ÖAW ÖSTERREICHISCHE AKADEMIE DER WISSENSCHAFTEN

Fusion Research in Austria

Activities in 2018 and 2019

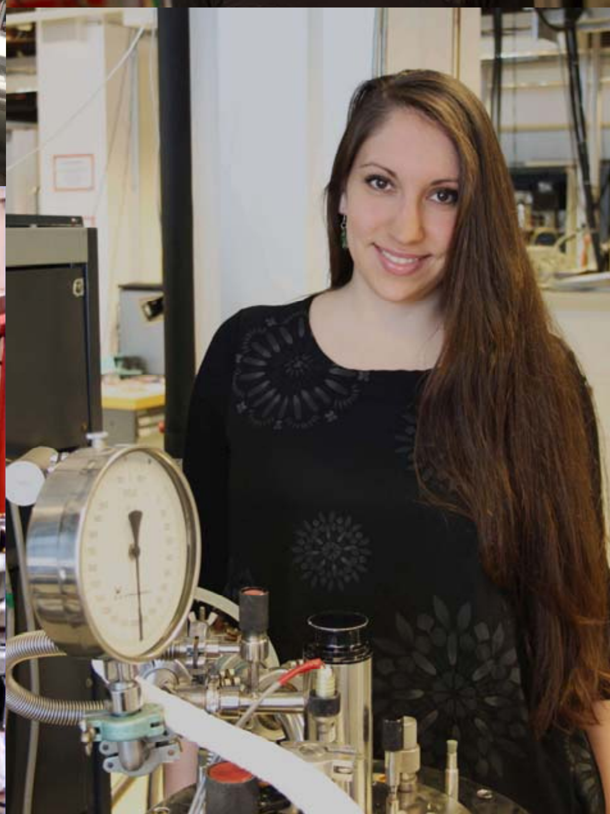

Photo collage on cover page:

Hands-on education at Austrian university laboratories.

Courtesy Technische Universität Wien, Institut für Angewandte Physik and Atominstitut, and Universität Innsbruck, Institut für Ionenphysik und Angewandte Physik

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Vienna
February 2020

Fusion Research in Austria - Activities in 2018 and 2019

Compiled and edited by Monika Fischer

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CONTENTS

INTRODUCTION

In the light of climate change as a present-day and future challenge, I clearly see fusion research as a contribution to a sustainable energy mix for the future. Even though progress may be criticized as very slow, we are step by step coming closer to the realization of fusion energy. Progress on the building site of ITER continues to be impressive, targeting first plasma in 2025 and first production of fusion power around 2035.

With the establishment of EUROfusion in 2014 as the first European Joint Programme under Horizon 2020, fusion research in Europe has become even more focused on the goal to develop the knowledge and design basis for future fusion power plants on the basis of the *European Research Roadmap to the Realisation of Fusion Energy*. As of 31 December 2019, the members of EUROfusion are 30 beneficiaries from 26 of 28 European Union member states. Together with the Programme Management Unit of EUROfusion, we are presently preparing our input to the proposal for the programme's successor in Horizon Europe.

This brochure is intended to highlight the integration of Austrian fusion research into the European Fusion Research Programme and make success visible. The largest part of Austrian fusion research is performed at university institutes, with approximately 21 PhD students participating per year. Education and training of young researchers therefore continues to be an important objective of the Austrian Fusion Research Programme, which is well recognized by the number of PhD theses supported within the EUROfusion work package Education. Selected theses completed in the period 2018/2019 or near completion are presented in chapter II.3.

As Austria does not have its own fusion facilities, opportunities to contribute to experiments and modelling at JET, ASDEX Upgrade and Wendelstein 7-X are vital for the successful participation of Austrian scientists in the fusion programme. I would therefore like to commend the efforts by the EUROfusion Programme Management Unit and task leaders to schedule and manage the experimental campaigns under the work packages *Small and Medium-Sized Tokamaks* (MST1 and MST2) as well as the campaigns at JET.

The involvement of industry in the European Fusion Programme and the accessibility of business opportunities triggered by the construction of ITER are of vital importance for the ITER project. In this respect, valuable support is provided by the Industrial Liaison Officer (ILO) at the Austrian Federal Economic Chamber who circulates information about calls and specialized meetings for industry to qualified companies and organizes the participation of delegations from industry in specialized meetings.

Last, but not least I wish to thank all members of our Research Unit for their unbroken commitment and enthusiasm and the institutions listed below for their cooperation and support:

the Austrian Federal Ministry of Education, Science and Research
the President, Presiding Committee and staff of ÖAW,
the Austrian Commission for the Coordination of Fusion Research at ÖAW, and
the responsible officers of the European Fusion Programme.

Vienna, February 2020

(Friedrich Aumayr
Head of Research Unit, Fusion@ÖAW)

I. ON THE ROAD TO FUSION ELECTRICITY

ITER

The tokamak ITER —designed to demonstrate the scientific and technological feasibility of fusion power—will be the world's largest experimental fusion facility. ITER is built in international cooperation, with components delivered by the domestic agencies of all ITER partners (People's Republic of China, European Union, India, Japan, Russian Federation, South Korea and United States of America). The ITER Organization and the seven Domestic Agencies are working collectively to achieve the milestone of first plasma at the end of 2025.

Concrete works for the tokamak building were completed in early November 2019. This was celebrated with an olive tree on the roof to be replanted on the ITER site.© ITER Organization

The crane hall structure above the tokamak building was completed in December 2019.

© *ITER Organization*

The European Domestic Agency - Fusion for Energy (F4E)

F4E was established for a period of 35 years from 19 April 2007 and is responsible for providing Europe's contribution to ITER. Calls for tender, vacancies and up-to-date information on the progress of the ITER project are published on F4E's website

Lower segment of sector 5 of the ITER vacuum vessel. © F4E

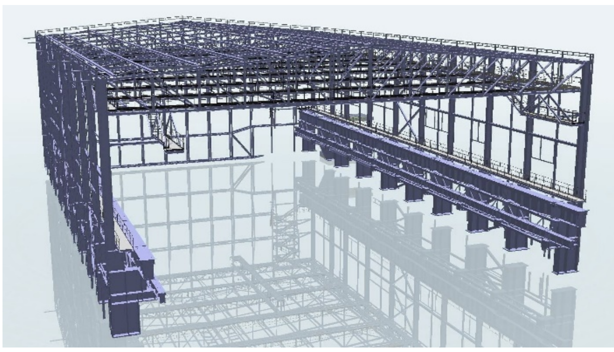


Illustration of the tokamak building roof steel structure. © ITER Organization

Information for Austrian industry

Harnessing fusion energy is an industrial effort to be backed by targeted research. The network of Industrial Liaison Officers (ILOs) raises awareness among qualified companies and advises them on ways to get involved in the ITER project. In Austria the function of ILO is performed by the Austrian Chamber of Commerce which acts as a contact forum for Austrian companies qualified for participating in high-tech industrial projects. An information day for Austrian industry was organized by the ILO in May 2018.

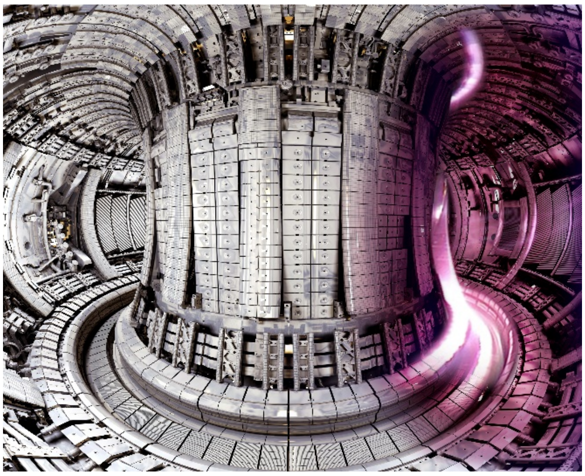
EUROfusion

The first plasma in ITER is expected to be generated in 2025. To prepare for the experimental campaigns at ITER, EUROfusion manages campaigns at European tokamaks such as JET (Culham, UK), ASDEX Upgrade (IPP Garching, Germany), TCV (Lausanne, Switzerland) and MAST (Culham, UK) and coordinates the advancement of the fusion research base. With a view to future fusion power plants, Wendelstein 7-X represents the largest device of the stellarator concept. Up-to-date information about recent results, news and vacancies within the European fusion research units can be found at https://www.euro-fusion.org/

JET (CCFE, Culham, United Kingdom)

JET at the Culham Centre for Fusion Energy (CCFE) is presently the largest tokamak in the world and the only fusion experiment in operation which is capable of producing fusion energy. EUROfusion provides the work platform for jointly exploiting JET in an efficient and focused way, managing experiments at JET within the annual work programmes of the ITER Physics Department.

The next deuterium-tritium campaign has seen some delay due to technical reasons and is now scheduled for 2020.



Virtual vessel of JET with plasma
Source: https://www.euro-fusion.org/

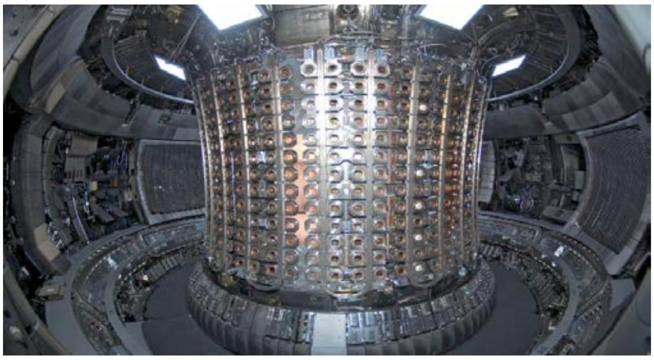
Experiments at medium-size tokamaks (MST) managed by EUROfusion

Under the medium-size tokamaks (MST) programme EUROfusion coordinates research on ASDEX Upgrade (AUG), TCV and MAST Upgrade, which will soon become ready for operation. This multi-machine approach is instrumental to progress in the field, as ITER and DEMO core/pedestal and scrape-off layer (SOL) parameters are not achievable simultaneously in present day devices. On the one hand, scenarios with tolerable transient heat and particle loads, including active edge localized mode (ELM) control are developed. On the other hand, divertor solutions including advanced magnetic configurations are studied. Considerable progress has been made on both approaches, in particular in the fields of: ELM control with resonant magnetic perturbations (RMP), small ELM regimes, detachment onset and control as well as filamentary scrape-off-layer transport.

In the period 2018/2019 a series of experiments has been conducted on the AUG and TCV devices to disentangle the role of plasma fueling and plasma shape for the onset of small ELM regimes. The results of this work are presented in B. Labit et al., "Dependence on plasma shape and plasma fueling for small ELM regimes in TCV and ASDEX Upgrade", *Nuclear Fusion* ***59/8****(2019),* https://doi.org/10.1088/1741-4326/ab2211; co-author from Fusion@ÖAW: G. Harrer (TU Wien); MST1 contributors also from TU Graz and Universität Innsbruck.

ASDEX Upgrade (IPP Garching, Germany)

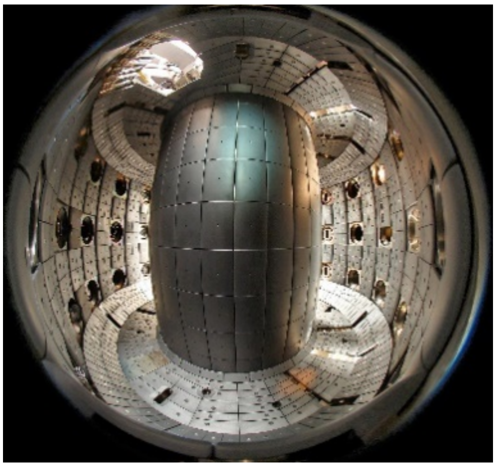
The ASDEX Upgrade tokamak at Max-Planck Institut für Plasmaphysik in Garching near München (Germany) started operation in 1991. In 2002, ASDEX Upgrade was opened to use by fusion laboratories from all over Europe. In 2014, joint exploitation started in the framework of the Medium Sized Tokamak Programme (MST) of EUROfusion.



ASDEX Upgrade vessel view during the 2016 shut-down. The new bellows protection plates and the modified support structure have been installed. The labyrinth-like protection plates as well as the protection plates for the lower ELM control coils and divertor targets are still missing in this picture.

Source: http://www.ipp.mpg.de/
Image: IPP, A. Herrmann

TCV (Swiss Plasma Center, Lausanne, Switzerland)



TCV tokamak at EPFL
Image: Alain Herzog/EPFL

The Tokamak à Configuration Variable (TCV) started operation at École Polytechnique Fédérale de Lausanne (EFPL) in 1992. In 2015/2016 the machine was upgraded to enforce its capabilities such as strong shaping and electron heating with ion heating, additional electron heating compatible with high densities and variable divertor geometry. The TCV programme aims at ITER support, explorations towards DEMO and fundamental research.

Recent upgrades and experimental results are described in S. Coda et al., "Overview of the TCV tokamak program: scientific progress and facility upgrades", *Nuclear Fusion* ***57*** (2017), 102011 (12pp); co-authors from Fusion@ÖAW: S. Costea, C. Ionita-Schrittwieser, B. Schneider and R. Schrittwieser (Universität Innsbruck).

MAST-U (CCFE, Culham, United Kingdom)

MAST-U is a spherical tokamak which can explore a wide range of alternative divertor configurations. The plasma is heated using neutral beam injection and is equipped with ELM control coils and an extensive suite of diagnostics. The first experiments are scheduled for 2020.

Source: www.euro-fusion.org

Photo: Christopher Roux, CEA-IRFM

Wendelstein 7-X

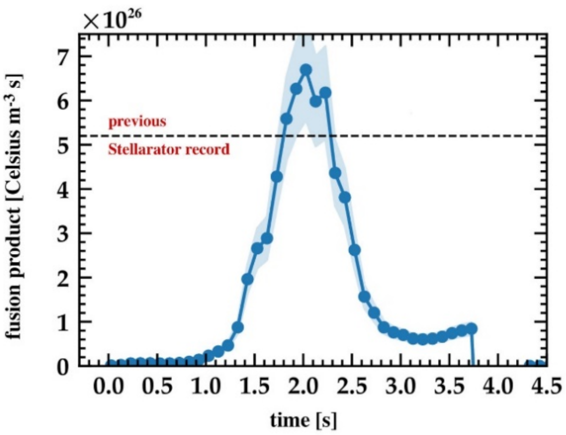
Wendelstein 7-X, located in Greifswald (Germany), is the worldwide largest stellarator. After completion of the main assembly phase, the first plasma was achieved in December 2015. The facility was officially inaugurated on 3 February 2016 in the presence of the German chancellor Angela Merkel.

After completion of the first experimentation phase 2015/16, the plasma vessel of Wendelstein 7-X was fitted with graphite tiles, thus allowing higher temperatures and longer plasma discharges. The divertor was installed which allows for controlling the purity and density of the plasma.

Whereas by the end of the first campaign pulse lengths of six seconds were attained, plasmas lasting up to 26 seconds were produced after the installation of the graphite tiles. In the second operation phase, the heating energy fed into the plasma was 18 times as much as in the first operation phase without divertor.

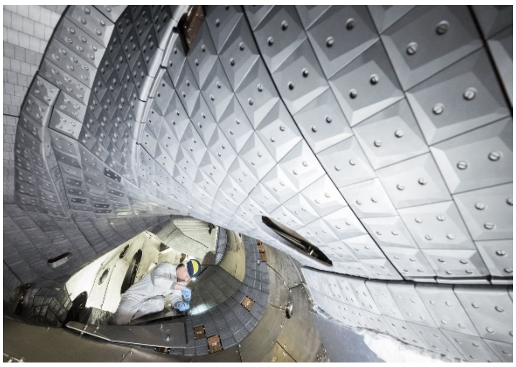
In this way a record value for the fusion product was attained. This product of the ion temperature, plasma density and energy confinement time indicates the closeness to reactor values needed to ignite a plasma. At an ion temperature of about 40 million degrees and a density of 0.8 x 10^{20} particles per cubic meter, Wendelstein 7-X has attained a fusion product affording a good 6 x 10^{26} degrees x second per cubic meter, the world's stellarator record.

Since the end of 2017 Wendelstein 7-X has undergone further extensions, including new measuring equipment and heating systems and reinforcement of the divertor. By the end of the first campaign attained pulse lengths were six seconds; after the enhancements plasmas can be produced up to 26 seconds. With the divertor installed, a heating energy of up to 75 megajoules can be fed into the plasma.



Wendelstein 7-X attained the Stellarator world record for the fusion product.
Image: IPP http://www.ipp.mpg.de

Source: https://www.ipp.mpg.de/



View inside the plasma vessel with graphite tile cladding.

Photo: IPP, Jan Michael Hosan

II. FUSION RESEARCH IN AUSTRIA

Activities in 2018 and 2019

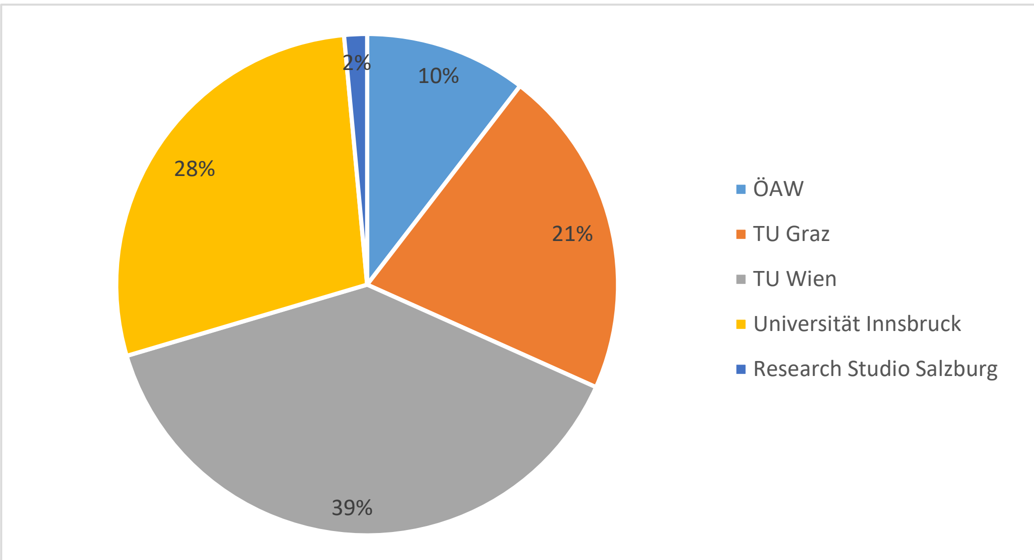
1. OVERVIEW

The Austrian Research Unit

The largest part of Austrian fusion research is performed at university institutes, with approximately 20 PhD students per year. Education and training of young researchers therefore continues to be the major focus of the Austrian Fusion Research Programme, building on strong cooperation with European fusion labs such as CCFE (Culham, United Kingdom), IPP Garching (Germany), EPFL (Lausanne, Switzerland), FZ Jülich and FZ Karlsruhe (Germany). Major activities/topics are measurements and experiments in medium-size tokamaks, plasma-wall interaction, modelling and simulation of plasma phenomena in tokamaks and stellarators, materials science, superconductors for fusion application and socio-economic studies on future energy scenarios.

Participation in EUROfusion

The Austrian Academy of Sciences (ÖAW) acts as national entry point and beneficiary of the EUROfusion Grant Agreement. Fusion research is performed at the Erich Schmid Institute of Materials Science at ÖAW and at four linked parties: Research Studio iSPACE in Salzburg, Technische Universität Graz, Technische Universität Wien and Universität Innsbruck. The share of ÖAW and its linked third parties is shown below.



Austrian participation in EUROfusion: Share of ÖAW and Linked Third Parties (based on expenditure 2018 and 2019)

Source: Fusion@ÖAW)

Participation in EUROfusion workpackages
Period: 2018/2019

PART OF THE PROGRAMME	*INSTITUTION*	*GROUPS INVOLVED*
ITER PHYSICS		
WP01 JET Campaigns (WPJET1)	TUWien/UIBK	D. Tskhakaya
WP05 Medium-Sized-Tokamak Campaigns (WPMST1)	TU Graz TU Wien UIBK	W. Kernbichler F. Aumayr A Kendl R. Schrittwieser
WP06 Preparation of the Exploitation of Medium-Sized Tokamaks (WPMST2)	UIBK	C. Ionita
WP07 Preparation of efficient PFC operation for ITER and DEMO (WPPFC)	TU Wien TU Wien/UIBK UIBK	F. Aumayr D. Tskhakaya M. Probst
WP11 Preparation and Exploitation of W7-X Campaigns (WPS1)	TU Graz TU Wien UIBK	W. Kernbichler F. Köchl R. Schrittwieser
WP12 Stellarator optimization theory development, modelling and engineering (WPS2)	TU Graz	W. Kernbichler
WP13 Code Development for integrated modelling (WPCD)	TU Wien UIBK	D. Tskhakaya M. Probst
POWER PLANT PHYSICS AND TECHNOLOGY		
WP15 Plant Level System Engineering, Design Integration and Physics Integration (WPPMI)I	TU Wien	H. Leeb
WP16 Magnet system (WPENR/MAG-PRD)	TU Wien	M. Eisterer
WP25 Materials (WPMAT)	ÖAW-ESI	R. Pippan
Socio-Economic Research on Fusion (SERF)		
WP28 Socio Economic studies (WPSES)	Research Studios Austria FG	M. Biberacher
EDUCATION		
WP30 Education (WPEDU)	TU Graz ÖAW-ESI TU Wien UIBK	Total: 21 PhD students 11 mentors
WP32 Enabling Research **(**WPENR) MFE19-ENR-MPG-04	UIBK	L. Einkemmer

Abbreviations:

TU Graz = Graz University of Technology
TU Wien = Vienna University of Technology
UIBK = University of Innsbruck
ÖAW-ESI = Erich Schmid Institute of Materials Science at ÖAW

2. *RESEARCH HIGHLIGHTS*

A novel mechanism for zonal flow generation for strong turbulence

M. Held, M. Wiesenberger, A. Kendl
Institut für Ionenphysik und Angewandte Physik, Universität Innsbruck

The article M. Held, M. Wiesenberger, R. Kube and A. Kendl (2018), "Non-Oberbeck–Boussinesq zonal flow generation", *Nuclear Fusion **58/10** (2018)*, https://doi.org/10.1088/1741-4326/aad28e describes new physical models for the generation of strong and coherent zonal flows and was declared one of the highlights of the year 2018 published in the journal.

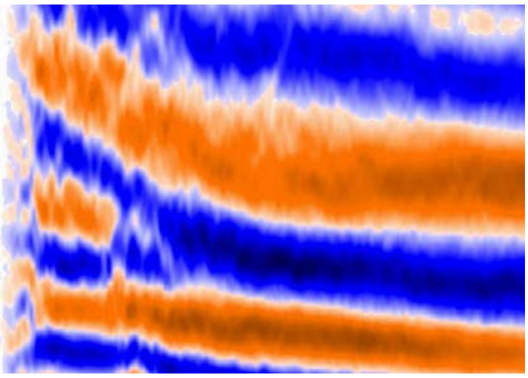


Figure 1. Computer simulation of zonal flows in strongly turbulent plasma.

Zonal flows are key players for improved confinement regimes in tokamaks. This positive effect is well known, but up to now theoretical models and simulations have only been able to describe the effect with small density fluctuations, limited to the edge region of a tokamak. The new statistical averaging methods described in this work extend modelling capabilities to strong turbulence with high amplitudes. In fusion devices turbulent transport leads to energy and particle loss. A better theoretical understanding of transport and turbulence may substantially contribute to the success of future large experiments and fusion power plants. The new models enable more realistic predictions of turbulence and zonal flows in hot plasmas and aim at making efficient use of computing resources.

WP05-MST1: Medium-Size Tokamaks - Campaigns

Small ELM scenarios at ASDEX Upgrade and TCV

G.F. Harrer, F. Aumayr et al.
Institut für Angewandte Physik, TU Wien

Edge localized modes (ELMs) are instabilities which occur in short periodic bursts during high-confinement regime (H-mode) in divertor tokamaks. The sudden outbursts of the plasma expel particles and deposit large heat flux onto the vessel wall. In high-power fusion devices such as ITER or DEMO powerful ELMs will cause erosion at the vessel wall. Finding methods to mitigate or suppress ELMs is therefore an important topic in fusion research. An investigation of the effects of heating and fueling on the formation of small ELMS may help to devise ways of mitigating strong ELMs in large fusion devices such as ITER.

The article G.F. Harrer, E. Wolfrum, M.G. Dunne, P. Manz, M. Cavedon, P.T. Lang, B. Kurzan, T. Eich, B. Labit, J. Stober, H. Meyer, M. Bernert, F.M. Laggner, F. Aumayr, the Eurofusion MST1 Team and the ASDEX Upgrade Team, "Parameter dependences of small edge localized modes (ELMs)", *Nuclear Fusion* ***58/11*** (2018), https://doi.org/10.1088/1741-4326/aad757 presents an overview on parameters affecting size and intensity of ELMs.

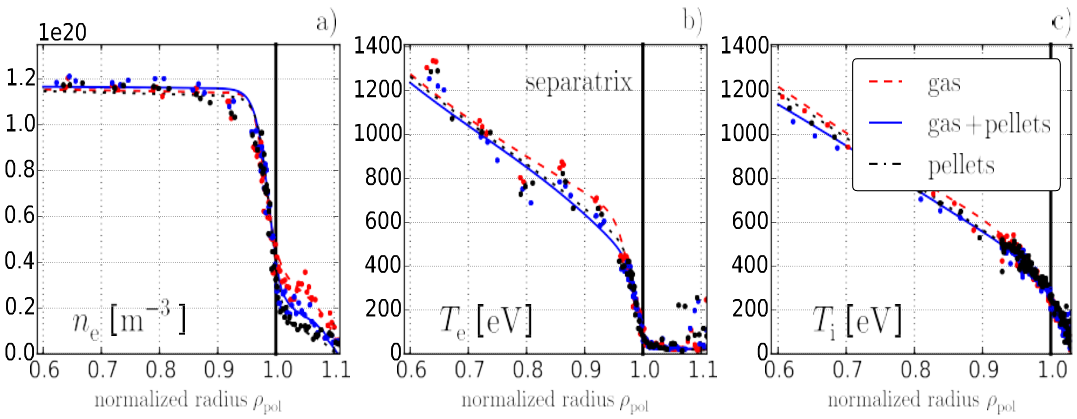


Figure 2. Edge profiles of electron density, electron temperature and ion temperature for three different phases in which fueling changes from pure gas puff ('gas') to a mixture of gas puff and pellets ('gas + pellets') to pure pellet fueling ('pellets'). The height of the density 'shoulder' changes significantly in the plasma edge.

WP06-MST2: Preparation of the Exploitation of Medium-Size Tokamaks

Prototyping and adaptation of plasma probes for use in MST1 devices

S. Costea, C. Ionita Schrittwieser, B.S. Schneider, R. Schrittwieser
Institut für Ionenphysik und Angewandte Physik, Universität Innsbruck

Plasma probes are relatively easy to build and handle and yield their floating potential as the easiest and fastest accessible parameter. However, much more important and relevant than the floating potential is the plasma potential. But in most types of plasmas, consisting mainly of electrons and positive ions, the floating potential is more negative than the plasma potential by a factor proportional to the electron temperature, which is due to the much higher mobility of the electrons. The publication C. Ionita, B.S. Schneider, S. Costea, O. Vasilovici, J. Kovacic, T. Gyergyek, V. Naulin, J. J. Rasmussen, N. Vianello, M. Spolaore, R. Stärz and R. Schrittwieser, "Plasma potential probes for hot plasmas", *European Physical Journal D (2019) 73:73,* https://doi.org/10.1140/epjd/e2019-90514-5 presents a review on probes with a floating potential close to or ideally equal to the plasma potential. Such so-called plasma potential probes (PPP) can either be electron emissive probes (EEP) or electron screening probes (EPS). These probes make it possible to measure the plasma potential directly and with high temporal resolution. An EEP compensates the plasma electron current by an electron emission current from the probe into the plasma, thereby rendering the current-voltage characteristic symmetric with respect to the plasma potential and shifting the floating potential towards the plasma potential.

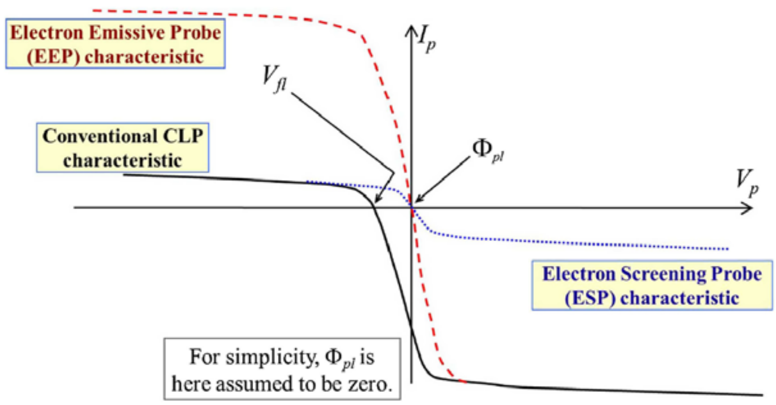


Figure 3. Schematics of current-voltage characteristics of three different types of probes in a conventional Maxwellian plasma: the black line shows the current-voltage characteristic of a normal cold Langmuir Probe (CLP), the red dashed line that of an electron emissive probe (EEP), the blue line that of an electron screening probe (ESP). For simplicity the plasma potential is here assumed to be zero.

WP07-PFC: Plasma-Facing Components

Sputtering behaviour of plasma-facing materials

R. Stadlmayr, P. Szabo, C. Cupak, F. Aumayr et al.
Institut für Angewandte Physik, Technische Universität Wien

In magnetic confinement the hot plasma core is kept at a distance from the materials of the first wall. High-energetic particles can, however, be diverted from the confined plasma and impinge on the first wall. Due to the magnetic configuration there is intensive interaction between the plasma and the divertor surface. Plasma particles as well as impurities are collected, neutralized and discharged at special divertor plates. High Ion and electron currents lead to elevated heat loads and may cause strong erosion of the first wall. The investigation of plasma-wall interaction is therefore a core topic of fusion research.

The key parameters of a plasma facing material are a high melting point, low fuel retention and a low sputtering yield. At the Institute of Applied Physics at Technische Universität Wien a highly sensitive quartz-crystal microbalance technique is used to evaluate the sputtering yield of samples of plasma-facing materials. The state-of-the-art 3D version of the Monte Carlo sputtering code TRIDYN was benchmarked with experimental results obtained for iron-tungsten model films. Results of the benchmarking studies show that the code TRI3DYN is able to predict the outcome of the experiments, provided that the information about the initial surface morphology and elemental depth profile measurements of the sample is taken into account. Not only the dynamic behaviour of the erosion yield with ion fluence, but also the emerging surface pattern and the observed tungsten enrichment at the structured surface can be reproduced. The code also gives first insight why a comparably small surface roughness in the nm range can already have a significant influence on the sputtering behaviour.

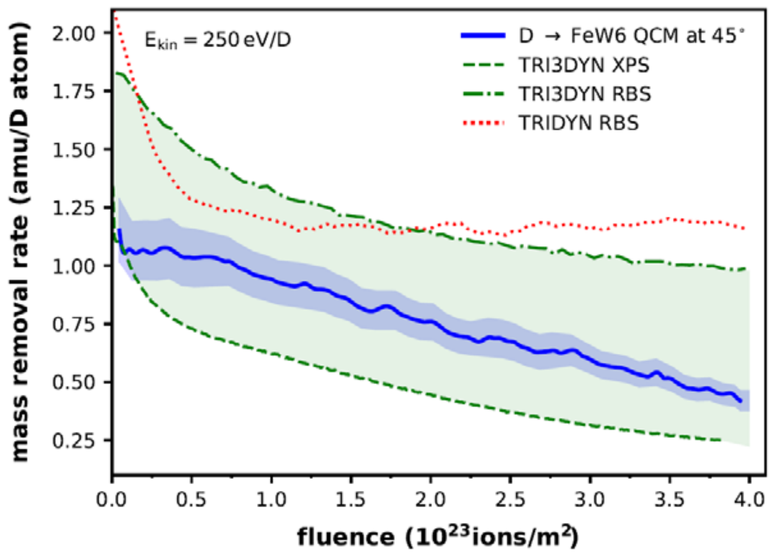


Figure 4. Fluence dependence of the mass removal rate under D ion bombardment at 250 eV/D and under 45°. The dashed and dashed-dotted line show TRI3DYN results, using Rutherford Backscattering (RBS) information and sputter-X-ray photoelectron spectroscopy (XPS) data as input. The full line represents experimental results evaluated with the QCM technique.

Graph: R. Stadlmayr et al., "Erosion of iron-tungsten model films by deuterium ion irradiation: a benchmark for TRI3DYN", *17th International Conference on Plasma-Facing Materials and Components for Fusion Applications (PFMC-17), Eindhoven, Netherlands, 20-24 May 2019*.

WP12-S2: Stellarator Optimization

Alpha particle losses, banana orbits and guiding centers – speeding up computing time

C.G. Albert, R. Buchholz, S.V. Kasilov, W. Kernbichler
Institut für Theoretische Physik – Computational Physics, TU Graz

The publication C.G. Albert, S.V. Kasilov and W. Kernbichler, "Symplectic integration with non-canonical quadrature for guiding-center orbits in magnetic confinement devices", *Journal of Computational Physics* (https://doi.org/10.1016/j.jcp.2019.109065) describes studies of guiding-center orbits in stationary magnetic equilibrium fields of an axisymmetric tokamak and a realistic three-dimensional stellarator configuration. Superior long-term properties of a symplectic Euler method are demonstrated in comparison to a conventional adaptive Runge-Kutta scheme. Statistics of fast fusion alpha particle losses over their slowing-down time are computed in the stellarator field on a representative sample, reaching a speed-up of computing time of a factor >3.

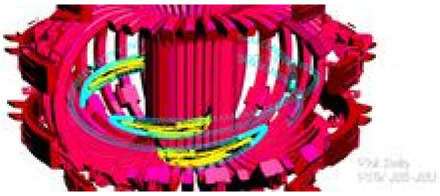


Figure 5. The properties of different particles affect their motion within a fusion device. The picture on the left is a schematic visualization of banana orbits in a tokamak, describing back-and-forth movements of plasma particles trapped in the outside region of a tokamak.

Graph: https://www.euro-fusion.org/

WP16-MAG: Magnet System

High-temperature superconductors for fusion application

D.X. Fischer, S. Holleis, M. Eisterer
Atominstitut, Technische Universität Wien

In high-temperature superconductors such as cuprate or iron-based compounds the critical current across grain boundaries is severely suppressed, if the grain boundary angle is larger than a few degrees. This is known from the low critical currents in un-textured conductors and measurements on bi-crystalline films. Textured conductors have been developed to overcome this limitation, however, a quantitative understanding between the degree of texture and the macroscopic critical current is still missing. A model for the prediction of the self-field critical current on the basis of experimental data obtained from bi-crystals is presented in M. Eisterer, "Predicting critical currents in grain-boundary limited superconductors", *Physical Review B* ***99*** *(2019)*, http://doi.org/10.1103/PhysRevB.99.094501. It is a mean-field approach based on percolation theory. Without any fit parameter, good agreement with recent studies on cuprates and iron-based superconductors was obtained, where the critical current and the texture were analyzed quantitatively. The simplified grain boundary physics describes the macroscopic properties of imperfectly textured materials.

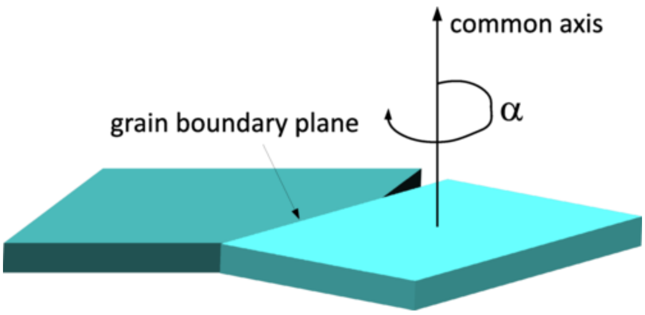


Figure 6. Sketch of a grain boundary

WP25-MAT: Materials

Improvement of ductility of high heat-flux materials

V. Nikolic, M. Pfeifenberger, R. Pippan
Erich Schmid Institut für Materialwissenschaft (ÖAW)

The brittleness of tungsten at room temperature poses severe challenges for structural applications. Special tungsten composites overcome the low ductility by utilizing the remarkable mechanical properties of ultrafine grained tungsten materials such as foils and wires. A comprehensive understanding of the strongly anisotropic fracture behaviour of these ultrafine grained tungsten materials is therefore essential for the further development of functional composites. However, the dimensions of specimens used for classical fracture toughness experiments cannot be used to test all directions of thin foils and wires, especially, in the direction of the presumably lowest fracture toughness along the elongated microstructure of the foil and wire materials, where intergranular fracture prevails. Femtosecond laser processing allows to fabricate micro single leg bending specimens which permit proper evaluation of the fracture toughness in this orientation. The fracture toughness value at crack initiation of the foil was 2.4 MPa√m, whereas for the wire a value of 5.3 MPa√m was determined. In both cases the results were significantly below the values reported for other orientations. FE simulations supported the findings from the experiments. The large difference of the fracture toughness at crack initiation between wire and foil specimens could be explained by the morphologies of the fracture surfaces, which show significant differences in roughness for both materials.

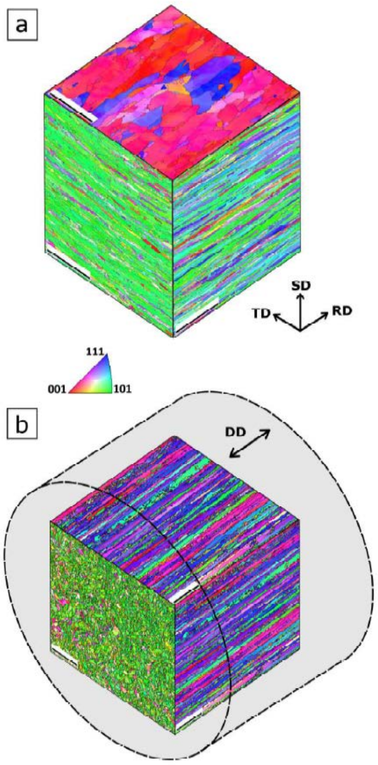


Figure 7. EBSD orientation maps of the three principal axes of (a) a pure W foil and (b) a K-W wire. The color coded unit triangle shown at the top represents the crystallographic directions (100), (110) and (111) perpendicular to the sample surface. The indicated micro bars correspond to 10 µm in (a) and to 5 µm in (b). In (b) the contour of the wire is indicated.

Source: M.J. Pfeifenberger, V. Nikolic, S. Žak, A. Hohen-warter and R. Pippan, "Fracture toughness anisotropy of ultrafine grained tungsten materials: Evaluating the intergranular crack growth resistance", *Acta Materialia* ***176 (2019)***
https://doi.org/10.1016/j.actamat.2019.06.051

3. FUSION EDUCATION

SELECTED PHD THESES COMPLETED /NEAR COMPLETION IN 2018/2019

ITER physics

Reactive ion surface collisions carried out and analyzed on a particle level

Lorenz Ballauf, Institut für Ionenphysik und Angewandte Physik, Universität Innsbruck

Supervisor: P. Scheier

In the newly built Surface Time of Flight experiment (SurfTOF - a tandem mass spectrometer for investigating ion surface interactions) mass selected ions collide with the same material which will be used inside a fusion reactor. The advantage of this equipment is to understand and characterize particular reactions on particle level, which brings new knowledge about how to support desired reactions and to suppress unwanted phenomena.

Part of this work focused on investigating the formation of beryllium hydride, as it is of special interest as a candidate for tritium retention in fusion devices. Experiments have shown that it can be synthesized in nearly all conditions comparable to plasma and wall temperature, with two mechanisms involved: First, BeD^+ is formed directly in a reaction of the D_2^+ molecules with the bulk beryllium surface. The second reaction pathway produces BeH^+ which is efficiently synthesized from water vapor adsorbed on the surface. Measuring the dependence of Be^+, BeH^+ and BeD^+ products on different parameters with impact energies from 20 to 426 eV reveals that the molecular BeD^+ is preferably produced at low energies. Surprisingly its yield is three times higher than that of pure Be^+ at 20 eV. When the surface temperature is raised from 298 to 673 K, sputtering yields increase two orders of magnitude for both Be^+ and BeD^+.

Journal publication:

L. Ballauf, F. Hechenberger, R. Stadlmayr, M. Daxner, S. Zöttl, F. Aumayr, Z. Herman and P. Scheier, "Tritium retention: Synthesis of beryllium hydrides in chemical sputtering by deuterium from 20 to 420 eV", submitted to *Nuclear Materials and Energy, 2019.*

Computational studies of beryllium, tungsten and their mixed systems

Lei Chen, Institut für Ionenphysik und Angewandte Physik, Universität Innsbruck

Supervisor: M. Probst

First wall materials are exposed to high-energy particles from the plasma. This thesis focused on mapping out these interactions under different conditions defined by heat loads, particle densities, temperature and other parameters and to understand subsequent processes like sputtering, adsorption and deposition that all influence both the plasma and the wall materials.

The core topic of this thesis was the development of a potential to simulate the dynamics of atoms in the first wall which are exposed to fast particles escaping the confined hot plasma. Important tools to achieve this goal were quantum chemical calculations and other simulations with the intention of providing input data for machine learning.

Journal publication:

L. Chen, A. Kaiser, I. Sukuba and M. Probst, "Beryllium, tungsten and their alloys Be_2W and $Be_{12}W$: Surface defect energetics from density functional theory calculations". *Nuclear Materials and Energy* ***16*** *(2018)*, p. 149-157, https://doi.org/10.1016/j.nme.2018.06.021

Experimental and numerical investigations of electrical probes and blobs in magnetically-confined fusion plasmas

Stefan Costea, Institut für Ionenphysik und Angewandte Physik, Universität Innsbruck

Supervisors: C. Ionita-Schrittwieser, R. Schrittwieser

This Ph.D. thesis focused on experimental and numerical investigations on electrical probes and blobs in magnetically-confined fusion plasmas and comprised the analysis and evaluation of data obtained with electrical probes used in international fusion experiments, with emphasis on particle and heat transport in the plasma-wall regions of the fusion devices. In order to understand the results better, experimental findings were compared with those obtained from synthetic electrical probe diagnostics of plasma simulations.

Experimental results from electrical probes not only shed light on the behaviour of plasma filaments, which are responsible for the degrading of the plasma confinement in fusion devices, but have also been used as input data for numerical investigations (i.e. plasma simulations). Due to its experimental nature, this work strongly depended on experimental campaigns, their outcome and close collaboration with other research groups working with complementary diagnostics.

Journal publication:

S. Costea, J. Kovačič, D. Tskhakaya, R. Schrittwieser and T. Gyergyek, "Bunker probe: a plasma potential probe almost insensitive to its orientation with the magnetic field", *Review of Scientific Instruments* ***87*** *(2016)*, https://doi.org/10.1063/1.4951688

Origin and transport of small ELMs

Georg Harrer, Institut für Angewandte Physik, Technische Universität Wien

Supervisor: F. Aumayr

This work focused on exploring the small Edge Localized Mode (ELM) regime of tokamak fusion devices. ELMs in a tokamak are comparable to solar eruptions on a small scale. They cause large bursts of particles and energy out of the plasma center where temperatures reach 100 million degrees C onto the wall of the device that should be kept at a temperature far below 1000°C. Data for modelling were obtained in experiments at ASDEX Upgrade and TCV. In larger machines such as ITER and DEMO the materials of the first wall cannot endure the high strains caused by large regular ELMs. One way to overcome this challenge is to find an operational scenario where large ELMs are replaced by more tolerable small ELMs. On ASDEX Upgrade a promising small ELM regime has been found which shows high performance, but causes weaker heat loads on the plasma-facing components.

Journal publication:

G.F. Harrer, E. Wolfrum, M.G. Dunne, P. Manz, M. Cavedon, P.T. Lang, B. Kurzan, T. Eich, B. Labit, J. Stober, H. Meyer, M. Bernert, F.M. Laggner, F. Aumayr, the Eurofusion MST1 Team and the ASDEX Upgrade Team, "Parameter dependences of small edge localized modes (ELMs)", *Nuclear Fusion* ***58/11*** *(2018)*, 10.1088/1741-4326/aad757

Retention of deuterium in fusion-relevant surfaces

Reinhard Stadlmayr, Institut für Angewandte Physik, Technische Universität Wien

Supervisor: F. Aumayr

The investigation of ion-surface interaction processes, in particular, the question how to reduce the erosion of the inner wall to a level which permits the economic operation of a fusion power plant for a long time, is crucial for the development of fusion power. Part of the work performed in the framework of this PhD thesis was to investigate samples of candidate materials irradiated with a high-flux ion source for their suitability for application in a fusion device. The results of these laboratory experiments were modelled with software codes on the high-performance computer system VSC3 at the Vienna Scientific cluster.

Benchmarking studies have shown that the code TRI3DYN is able to predict the outcome of the experiments based on the information about the initial surface morphology and elemental depth profile measurements of the sample. Not only the dynamical behaviour of the erosion yield with ion fluence, but also the emerging surface pattern and the observed tungsten enrichment at the structured surface can be reproduced. The code also gives first insight, why comparably small surface roughness in the nm range can already have a significant influence on the sputtering behaviour.

Journal publication:

R. Stadlmayr, P.S. Szabo, B.M. Berger, C. Cupak, R. Chiba, D. Blöch, D. Mayer, B. Stechauner, M. Sauer, A. Foelske-Schmitz, M. Oberkofler, T. Schwarz-Selinger, A. Mutzke and F. Aumayr, "Fluence dependent changes of surface morphology and sputtering yield of iron: Comparison of experiments with SDTrimSP-2D", *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 430 (2018*), pp. 42-46, https://doi.org/10.1016/j.nimb.2018.06.004

Power Plant Physics and Technology

Thallium-based high-temperature superconductors

Sigrid Holleis, Atominstitut, Technische Universität Wien

Supervisor: M. Eisterer

The potential of the high temperature superconductor thallium-bismuth-barium-strontium-calcium-copper-oxide (in short: Tl-1223) has never been fully exploited. Other copper-oxides (e.g. REBCO or BSCCO compounds) are well- developed, but they show certain weaknesses in application. The use of thallium-based superconductors permits higher currents at higher temperatures and promises a cheap and simple production process.

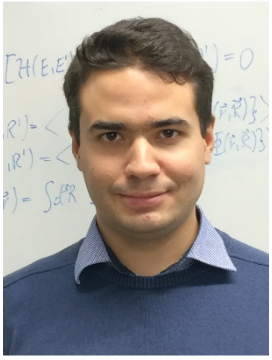
This work focused on the superconducting properties of Tl-1223 thin films, investigating the critical current in the superconducting grains and across grain boundaries with Hall Probe microscopy. Results were compared with the microstructure of the superconductor in order to determine the reasons for good or bad current flow in different parts of the sample.

The magnet coils for ITER consist of superconductors which can only operate at very low temperatures and require cooling with expensive liquid helium. For commercial application in fusion reactors a cheap and easy-to-produce superconductor is necessary. Thallium-based superconductors may achieve higher performance, make the magnet design more compact and permit cooling with much cheaper liquid nitrogen.

Nuclear data evaluation of light nuclei with special focus on* neutron-^{9}*Be reactions

Benedikt Raab, Atominstitut, Technische Universität Wien

Supervisor: Helmut Leeb



The topic of this work was the nuclear data evaluation of light nuclei with a special focus on neutron- ^{9}Be reactions (^{10}Be compound system). The goal was to develop a microscopically based R-matrix formulation which also allows an explicit treatment of breakup channels not accounted for by standard R-matrix theory.

Beryllium plays an essential role in fusion devices. It is an important ingredient of plasma facing components and a neutron multiplier for tritium breeding. Therefore, good knowledge of the neutron-induced reaction cross sections of ^{9}Be is important for the design and operation of fusion facilities with a view to optimizing the facility regarding maintenance, safety and production rate.

Reaction data were obtained by means of the Unified Bayesian Evaluation Technique which was developed by H. Leeb et al. Starting from a prior generated by the extended R-matrix formalism and statistical model calculations, available experimental data were included in the evaluation procedure by means of Bayesian statistics. Thus, mean values of the reaction cross sections and the associated uncertainties were obtained.

The concept of R-matrix theory is based on two particle channels. Its extension to capture reactions to three- and more-particle channels is quite challenging. Another problem to be solved was the solution of the microscopic equations which had to be optimized in order to get results acceptable for large scale evaluations in a reasonable timeframe.

OUR FUSION DAYS

Every year in November we organize a one-day workshop called “Fusion Day”. At this event PhD-students are asked to present their work and the scientific community of Fusion@ÖAW has the opportunity to meet in person and exchange views and experience. Our 5th Fusion Day was held in Vienna on 16th November 2018, with Sebastijan Brezinsek (FZ Jülich) as the guest speaker. The 6th Fusion Day took place in Salzburg on 15th November 2019 (see photo below). Key-note speakers were Chiara Bustreo (Consortio RFX) and Yolanda Lechon (CIEMAT).

Photo: ©Fusion@OEAW

4. PUBLIC INFORMATION AND OUTREACH

Workshop for physics teachers

On 7th November 2019 F. Aumayr organized a seminar on nuclear fusion for high-school teachers of physics at Technische Universität Wien. Topics were basic facts and challenges of nuclear fusion, ITER construction, scientific contributions to the European Fusion Programme by Fusion@ÖAW and discussion / questions and answers. The picture below was taken on the roof of the Freihaus building in Vienna. Fusion@ÖAW sends regular newsletters to teachers all over Austria and provides them with up-to-date links to news and teaching materials.

Photo: © TU Wien

Coming soon: the new Fusion Expo

EUROfusion is presently preparing a new version of the Fusion Expo based on a modern interactive concept. The exhibition will be shown in science museums, libraries and other public spaces and is designed to make the "general public" aware of progress in fusion research and raise awareness among citizens. A principal aim of the exhibition is to reach out beyond audiences generally interested in science by using diverse media channels (displays, websites, social media, game-based storytelling, role models).

The new fusion expo will first be shown on the occasion of the 28th IAEA Fusion Energy Conference (FEC 2020), which will take place in Nice (France) from 12-17 October 2020.

4. PUBLICATIONS

Erich-Schmid Institute of Materials Science at ÖAW

Conference contributions

2019

Nikolić, V., M. Pfeifenberger, A. Hohenwarter and R. Pippan, "Fracture resistance study of tungsten wires as base component of fibre-reinforced plasma facing materials", *30th Symposium on Fusion Technology (SOFT), Giardini Naxos, Italy, 16-21 September 2018*.

Pfeifenberger M., V. Nikolic, S. Žak, A. Hohenwarter and R. Pippan, "Fracture toughness anisotropy of ultrafine grained tungsten materials", *Nineteenth International Conference on Fusion Reactor Materials (ICFRM-19), La Jolla, USA, 27 October – 1 November 2019*.

Articles in scientific journals

2018

Nikolić, V., J. Riesch, M. Pfeifenberger and R. Pippan, "The effect of heat treatments on the microstructure and fracture toughness properties of drawn tungsten wires, Part I - Microstructural characterization*", Materials Science and Engineering: A* ***737*** *(2018)*, pp. 422-433 https://doi.org/10.1016/j.msea.2018.09.027

Nikolic, V., J. Riesch, M.J. Pfeifenberger and R. Pippan, "The effect of heat treatments on pure and potassium doped drawn tungsten wires: Part II – Fracture properties", *Materials Science and Engineering: A,* ***737*** *(2018)*, pp. 434-447, https://doi.org/10.1016/j.msea.2018.09.029

Nikolić, V., S. Wurster, D. Firneis and R. Pippan, "Fracture toughness evaluation of UFG tungsten foil", *International Journal of Refractory Metals and Hard Materials* ***76*** *(2018)* https://doi.org/10.1016/j.ijrmhm.2018.06.008, pp. 214-225.

2019

Pfeifenberger, M.J., *V. Nikolic*, *S. Žak*, A. Hohenwarter and R. Pippan, "Evaluation of the intergranular crack growth resistance of ultrafine grained tungsten materials", *Acta Materialia* ***176*** *(2019),* https://doi.org/10.1016/j.actamat.2019.06.051

Research Studio Salzburg

Conference contributions

2018

Meskens, G., M. Biberacher, C. Bustreo, H. Cabal Cuesta, A. Delicado, C. Jones, R. Kembleton, Y. Lechon Perez, I. Milch, C.B. Oltra Algado, T. Perko, A. Prades Lopez, R. Sala Escarrabill, L. Schmidt, M.T. Orlando and C. Turcanu, "First results of the Delphi Exercise on the possible role of fusion energy technology in the future global energy system", *30th Symposium on Fusion Technology (SOFT), Giardini Naxos, Italy, 16-21 September 2018*.

2019

Cabal, H., F. Gracceva, C. Bustreo, M. Biberacher, R. Kembleton, Y. Lechón, and D. Dongiovanni, "Impact of external costs on the penetration of fusion power plants in the future global electricity system", *30th Symposium on Fusion Technology (SOFT), Giardini Naxos, Italy, 16-21 September 2018.*

Technische Universität Graz/Institut für Theoretische Physik – Computational Physics

Conference contributions

2018

Albert, C.G., M.F. Heyn, S.V. Kasilov, W. Kernbichler and the EUROfusion MST1 Team, "Kinetic modeling of plasma response to RMPs for a tokamak in full toroidal geometry", *45th European Physical Society Conference on Plasma Physics (EPS), Prague, Czech Republic, 2-6 July 2018.*

Albert, C.G., M.F. Heyn, G. Kapper, S.V. Kasilov, W. Kernbichler and A.F. Martitsch, "Modelling of neoclassical toroidal viscous torque in tokamak plasmas with perturbed axisymmetry", *International Conference on Plasma Physics and Controlled Fusion, Kharkiv, Ukraine, 10-13 September 2018*.

Pokol, G.I., A. Hadar, B. Erdos, G. Papp, M. Aradi, T. Jonsson, Y. Peysson, J. Decker, M. Hoppe, T. Fülöp, D. Coster, D. Kalupin, P. Strand and J. Ferreira, "Runaway electron modelling in the ETS self-consistent core transport simulator", *27th IAEA Fusion Energy Conference, Ahmedabad, India. 22–27 October 2018*.

2019

Aradi, M., V. Igochine, S.V. Kasilov and W. Kernbichler, "Modelling of neoclassical toroidal viscosity from internal MHD modes in ASDEX Upgrade", *46th European Physical Society Conference on Plasma Physics (EPS), Milan, Italy, 8-12 July 2019.*

Buchholz R., C. Albert, L. Bauer, S. Kasilov and W. Kernbichler, "Modelling of neoclassical toroidal viscosity from internal MHD modes in ASDEX Upgrade", *46th European Physical Society Conference on Plasma Physics (EPS), Milan, Italy, 8-12 July 2019.*

Eder, M., C.G. Albert, L.M.P. Bauer, S.V. Kasilov and W. Kernbichler, "Three dimensional geometric integrator for charged particle orbits in toroidal fusion devices", *46th European Physical Society Conference on Plasma Physics (EPS), Milan, Italy, 8-12 July 2019.*

Articles in scientific journals

2018

Kapper, G., S.V. Kasilov, W. Kernbichler and M. Aradi, "Evaluation of relativistic transport coefficients and the generalized Spitzer function in devices with 3D geometry and finite collisionality", *Physics of Plasmas* ***25*** *(2018)*, https://doi.org/10.1063/1.5063564

2019

Albert, C.G., S.V. Kasilov and W. Kernbichler, "Symplectic integrators with non-canonical quadrature for guiding center orbits in magnetic confinement devices", *Journal of Computational Physics* ***403*** *(2020)*, https://doi.org/10.1016/j.jcp.2019.109065

Technische Universität Wien / Institut für Angewandte Physik

Conference contributions

2018

David P., T. Eich, M. Bernert, P. Manz, G. Harrer, E. Wolfrum and A. Kallenbach, "Pedestal confinement degradation in the vicinity of the H-mode density limit in ASDEX Upgrade", *23rd Joint EU-US Transport Task Force Meeting, Seville, Spain, 11th September 2018.*

Labit, B., T. Eich, G. Harrer, M. Bernert, H. de Oliveira, M. Dunne, L. Frassinetti, P. Hennequin, R. Maurizio, A. Merle, H. Meyer, P. Molina, U. Sheikh, J. Stober, E. Wolfrum, the TCV Team, the AUG team and the EUROfusion MST1 Team, "Plasma shape and fueling dependence on the small ELMs regime in TCV and AUG", *27th IAEA Fusion Energy Conference, Ahmedabad, India, 22-27 October 2018*.

Trier, E., P. Hennequin, J. Pinzon, M. Hoelzl, G. Conway, T. Happel, G. Harrer, F. Mink, F. Orain and E. Wolfrum, "Studying ELM filaments with Doppler reflectometry in ASDEX Upgrade", *45th European Physical Society Conference on Plasma Physics (EPS), Prague, Czech Republic, 2-6July 2018.*

Vasileska, I., D. Tskhakaya, L. Kos, R. A. Pitts and the EUROfusion-IM Team, "Kinetic flux limiters for the ITER scrape-off layer", *45th European Physical Society Conference on Plasma Physics (EPS), Prague, Czech Republic, 2-6 July 2018*.

Viezzer, E., M. Cavedon, E. Fable, F.M. Laggner, R.M. McDermott, A. Kappatou, C. Angioni, P. Cano-Megias, D. Cruz-Zabala, R. Dux, G. Harrer, U. Plank, T. Puetterich, F. Ryter, E. Wolfrum, the ASDEX Upgrade Team and the EUROfusion MST1 Team, "ELM-induced energy and momentum transport in ASDEX Upgrade", *27th IAEA Fusion Energy Conference, Ahmedabad, India. 22–27 October 2018*.

2019

Griener, M., E. Wolfrum, G. Harrer, P. Hennequin, P. Manz, R. Rischer, B. Tal, U. Stroth, the ASDEX Upgrade Team and the EUROfusion MST1 Team, "Investigation of intermittent and continuous transport in the scrape-off layer of ASDEX Upgrade", *46th European Physical Society Conference on Plasma Physics (EPS), Milan, Italy, 8-12 July 2019.*

Harrer, G.F., E. Wolfrum, M. Faitsch, P. David, M.G. Dunne, T. Eich, M. Griener, P. Hennequin, B. Labit, P. Manz, I. Radovanovic, F. Aumayr, the EUROfusion MST1 Team and the ASDEX Upgrade Team, "On the effect of heating and fuelling on small ELM regimes", *H-mode Workshop 2019, Shanghai, China, 9 October 2019.*

Harrer, G.F., E. Wolfrum, M.G. Dunne, T. Eich, R. Fischer, M. Griener, P. Hennequin, A. Bock, B. Labit, P. Manz, H. Meyer, I. Radovanovic, S. Saarelma, M. Willensdorfer, F. Aumayr, the EUROfusion MST1 Team and the ASDEX Upgrade Team, "The ballooning structure of small edge localized modes on AUG and TCV", *46th European Physical Society Conference on Plasma Physics (EPS), Milan, Italy, 8-12 July 2019.*

Stadlmayr, R., P.S. Szabo, D. Mayer, T. Schwarz-Selinger, M. Oberkofler, T. Dittmar, U. von Toussaint, A. Mutzke, W. Müller and F. Aumayr, "Erosion of iron-tungsten model films by deuterium ion irradiation: a benchmark for TRI3DYN", *17th International Conference on Plasma-Facing Materials and Components for Fusion Applications (PFMC-17), Eindhoven, Netherlands, 20-24 May 2019*.

Szabo, P.S., K. Kantre, M.V. Moro, C. Cupak, L. Zendejas Medina, R. Stadlmayr, K. Schmid, D. Primetz-hofer and F. Aumayr, "In-situ investigation of deuterium retention in tungsten with ion beam analysis and thermal desorption", *24th International Conference on Plasma Surface Interactions in Controlled Fusion Devices (PSI 2020), Jeju, Korea, 31 May-5 June 2020*.

Articles in scientific journals

2018

Cavedon, M., R. M. Dux, T. Puetterich, E. Viezzer, E. Wolfrum, M. Dunne, E. Fable, R. Fischer, G.F. Harrer, F.M. Laggner, A. F. Mink, U. Plank, U. Stroth, M. Willensdorfer and the ASDEX Upgrade team, "On the ion and electron temperature recovery after the ELM crash at ASDEX Upgrade", *Nuclear Materials and Energy **18** (2019), pp.275-280,* https://doi.org/10.1016/j.nme.2018.12.034

Harrer, G.F., E. Wolfrum, M.G. Dunne, P. Manz, M. Cavedon, P.T. Lang, B. Kurzan, T. Eich, B. Labit, J. Stober, H. Meyer, M. Bernert, F.M. Laggner, F. Aumayr, the Eurofusion MST1 Team and the ASDEX Upgrade Team, "Parameter dependences of small edge localized modes (ELMs)", *Nuclear Fusion **58/11** (2018)*, https://doi.org/10.1088/1741-4326/aad757

Mink, A.F., E. Wolfrum, M. Dunne, M. Hoelzl, M. Maraschek, R. Fischer, M. Cavedon, G.F. Harrer and U. Stroth, "*Scaling of the toroidal structure and nonlinear dynamics of ELMs on ASDEX Upgrade*", *Plasma Physics and Controlled Fusion **60/12** (2018)*, https://doi.org/10.1088/1361-6587/aae33a

Stadlmayr, R., P.S. Szabo, B.M. Berger, C. Cupak, R. Chiba, D. Blöch, D. Mayer, B. Stechauner, M. Sauer, A. Foelske-Schmitz, M. Oberkofler, T. Schwarz-Selinger, A. Mutzke and F. Aumayr, "Fluence dependent changes of surface morphology and sputtering yield of iron: Comparison of experiments with SDTrimSP-2D", *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms,* ***430*** *(2018*), pp. 42-46, https://doi.org/10.1016/j.nimb.2018.06.004

Vanovac, B., E. Wolfrum, M. Hoelzl, M. Willensdorfer, M. Cavedon, G. Harrer, F. Mink, S. Denk, M. Dunne, P. Manz, N.C. Luhmann Jr and the ASDEX Upgrade Team, "Characterization of low frequency inter-ELM modes of H-mode discharges at ASDEX Upgrade", *Nuclear Fusion* ***58/11*** *(2018),* https://doi.org/10.1088/1741-4326/aada20

2019

B. Labit, T. Eich, G. Harrer, E. Wolfrum, M. Bernert, M. Dunne, L. Frassinetti, P. Hennequin, R. Maurizio, A. Merle, H. Meyer, S. Saarelma, U. Sheikh, the TCV team, the ASDEX Upgrade team and the EUROfusion MST1 team, "Dependence on plasma shape and plasma fueling for small ELM regimes in TCV and ASDEX Upgrade", *Nuclear Fusion* ***59/8*** *(2019),* https://doi.org/10.1088/1741-4326/ab2211

Technische Universität Wien / Atominstitut

Conference contributions

2018

Fischer, D.X., R. Prokopec, J. Emhofer and M. Eisterer, "Effect of neutron irradiation on the superconducting properties of REBCO tapes", *Coated Conductors for Applications, Vienna, Austria, 10 September 2018.*

Holleis, S., T. Baumgartner, J. Bernardi, A. Leveratto, E. Bellingeri, M. Putti, C.O. Ferdeghini, S. Calatroni and M. Eisterer, "Revival of the thallium-based cuprates: microstructure and current transport of Tl-1223 thin films", *Applied Superconductivity Conference (ASC 2018), Seattle USA, 28 October-2 November 2018*.

Malagoli, A., I. Pallecchi, A. Leveratto, V. Braccini and M. Eisterer, "Investigation of inter-grain critical current density in $Bi_2Sr_2CaCu_2O_{8+\delta}$ superconducting wires and its relationship with the GB oxygenation", *Applied Superconductivity Conference (ASC 2018), Seattle USA, 28 October-2 November 2018*.

2019

Bader, D.G., M.O. Rikel, J. Jiang, Y. Oz, D.C. Larbalestier and M. Eisterer, "Effects of oxygen doping in Bi-2212 wires and bulk samples", *14th European Conference on Applied Superconductivity (EUCAS), Glasgow, UK, 1-5 September 2019*.

Eisterer, M., D.X. Fischer, D. Kagerbauer, R. Unterrainer, T. Baumgartner, S. Pfeiffer and J. Bernardi, "Neutron irradiation: introduced defects and effects on various superconductors", *14th European Conference on Applied Superconductivity (EUCAS), Glasgow, UK, 1-5 September 2019*.

Unterrainer, R., D.X. Fischer and M. Eisterer, „The influence of single displaced atoms on the superconducting properties of Gd-123 coated conductors", *14th European Conference on Applied Superconductivity (EUCAS), Glasgow, UK, 1-5 September 2019*.

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2018

Fischer, D.X., R Prokopec, J Emhofer and M Eisterer, "The effect of fast neutron irradiation on the superconducting properties of REBCO coated conductors with and without artificial pinning centers", *Superconductor Science and Technology* ***31*** *(2018)* https://doi.org/10.1088/1361-6668/aaadf2

Fischer, U., M. Angelone, M. Avrigeanu, V. Avrigeanu, C. Bachmann, N. Dzysiuk, M. Fleming, A. Konobeev, I. Kodeli, A. Koning, H. Leeb, D. Leichtle, F. Ogando, P. Pereslavtsev, D. Rochman, P. Sauvan and S. Simakov, "The Role of Nuclear Data for Fusion Nuclear Technology", *Fusion Engineering and Design 136 Part A (2018),* https://doi.org/10.1016/j.fusengdes.2018.01.036

2019

Eisterer, M., "Predicting critical currents in grain-boundary limited superconductors", *Physical Review B* ***99*** *(2019)*, http://doi.org/10.1103/PhysRevB.99.094501

Universität Innsbruck / Institut für Ionenphysik und Angewandte Physik

Conference contributions

2018

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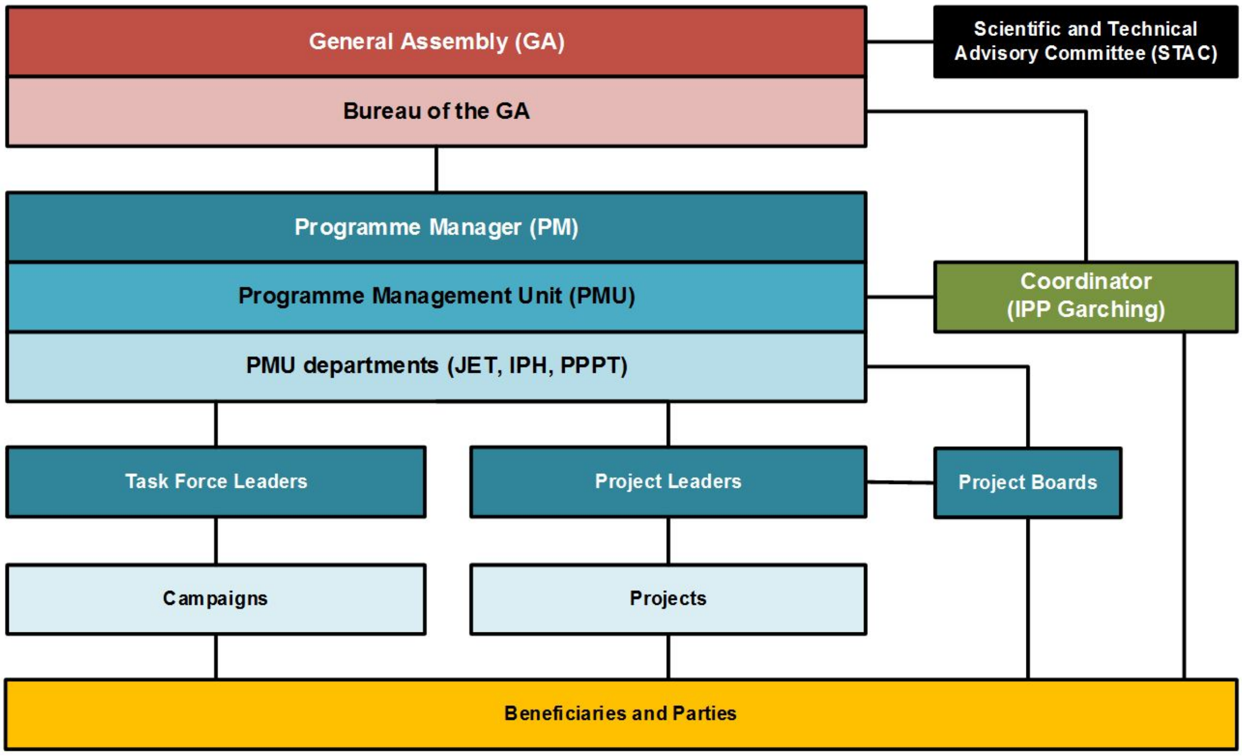
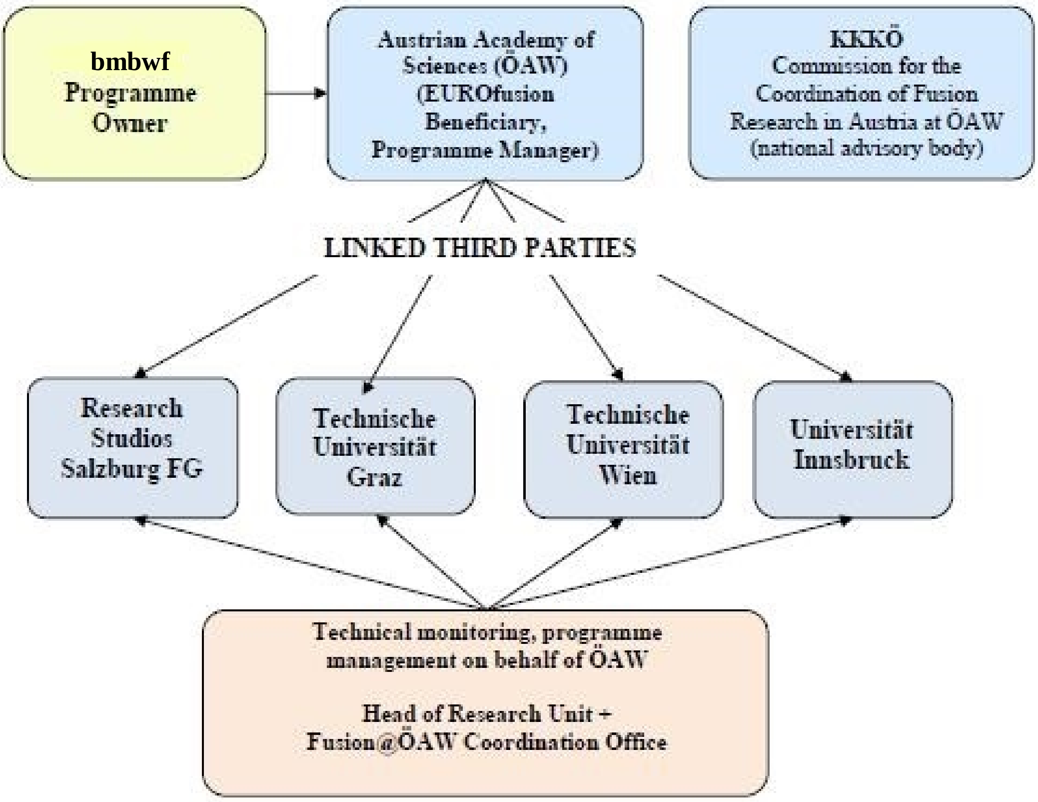
MANAGEMENT STRUCTURE

EUROFUSION ORGANIGRAM



AUSTRIAN PARTICIPATION (Fusion@ÖAW)



AUSTRIAN REPRESENTATIVES IN COMMITTEES RELEVANT FOR FUSION RESEARCH AND DEVELOPMENT (2018/2019)

Fusion Programme Committee

Dr. Daniel Weselka	Federal Ministry of Science, Research and Economy
Univ.Prof.Dr. Friedrich Aumayr (expert)	Institute of Applied Physics / Technische Universität Wien

EUROFusion General Assembly

Univ.Prof.Dr. Friedrich Aumayr	Institute of Applied Physics /Technische Universität Wien

FUSECom (EUROfusion Communicators`network)

Mag. Monika Fischer	Austrian Academy of Sciences
Lätitia Unger, BSc.	Austrian Academy of Sciences

Fusion for Energy (F4E) Governing Board

Dr. Daniel Weselka	Federal Ministry of Science, Research and Economy
Univ.Prof.Dr. Harald W. Weber	Atominstitut / Technische Universität Wien

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Mag. Monika Fischer	Austrian Academy of Sciences

Industrial Liason Officer

Dr. Georg Weingartner	Austrian Federal Economic Chamber

Kommission für die Koordination der Kernfusionsforschung in Österreich (KKKÖ)

Chair:	Univ.Prof.Dr. Peter Steinhauser (ÖAW)

GLOSSARY OF SCIENTIFIC AND TECHNICAL TERMS[1]

Bootstrap current

Theory predicted in 1970 that a toroidal electric current will flow in a tokamak which is fueled by energy and particle sources that replace diffusive losses. This diffusion-driven bootstrap current, which is proportional to ß and flows even in the absence of an applied voltage, could be used to provide the confining magnetic field: hence the concept of a bootstrap tokamak, which has no toroidal voltage. A bootstrap current consistent with theory was observed many years later on JET and TFTR; it now plays a role in the design of experiments and power plants (especially advanced tokamaks).

Collisionality

A measure of how frequently collisions occur in a tokamak plasma. A collisionality of unity corresponds to a trapped particle performing a single banana orbit before being scattered.

Confinement regime

In a magnetic field charged particles (ions and electrons) are forced to follow circular and helical orbits around the field lines. The low-confinement regime of tokamak plasmas with purely Ohmic or weak auxiliary heating is not viable for future fusion power plants. The latter will have to operate in so-called H-mode, i.e. in high-confinement regime with energy confinement in the presence of strong heating.

ELMs

Edge localized modes - instabilities which occur in short periodic bursts during the H-mode in divertor tokamaks. They cause sudden outbursts of the plasma thus expelling particles and depositing large heat flux onto the vessel wall. The plasma loses severe amounts of energy. In high-power fusion devices such as ITER or DEMO, powerful ELMs will cause erosion at the vessel wall. Finding methods to mitigate or suppress ELMs is therefore an important topic in present-day fusion research.

Guiding center orbit

The motion of an electrically charged particle such as an electron or ion in a plasma in a magnetic field can be treated as the superposition of a relatively fast circular motion around a point called the guiding center and a relatively slow drift of this point. The drift speeds may differ for various species depending on their charge states, masses or temperatures, possibly resulting in electric currents or chemical separation.

Pedestal

H-mode's high confinement stems from a sharp increase in the pressure at the edge of the plasma, known as the e**dge transport barrier** or **pedestal**.

Zonal flows

Turbulence arising from the enormous difference in temperature between the core and edge of the plasma in e torus-shaped tokamaks or stellarators may lead to substantial particle loss and reduced fusion power generation. Like in the giant gas planets Saturn and Jupiter, this temperature gradient also gives rise to global flows around the small torus circumference. The flows can be detected by sampling the electric potential, which shows pronounced bands, each extending on a complete flux surface. The flows exert a damping effect on the turbulence, which is favourable for plasma confinement and reduces the technical effort necessary to keep the plasma burning.

[1] Sources: https://www.euro-fusion.org/
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Back cover:

Collection of answers by PhD students at Austrian universities participating in EUROfusion to the question:

Why is fusion research fascinating for you?

Why fusion?

... fusion is the most elegant, safe and sustainable solution ...

... we participate in one of the biggest research projects worldwide ..

... fusion has many connections to other fields, e.g. astrophysics, geophysics ...

... I am proud of being involved in cutting-edge science ...

... we are working on building a baby sun on earth ....

... fusion will be a necessary supplement to renewable energy ...

... fusion will potentially provide unlimited amounts of clean (CO_2 free) energy ...

... nuclear physics, especially the theory, is fascinating ...