods for heating plasmas. If the plasma density becomes too high, the microwave is in cut-off, it cannot propagate any further and is reflected. Such plasmas are often referred to as over-dense. The stellarator TJ-K is typically operated with over-dense plasmas. Preliminary studies in TJ-K have shown that during these kinds of scenarios a component of fast electrons can be detected.

In this work, a pulse-height analyzer including a semiconductor detector being sensible in the soft X-ray range was used to measure the spectral distribution of the soft X-rays emitted by the plasma. Part of this radiation is generated by a hot electron component whose energy can be determined after calibrating the diagnostic against known X-ray sources. The occurrence of the hot electron component is studied under different discharge conditions to identify their generation mechanism.

P 11.29 Wed 14:00 HSZ EG

Properties of Metal Droplets Ejected During Arcing — •Alberto Castillo Castillo[1,2], Martin Balden[1], Volker Rohde[1], Peter Siemroth[3], Michael Laux[3], Heinz Pursch[3], Juergen Sachtleben[3], and Rudolf Neu[1,2] — [1]Max-Planck-Institut für Plasmaphysik, 85748 Garching, Germany — [2]Technische Universität München, 85748 Garching, Germany — [3]retired, was with Arc-Precision GmbH, 15711, Germany

Droplet generation by arcing is one of the mechanisms that can generate dust in a fusion device. Metal droplets expelled by arcs can potentially introduce impurities in the plasma and influence operation. The diameter and velocities of droplets determine their capacity to penetrate the outer layers and, therefore, the measurement of their distributions allows prediction of the impact on plasma operation.

In order to investigate the properties of the droplets produced by arcs a dedicated laboratory device is used based on time of flight detection by light scattering. Additionally, a high speed camera has been added for the observation of expelled droplets in larger quantities than the time of flight system. Tracking software obtains trajectories from video recording to complement the statistics obtained from the time of flight system and allow back-tracking of the droplets point of origin as well as calculating the velocity distribution. Video recording reveals the existence of explosive droplet emission events that could potentially be the source of larger diameter droplets. Microscopy observations of the remaining origin craters provide insight on the emission process of different fusion relevant materials, focusing on tungsten.

P 11.30 Wed 14:00 HSZ EG

First Measurements of the Imaging Heavy Ion Beam Probe at ASDEX Upgrade — •Hannah Lindl[1,2], Gregor Birkenmeier[1,2], Pablo Oyola[3], Jose Rueda Rueda[3], Balazs Tal[1], Joey Kalis[1,2], and The ASDEX Upgrade Team[1] — [1]Max Planck Institute for Plasma Physics, Garching, Germany — [2]Physics Department E28, Technical University Munich, Garching, Germany — [3]Department of Atomic, Molecular and Nuclear Physics, Universidad de Sevilla, Sevilla, Spain

The imaging Heavy Ion Beam Probe (i-HIBP) is a new diagnostic developed at the tokamak ASDEX Upgrade in order to measure perturbations of the magnetic field, density and electrostatic potential at the plasma edge. The i-HIBP is based on launching neutrals into the plasma, where they are ionized and deflected by the Lorentz force due to the tokamak magnetic field onto a scintillator detector placed in the limiter shadow inside the vacuum vessel. The light pattern created by the scintillator contains information about the above mentioned quantities. First measurements have been obtained recently and are now evaluated. In order to obtain a quantitative understanding of the results, the simulation code iHIBPsim is used. The code solves the equation of motion for 3D fields including ionization and attenuation models for a beam with finite width and divergence.

Results will be shown demonstrating the agreement of simulation and experiment as well as the ability to observe perturbations in the edge plasma quantities. The ability of the i-HIBP to measure filaments, edge current densities and zonal flows is discussed in this contribution.

P 11.31 Wed 14:00 HSZ EG

Influence of beam profile on ion-driven permeation experiments — Philipp Sand and •Armin Manhard — Max Planck Insitute for Plasma Physics, 85748 Garching, Germany

Ion-driven permeation experiments can be used to determine e.g. solubility, diffusivity, defect binding energies and surface/interface transport in materials relevant for wall components in nuclear fusion devices. Especially under conditions where surface processes or trapping of hydrogen isotopes at defects play a significant role, such experiments are influenced by the distribution of the ion flux density across the irradiated surface. In suitable energy and ion flux ranges, the beam profile can be quantified by measuring the height profile across the sputter erosion crater of a bulk Cu sample. In this contribution, the beam profile in the high-current, ion-driven permeation setup TAPAS was determined. A 200 eV/D beam with a total current of 80 μA of D_3^+ ions was characterised and exhibits an averaged ion flux densitiy of $8\text{x}10^{19}$ D/m^{2}s, while local values vary from $1\text{x}10^{19}$ to $3\text{x}10^{20}$ D/m^{2}s. A calculation scheme was implemented in the diffusion trapping code TESSIM-X. Permeation data for tungsten annealed at 2000 K was measured at 600 K and compared to simulations using the averaged ion flux as well as the detailed histogram of ion flux density. The relevance of the ion flux histogram is shown for 600 K, where trapping appearantly still plays a significant role. The best agreement between simulations and experiment was obtained for a trap concentration of $1.2\text{x}10^{-4}$ and a binding energy of 1.45 eV. For high temperatures, where most traps are empty, both calculated solutions converge.

P 11.32 Wed 14:00 HSZ EG

Experimental characterization of the quasi-coherent mode in EDA-H and QCE plasmas — •Joey Kalis[1,2], Gregor Birkenmeier[1,2], Peter Manz[3], Ridhesh Goti[1,4], Michael Griener[1], Elisabeth Wolfrum[1], Thomas Eich[1], and Ulrich Stroth[1,2] — [1]Max-Planck-Institut für Plasmaphysik, Garching — [2]Physik-Department E28, TUM, Garching — [3]Institut für Physik, Universität Greifswald, Greifswald — [4]Ludwig-Maximilians-Universität, München

For future reactors based on the tokamak concept, it is necessary to establish high confinement modes without type-I ELMs. In the past years, several natural ELM-free operation scenarios, such as EDA-H-mode or quasi-continuous exhaust (QCE), have been achieved in ASDEX Upgrade. A quasi-coherent mode (QCM) appears in both scenarios at the plasma edge and may be the key feature for the stabilization of ELMs and thus the better confinement. In order to understand and extrapolate a possible EDA-H or QCE scenario at large-scale machines like ITER or DEMO, it is necessary to determine different spectral properties of the QCM. Due to its high spatial and temporal resolution, the He-beam diagnostic and magnetic pick-up coils are used for this purpose. The results include frequency scaling and coherency behaviour, poloidal and radial wavenumber analysis and radial localization as well as a link of the QCM to other higher harmonic modes (HHMs) appearing in the magnetic coils, and are compared with theoretical predictions.

P 11.33 Wed 14:00 HSZ EG

GPU development of the Gyrokinetic Turbulence Code GENE-X with Native Fortran/C++ Interface — •Jordy Trilaksono[1], Philipp Ulbl[1], Andreas Stegmeir[1], and Frank Jenko[1,2] — [1]Max Planck Institute for Plasma Physics, Boltzmannstraße 2, 85748 Garching, Germany — [2]University of Texas at Austin, Austin, TX 78712, USA

Turbulence plays a significant role in plasma confinement inside of magnetic confinement fusion devices. A gyrokinetic turbulence model is used in the GENE-X code [1-3] to simulate turbulence anywhere within magnetic confinement fusion devices from the core to the edge and scrape-off layer. GENE-X leverages hybrid MPI+OpenMP parallelization to meet its expensive computational demands. Here, our effort extends this to GPUs for extensive scalability towards simulations of larger reactor-relevant devices which currently are not feasible with a reasonable amount of computing resources. The abstraction of several GPU backends via native Fortran/C++ interfaces provides portability and non-invasive development parallel to the main Fortran layer. Our Fortran/C++ hybrid approach overcomes compiler limitations that often hinder GPU development of Fortran legacy codes. The current build configuration of GENE-X supports GPU backends such as OpenACC, OpenMP offload and CUDA. Directive-based OpenACC and OpenMP offload are prioritized in the C++ layer of GENE-X.

[1] D. Michels, et. al., Comput. Phys. Commun. 264, 107986 (2021)
[2] D. Michels, et. al., Phys. of Plasmas. 29, 032307 (2022)
[3] P. Ulbl, et. al., Contrib. Plasma Phys., e202100180 (2021)

P 11.34 Wed 14:00 HSZ EG

Helium exhaust and impurity transport in W7-X — •Thilo Romba, Felix Reimold, Thomas Klinger, and W7-X team — Max-Planck-Institut for Plasmaphysik, 17491 Greifswald, Deutschland

The precise monitoring of the impurity content and the understanding of the transport mechanisms is crucial for future fusion reactor operation due to the associated restrictions to the operational parameter space via dilution and increased radiative losses.

This work aims to analyze the transport of impurities in the confined region of the optimized stellarator Wendelstein 7-X (W7-X) [1] with focus on the fusion ash helium. Local impurity densities are measured using charge exchange recombination spectroscopy (CXRS) [2]. While CXRS allows to measure profiles of densities of individual impurity charge states, it has a low sensitivity to the transport coefficients in steady state scenarios [3]. To increase the sensitivity to the transport coefficients in those scenarios, modulated impurity sources outside the confined region are used.

The impurity transport will also be assessed in transient phases of neutral beam heated plasmas. In these scenarios it was found that impurity transport is dominated by inwards directed neoclassical convection and impurity density peaking is observed [4]. This work aims to extend this analysis to different magnetic configurations and impurity species.

[1] Erckmann 1997, [2] Fonck 1985, [3] Romba, in preparation [4] Romba, in preparation

P 11.35 Wed 14:00 HSZ EG

Automated workflow for energetic particle stability — •Virgil - Alin Popa, Philipp Lauber, and Thomas Hayward-Schneider — Max Planck Institute for Plasma Physics, Garching, Germany

EPs (Energetic Particles) driven instabilities are a concern for present (AUG, JET) and future (ITER, DEMO) fusion devices. These particles can come from Neutral Beam Injection or be generated from fusion reactions (alpha particles). Their impact on electromagnetic instabilities in tokamak plasmas can lead to energetic particle transport which affects the heating efficiency of the plasma. Different codes that can study predictive scenarios and/or experimental results are emerging and with them the need of automatic analysis and management of the data they produce. In order to study the linear/non-linear, local/global effects, a workflow that manages the work of several codes is necessary and has been developed using the IMAS framework (Integrated Modelling & Analysis Suite). In addition, several techniques for reducing the dimensionality of the physics results have been implemented, such as: using statistical methods to improve analytical formulas and splitting of the workload in relevant/non-relevant data.

P 11.36 Wed 14:00 HSZ EG

Quasi-Neutral Multi-Fluid Models: A Variational Principle and Numerical Methods — •Sayyed Amin Raiessi Toussi, Omar Maj, and Tomasz Tyranowski — Max Planck Institute for Plasma Physics, D-85748 Garching, Germany

Quasi-neutral multi-fluid models are commonly used to describe particle and energy transport in the edge and scrape-off layer (SOL) of magnetically confined fusion plasmas [R. Schneider, Contrib. Plasma Phys., 46, 2006]. In this work we present a generalization of the variational principle for incompressible Euler equations [V. Arnold, Ann. Inst. Fourier 16, 319-361 (1966)] to quasi-neutral multi-fluid models, including only ideal processes. Also some preliminary considerations on appropriate numerical methods are offered.

P 11.37 Wed 14:00 HSZ EG

Towards Laboratory Astrophysics in Wakefield Accelerators — •Erwin Walter[1], John P. Farmer[2], Martin S. Weidl[1], Patric Muggli[2], and Frank Jenko[1] — [1]Max Planck Institute for Plasma Physics, 85748 Garching, Germany — [2]Max Planck Institute for Physics, 80805 Munich, Germany

From supernovae in distant galaxies to wakefield accelerators in laboratories, the interaction of relativistic particles with plasma is relevant to many physical scales. The electromagnetically dominant current filamentation instability (CFI), which transversely breaks the beam into narrow filaments, may generate a sufficiently strong magnetic field to form collisionless shocks. By changing the operating parameters of beam-driven wakefield accelerators, it may be possible to access this regime relevant to astrophysics.

Due to the large difference in scales, numerical studies with quasistatic particle-in-cell (PIC) methods greatly reduce computational overhead compared to fully electromagnetic PIC. A quasineutral fireball beam consisting of positrons and electrons is simulated to determine to what extent the physics of CFI can be modelled by quasistatic codes and how different numerical methods affect the instability.

This work potentially paves the way to provide insight into analogous astrophysical scenarios in a laboratory setup.

P 11.38 Wed 14:00 HSZ EG

Integrated modelling of impurity transport in ASDEX Upgrade — •Daniel Fajardo[1], Clemente Angioni[1], Giovanni Tardini[1], Emiliano Fable[1], Pierre Manas[2], Rachael McDermott[1], and the ASDEX Upgrade Team[1] — [1]Max-Planck-Institut für Plasmaphysik, Garching, Germany — [2]CEA/IRFM, Saint-Paul-les-Durance, France

A database of experimentally measured boron (B) density profiles at ASDEX Upgrade (AUG) [R.M. McDermott *et al* 2022 *Nucl. Fusion* **62** 026006] is studied via 1.5D integrated modelling with ASTRA. An additional tungsten (W) impurity is evolved and the profile predictions are compared to experiments, which feature variations of the NBI–ECRH heating power mixture. The turbulent transport is calculated with the quasilinear codes TGLF and QuaLiKiz, allowing us to validate the impurity transport predictions of these models. The neoclassical component of B is calculated with NCLASS, whereas the FACIT model is used for W due to the stronger effects of rotation-induced poloidal asymmetries on heavy impurities. The correlation between the predicted logarithmic impurity density gradients and the main plasma gradients is discussed, also in comparison with gyrokinetic results. Moreover, in an additional set of simulations STRAHL is used for the self-consistent calculation of radiated power profiles, which are compared to experimental bolometry estimations.

P 11.39 Wed 14:00 HSZ EG

ECRH in early plasma formation — •Carl Albert Vilhelm Johansson and Pavel Aleynikov — IPP Greifswald, Wendelsteinstraße 1, Germany

The usage of electron cyclotron resonant heating (ECRH) is important in current operation of, amongst other devices, Wendelstein 7-X (W7-X) stellarator, and for future fusion devises. ECRH in the quasi–linear limit is theoretically well understood. However, because the ECRH system is used for plasma breakdown, there exists an interest in understanding the non–linear limit.

In this work, we consider the pre–ionization state. We show the energy gain of a single-electron interacting with the gyrotron beam once. For this interaction, we consider different magnetic field configurations. The interaction between electron and gyrotron beam yield a stronger coupling when located at the slope of the background magnetic field. The slope of the magnetic field dominates the effect for third harmonic interaction, whereas the second harmonic is less affected by the slope.

P 11.40 Wed 14:00 HSZ EG

Modeling of runaway electrons in disruption mitigation scenarios with DREAM — •Peter Halldestam[1], Gergely Papp[1], Hannes Bergström[1], Mathias Hoppe[2], Oskar Vallhagen[3], István Pusztai[3], and Tünde Fülöp[3] — [1]Max Planck Institute for Plasma Physics, Garching, Germany — [2]Swiss Plasma Center, Lausanne, Switzerland — [3]Department of Physics, Chalmers University of Technology, Göteborg, Sweden

One of the main issues threatening the success of future reactor-scale tokamaks is disruptions. It is the sudden loss of confinement where the plasma rapidly dissipates its energy onto the surrounding structures, exposing the device to excessive mechanical stress and heat loads. In addition, an electric field is induced that can accelerate a significant fraction of the electrons to relativistic energies, giving rise to runaway electrons (REs). Unmitigated disruptions could potentially cause severe damage to the device and, thus, modeling such events is crucial for being able to assess the effectiveness of various mitigation techniques.

Using the numerical RE modeling framework DREAM [Hoppe CPC 2021], we study the effects massive material injection (MMI) of deuterium and neon has on disrupting plasma representative of ITER, particularly the RE generation and the dissipation of its energy content. We self-consistently evolve the electric field, ion charge state densities, thermal electron temperature and density as well as the RE density in a flux surface-averaged fluid description of the plasma. This model is used together with a Bayesian optimisation tool to find suitable MMI parameters that minimise potential damage to the device.

P 11.41 Wed 14:00 HSZ EG

Electromagnetic flutter in the full-f edge turbulence fluid code GRILLIX — •kaiyu zhang, wladimir zholobenko, andreas stegmeir, christoph pitzal, konrad eder, and frank jenko — Max Planck Institut für Plasmaphysik, Boltzmannstr.2, 85748 Garching, Germany

Electromagnetic flutter has been implemented and verified in GRILLIX, a full-f turbulence code for the edge and scrape-off layer in tokamaks. Simulations for L-mode ASDEX Upgrade are performed with electromagnetic flutter. We particularly investigate how flutter transport contributes to the density advection and heat conduction perpendicular to the magnetic flux surfaces.

An issue arising during the computation of flutter is that a large-scale magnetic shift will be double-counted in the fixed background magnetic equilibrium and in the full-f turbulence. Commonly, the toroidal average of magnetic potential was stripped to remove this shift. However, this method is found to cause a spurious reduction of the perpendicular flutter turbulent transport in GRILLIX. Two refined methods are explored: (1) removing the time averaged magnetic field; (2) tracing the evolution of Pfirsch-Schluter currents analytically and removing the corresponding induced magnetic field. The new methods seem superior in preserving the amplitude of the perpendicular flutter turbulence transport.

P 11.42 Wed 14:00 HSZ EG

Engineering tool for the robust optimization of a full-W divertor in W7-X — •Antara Menzel-Barbara[1,2], Joris Fellinger[1], Rudolf Neu[2,3], Dirk Naujoks[1], and Thomas Pedersen[1] — [1]Max Planck Institute for Plasma Physics, 17491 Greifswald, Germany — [2]Technische Universität München, 85748 Garching, Germany — [3]Max Planck Institute for Plasma Physics, 85748 Garching, Germany

High levels of fuel retention due to co-deposition make C-based materials such as CFC, currently used on the W7-X divertor, incompatible for a fusion reactor. As part of an ongoing investigation into a W-based divertor for W7-X, an engineering tool for the robust optimization of leading edges is being developed. Leading edges, resulting from assembly tolerances and deformation during operation, lead to very high incidence angles and to strongly increased heat fluxes. Compared to a C-based divertor, leading edges in a W design are more problematic because of W melting. Since manufacturing and assembly tolerances are major cost drivers, relaxing them is another priority for a new divertor. Because particles in W7-X can come from opposite directions on the target surface in different magnetic configurations, the usual strategy of entirely shadowing divertor plates to avoid leading edges is not possible. Instead, a more refined approach that optimizes the divertor surface while considering all major magnetic configurations simultaneously is necessary. A variety of tools, including the code EMC3-Lite and Ansys, is used to rapidly evaluate a modified surface, and identify the problematic areas. Strategies to effectively explore the design space of geometric modifications are currently being investigated.

P 11.43 Wed 14:00 HSZ EG

Validation of theoretical upper bounds on local gyrokinetic instabilities — •Linda Podavini, Per Helander, Gabriel Plunk, and Alessandro Zocco — Max-Planck-Institut für Plamsaphysik, Wndelsteinstraße 1, 17491 Greifswald

Turbulence in magnetic confinement fusion devices is driven by the presence of gyrokinetic microinstabilities. In the last decades these instabilities have been extensively studied considering various assumptions about plasma parameters and magnetic geometry, thus hampering a desirable unified theory.

Only recently, it was shown by Helander and Plunk [1] that it is possible to obtain universal upper bounds on the growth rates of local gyrokinetic instabilities via thermodynamic considerations. These bounds are valid for all possible microinstabilities and they are independent of the magnetic field configuration and some plasma parameters, such as the number of particle species, beta and collisions.

In this work, we compare the theoretical upper bounds on growth rates with numerical and analytical results in different geometries, including stellarator, tokamak and z-pinch. For the numerical results, linear, flux-tube simulations are obtained using the gyrokinetic code stella.

[1] P. Helander and G. G. Plunk, Physical Review Letters, 127, 155001, (2021)

P 11.44 Wed 14:00 HSZ EG

Experimental impurity transport analysis for the tokamak plasma edge — •Tabea Gleiter[1,2], Ralph Dux[1], Francesco Sciortino[1], and the ASDEX Upgrade Team[3] — [1]Max-Planck-Institut für Plasmaphysik, Garching, Germany — [2]Physik-Department E28, Technische Universität München, Garching, Germany — [3]Authors of U. Stroth et al. 2022 Nucl. Fusion 62 042006

Impurity transport in the pedestal and SOL region impacts energy confinement and radiative power exhaust in tokamaks. However, thorough understanding is lacking for many confinement modes. This includes promising regimes for future reactor scenarios without type-I ELMs, such as the quasi-continuous exhaust (QCE) mode.

A series of impurity seeded (Ne, Ar or N) discharges in various confinement modes was conducted at ASDEX Upgrade. Their experimental setup was tailored for high resolution charge exchange recombination spectroscopy (CXRS) measurements at the plasma edge. From the observed line radiation, density profiles of multiple impurity charge states are derived, making use of a neutral beam model, the beam attenuation code COLRAD and ADAS atomic rates. Fitting the charge state distribution with a diffusive-convective transport model such as STRAHL or Aurora, insight can be gained about the impurity transport. Both a Levenberg-Marquardt fit as well as a Bayesian nested sampling algorithm are used for this inverse inference.

Current work focuses on the QCE plasmas in our dataset, comparing them to H-mode with type-I ELMs. In particular, discharges with a stepwise transition between both regimes are evaluated.

P 11.45 Wed 14:00 HSZ EG

ASDEX Upgrade shattered pellet injection experiments

— •Paul Heinrich[1], Gergely Papp[1], Matthias Bernert[1], Pascal de Marné[1], Mathias Dibon[1], Stefan Jachmich[2], Michael Lehnen[2], Tobias Peherstorfer[3], Umar Sheikh[4], Jakub Svoboda[5], The ASDEX Team[6], and The MST1 Team[7] — [1]Max-Planck-Institut für Plasmaphysik, Garching, Germany — [2]ITER, St. Paul-lez-Durance, France — [3]Institute for Applied Physics, Wien, Austria — [4]EPFL, Lausanne, Switzerland — [5]IPP CAS, Prague, Czech Republic — [6]See author list of U. Stroth et al. 2022 Nucl. Fusion 62 042006 — [7]See author list of B. Labit et al. 2019 Nucl. Fusion 59 086020

In December 2021, the shattered pellet injection (SPI) system was successfully installed on the tokamak ASDEX Upgrade (AUG). Hereby, large amounts of material are injected into the plasma, radiating strongly and thereby spreading the previously confined energy over a larger area in comparison to unmitigated disruptions. The AUG SPI system allows a large variation in pellet parameters – such as pellet size, velocity or composition – and different shatter geometries. The ultimate goal is to assist the design of the ITER disruption mitigation system (DMS). In the 2022 campaign at ASDEX Upgrade around 240 discharges were performed for the SPI experiments. Different shatter heads were installed at the end of each of the three independent guide tubes. The focus of the analysis presented here is to find the optimal pellet parameters and shatter geometries for maximizing the radiated energy, while reducing localized heat loads.

P 11.46 Wed 14:00 HSZ EG

Investigation of Tearing Modes in ASDEX Upgrade — •Magdalena Bauer, Louis Giannone, Anja Gude, Felix Klossek, Marc Maraschek, Bernhard Sieglin, Wolfgang Suttrop, Hartmut Zohm, and The ASDEX Upgrade Team — Max Planck Institute for Plasma Physics, Garching

Tearing modes with toroidal mode number n=1 are precursors of and significantly involved in disruptions, especially when they are locked to the vessel. While rotating modes can be observed by many Mirnov coils measuring the time derivative of the poloidal magnetic perturbation field, locked modes require a radial field measurement. In addition to the saddle coils on the high field side, toroidally distributed radial field coils at two different poloidal positions on the low field side can be used to gain information on slowly rotating and locked modes. A 3D finite element model, simulating the field generated by a single helical perturbation current in all coils, has been improved by considering the detailed coil geometry and a better description of conducting in-vessel parts in which mirror currents affecting the local perturbation field are induced. Coupling of n=1 modes with different poloidal mode numbers is believed to play a large role in the disruption process. The projection of the measured complex amplitudes in all coils on the modelled perturbation amplitudes with single helicities allows to determine the contribution of different poloidal mode numbers for rotating modes. For locked modes, only the three poloidal positions of the radial field coils are available. The opportunities and limitations of the poloidal mode structure analysis are investigated.

P 11.47 Wed 14:00 HSZ EG

Power balance analysis and predictive modelling using the codes neotransp and NTSS — •Markus Wappl, Marc Beurskens, Sergey Bozhenkov, Hakan Smith, and Yuri Turkin — Max-Planck-Institute for Plasma Physics, Greifswald, Germany

One effect seriously limiting the plasma performance of the stellarator Wendelstein 7-X is ion temperature clamping, which restricts ion temperatures to about 1.5 keV in a wide range of scenarios. Empirical scaling laws such as ISS04 predict the performance of stellarators. However, no first-principle models offering a physical understanding or a clear explanation for the clamping are available. It has been shown that turbulent flux losses limit the achievable performance of a stellarator. ITG modes are thought to be the dominating turbulent process for ion heat losses and might be the cause for the ion temperature clamping observed at W7-X.

Power balance analysis allows a physics-motivated understanding of plasma performance including ion temperature clamping. Detailed modelling of neoclassical and turbulent heat fluxes is critical for this approach. A novel webtool for the power balance analysis of Wendelstein 7-X plasma discharges is presented. It employs the codes neotransp and NTSS for neoclassical calculation as well as Monte Carlo sampling for reliable error propagation. Predictive modelling of ion temperature profiles is performed in the code NTSS using a dummy density profile and ECR heating deposition profile. Ion temperature clamping is reproduced with simplified model assumptions which indicates that ITG modes might not be the primary reason for clamping.

P 11.48 Wed 14:00 HSZ EG

Non-Axisymmetric Generalization of the Gyrokinetic Turbulence Code GENE-X — •Marion Smedberg[1], Andreas Stegmeir[1], Philipp Ulbl[1], and Frank Jenko[1,2] — [1]Max Planck Institute for Plasma Physics, Boltzmannstraße 2, 85748 Garching, Germany — [2]University of Texas at Austin, Austin, TX 78712, USA

For optimized stellarators, edge plasma turbulence both sets the boundary condition for core performance and determines the heat fluxes onto the plasma-facing components. Thus realistic simulations of plasma turbulence in the edge and scrape-off layer (SOL) are a key step towards a stellarator power plant. The gyrokinetic turbulence code GENE-X [1] is well-equipped to simulate edge and SOL turbulence due to the use of a flux-coordinate independent (FCI) coordinate system [2]. However, until now the code has only simulated in axisymmetric geometries, such as tokamaks. Here progress towards a non-axisymmetric upgrade of the GENE-X code is presented. The focus will be on the implementation of stellarator magnetic fields, the development of numerical methods for representing the shape of three-dimensional flux surfaces, and simulating simple diffusion and advection models in a fully three-dimensional geometry.

[1] D. Michels, et. al., Comput. Phys. Commun. 264 (2021)
[2] F. Hariri, et. al., Comput. Phys. Commun. 184 (2013)