Workshop on Electric Fields, Turbulence and Self-Organization in Magnetized Plasmas (EFTSOMP 2019)

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Consorzio RFX, Padova

Book of Abstracts

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Study of the role of divertor neutrals and SOL turbulence in the density shoulder formation and evolution in ASDEX Upgrade

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The formation of flat density profile in the low field side Scrape Off Layer (SOL), the so called shoulder formation, is characterized in the ASDEX Upgrade tokamak. The two main candidate mechanisms for its formation, i.e. modification of SOL turbulence and divertor plasma-neutrals interaction, are studied. Turbulence and blobs are characterised with midplane Langmuir probes; divertor neutrals are estimated measuring the 2D map of Da and Dg emission through the tomographic inversion of their brightness measured by two cameras. The strong interplay between upstream profiles, upstream turbulence and divertor conditions will be highlighted.
In the considered ASDEX Upgrade dataset, upstream midplane density shoulder forms when increasing the electron density and it is linked with detachment. The shoulder formation is correlated with the change of edge turbulent transport, resulting in an increase of the blobs perpendicular size, and also in a change in the neutral emission, reflecting a modification in the neutral distribution in the divertor region. In particular, while the neutral D emission is localized in the inner divertor at low electron density, the emission moves towards the outer divertor target and then covers the whole lower divertor region when the upstream electron density shoulder forms.

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Suprathermal ion studies in TORPEX

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Cross-magnetic field suprathermal ion transport has been extensively studied at the Swiss Plasma Center, in Lausanne (Switzerland) where, for the last decade or so, dedicated simulations, theoretical modeling and experiments [1] have involved the TORoidal Plasma Experiment (TORPEX).
In TORPEX, we inject a Li-6 ion beam into a turbulent plasma in a simple magnetized torus configuration. The injection is performed in a direction nearly parallel to the helical magnetic field lines at an energy (30–70 eV) that is much higher than the plasma temperature (< 5 eV). Using a detector based on a gridded energy analyzer, we determine the average suprathermal ion current at different locations on the poloidal cross section, allowing us to determine the average cross-field spreading of the Li-6 ions. By establishing how the spreading changes with toroidal location and comparing the results to GBS simulations [1], we have determined important features of perpendicular transport of the ions, most notably that it is in general non-diffusive. Indeed, different transport regimes can be accessed at different propagation times depending on the injection energy, from sub-diffusive to ballistic.
Improvements in the electronics have more recently allowed us to observe the time evolution of the detected ion currents [2] and, once sampled and stored as time series, study some of their properties. We developed a model that shows [3] that the average value of these time series is closely related to

their higher order moments, such as the variance and the skewness. This has important implications in the quantification of intermittency. Predictions of the model have been compared to data from dedicated simulations and shown good agreement. Furthermore, the model has been compared to an extensive set of time series collected in experiments using different Li-6 ion energies and distances from source to detector [4].
In this talk, I will discuss the results of this comparison, as well as a summary of the most important results on suprathermal ion transport obtained in TORPEX to date.

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Turbulent generation of poloidal asymmetries in a tokamak

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Poloidal variations of an impurity distribution function can significantly modify the neoclassical transport. According to conventional neoclassical theory, the level of poloidal asymmetry is expected to be very small. Therefore, this effect is usually neglected in standard neoclassical theory. But poloidal flow asymmetries can be driven by small scale turbulence via nonlinear coupling. Therefore, neoclassical transport of impurities can be significantly modified by the presence of turbulence, breaking the standard assumption of independence of turbulent and neoclassical transports.
In this presentation, a general theoretical framework for the generation of axisymmetric structures of the electric potential by turbulence will be given. It allows one to describe within a single framework the evolution of axisymmetric modes of the electric potential like zonal flows, geodesic acoustic modes and convective cells. This model is derived by solving the gyrokinetic equation coupled to quasi-neutrality. This calculation provides a prediction for the axisymmetric part of the electric potential given a specified forcing due to turbulence.
Two mechanisms for the generation of poloidal asymmetries of the electric potential are identified. The first one comes from zonal flow compression. It leads to up/down asymmetries and dominates at intermediate frequencies. This mechanism is for instance at the origin of geodesic acoustic modes. The second mechanism is associated with the ballooning of the turbulent Reynolds stress and leads to in/out asymmetries. It appears to be the main drive at low frequency.
A qualitative agreement is found between these theoretical predictions and the potential calculated by the gyrokinetic code GYSELA. The comparison will be discussed during the presentation. The link between these axisymmetric flows and the structure of the distribution function, impacting the pressure tensor, will also been made.

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3D filamentary transport and the role of edge sheared radial electric fields in the RFX-mod tokamak

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Sheared radial electric field is an important parameter in regulating cross-field transport in fusion devices. The edge and scrape-off layer (SOL) turbulence coupling, as well as the parallel dissipation, are responsible for the SOL width maintenance, which, in turn, is a critical parameter for particle and energy exhaustion in tokamaks \cite{Grenfell:2019}. This coupling is usually attributed to the transport of streamers or blobs (also called filaments). They are mostly created in the plasma edge, in high gradient free energy regions, and transported radially by E × B drift. The turbulent filaments properties, e.g. velocity and size, and ultimately their penetration into the SOL, are defined by the type of instability that generates them as well as how they interact with the background \cite{Myra:2013}. High beta filaments, on the other hand, tend to be more resilient to the background. This is the case of the Edge-Localized Mode filaments in H-mode regimes, one of the current threats for the feasibility of future fusion reactors. In this work, we study the filament or blob cross-field transport in the RFX-mod operating as tokamak in different plasma regimes by using a set of electrostatic and magnetic probes \cite{Grenfell:2018}. It has been shown recently that H-mode ELM-free and ELMy are induced in the RFX-mod tokamak by electrode biasing technique \cite{Spolaore:2017}. We show that the properties of filaments in these regimes, as well as in L-mode, are distinct. While in L-mode blobs propagate almost freely into the SOL scaling as sheath-connected filaments \cite{Manz:2013}, in the ELM-free H-mode, filaments are trapped (their cross-field velocity approaches to zero) and dissipated around the plasma boundary, where the E×B shearing rate is marginally comparable to their effective convective time \cite{Grenfell:2018}. ELMs filaments propagate further into the SOL carrying a larger parallel current density associated with the edge transport barrier relaxation.

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On the nature of I-phase bursts at ASDEX Upgrade

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In magnetically confined fusion plasmas regular pulsations are observed in the lasma edge region in the regime between the low confinement mode (L-mode) and the high confinement mode (H-mode). In ASDEX Upgrade this regime close to the L- to H-mode power threshold is called I-phase [1]. The characteristic pulsations in this I-phase are called bursts. They occur regularly with a frequency of 1–2 kHz, which scales inversely with the plasma density.

The bursts are visible in many diagnostic signals such as the Ha signal, divertor shunt current measurements, magnetic pick up coils, reflectometry signals and the new thermal helium beam diagnostic. The latter one is unique as it covers the plasma edge region up to the far scrape-off layer (SOL) with simultaneous measurements of the electron density ne and, as a new element, the temperature Te [2].

This new diagnostic access reveals that ne and Te profiles are modulated in phase by I-phase bursts, which cause a gradient relaxation in the region around the separatrix from rpol = 0:98 to 1:03. Filamentary structures in the far SOL, however, seem not to be directly connected to the regular profile modulation at the plasma edge.

Previous investigations [3] indicate the presence of burst precursors with an activity in the 50–100 kHz frequency range, which point to the bursts being type III ELMs. In the helium beam signals these precursors are clearly visible for each burst within the confined region.
This contribution addresses the spatiotemporal evolution of the I-phase burst, their precursors and effect in the SOL. A distinction of the bursts from the intermittent filamentary structures in the far SOL is made.

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Probe measurements of electric field and potential dependence on the X-point position in COMPASS

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Results from recent new experiments in the COMPASS tokamak with the ohmic L-H transition induced by a ramped movement of the X-point with different constant plasma currents and high densities will be presented. These experiments offer a unique opportunity to study the electric field and potential profiles as measured by both Langmuir and ball-pen probes in the divertor as well as on the midplane in L-mode, close to the L-H transition and in the ELM-free H-mode. These measurements are further enhanced by an additional integrated set of diagnostics focused on the edge plasma (in particular high-resolution edge Thomson scattering, Lithium beam emission spectroscopy, plasma blob tomography from visible light fluctuations). The changes in the observed profiles will be described and a preliminary picture of the edge plasma behavior at different X-point positions will be drawn.

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Investigation of isotope effect in particle and energy transport phenomena at the FT-2 tokamak at different densities

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The isotope effect in a tokamak anomalous transport manifesting itself as a confinement improvement with growing isotope atomic mass [1] is favourable for fusion [2], but the explanation for it is still missing, appealing for further investigations [3]. The structure of axisymmetric E×B flows, which are able to control transport by shearing turbulent eddies [4], is modified by turbulence-driven zonal flows [5, 6], in particular, by geodesic acoustic modes (GAMs). In several experiments [7-9] the GAM amplitude determining the turbulence long-range correlations was found to be higher in deuterium (D) than in hydrogen (H) which could be responsible for the transport isotope effect. In FT-2 the turbulence and flows are investigated experimentally by a set of microwave Doppler diagnostics and numerically by the gyrokinetic code ELMFIRE [10-12]. Explanation of the effect involves

the self-organized balance of micro-turbulence and large-scale flows, with an effect only on particle confinement for discharges with modest central density ($n_{e0} < 4 \times 10^{19}$ $\mathtt{m}^{-3}$). On contrary, for high density (10×10^{19} $\mathtt{m}^{-3}$) regimes the strong difference in energy confinement $\tau_{\mathtt{D}} \approx 2\tau_{\mathtt{H}}$ was observed and analysed recently with nonlinear GENE code. The discharge possessing features of Ohmic H-mode in D-case was revealed.
Support of the Russian Science Foundation grant 17-12-01110 is acknowledged.
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Gyrokinetic Landau Collision Operator vs. Sugama Model-Collision Operator with Respect to Flow and Turbulence Damping

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Since implementing the full Landau collision operator into gyrokinetic codes is complicated by the transformation between gyro-center and real space coordinates, it has been useful in the CGYRO code [1] to apply a sophisticated model collision operator [2], which only uses the test particle component of the full Landau collision operator, adds ad hoc terms conserving energy and all momentum components in real space, and obeys Galilean invariance. (In various codes, the full operator has so far only been implemented ignoring the difference between gyro-center and real space coordinates.)
The collision operator is sufficiently accurate to reproduce the two-fluid damping of GAMs and residual zonal flows in the limit of large collision frequency. However, simulations of very collisional turbulence (as is often encountered in the tokamak edge) involving temperature fluctuations produce a saturation level different from fluid simulations based on the Braginskii transport coefficients [3]. It turns out that this is in part due to a tendency of the model collision operator to overestimate dissipation involving higher than first order moments in the distribution functions, such as perpendicular viscosity and heat fluxes.
The situation can be improved by treating the "field" part (i.e. non test-particle part) of the Landau collision operator exactly for higher order moments of the distribution function. Comparisons with such improved model operators and a preliminary implementation of the full operator are shown.
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Stability of microtearing modes

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The stability of a microtearing mode (MTM) as the function of collisonality is investigated by means of linear theoretical calculations and numerical simulations using the gyrokinetic code GKW. The study is focused on the role of the electric potential and the magnetic drift, which are potential candidates to explain the destabilization of MTM observed at low collsionality in some recent gyrokinetic simulations. In the simulations, the magnetic drift and electric potential are found destabilizing in presence of a finite collisionality. This destabilizating role is captured in the analytical calculation, which further highligths the requirement for a finite collisionality. Then, the properties of MTM turbulence and the evaluation of the electron heat transport in particular in the pedestal region is investigated.

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Intermittent fluctuations associated with the different phases of the ELM cycle in ASDEX Upgrade

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High performance regimes (H-mode) are reached through the spontaneous formation of a transport barrier resulting from the shear-flow suppression of turbulence. The steep density and temperature gradients that form at the edge are subject to instabilities such as edge localized modes (ELMs), provoking repetitive collapses of the edge pressure profile. Between ELMs, temperature and density profiles build up again on different time scales [1], raising the question of which transport mechanisms determine the profile evolution until the next ELM. Intermittent density fluctuations persist in the inter-ELM phase, although the overall fluctuation level is reduced as expected in the pedestal region. They appear in Doppler back-scattering signals as bursts at different levels, with different time dynamics and statistical properties with respect to the L-mode, for instance significant non Gaussian Probability Density Functions. The intermittency and time dynamics of these density fluctuations evolve along the different phases of the ELM cycle [2], linked to the recovery of density and temperature profiles. Inside the separatrix, filament-like bursts coexist or dominate over intermittent, high frequency fluctuations. The bursts can be grouped in regular trains, with a repetition rate which evolves similarly to the mode frequencies observed in magnetics or ECE fluctuations along the ELM cycle [1,3], and are well correlated with density perturbation detected with the Thermal He Beam diagnostic. The strong bursts, filament-like or solitary structures, that are observed in the late ELM cycle phase, are often linked to bursts in radiation observed later in the SOL and in the divertor Langmuir probes. The potential role of these intermittent events in profile clamping between ELMs will be discussed. Their evolution at high density [4] and in different ELM regimes is also investigated.

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Turbulence in the island divertor SOL in Wendelstein 7-X

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The optimized stellarator Wendelstein 7-X employs the island divertor concept, where the exhaust to the divertor modules is controlled by a chain of large, resonant magnetic islands at the plasma edge. Due to the complex magnetic field geometry, the Scrape-Off Layer in W7-X is inherently three-dimensional and can feature very wide temperature and density profiles with shallow gradients across the magnetic islands. Furthermore, turbulent transport is expected to play a major role for the heat and particle transport as the connection lengths to the targets are quite long (several 100 m).

Besides drastically increasing the SOL width, the magnetic islands also affect plasma dynamics. Reciprocating probe measurements and reflectometry reveal a reversal of the radial electric field inside the islands deduced from the poloidal correlation analysis of plasma fluctuations. The electric field reversal is accompanied by ExB rotation of the island, indicating that the islands can act as plasma confining regions. In addition, reciprocating probe measurements show that the turbulent radial flux and further turbulence characteristics such as correlation lengths and life-times are significantly modified in the presence of islands. Furthermore, the parallel dynamics of turbulent filaments are investigated by exploiting the direct magnetic connection between the reciprocating probe and divertor probes. Finally, the role of different magnetic configurations and plasma (heating/fueling) scenarios for the SOL turbulence is explored and implications for divertor operation are concluded.

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Experimental evidences showing how sensitive are the properties of low frequency zonal flows to plasma conditions in TJ-II stellarator

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We investigated the spatial structure of the low frequency zonal flows, in TJ-II laboratory plasmas. In two plasmas produced by different heating schemes (electron cyclotron resonance heating and neutral beam injection heating) and characterized by different mean radial electric field structures, frequency-space-decomposed spectra of the global potential oscillation were obtained. In both cases, the oscillatory field had a single-peaked potential structure and a dipole radial electric field structure. The oscillating structure depends on its frequency as well as on the heating scheme. The frequency dependent wavelength spectrum was obtained, which strongly depended on the plasma conditions.

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Plasma electric potential in the TJ-II stellarator: neoclassical formulation versus measurements

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The database of the TJ-II heliac-type stellarator has a large contribution from the Heavy Ion Beam Probe (HIBP) diagnostics installed in the device. A program has been started to analyze part of these data in view of the neoclassical formulations for the ambipolar radial particle fluxes [Gutierrez-Tapia et al., Plasma Phys. Controll. Fusion 57 (2015) 115004]. The neoclassical formulation is quite robust in predicting the electric potential, but the magnitude of the transport coefficients is very sensitive to the effective ripple profile. Here, aside from comparing the plasma potential with HIBP data, we confront the modeling with numerical estimates of the transport coefficients. The results are the basis for further studies including data from plasma-edge biasing experiments.

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Geodesic Acoustic Mode features and radial structure in the T-10 tokamak

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Geodesic Acoustic Modes (GAMs), a high-frequency counterpart of Zonal flows, are considered as a possible mechanism of the plasma turbulence self-regulation. In the T-10 tokamak GAMs have been extensively studied by the advanced multi-channel heavy ion beam probing (HIBP), correlation reflectometry and multipin Langmuir probes.
The regimes with Ohmic, on-axis and off-axis electron cyclotron resonance heating (ECRH) were studied (B = 1.5−2.45 T, Ip = 100−280 kA, ne = (0.6 − 3) 10^19 m-3, PEC < 2.2 MW).
It has been shown that GAM has poloidally symmetric (m=0) radially homogeneous structure of plasma potential global eigenmode. In contrast to the expectation by local theory, the radial distribution of GAM frequency fGAM is almost uniform in spite of the temperature dependence on the radius, however, fGAM grows with radially averaged temperature as Te1/2. The GAM amplitude varies from 20 to 80 Volts on the background mean values of core plasma potential ~ -1 keV. The bicoherence analysis shows the three-wave coupling between GAM and drift-wave broadband turbulence. GAMs are enhanced during ECRH, when the typical frequencies were seen in the narrow band from 22 to 27 kHz for the main GAM peak and 25-30 kHz for the higher frequency satellite GAM peak. GAM characteristics and limits of GAM existence were investigated as functions of density, magnetic field, safety factor and ECRH power.

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The phenomenology of fast reconnection events in the reversed field pinch

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Reconnection is a basic phenomenon in magnetized plasmas by which the plasma relaxes to a state of lower magnetic energy. It plays a fundamental role in a variety of instabilities common to most fusion devices, as sawtooth or tearing modes. Often it occurs in impulsive events (crash phase), following a longer period in which the magnetic fields evolve slowly. Energy conversion and topological change are two highly linked aspects of reconnection.
Hot fusion plasmas may contain multiple reconnection sites and this is particularly true for the Reversed Field Pinch (RFP), due to the peculiar current density distribution, associated to a variety of resonant tearing modes. In addition, large RFPs involve large plasma currents and therefore a large amount of available magnetic energy. This makes the RFP a good device to observe and analyze reconnection events.
In this contribution the phenomenology of the impulsive and periodic reconnections in the RFX-mod device is analyzed in detail, through an ensemble average of the data from many reconnection events in high plasma current discharges (1.5 MA). Spatial and temporal scales are invoked as fundamental observables. Roughly speaking, an almost stationary helical state is considered typical of phases before the crash. The crash destroys this symmetry, and the plasma topology undergoes a transition to a more chaotic state with broad MHD spectra. The crash evolution is described as a sequence of events. A trigger of the crash has been associated for the first time to a slight change in the helical equilibrium, which pushes closer the inner most important resonant flux surfaces in the core. Reconnection starts when the resonant surfaces - and therefore the intense related current sheets - are close enough and a precursor of the crash is found in the locking in phase of these resonant modes. After these slowly evolving phases, fast reconnection takes place, which lasts about 1 ms. Plasma parameters and magnetic measurements suggest that crashes are related with the interaction between tearing modes at different radii, and the reconnection process evolves according to the safety factor profile.

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Direct Measurement of a Toroidally Directed Zonal Flow in a Toroidal Plasma

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Zonal flow appears in toroidal, magnetically confined plasmas as part of the self-regulated interaction of turbulence and transport processes. For toroidal plasmas having a strong toroidal magnetic field, the zonal flow is predominately poloidally directed. We report the first observation of a zonal flow that is toroidally directed. The measurements are made just inside the last closed flux surface

of reversed field pinch plasmas that have a dominant poloidal magnetic field. A limit cycle oscillation between the strength of the zonal flow and the amplitude of plasma potential fluctuations is observed, which provides evidence for the self-regulation characteristic of drift-wave-type plasma turbulence. The measurements help advance understanding and gyrokinetic modeling of toroidal plasmas in the pursuit of fusion energy.

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Study of the Radial Electric Field Behaviour in the Scrape-off Layer at the L-H Transition

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In tokamaks the H-mode confinement regime exhibits strong gradients in the radial electric field (E_r) at the very edge of the confined plasma region. These gradients lead to an $\mathbf{E}\times\mathbf{B}$ velocity shear flow which is believed to be the reason for suppression of turbulent transport at the plasma edge and thus for the transition from L- to H-mode. Experimental studies at ASDEX Upgrade show that for a wide plasma parameter range a critical value of the $v_{\mathrm{E}\times\mathrm{B}}$ minimum, a proxy for the $v_{\mathrm{E}\times\mathrm{B}}$ shear, is needed to enter H-mode. For a more complete understanding of the L-H transition physics, the exact location of the steepest E_r gradient is crucial. Findings from several machines suggest that the scrape-off layer (SOL) physics influences the H-mode onset. These are supported by modelling results indicating that the divertor and wall conditions can change E_r in the SOL. This in turn would directly impact the $v_{\mathrm{E}\times\mathrm{B}}$ shear across the separatrix and thus might modify the condition for the L-H transition. To experimentally address these questions, a new active spectroscopy diagnostics was installed at ASDEX Upgrade. Thermal helium atoms with a flow rate of about 10^{19} el/s are injected locally into the plasma at the outer midplane by a piezoelectric driven gas valve. The detected spectral lines of singly ionized helium, created by electron impact excitation, are resolved with high radial precision and a temporal resolution of about $2.5\,\mathrm{ms}$. Making use of the radial force balance, this diagnostics is able to measure E_r across the separatrix up to the near SOL during the L-H transition. Measurements of the SOL E_r at the L-H transition for discharges with different divertor conditions will be presented.

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Development of a phase contrast imaging system in the near infrared region

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This work presents initial results of the development of a Phase Contrast Imaging (PCI) diagnostic [1-3] operating with a probe wavelength of 1.55 µm. While worldwide PCI systems use a 10.6 µm probe laser to relax technical constraints on the interferometric measurement, this reduced wavelength would permit new capabilities by significantly extending the range of measurable scattering wavelengths and frequencies. Indeed, the shorter probing wavelength will allow one to collect larger

scattering wave-vectors at a fixed size of the receiving optics; moreover, the frequency bandwidth of detectors in the NIR is about three orders of magnitude faster than that in the MIR, thus giving access to density fluctuations with frequencies up to 1 GHz, suitable to detect even radio frequency (RF) waves. In practice, while maintaining medium wave-number detection capability (k ≥ 1 cm-1), fluctuations at wave-numbers exceeding k ≥ 80 cm-1 would also be accessible at frequencies up to 1 GHz, thus covering density perturbations induced by electron-scale fluctuations. Recent progress in achieving the above goals will be reported here. A number of phase plates with various groove dimensions suitable for this probing wavelength were manufactured using a masked coating technique. Other than the custom made phase plates, this prototype system uses only off the shelf components to maximize ease of construction in future experiments; more specifically, a 100mW fiber optics laser is collimated, expanded, and focused on the phase plate and subsequently imaged on an array of detectors. Calibrating sound waves of 4 mm wavelength were propagated through the expanded beam and detected in the mV range without the need for pre-amplifiers. Future work will focus on quantifying the SNR of the system at various scattered wavelengths, as well as evaluating the impact of mechanical vibrations on the detected signal. Once optimized on the bench, the system will be ready for implementation on a plasma fusion experimental facility.
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Parallel flow driven instability due to toroidal return flow in H-mode plasmas

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We theoretically investigate turbulence in H-mode plasmas with the pressure gradient and the strong mean flow. The toroidal flow, which is induced by the poloidal mean flow so as to satisfy the divergence free condition, is strong in H- mode, thus the effect of the toroidal return flow on instabilities is considered. The proposed model self-consistently includes not only the destabilization of the drift wave and the parallel flow shear instability, called D'Angelo mode, but also the stabilization due to the poloidal flow shear. Depending on the strength of the flow shear or on the magnetic geometrical parameter, we obtain the stabilization of drift wave and the destabilization of the D'Angelo mode. The competition between different instabilities through coupling of the poloidal flow with the toroidal return flow could be a key concept for understanding the turbulence in H-mode. The characteristics of the instabilities are similar to the observations of the precursor of the type-III ELM.

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Helical inward orbits of heavy ions associated with transient axial flows in tokamak

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The mechanism that is able to transport heavy impurity ions from the edge of a toroidal magnetically confined plasma to the core is of high concern for the tokamak reactor. Just a weak concentration of Tungsten in the center of tokamak may be an obstacle to the reactor regime.
We propose a physical picture of the advection of heavy (Tungsten) ions from the edge to the core, based on a combination of the poloidal rotation and the baroclinic effect. The poloidal rotation is supported by the Stringer mechanism based (as shown by experiments) on poloidal nonuniformity of the radial fluxes. The baroclinic term generates vorticity as results from the existence of a poloidal gradient of pressure.
The geometry of the problem is similar to the fluid "smoke ring" with swirl but with the particularity that there may be strong transient acceleration of the rotation in the toroidal direction. The transient acceleration of the axial flow (already noticed in experiments) which must be associated to transient radial inflow but with no formation of the conical singularity usually seen in static linear swirl motion in fluids (i.e. toroidal symmetry is preserved). The origin of the transient axial acceleration can be attributed to the Neutral Beam Injection ions, transferring substantial momentum to the background plasma. When the axial flux increases any mechanism leading to saturation of the axial velocity implicitly requests the density to increase and triggers converging radial inflow of particles. The orbits are helical.
We compare this source of helical inward advection with the current explanation for the impurity inflow. The latter is based on neoclassical intrinsic loss of balance between the ion radial fluxes or on the poloidal electric field generated by longer presence of ion bananas at the outer region . The mechanism that we propose here is transient but more effective in terms of ion flux and is compatible with the particularities of the H mode regime (High confinement) in tokamak.

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High Resolution Probe for filament transport and current density study at the edge region of W7-X

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For the study of electrostatic and magnetic properties of filaments characterizing the edge region of the stellarator experiment W7-X, a specifically designed insertable probe head was constructed within the framework of EUROfusion WP.S1 work package in collaboration between Consorzio RFX, IPP Greifswald and FZJ Julich. The probe head, named High Resolution Probe (HRP), was conceived to be installed on the mid-plane multi-purpose fast reciprocating manipulator on W7-X.
Electromagnetic filamentary turbulent structures are found to characterize the edge region of different magnetic configurations [M. Spolaore et al., PoP 2015] including Reversed Field Pinch, stellarator and tokamak, where strong currents are associated also to ELM filamentary structures. The study of those phenomena in W7-X stellarator is of particular interest as the electromagnetic features of filaments are expected to become more relevant with the increase of the local plasma beta. In particular the aim is to provide information about the presence and the features of parallel current density associated to filamentary turbulent or ELM-like structures. Furthermore, the possibility to measure the time evolution of the flow radial profiles using the Mach probe array was considered as a further interesting part of the study, given the strong interplay expected between the turbulent fluctuation and the average flows. Further important information provided is the radial propagation of turbulent flux.
The contribution will present the design development, the R&D studies and the applied solutions for the sensors embedded in the probe head. In particular, the presence of 140 GHz ECRH plasma environment represents one of the main challenges for reliable magnetic fluctuation measurements.

First measurements were performed during the W7-X experimental campaign OP1.2b, where in particular the probe was exploring different magnetic configurations. The respective features of the electromagnetic turbulence will be compared.

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Strange fluxes in drift turbulence and plasma poloidal rotation

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Turbulence can have a self-organizing character, which consists of the generation of quasi-coherent large scale structures and flows. In addition to that, we have found more subtle effects, the hidden drifts (HDs) [1]. They appear in the presence of poloidal rotation of the plasma and have radial orientation. Essentially, the HDs are two opposite average velocities that compensate one another. Their most important effect consists of the generation of strange turbulent fluxes (STFs), which are stochastic advection processes that depend on the sign of the fluctuations. The sign of the advected fluctuations is associated to the sign of the HD, so that the positive and the negative fluctuations move in opposite directions and generate fluxes, although the average velocity is zero.
We discuss here the effects of the HDs and STFs in the drift turbulence. Our study is semi-analytical, based on an iterated self-consistent approach that combines the analysis of the test particles and test modes in turbulent plasmas [2]. Both studies start from given statistical description of the turbulence, but coupling and iterating them provide an evaluation of turbulence evolution. Essentially, each iteration contains the calculation of the frequencies ω(k) and growth rates γ(k) of the modes as functions of the momentary spectrum S(k,t) of the turbulence and the evolution of S on a small time interval. The average propagator of the modes is determined using the statistics of the trajectories, which include the effects of the eddying process and correlations that appear in the nonlinear test particle motion. We show that this approach goes beyond the quasilinear stage of turbulence and provides the physical image of the nonlinear processes that are generated.
We have found a radial drift Vφ of the potential fluctuations that is of STF type. Vφ is the result of the Lagrangian correlation of the potential with the velocity and it influences both the frequency and the growth rate of the modes.
Vφ adds to the diamagnetic frequency in the equation for ω(k), which shows that it determines the radial drift of the potential fluctuations. This potential flux drives a STF for the vorticity fluctuations that has opposite sign due to the Eulerian correlation potential-vorticity. These STFs depend on the sign and amplitude of the poloidal velocity Vθ. The vorticity flux influences the large-scale vorticity that corresponds to the sheared rotation of the plasma. Its contribution can increase or attenuate the poloidal rotation, depending on Vθ and on the parameters of the turbulence.
Vφ also modifies the growth rate of the modes. It provides a new mechanism for the generation of the zonal flow modes. It is a nonlinear process determined by the STF of the potential fluctuations, which drives radial oscillations of the potential. A first evaluation of the importance of the process identified here shows that the zonal flow modes can reach amplitudes that are high enough to produce the decay of the drift turbulence. This process adds (with expected synergistic influences) to the other mechanisms of zonal flow mode generation.

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Turbulence in the Tokamak Divertor

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Turbulence in the tokamak periphery is a key mechanism by which heat and particles are transported across the magnetic field, from the hot core plasma towards a material interface. There is a complex zoology of turbulent processes that occur in this boundary region, all of which have the potential to impact the exhaust properties of the machine. Below the X-point, in the divertor legs of the plasma, recent observations from MAST have demonstrated the existence of turbulent structures close to the separatrix, in isolation from the upstream plasma. A survey of operating conditions in MAST reveals that these observations are ubiquitous and have the potential to redistribute plasma fluxes in the divertor volume. By comparing tomographic inversions of these fluctuating structures in the MAST divertor with high fidelity 3D simulations conducted with the STORM code, the drive mechanisms underlying this turbulence have been elucidated. The curvature of the magnetic field drives turbulence on the inner divertor leg where the large pressure gradient at the separatrix is partially anti-parallel to the curvature vector. In the outer divertor leg turbulence is largely driven by the Kelvin-Helmholtz and resistive drift-wave mechanisms, with the magnetic curvature now playing a regulatory role. In advanced divertors turbulence may play an even more prominent role where divertor legs may be closer to horizontal in the poloidal plane, as in the Super-X design, or where an enhanced null region may lead to increased radial transport as recently evidenced in the TCV snowflake divertor.