# P 10: Poster Session 2

Time: Tuesday 16:30–18:30 Location: Empore Lichthof

P 10.1 Tue 16:30 Empore Lichthof

**High-pressure melting line of helium from ab initio calculations** — Martin Preising and •Ronald Redmer — Institut für Physik, Universität Rostock, D-18051 Rostock

Knowledge of the high-pressure melting line of helium up to the TPa region is important to astrophysics, e.g., for the determination of the region of hydrogen-helium phase separation as predicted in the interior of gas giants like Saturn and Jupiter. We applied two-phase simulations to directly calculate the high-pressure melting line of helium from 425 to 10 000 K and from 15 GPa to 35 TPa by using molecular dynamics based on density-functional theory. The implementation of the two-phase simulation method and the relaxation of the simulation to an equilibrium state was studied in detail, as well as its convergence with respect to particle number. We performed extensive two-phase simulations with the Perdew, Burke and Ernzerhof (PBE) and the van der Waals density functional (vdW-DF) exchange-correlation functional and found almost identical results. The P(T) melting line shows a slight downward curvature at higher pressures but not as pronounced as predicted in earlier studies.

P 10.2 Tue 16:30 Empore Lichthof

**Physics applications of the ASDEX Upgrade flight simulator Fenix** — •Michael Englberger[1,2], Filip Janky[2], Emiliano Fable[2], Ralph Dux[2], Ondrej Kudlacek[2], Thomas Pütterich[2], Hartmut Zohm[2], and the ASDEX Upgrade Team[2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität München, Schellingstraße 4, D-80799 München — [2]Max-Planck-Institut für Plasmaphysik, D-85748 Garching b. München, Germany

Fenix, the ASDEX Upgrade (AUG) flight simulator, is a tool based on the ASTRA transport code, coupled with the 2-D equilibrium code SPIDER and a Simulink model of the actuators and the AUG control system. In this work Fenix was used to simulate existing AUG discharges in order to study and improve the models of Fenix. We focused on plasma discharges in which the loss of heating sources led to a disruption of the plasma. The relevant plasma and control system parameters already showed a realistic behavior, while some deviations require further analysis. Another aim of this work was to find a description of the tungsten influx into the vessel. Tungsten is the dominant radiation source in AUG, therefore, it is essential to include a tungsten influx model. An estimate of the tungsten influx was calculated from measurements for a set of typical H-mode plasma discharges. Using experimental data, a scaling for tungsten influx as a function of plasma parameters (e.g. electron temperature and density) was found. The implementation of the tungsten influx improved the behavior of the simulated plasma radiation, however, some remaining discrepancies showed the tungsten transport needs further improvement.

P 10.3 Tue 16:30 Empore Lichthof

**Self-sustained divertor oscillations in ASDEX Upgrade** — •Paul Heinrich[1,2], Peter Manz[2,1], Matthias Bernert[2], Gregor Birkenmeier[2,1], Dominik Brida[2], Marco Cavedon[2], Pierre David[2], Michael Griener[2], Tim Happel[2], Ulrike Plank[2], Felix Reimold[3], Ulrich Stroth[2,1], Marco Wischmeier[2], and Wei Zhang[2] — [1]Physik-Department E28, Technische Universität München, James-Franck-Str. 1, 85748 Garching, Germany — [2]Max-Planck-Institut für Plasmaphysik, Boltzmannstr. 2, 85748 Garching, Germany — [3]Max-Planck-Institut für Plasmaphysik, Wendelsteinstr. 1, 17491 Greifswald, Germany

Alternating radiation phenomena between the inner and outer divertor regions in the sub kHz range are investigated in the tokamak ASDEX Upgrade. While the inner divertor oscillates between the onset and fluctuating state of detachment, the outer divertor oscillates between conditions where it can maintain high recycling conditions or not. The detachment state of the inner divertor determines the magnitude of the neutral flux through the private flux region, thus sets the recycling conditions at the outer divertor. In return these recycling conditions determine the particle content in the divertor, hence the detachment state at the inner divertor.

P 10.4 Tue 16:30 Empore Lichthof

**Observation of Alfvénic mode activity at the Wendelstein 7- X stellarator** — •Kian Rahbarnia[1], Torsten Bluhm[1], Matthias Borchardt[1], Bernardo B Carvalho[2], Ralf Kleiber[1], Axel Könies[1], Sara Mendes[1], Jonathan Schilling[1], Christoph Slaby[1], Henning Thomsen[1], Manfred Zilker[1], and Wendelstein 7-X[1] — [1]Max Planck Institute for Plasma Physics, Wendelsteinstr. 1, 17491 Greifswald, Germany — [2]Instituto de Plasmas e Fusao Nuclear Instituto Superior Tecnico, Lisbon, Portugal

During the last divertor campaign at the Wendelstein 7-X stellarator (Greifswald, Germany) no dedicated experiments have been carried out to investigate the excitation mechanism of Alfvén eigenmodes (AE) in the plasma. Nevertheless fairly independent from magnetic configuration and heating scenario (electron cyclotron resonance heating and/or neutral beam injection) broadband fluctuations around 200 kHz have been observed by the Mirnov diagnostic. A complete amplitude and phase calibration of the in total 125 individual probes including all relevant data acquisition system components allows a detailed spectral and mode analysis, using damped multiple signal classification (DMUSIC) and stochastic system identification techniques (SSI). The results are compared with theoretically predicted Alfvén continua calculated with the 3D-MHD continuum code CONTI. The nature of these fluctuations is most likely associated with ellipticity-induced Alfvén eigenmodes in the outer regions of the plasma. The role of density and temperature profiles, as well as iota profiles and Doppler shift effects due to electric fields at the plasma edge are investigated.

P 10.5 Tue 16:30 Empore Lichthof

**Tomographic inversion analysis of current-driven MHD collapses in Wendelstein 7-X stellarator plasmas** — •Henning Thomsen, Christian Brandt, Yu Gao, Sara Mendes, Kian Rahbarnia, Jonathan Schilling, Torsten Stange, and Marco Zanini — MPI f. Plasmaphysik, Wendelsteinstr 1, 17491 Greifswald

The X-ray tomography system XMCTS has been operated in the recent campaign of Wendelstein 7-X stellarator. The diagnostic consists of 20 cameras inside the plasma vessel and enables tomographic image reconstruction from more than 300 lines of sight. Problems in the camera shutter setup were identified and are considered in the tomographic inversion procedures. Tomogram series of intervals with high time resolution are used to visualize fast internal MHD plasma events in order to understand the underlying instability mechanisms. One important data analysis tool for post-processing is the filtering of the spatio-temporal data with the singular value decomposition. This technique can be used to remove the background radiation distribution of the tomograms. We apply these methods to X-ray data recorded during experiment programs with toroidal electron cyclotron current drive, in which fast collapses of the central plasma temperature profile have been observed.

P 10.6 Tue 16:30 Empore Lichthof

**Plasma beta effects on the island divertor of Wendelstein 7-X** — •Alexander Knieps[1], Yunfeng Liang[1], Yasuhiro Suzuki[2], Carsten Killer[3], Olaf Grulke[3], Marcin Jakubowski[3], Holger Niemann[3], Yu Gao[3], Olaf Neubauer[1], Guruparan Satheeswaran[1], Philipp Drews[1], Dirk Nicolai[1], Joachim Geiger[3], Michael Endler[3], and W7-X Team[1,2,3] — [1]Forschungszentrum Jülich, Jülich, Germany — [2]National Institute for Fusion Science, Toki, Japan — [3]Institut für Plasmaphysik, Greifswald, Germany

The Wendelstein 7-X (W7-X) stellarator relies on an island divertor for heat- and particle-exhaust. It aims to demonstrate long-pulse operation in fusion relevant performance regimes, aiming at a plasma beta of around 5%. At such performance levels, pressure-gradient-driven currents can modify the structure of the edge magnetic field. W7-X is a multi-configuration machine, and there are strong differences between the individual configurations' responses to high plasma pressure. This work presents simulations of pressure-related magnetic field changes in multiple configurations, obtained using the HINT code. The beta-induced changes of the heat-fluxes onto the divertor targets are simulated using fieldline-diffusion and compared to experimental data obtained during the divertor campaigns of W7-X in 2017 and 2018.

P 10.7 Tue 16:30 Empore Lichthof

**Conceptual design study of an Energy Recovery System for the DEMO NBI** — •Giuseppe Starnella, Christian Hopf, and

Niek den Harder — Max-Planck-Institut für Plasmaphysik, Garching, Germany

The commercial viability of a fusion power plant requires Neutral Beam Injectors with a high energy efficiency. The main limitation on the ITER NBI is represented by the gas neutralisation efficiency. In this regard, the plasma neutraliser is one of the promising new technologies that are under investigation for the DEMO NBI. As an alternative option, the concept of Energy Recovery makes the current technique of gas neutralisation still a viable choice. The idea is to recover the energy of the residual ions of the neutralisation process by decelerating them onto electrically biased collectors, after separating the negative and positive ions from the neutral beam in opposite directions. We present the CAD model of the conceptual design of an ERS and its integration into an NBI ITER-like beamline. A 3D ion optics code is used to simulate the ion trajectories. The ERS efficiency and the relative improvement of the NBI wall-plug efficiency are studied as functions of the residual ion deceleration energy. We show that a recovery energy of 50 keV allows the collection of all the ions. The impact of the beamline new configuration on the gas density profile is also investigated, especially in terms of neutral beam and residual ion losses.

P 10.8 Tue 16:30 Empore Lichthof

**Adapting a hybrid kinetic/gyrokinetic semilagrangian code for the studying of fusion plasmas** — •Aleksandr Mustonen[1], Karen Pommois[2], Felipe Nathan DeOliveira[3], Simon Lautenbach[4], Florian Allmann-Rahn[5], Rainer Grauer[6], and Daniel Told[7] — [1]Aleksandr.Mustonen@ipp.mpg.de — [2]Karen.Pommois@ipp.mpg.de — [3]Nathan.DeOliveira@ipp.mpg.de — [4]Simon.Lautenbach@ruhr-uni-bochum.de — [5]Florian.Allmann-Rahn@rub.de — [6]Grauer@tp1.ruhr-uni-bochum.de — [7]Daniel.Told@ipp.mpg.de

An investigation of many important fusion plasma phenomena, directly affecting the confinement and stability, is only possible through a kinetic modeling because of the underlying effects which have relatively small characteristic scales. Fully kinetic simulations providing all of the information about the particle distribution, however, have a major drawback of their high computational cost.

The usage of a hybrid models is one of the possible ways if one would like to circumvent this limitation and investigate the nature and the physics of the edge transport barrier. By using of a hybrid: a kinetic model for ions and a drift/gyrokinetic for electrons we can resolve all of the effects related to ions without any reduction while still retaining kinetic electron effects.

Basing on the "ssV" code by the computational plasma physics group at Ruhr-Universität Bochum, we are developing a new flux conservative model for the edge tokamak plasma with a flux-aligned coordinates. A delta-f version of code is under development, which is used for the code comparison for the modeling of Landau damping and ITG mode.

P 10.9 Tue 16:30 Empore Lichthof

**Towards nonlinear simulations of mitigated disruptions in ASDEX Upgrade** — •Fabian Wieschollek, Matthias Hölzl, and Sibylle Günter — Max Planck Institute for Plasma Physics, 85748 Garching bei München, Germany

Disruptions constitute a significant threat for large-scale tokamak devices due to associated massive heat loads and mechanical stresses. Hence, disruptions have to be studied extensively to improve detection, avoidance or mitigation schemes. One promising tool for disruption mitigation foreseen also for the ITER tokamak are shattered pellet injections (SPI), where pellets consisting of Deuterium or low-Z impurities like Neon or Argon are injected after shattering.

Simulations of mitigated disruptions in ASDEX Upgrade using the nonlinear MHD code JOREK are under preparation. We investigate SPI both into unperturbed plasmas and into configurations that exhibit disruption precursors, to understand the effectiveness of SPI depending on plasma dynamics. First results for deuterium SPI are shown. For realistic simulations of impurity-SPI, JOREK needs to be extended. We plan to trace each charge state of the impurities separately using a coronal model. First tests and further plans are shown.

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**Implementation and testing of stellarator-capable models in JOREK** — •Nikita Nikulsin[1], Matthias Hoelzl[1], Alessandro Zocco[2], Rohan Ramasamy[1], Karl Lackner[1], and Sibylle Günter[1] — [1]Max Planck Institute for Plasma Physics, Garching, Germany — [2]Max Planck Institute for Plasma Physics, Greifswald, Germany

The JOREK nonlinear MHD code, which currently only supports tokamak simulations, is being extended to stellarators. This is a two-part process. First, a stellarator-capable model, i.e. a model that does not make any assumptions on the underlying geometry, needs to be implemented. The second step involves modifying the currently implemented axisymmetric flux-aligned grids to allow alignment to non-axisymmetric flux surfaces.

We have derived a hierarchy of stellarator-capable models which have better conservation properties than presently used models, but also a different and more complicated mathematical structure [1]. Here, we present our work on the implementation of these new models, first testing results and the peculiarities associated with the new models. A comprehensive benchmark of the new models against presently used models will be carried out in the tokamak limit before we proceed to stellarator simulations.

[1] N. Nikulsin et al, Phys. Plasmas 26, 102109 (2019).

P 10.11 Tue 16:30 Empore Lichthof

**Self-consistent 2D fluid model for optimizing RF coupling at NNBI ion sources** — •Dominikus Zielke[1,2], Stiliyan Lishev[3], Stefan Briefi[1,2], and Ursel Fantz[1,2] — [1]Max-Planck-Institut für Plasmaphysik, 85748 Garching, Germany — [2]AG Experimentelle Plasmaphysik, Universität Augsburg, 86135 Augsburg, Germany — [3]Faculty of Physics, Sofia University, 1164 Sofia, Bulgaria

In Negative-ion based Neutral Beam Injection systems (NNBI) for fusion, a hydrogen plasma is generated via inductive RF coupling at a frequency of 1 MHz inside the ion source in cylindrical vessels, called drivers. At low gas pressures of 0.3 Pa, electron densities and temperatures of $10^{18}\,\mathrm{m}^{-3}$ and 10 eV are reached. Only a fraction $\eta$ of the generator power of up to 100 kW per driver is absorbed by the plasma, the rest is lost via eddy currents in the RF network, the internal Faraday screen and the surrounding steel structure. Since at 100 kW, the RF components work close to their technological limits, it is desirable to use lower generator powers while increasing $\eta$.

To optimize the RF coupling with respect to e.g. RF frequency or geometry, a 2D cylindrically symmetric multi-species fluid model is used, which describes the coupling between the RF fields and the electrons in the stochastic heating regime self-consistently.

The model is successfully validated with electrical and Langmuir probe measurements from the BATMAN Upgrade ion source testbed, where $\eta$ is measured to be around 70-80%. The model is then utilized to study the impact of the distances between RF coil windings, coil and discharge, Faraday screen and surrounding steel structure on $\eta$.

P 10.12 Tue 16:30 Empore Lichthof

**Braginskii Transport Coefficients for the Gyrokinetic Sugama Collision Operator versus the full Landau Operator** — •Mario Raeth and Klaus Hallatschek — Max Planck Institute of Plasma Physics, Garching, Germany

The ad-hoc model collision operator derived by Sugama et al. and implemented in a Eulerian gyrokinetic solver (CGYRO) is tested in detail against the multi-fluid transport equations for magnetised plasmas derived from the Landau collision operator by Braginskii . It has been shown that the anomalous transport levels in gyrokinetic turbulence simulations with this collision operator do not match Braginskii fluid levels in the presence of significant temperature fluctuations.
To further investigate the transport processes, scenarios are created which allow us to isolate the various transport processes described by the Braginskii fluid model. By this method, it is possible to see precisely which transport coefficients result from the Sugama operator. In addition to the deviation of the parallel transport processes of $\sim 20\%$, it is shown that the perpendicular heat flux is significantly larger (by $\sim 50\%$ for the ion heat conductivity) than the quantities derived from the Landau operator. The ion stress caused by a sheared perpendicular heat flux is ten times larger than expected and the ion viscosity deviates by $\sim 40\%$. This indicates that the Sugama operator is not sufficiently accurate to achieve a close agreement between fluid and kinetic models, especially in the case of temperature perturbations in the plasma. Furthermore, ongoing work on the comparison with a full 6D kinetic model implemented by Kormann et al. will be presented.

P 10.13 Tue 16:30 Empore Lichthof

**Simulating turbulence and profile evolution in the tokamak periphery with GRILLIX** — •Wladimir Zholobenko, Thomas Body, Andreas Stegmeir, David Coster, and Frank Jenko — Max-Planck-Institut für Plasmaphysik, 85748 Garching, Germany

To be economically viable, magnetic confinement nuclear fusion reactors must be big. This makes the construction of practice relevant experiments like ITER very costly, leaving little room for experimentation and none for failure. Therefore, theoretical understanding and predictive capability are vital. Most promising are first principle based plasma turbulence codes, such as GRILLIX.

GRILLIX' main feature is the simulation of turbulent flows in complex, experimentally relevant magnetic geometry. The physical model[1] - global drift-reduced Braginskii equations - has no splitting between background and fluctuations. This allows to not only simulate gradient driven turbulent transport, but also the profile evolution itself. The results depend only on magnetic geometry, plasma sources and initial conditions - yielding high predictive capability for the price of high computational expense.

The code and the physical model are yet under development, to increase performance, reliability and realism. However, first applications to today's tokamaks like ASDEX Upgrade are able to reproduce important qualitative features, such as the self-consistent electric field and its impact on turbulence and profiles.

[1] W. Zholobenko *et al.*, Thermal dynamics in the FCI turbulence code GRILLIX, 17th PET workshop, submitted to CtPP (2019).

P 10.14 Tue 16:30 Empore Lichthof

**Hamiltonian emulators for charged particleorbits in magnetized plasmas** — •Katharina Rath[1,2], Christopher G. Albert[1], Bernd Bischl[2], and Udo von Toussaint[1] — [1]Max-Planck-Institut für Plasmaphysik, Boltzmannstraße 2, 85748 Garching, Germany — [2]Department of Statistics, Ludwig-Maximilians-University Munich, Ludwigstraße 33, 80539 Munich, Germany

Currently used full models to trace orbits inside 3D configurations of magnetic plasma confinement for low-collisional reactor-relevant plasmas require highly accurate tracing of thousands of particles over billions of time-steps, which is too time-consuming to be part of optimization routines. A fast structure-preserving model emulator for Hamiltonian systems is developed to significantly speed up the computation of fusion alpha particle orbits in 3D fields of perturbed tokamaks and stellarators. The model emulator is constructed via physics-informed machine learning methods, in particular kernel based statistical methods such as Gaussian processes combined with geometric numerical methods. The tailored kernel functions allow to preserve phase-space structure and conserve invariants of motion such as energy and momentum over long periods of time.

P 10.15 Tue 16:30 Empore Lichthof

**Towards a Realistic Dimits Shift Prediction using Gyrokinetic Tertiary Instability Calculations** — •Axel Hallenbert and Gabriel Plunk — Max-Planck-Institut für Plasmaphysik, Greifswald, Germany

A frequently observed feature in gyrokinetic simulations close to marginal stability is the quenching of transport by persistent, self-generated shearing zonal flows, resulting in a nonlinear upshift of the effective critical gradient known as the Dimits shift. Unfortunately a consistent way to predict the size of the Dimits shift has so far been lacking. In an attempt to remedy this, tertiary instability investigations together with full nonlinear simulations within the Dimits shift regime have been performed for various cases using GENE. Two main conclusions can be drawn, the first of which is that the tertiary instabilities corresponding to the simplified zonal flow profiles previously sufficient to predict the Dimits shift for the Terry-Horton system and the strongly driven gyrofluid limit of gyrokinetics are generally insufficient to explain the Dimits shift in full gyrokinetics. Secondly a further subdivision into two qualitatively different regimes is consistently observed whose separation seems linked with the evolution of the zonal flow profiles in the presence of small-amplitude drift waves.

P 10.16 Tue 16:30 Empore Lichthof

**Self-similar hydrodynamics and pellet injection** — •Alistair Arnold, Per Helander, and Pavel Aleynikov — IPP Greifswald, Stellarator Theory Department

Pellet injection is a kind of refuelling used in stellarators and tokamaks (in particular the Wendelstein 7-X stellarator[1]), and is associated with a large and rapid net exchange of energy between electrons and ions[2]. From a hydrodynamic perspective, assuming that pellet ions remain at zero temperature, the result of the cold pellet electrons being heated by a background of hot electrons is ambipolar expansion of the entire cloud, with the electrons 'dragging along' the cold ions. The early phase of the expansion is self-similar in nature, due to the lack of inherent length scale associated with the hydrodynamic problem. Approximately half of the heating power provided to the cold electrons is transferred to the cold ions in the form of flow velocity kinetic energy, which is eventually converted to heat by collisions with the background. The limits of the validity of the hydrodynamic approach are investigated as well as the microscopic collisional picture of pellet injection, in particular the role of energy transfer between cold ions and electrons, and the conversion of the pellet ions' parallel energy to heat on a collisional timescale that is slow compared to the cloud expansion.

[1] R C Wolf et al. Major results from the first plasma campaign of the wendelstein 7-x stellarator. Nuclear Fusion, 57(10):102020, 2017.

[2] A Aleynikov et al. Plasma ion heating by cryogenic pellet injection. Journal of Plasma Physics, 85(905850105), 2019.

P 10.17 Tue 16:30 Empore Lichthof

**Analysis of Optimal Quasi-isodynamic Stellarator Magnetic Equilibria Using a Direct Construction Approach** — •Katia Camacho Mata, Gabriel G. Plunk, Michael Drevlak, and Per Helander — Max-Planck-Institut für Plasmaphysik, Greifswald, Germany

Two important requirements for a viable stellarator reactor are easy-to-build-coils and good confinement. Omnigenous configurations, those in which the time-averaged radial drift is zero, fulfill the good confinement properties requirement. Such configurations are traditionally found by numerical optimization, but these designs have been generally found to feature complex coils. However, it is unknown whether such complexity is fundamentally necessary. To explore this question, we will use a recently developed [1] method for the direct construction of omnigenous MHD(Magnetohydrodynamic) equilibria, which avoids the computational cost of conventional optimization, allowing a thorough survey of the space of omnigenous stellarators at large aspect ratio. We present an analysis of such solutions, focusing on the quasi-isodynamic case, a particular case of omnigeneity. We analyze the space of solutions using NESCOIL to identify equilibria that can be constructed using simple planar coils.

[1] Plunk, G. G., Landreman, M., & Helander, P. (2019). Direct construction of optimized stellarator shapes. Part 3. Omnigenity near the magnetic axis. Journal of Plasma Physics, 85(6).

P 10.18 Tue 16:30 Empore Lichthof

**CO2 conversion and energy efficiency of a microwave plasma torch** — •Katharina Wiegers, Irina Kistner, Andreas Schulz, Matthias Walker, and Günter Tovar — Institute of Interfacial Process Engineering and Plasma Technology IGVP, University of Stuttgart, Stuttgart, Germany

Mankind nowadays is strongly affected by the ongoing climate change which is caused mainly by the increasing emission of carbon dioxide (CO2) from e.g. traffic, coal power plants and industry. An inherent problem of the energy production by renewable sources such as photovoltaics and wind mills is the often observed discrepancy between actual energy "production" and energy demand, due to their discontinuous availability. The so-called "excess" energy can be used to operate a microwave plasma torch at atmospheric pressure. The CO2 plasma leads to the formation of carbon monoxide (CO) and oxygen radicals (O). To avoid the thermodynamically forced recombination of both back to CO2, when leaving the plasma state an effective separation process is required. The separation is achieved by ceramic hollow fibers. The remaining CO can be used as an important chemical C1-building block, which can be further employed for creating molecules with a higher commercial value. This work is focused on the conversion and energy efficiency of the CO2 plasma by different process parameters like microwave power, gas flow and distance from inside the plasma to the afterglow. The efficiencies are determined via FT-IR and mass spectrometry.

P 10.19 Tue 16:30 Empore Lichthof

**Ro-vibrational excitation measurement in transient ns-discharges by multiple optical diagnostics** — •Yanjun Du, Dirk Luggenhölscher, and Uwe Czarnetzki — Institute for Plasma and Atomic Physics, Ruhr University Bochum, D-44780 Bochum, Germany

$CO_2$ conversion is of growing interest in the context of greenhouse gas abatement and renewable energy exploration. The non-thermal plasma is promising means for efficient conversion since the unique electron, vibrational, rotational and gas temperatures in these plasmas allow focusing the discharge energy to the desired channels instead of heating the gas. Specifically, the vibrational excitation can lower activation barriers for direct dissociation and, thus, improve the final energy efficiency. This project aims at a fundamental understanding of the vibrational-stimulated $CO_2$ conversion by providing detailed experimental data. ns-pulsed atmospheric pressure plasma jets will be used to achieve independent control of plasma generation and molecular excitation by separating the relevant time scales. The evolution of the ro-vibrational distribution of both symmetric and asymmetric vibrational modes in $CO_2$ can be monitored by TDLAS at 2285 $cm^{-1}$. The plasma condition can be examined by temporally and spatially resolved optical emission spectroscopy. Here results from these investigations will be presented and discussed. The investigations are supported by the Alexander von Humboldt Foundation and the DFG in the frame of the CRC 1316.

P 10.20 Tue 16:30 Empore Lichthof

**Treatment of methylene blue solution with a cold atmospheric pressure plasma** — •Nils Dose, Kerstin Sgonina, and Jan Benedikt — Institute of Experimental and Applied Physics, Kiel University, Kiel, Germany

Methylene blue solutions have previously been treated with different plasma sources resulting in its degradation due to following reactions. The degradation mechanism has also been investigated using dielectric barrier discharge showing that methylene blue reacts with various forms of oxygen like $O_3$ and OH [1]. In addition, the effluent of a $He/O_2$-plasma ignited in the COST-Jet has already been analysed with mass spectrometry to determine the density of atomic oxygen and ozone. In this work, the reaction of methylene blue with atomic oxygen and ozone is investigated.

An aqueous methylene blue solution was treated with the effluent of the COST-Jet, using a $He/O_2$ gas mixture. By observing the degradation of methylene blue, the influence of different parameters was investigated. The $O_2$ admixture as well as the distance between the plasma and the liquid were varied to see how O and $O_3$ react with methylene blue while distinguishing both reactants. Additionally, the concentrations of methylene blue were used to observe the influence on the degradation.

[1] F. Huang *et al.*, Chemical Engineering Journal 162.1 (2010)

P 10.21 Tue 16:30 Empore Lichthof

**Electric Field Measurements via EFISH in a CARS Setup** — Jutta Püttman, Jan Kuhfeld, •Dirk Luggenhölscher, and Uwe Czarnetzki — Ruhr-University Bochum, Experimental Physics V, Germany

The electric field strength is a basic parameter of non-thermal plasmas since it determines the energy of the electrons which governs the discharge dynamics in high pressure plasmas. Further, if the electric field strength and its temporal development are known, this can be combined with additional diagnostics like voltage and current measurements to infer many other quantities of interest e.g. displacement and conduction current, dissipated power, and electron density. The electric field is measured by "Electric field induced second harmonic generation" (EFISH) [1] using the second harmonic of a pulsed Nd:YAG laser which is part of a more complex CARS setup for measuring the ro-vibrational distribution of N2 and CO2. The presence of an electric field induces an asymmetry in the polarizability of the gas which enables the otherwise forbidden generation of the second harmonic radiation. The method is species independent and allows for spatial and temporal resolved measurements in which the resolution is governed by the focal parameter and pulse duration of the laser. The method is characterized, calibrated and first measurements in an atmospheric pressure nanosecond pulsed discharge are presented.

[1] A. Dogariu, B. Goldberg, S. O'Byrne, and R. Miles, Phys. Rev. Appl. (2017) 024024

P 10.22 Tue 16:30 Empore Lichthof

**2D Model Simulation for Single Filament Dielectric Barrier Discharge in Air** — •Bahram Mahdavipour[1], Sebastian Dahle[2,3], and Jens Oberrath Oberrath[4] — [1]Institute of Product and Process Innovation, Leuphana University Lüneburg, Germany — [2]Clausthal Center for Material Technology, Clausthal University of Technology, Leibnizstr. 9, 38678 Clausthal-Zellerfeld, Germany — [3]Department of Wood Science and Technology, Biotechnical Faculty, University of Ljubljana, Jamnikarjeva 101, 1000 Ljubljana, Slovenia — [4]South Westphalia University of Applied Science, Department of Electric Power Engineering, Modeling and Simulation, Soest, Germany

Dielectric-barrier discharges (DBD) are devices that are being used in several applications such as surface modification, plasma chemical vapor deposition, plasma medicine, pollution control, gas, and air cleaning. Filamentary DBDs are created as a number of short time duration individual breakdown channels and are known as microdischarges. Most of the chemical reactions of DBDs take place in their microdischarges. The aim of this work is to study microdischarges at low temperatures and atmospheric pressure conditions in an air DBD to analyze their creation, the chemical reactions, and the physical mechanisms that occur. The microdischarge is simulated in a 2D fluid model in PLASIMO with simplified air (nitrogen-oxygen mixture) in a needle to needle geometry. At the powered and dielectrically insulated electrode, a sinusoidal voltage is applied and the counter electrode is grounded. Through the simulation, parameters like electron density, N2+, O2+, and ozone production can be studied.

P 10.23 Tue 16:30 Empore Lichthof

**Influence of secondary electron emission and dielectric permittivity on argon dielectric barrier discharges** — •Marjan Stankov, Markus M. Becker, Robert Bansemer, and Detlef Loffhagen — Leibniz Institute for Plasma Science and Technology (INP), 17489 Greifswald, Germany

In this contribution the behavior of dielectric barrier discharges (DBD) in argon at subatmospheric pressure with the variation of the secondary electron emission coefficient ($\gamma$) and dielectric permittivity ($\varepsilon_r$) of the dielectric layers is studied by means of fluid modeling. The investigated plasma source has a symmetric plane-parallel geometry with the electrodes covered by quartz dielectrics and a gap width of 3 mm. A time-dependent, spatially one-dimension fluid model comprising balance equations for particle number densities and the electron energy density coupled with Poisson's equation was employed for modeling of the DBD. Model calculations were carried out for different values of $\gamma$ and $\varepsilon_r$ of dielectric layers at pressures from 100 to 650 mbar. Very good agreement between modeling results and measured data for the discharge current and dissipated power was obtained over the complete pressure range. It was found that the increase of $\gamma$ and $\varepsilon_r$ leads to an earlier occurrence of gas breakdown and decreasing of the breakdown voltage. The analysis of the average dissipated power reveals that the variation of $\varepsilon_r$ has a stronger influence on the modeling results in comparison with $\gamma$ variation, especially at higher pressures.

Funded by the Deutsche Forschungsgemeinschaft (DFG) - project number 368502453.

P 10.24 Tue 16:30 Empore Lichthof

**Influence of oxygen on deuterium retention and release in self-damaged tungsten** — •Maximilian Brucker[1,2], Kristof Kremer[1,3], and Thomas Schwarz-Selinger[1] — [1]Max Planck Institute for Plasma Physics, Boltzmannstr. 2, D-85748 Garching, Germany — [2]Ulm University, Albert-Einstein-Allee 11, D-89081, Ulm, Germany — [3]Technische Universität München, James-Franck-Straße 1, D-85748, Garching, Germany

Understanding hydrogen isotope (HI) retention in first-wall materials is crucial to predict fuel loss in future fusion devices. The influence of oxygen is discussed controversly in literature. Since in almost all experiments tungsten (W) is exposed to air prior to and/or after loading with deuterium (D), a thin surface oxide layer is naturally present at W surfaces. The effect of such a tungsten oxide layer could play a role on the retention and release of HIs and is examined in ex-situ experiments. As samples, self-damaged W is used. Due to self-damaging of pure tungsten with 20 MeV W ions an about 2 $\mu m$ thick defect-rich getter layer is created which can trap up to about 2 % HIs. In order to load the damaged tungsten with D, a low-temperature D plasma is used. To examine the effects of outgassing, the samples are first D loaded and then electro-chemically oxidized to oxide layer thicknesses of 25 nm to 100 nm. After oxidation, Rutherford Backscattering Spectroscopy, Nuclear Reaction Analysis and Thermal Desorption Spectroscopy are used to quantify the amount of oxygen, the depth profiles of the retained deuterium and the outgassing behavior. A quantitative discussion of the result will be presented.

P 10.25 Tue 16:30 Empore Lichthof

**Investigating the deformation of drawn tungsten wires** — •Maximilian Fuhr[1,2], Bailey Curzadd[1,2], Johann Riesch[1], Martin Balden[1], and Rudolf Neu[1,2] — [1]Max-Planck-Institut für Plasmaphysik, Boltzmannstraße 2, 85748 Garching bei München — [2]Technische Universität München, Boltzmannstraße 15, 85748 Garching bei München

Drawn tungsten wires are used as reinforcement fibres in tungsten fibre-reinforced tungsten composites ($W_f/W$). These composites mitigate the embrittlement issue of tungsten materials used in nuclear fusion technology by utilising extrinsic toughening mechanisms.

Tungsten wires show both a high strength and ductility when deformed in a room temperature tensile test. After reaching the maximum stress, the stress-strain curve exhibits a plateau that is followed up by a sharp stress drop. Contradicting the current theories, the localisation of plastic deformation to a specific specimen region (necking) is clearly visible only after the stress drop has occurred. Several different deformation mechanisms have so far been discussed to explain this behaviour of tungsten wires.

Thus, the tensile stress-strain behaviour of drawn tungsten wires is investigated using interrupted tensile tests at room temperature. The microstructure of the deformed specimens is studied using SEM and EBSD techniques. Special focus is thereby directed to the characteristic grain structure consisting of highly elongated grains and the strong fibre texture.

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**Zirconium oxide based layers investigated by the 3 omega method** — •Vitali Bedarev[1], Philipp A. Maass[1], Marina Prenzel[2], Marc Böke[1,2], and Achim von Keudell[1,2] — [1]Institute for Experimental Physics II, Ruhr-University Bochum, Universitätsstr. 150, D-44780 Bochum,Germany — [2]Research Department Plasmas with Complex Interactions, Ruhr-University Bochum, Universitätsstr. 150, D-44780 Bochum,Germany

Aim of the project is to develop thin layers by using deposition techniques like CVD and later PECVD which can be used for galvanic isolation. First step will be the evaporation of a precursor (based on a zirconium oxide bond). The evaporated gas is guided into the main chamber by using nitrogen (with a flow of 25/50 sccm). Hence a zirconium oxide layer is expected to be synthesized. The main focus is to study thermal conductivity of thin layers in-situ, therefore, one can use the 3 omega method.

Furthermore, we will analyze the change of the thermal conductivity depending on the morphology of the layer. The layer growth rate is expected to be $>$ 500 nm/h and the layer thickness $<$ 30 microns.

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**Spoke-synchronised optical emission spectroscopy in a high-power impulse magnetron discharge** — •Philipp Maass, Julian Held, Volker Schulz-von der Gathen, and Achim von Keudell — Experimental Physics 2, Ruhr-University Bochum, Germany

High-power impulse magnetron sputtering (HiPIMS) is a physical vapour deposition technique in which a plasma is ignited in front of a target in order to sputter atoms from the target and coat a substrate. In such a plasma, inhomogeneities, which appear as localised light emissions - so-called spokes -, can be detected. They move in ExB-direction at a velocity of about 10 km/s.

Spokes appear in the magnetic trap region in front of the magnetron. In order to further investigate them, non-intrusive measurements are needed. Optical emission spectroscopy seems the best option, is however limited due to the stochasticity of the spokes' appearance in space and time. Therefore, a triggering system was developed that enables the recording and investigation of spoke-synchronised measurements.

The triggered OES measurements were performed using a CCD-camera and filters in a frontal and an orthogonal set-up aimed at the target. The spokes were found to have very complex internal structures indicated by the sequence of filtered emissions. The spread of the spokes was discovered to be large, extending to the last closed magnetic field line.

P 10.28 Tue 16:30 Empore Lichthof

**Control of Spokes in HiPIMS Discharge** — •Mathews George and Achim von Keudell — Experimentalphysik II, Ruhr-University Bochum

Magnetron Sputtering is a Plasma Vapour Deposition (PVD) process widely used in industry and scientific communities. HiPIMS produces plasmas of very high density of the order $10^{19}\mathrm{m}^{-3}$ without overheating the target. The plasma appears to be homogeneous to the human eye, but shows localised zones of high brightness rotating in the E x B direction when observed with an ICCD camera with exposure times below $1\mu$s[1] [3]. These so called spokes are assumed to play a role in the transport of particles and energy away from the target [2]. The primary objective is the control of spokes by using externally applied field on a Langmuir probe in HiPIMS. The major motive behind spoke control is to regulate the deposition rate and quality of the film. DCMS was chosen for the starting phase since the spokes in DC regime are more uniform compared to HiPIMS. Amplified sinusoidal voltage signals are applied on a Langmuir probe to draw electron current from the plasma at the highest gradients in the E x B direction. The variation of spoke frequency or any kind of influence on the spokes characteristics with respect to the applied frequency are detected by measuring the spoke frequency using a photomultiplier. [1] A Hecimovic, A von Keudell *J. Phys. D: Appl. Phys.* 51 (2018) 453001 (15pp) [2] N Brenning, *et al.* 2013 *J. Phys. D: Appl. Phys.* 46 084005 [3] Andre Anders, Yuchen Yang *Appl. Phys. Lett.111*, 064103 (2017)

P 10.29 Tue 16:30 Empore Lichthof

**Wigner crystals in bunches with finite emittance in the bubble regime** — •Lars Reichwein, Johannes Thomas, and Alexander Pukhov — Institut für Theoretische Physik I, Heinrich-Heine-Universität Düsseldorf, Düsseldorf

The influence of non-zero emittance onto the spatial structure of an equilibrium electron bunch in a quasi-static bubble model is studied. The full Liénard-Wiechert potentials are used to calculate the relativistic inter-particle interaction while the external force is described in the context of a simplified bubble model [1]. We introduce transverse momenta as a perturbation approach of the previous zero-emittance model [2]. For low emittances the crystalline structure of the bunch is preserved, while for higher emittances the observed symmetry is broken. In the region of this phase transition a widening of the structure and formation of various shells can be observed. These structural changes resemble those of the zero-emittance model when the parameters momentum, plasma wavelength and total particle number were varied.

[1] I. Kostyukov et al., Phys. Plasmas 11, 5256 (2004)
[2] L. Reichwein et al., arXiv:1903.04858 (2019)

P 10.30 Tue 16:30 Empore Lichthof

**Analytical models for the Trojan Horse regime of underdense photocathode plasma wakefield acceleration** — •Johannes Thomas and Alexander Pukhov — Heinrich Heine Universität Düsseldorf

Broken plasma wake fields in homogeneous plasmas provide a feasible path for high- gradient particle acceleration. Especially efficient is the so-called blow-out regime of particle wake field acceleration[1], where a short, highly dense particle bunch excites a distorted spherical cavity from which all electrons are banished. The blow-out moves with nearly the speed of light through the plasma and generates quasi-monoenergetic electron bunches. In the context of underdense photocathode plasma wakefield acceleration (also known as the Trojan Horse regime) it could be shown that a laser-controlled release of electrons directly into a blow-out allows the generation of electron bunches with ultralow emittance and ultra-high brightness [2]. In our presented work we show:

(i) why known (semi-)analytical blow-out models have difficulties to correctly describe the acceleration of single electrons in the quasi-static fields of the Trojan Horse regime;

(ii) how a quasi-static model for the special parameter range of the Trojan Horse regime can be formulated;

(iii) that tailored plasma channels can stabilize the injection mechanism.

[1] P. Chen et. al, Phys. Rev. Lett 54, 693 (1985).
[2] B. Hidding et. al, AIP Conference Proceedings 1507, 570 (2012).

P 10.31 Tue 16:30 Empore Lichthof

**Time-resolved Simulations of Laser-induced Ionization in the Tunneling Regime** — •Michael Stumpf and Georg Pretzler — Institut für Laser- und Plasmaphysik, Heinrich-Heine-Universität Düsseldorf

Ionization rate calculations are a common and necessary tool to simulate the interaction of laser pulses with matter. We investigated different models and compared them with experimental results. For our simulations, we calculated the exact temporal and spatial field distributions within a fs-laser focus with high precision and used quasi-static approximations to simulate the ionization rates. In order to verify our simulations, we experimented with a wide range of parameters using the PHASER few-cycle Ti:Sa-system in Düsseldorf and a novel pulse energy attenuator as well as a new beam-shaping device called AMBER (Axicon Mirror Beam ExpandeR). The results are used to design the internal injection of electrons inside of a Plasma Wakefield structure following the Trojan Horse Injection model.

P 10.32 Tue 16:30 Empore Lichthof

**Construction of a Pre-Pulse Generator for Few-Cycle Laser Pulses** — •Jonah Book, Steffen Mittelmann, and Georg Pretzler — Institut für Laser- und Plasmaphysik, Heinrich-Heine-Universität Düsseldorf

Here we report the design, setup and characterization of a pre-pulse generator for high-intensity few-cycle pulses. The difficulty in contrast to longer pulse durations is keeping the dispersion low for both pulses and at the same time preserving their beam quality. A pre-pulse generator offers a variety of valuable uses in laser-plasma-physics. When splitting a laser pulse into two pulses with differing intensities, one can be used to ignite a surface plasma which constitutes a target with adjustable properties for the other, stronger pulse, such that certain aspects of the interaction can be optimized, like plasma temperature, ionization state or harmonic generation. We present our new design together with the characterization of both pulses, most of all pulse duration and focus quality, as well as their temporal and spatial overlap.

P 10.33 Tue 16:30 Empore Lichthof

**Recent experiments on waves in a complex plasma in the PK-4 Laboratory under microgravity** — •Mierk Schwabe, Mikhail Pustylnik, and Hubertus Thomas — Institut für Materialphysik im Weltraum, Deutsches Zentrum für Luft- und Raumfahrt, Weßling, Deutschland

The PK-4 Laboratory is a Russian-European laboratory for studies on complex plasmas on board the International Space Station ISS. Its heart consists of a direct current plasma tube with 3 cm diameter and a total length of the working area of 20 cm. Microparticles of various sizes can be injected into the plasma. Microparticles can be trapped in the discharge by, for example, quickly switching the discharge polarity, or by applying a longitudinal thermal gradient. The polarity switching causes the ions and electrons of the plasma to stream around the microparticles, and the ions form wakes in downstream direction of the microparticles, which in turn attract other microparticles and lead to the formation of microparticle strings. Here, we report on recent experiments on waves that form in a cloud of trapped microparticles with a special emphasis on the influence of string formation on wave propagation.

P 10.34 Tue 16:30 Empore Lichthof

**Thermal gradient induced dust convections in a dc plasma under microgravity conditions** — •Andreas Schmitz, Ivo Schulz, Michael Kretschmer, and Markus Thoma — I. Physikalisches Institut, Justus-Liebig-Universität, Gießen, Germany

Experiments with complex plasmas were conducted in an engineering model of the International Space Station's laboratory setup Plasmakristall 4 during ESA's 71th parabolic flight campaign in the A310 ZERO-G aircraft in May 2019. In some of these microgravity experiments a DC discharge plasma was generated within the elongated glass tube of PK-4. The investigated complex plasma was introduced to a thermal gradient caused by a heater ring mounted around the plasma chamber. The dust cloud was trapped near the heater where the cloud convected. It was concluded that this dust cloud convection was induced by a gas flow via drag. Analysis of the dust cloud convection showed this gas flow to have been caused by thermal creep, a phenomenon which is common in rarefied gases with a temperature gradient along a boundary.

P 10.35 Tue 16:30 Empore Lichthof

**Two dimensional absolute density distributions of Nitric Oxide (NO) in the effluent of the "COST Reference Microplasma Jet"** — •Patrick Preissing[1], Ihor Korolov[2], Volker Schulz-von der Gathen[1], and Marc Böke[1] — [1]Experimental Physics II, Ruhr-University Bochum, Bochum — [2]Institute for Electrical Engineering and Plasma Technology, Ruhr-University Bochum, Bochum

In cold atmospheric pressure plasmas (CAPs) the heavy particles remain cold (i.e. near room temperature), while the electrons can be effectively heated. This leads to a high temperature chemistry with low thermal stress for the sample. Therefore, CAPs provide great properties for applications, such as for biomedical ones. In this context a robust, stable micro RF reference jet was developed with a high degree of reproducibility (COST reference jet). Owing to the non-equilibrium character various types of dissociation products are created. Species as for example Nitric Oxide or Ozone typically have longer lifetimes and are therefore likely candidates to interact with the treated sample. While at larger concentrations NO was found to be extremely harmful to the human body, at lower concentrations the molecule triggers many important biological processes as intercellular messenger and diffuses rapidly through most tissues which makes it an important component for tissue and wound treatments. In this work we present two dimensional, time averaged, absolute density distributions of NO in the effluent of the COST-Jet measured by means of Laser Induced Fluorescence (LIF). The measurements are performed within the framework of the SFB1316.