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87	P4b.101	Crescent-shaped spot modeling of runaway electron synchrotron radiation	Magnetic Confinement Fusion	Volodymyr	Bochko
105	P4b.102	Quantifying electron cyclotron power deposition broadening in DIII-D	Magnetic Confinement Fusion	Jelle	Slief
123	P4b.103	Impact of impurities on drift wave instabilities in reversed-field pinch plasmas	Magnetic Confinement Fusion	Jingchun	Li
125	P4b.104	Experimental investigation of halo currents during vertical displacement events in the KSTAR tokamak	Magnetic Confinement Fusion	Jun-Gyo	Bak
136	P4b.105	The first observations of beta-induced Alfvén eigenmodes in edge remnant magnetic island on J-TEXT	Magnetic Confinement Fusion	Jie	Yang
143	P4b.106	Machine-learning enabled automatic classification of KSTAR ECE images	Magnetic Confinement Fusion	Ralph	Kube
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161	P4b.108	Start-up runaway generation with neutral and low Z impurity reduced screening effects at the KSTAR Ohmic plasmas	Magnetic Confinement Fusion	Yeongsun	Lee
167	P4b.109	H-mode operation in Helium plasmas on TCV: access and pedestal characterisations	Magnetic Confinement Fusion	Benoit	Labit
193	P4b.110	Non-linear visco-resistive MHD modelling of reversed field-pinch fusion plasmas: viscosity coefficient studies	Magnetic Confinement Fusion	Nicholas	Vivenzi
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223	P4b.112	Self-consistent simulation of Magnum-PSI target in SOLPS-ITER with a Finite Element Wall model	Magnetic Confinement Fusion	Jorge	Gonzalez
225	P4b.113	Global stability and MHD dynamics in TCV negative triangularity plasmas	Magnetic Confinement Fusion	Leonardo	Pigatto
273	P4b.114	ECWC experiments and modeling on TCV	Magnetic Confinement Fusion	Johan	Buermans
281	P4b.115	Integrated core transport modeling of NSTX plasmas	Magnetic Confinement Fusion	Galina	Avdeeva
336	P4b.116	Isotope effects on particle transport in TCV ohmic discharge	Magnetic Confinement Fusion	Kenji	Tanaka
343	P4b.117	Effects of the external current drive on three-dimensional magnetic islands in the CFQS quasi-axisymmetric stellarator	Magnetic Confinement Fusion	xiang	su
354	P4b.118	Performance assessment of a tightly baffled, long-legged divertor configuration in TCV with SOLPS-ITER simulations	Magnetic Confinement Fusion	GUANGYU	SUN
370	P4b.119	Magnetic reconnection events in RFX-mod high current plasmas	Magnetic Confinement Fusion	Marco	Gobbin
436	P4b.120	Benchmarking DIV1D on SOLPS-ITER simulations of TCV plasmas	Magnetic Confinement Fusion	Gijs	Derks
483	P4b.121	Effect on the tearing mode by adding rotating resonant magnetic perturbation with different frequency in J-TEXT	Magnetic Confinement Fusion	Ruo	Jia
496	P4b.122	Systematic design and demonstration of a MIMO gas injection controller for the N-II emission front and line averaged electron density in TCV	Magnetic Confinement Fusion	Jesse	Koenders
553	P4b.123	Effects of isotopes on pedestal structure in DIII-D	Magnetic Confinement Fusion	Ryan	Chaban
581	P4b.124	Numerical simulation of thermal quench triggered by density source in HL-2A	Magnetic Confinement Fusion	Shilin	Hu
599	P4b.125	Study of the shattered pellet injection on runaway current dissipation in the J-TEXT tokamak	Magnetic Confinement Fusion	You	Li
600	P4b.126	Measurement of the phase relationship of coupled n = 1 tearing modes in J-TEXT	Magnetic Confinement Fusion	Zhengkang	Ren
591	P4b.127	High heat fluxes testing of tungsten materials with different microstructure under QSPA transient plasma impacts	Magnetic Confinement Fusion	Vadym	Makhlai
607	P4b.128	Design of the calibration setup for VUV spectrometers using calibrated photo-diode detector in the wide range of VUV wavelength	Magnetic Confinement Fusion	Changrae	Seon
121	P4b.201	On the effects of multi-pump Raman amplification of short laser pulses	Beam Plasmas and Inertial Fusion	Kirill	Lezhnin
138	P4b.202	Modulating far-field properties of attosecond pulses based on relativistic plasma mirrors	Beam Plasmas and Inertial Fusion	Yi	Zhang
166	P4b.203	Efficient high-order harmonic generation via surface plasma compression with lasers	Beam Plasmas and Inertial Fusion	Boyuan	Li
240	P4b.204	Generation of second-harmonic in focusing structured laser beams inside dielectrics	Beam Plasmas and Inertial Fusion	Kazem	Ardaneh
324	P4b.205	Electromagnetic emission via linear mode conversion mediated by stimulated Raman backscattering	Beam Plasmas and Inertial Fusion	Xuyan	Jiang
415	P4b.206	Superradiance from superluminal nonlinear plasma wakefields	Beam Plasmas and Inertial Fusion	Bernardo	Malaca
438	P4b.207	Generation and control of internal-injected electron beams in plasma for cancer therapies	Beam Plasmas and Inertial Fusion	Celine	HUE
484	P4b.208	High Frequency Incoherent and Coherent Radiation in SMILEI: application to XUV emission from electrons accelerated in surface waves	Beam Plasmas and Inertial Fusion	Paula	Kleij
512	P4b.209	Scanning the optical path of a tabletop vortex EUV beam	Beam Plasmas and Inertial Fusion	Patrícia	Estrela
585	P4b.210	Terahertz radiation emission from laser-induced plasmas inside dielectrics	Beam Plasmas and Inertial Fusion	Kazem	Ardaneh
480	P4b.302	Decoupling of dust cloud and embedding plasma for high electron depletion in nanodusty plasmas	Low Temperature and Dusty Plasmas	Andreas	Petersen
28	P4b.401	Fractality and cumulative entropy of a magnetized plasma driven by fractional Brownian motion	Basic, Space and Astrophysical Plasmas	Víctor	Fernández
70	P4b.403	Analyzing the solar activity using the horizontal visibility graph method	Basic, Space and Astrophysical Plasmas	Tomás	Zurita-Valencia
189	P4b.404	Solitary structures associated with parallel whistler field at magnetopause	Basic, Space and Astrophysical Plasmas	JYOTI	RANI
614	P4b.405	Kinetic models of solar wind current sheet	Basic, Space and Astrophysical Plasmas	Thomas	Neukirch
606	P4b.406	Alfvénic Transport in the Storm-time Magnetosphere	Basic, Space and Astrophysical Plasmas	Christopher	Chaston

Crescent-shaped spot modeling of runaway electron synchrotron radiation

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The energy of disruption generated runaway electrons (REs) can reach as high as tens of MeV and they can cause serious damage to plasma-facing surfaces in large tokamaks and ITER (see, e. g., [1]). At the same time, the quiescent RE generation in low density Ohmic discharges allows accurate measurement of runaway electron parameters [2].

For analysis of the synchrotron emission (SE) of REs in tokamaks (case of the finite pitch angle parameter, $v_{\perp}/|v_{\parallel}| \sim 1$) the analytical expressions have been obtained in [3] (nonlinear cone model). The motion along tokamak helical magnetic field with the longitudinal velocity $v_{\parallel}$, cyclotron gyration motion around the guiding centre with the finite transverse velocity $v_{\perp}$ with respect to the tokamak magnetic field, safety factor *q(r)*, the horizontal displacement of the drift surfaces of electrons with respect to the magnetic surfaces, and the position of the detector are taken into account. The results of [3] are used for qualitative modeling of DIII-D experiment [2] where the SE crescent-shaped spot was observed.

Presented results show that a crescent shape appears for a large pitch angle ($v_{\perp}/|v_{\parallel}| \sim 1$) and the relative absence of SE on the magnetic field lfs side is an artifact of the conservation of magnetic moment. These our conclusions confirm the statements of Refs. 2, 4.

Recall that the case of the small parameter $v_{\perp}/|v_{\parallel}| \ll 1$ (linear cone model) was considered in [5] and is used for experimental data analysis till now.

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Quantifying electron cyclotron power deposition broadening in DIII-D

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Electron cyclotron (EC) radiation is a powerful tool in fusion devices. Compared to other heating and current drive methods, millimeter EC waves exhibit a particularly localized resonance and a radially narrow power deposition region. Localized deposition allows EC radiation to be used for a wide variety of applications, including (but not limited to) perturbative transport studies, profile control, and MHD control.

The exact width and shape of the power deposition profile must be well known for the above applications and is typically estimated using forward methods (i.e. beam/ray tracing). However, both experimental and numerical studies have indicated that power deposition profiles may be broader than traditional forward methods indicate and have linked this effect to plasma edge turbulence [1]. This has significant implications for EC applications in future large fusion devices [1]. To help quantify this effect ahead of ITER operation, we aim to measure the ECH power deposition profile in a set of DIII-D discharge and compare that to forward estimations.

We use four inverse methods to compute the deposition profile from ECE and Thomson scattering measurements: break-in-slope (BIS) [2], maximum likelihood estimation (MLE) [3], frequency domain least squares (FDLS) [4] and flux fit [5]. We apply these methods to a set of 6 discharges from DIII-D spanning a range of confinement modes (limited and diverted L-mode, H- and QH-mode and negative triangularity) and compare against the established ray-tracing code TORAY [6].

We measure significant broadening across all six discharges: between 1.6 and 6.2 times over the TORAY estimates depending on the discharge and method. Most of the broadening (i.e. in five out of six discharges) observed is between 1.6 and 3.6 times. We show that this level of broadening in ITER will have serious consequences for the NTM control system.

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Impact of impurities on drift wave instabilities in reversed-field pinch plasmas

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The drift wave in the presence of impurity ions was investigated numerically in reversed-field pinch (RFP) plasmas, using the gyrokinetic integral eigenmode equation. By comparing the results of regular and hollow plasma density profiles, it was found that the ITG mode for the hollow density profile case is much harder to excite. For the impurity effects, when the impurity density gradient is opposite to the primary ions, namely when L_{ez} is negative, the impurities can enhance the instability. On the contrary, when L_{ez} is positive, the instability is stabilized. Regarding the trapped electron mode (TEM), the growth rate for plasmas with a hollow density profile remains smaller than that of the standard density gradient. There exists a threshold in L_{ez}. When L_{ez} is less than this value, the impurities destabilize the TEMs, while when L_{ez} is greater than this value, the impurities stabilize the TEMs. In addition, the influence of the collisionality on the TEMs was also studied.

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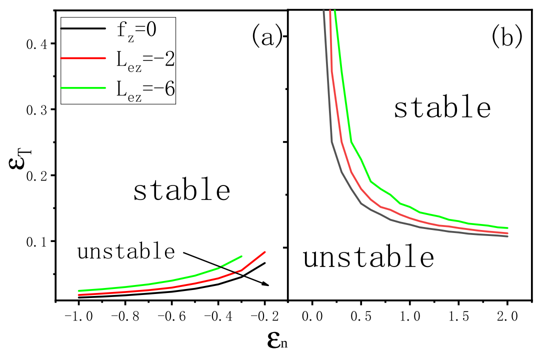

Figure 1: *Thresholds for ITG in the ion temperature gradient ($\varepsilon_T = L_T/R$) and density gradient ($\varepsilon_n = L_n/R$) plan in pure and mixture plasmas with hollow (a) and normal (b) density profile.*

Experimental investigation of halo currents during vertical displacement events in the KSTAR tokamak

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The characteristics of poloidal halo currents (HCs), which flow through the supporting structures for the lower divertors between plasma and the wall of the vacuum vessel during downward vertical displacement events (VDEs) eventually causing plasma disruptions, are experimentally investigated in the KSTAR tokamak. The poloidal HCs are measured with small Rogowski coils (RCs) called as halo current monitors (HCMs) mounted on the supporting structure for the disrupted plasmas due to the downward VDEs under experimental conditions such as plasma current I_p of 0.4 -1.0 MA and toroidal field B_T of 1.5 – 2.7 T, and its magnitude I_h is estimated as 5 ~ 30 % of I_p in the operational range of I_p and B_T. Firstly, the value of I_h is inversely proportional to the current quench (CQ) rate which is evaluated from the linear fit on the wave-form of a plasma current in the phase of the CQ. Plasma current evaluated by using the sum of local poloidal fields measured at plasma facing components (PFCs) is used for evaluating the CQ time because the plasma current previously measured with the RCs on the wall includes the toroidal eddy current on the PFCs during the disruption. Secondly, the value of I_h can be reduced down to 50 % by increasing the amount of the impurity puff (such as N_2) at the lower divertor region which affects the electric resistance in the halo region. Thirdly, the toroidal asymmetric distributions of the HC including the rotating HCs correlating with the occurrence of the n = 1 MHD mode are observed, and the distribution can be changed by the resonance magnetic perturbation (RMP) field (n = 1) for producing the 3D magnetic field in the plasma edge region. Finally, the HC is also measured with the Langmuir probes (LPs) in the lower divertor region and its magnitude is confirmed by comparing with the HCM measurement, and the halo width can be estimated from the LP measurement.

In this work, the results from the experimental investigations on the HCs, which are needed for the study of the electromagnetic force on the PFCs due to the HC as one of the critical issues on the machine safety for higher operational conditions such as I_p (> 1.0 MA) and B_T (> 3.0T) in the KSTAR, will be presented.

The first observations of beta-induced Alfvén eigenmodes in edge remnant magnetic island on J-TEXT

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Alfvén eigenmodes (AEs), such as toroidal AEs (TAEs) and beta-induced AEs (BAEs) are observed in various tokamaks and stellarators. AEs can resonantly interact with energetic particles and then result in significant losses of them [1], which would lead to degrading the plasma performance and even damage reactor's first wall. In J-TEXT tokamak, the BAE at f~30kHz was observed inside the edge m/n=3/1 island excited by the m/n=3/1 resonant magnetic perturbations (RMPs) through multiple diagnostics. Here, m and n are the poloidal and toroidal mode number respectively). The BAE is shown as a m/n=3/1 standing wave structure with nodes located at the O- and X-points of the magnetic island. In this experiment, the q=3 surface was pushed outwards by increasing the plasma current, and then the magnetic island was gradually opened by interacting with the local poloidal limiters. According to the poloidal and toroidal distributions of magnetic fluctuations measured by the Mirnov probe array, the BAE mode still exists in the remnant island, but its amplitude decreases as the width of the remnant island becomes smaller.

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Machine-learning enabled automatic classification of KSTAR ECE images

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A significant amount of data generated by high temperature plasma diagnostics is never analyzed in depth. While reasons for this fact are manifold, easier access to relevant measurements is a key enabler for better scientific study of fusion plasmas. The current state of identifying measurements relevant to a particular study requires human knowledge of the measurement corpus as well as human interpretation of measurements. That is, humans have to know where to look and how to identify relevant parts of the measurements. Being able to automatically query a database, only providing a semantic description of the required data could dramatically accelerate this workflow. In particular, measurements from fusion experiments need to be added continuously to this database. The sheer amount of this data is overwhelming makes manual labelling of new data unfeasible.

To start solving this problem, this work explores how unsupervised machine learning models can be used to classify a corpus of electron cyclotron emission imaging (ECEI) data from the KSTAR tokamak. A dataset consisting of prominent phenomena such as magnetic islands and sawtooth instabilities is collected and a set of unsupervised learning algorithms, various clustering algorithms as well as deep learning based methods [1] [2] [3], are used to cluster the data. The performance of the various algorithms on the dataset at hand is presented, highlighting particular issues of the various algorithms when applied to ECEI data

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Establishment of island divertor configuration in the J-TEXT tokamak

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The island divertor configuration has been proposed first in 1977 for tokamak [1] and established successfully in stellarators [2], such as W7-AS, LHD and recently in W7-X. This concept provides a very efficient way to exhaust heat and particles, which is crucial for long-pulse high-performance plasma operation. What's more, a stable, thermally fully detached island divertor regime has been realized and demonstrated in W7-X [3]. Therefore, applying the island divertor configuration to tokamak is of great promise and significance.

Recently, the establishment of island divertor configuration has been demonstrated successfully in the J-TEXT tokamak. The edge 3/1 (or 4/1) islands have been excited by applying the resonant magnetic perturbation (RMP) with dominate m/n = 3/1 (or 4/1) component to a plasma with edge safety factor q_a >~ 3 (or 4). Once the edge 3/1 (or 4/1) islands have been excited, the radial profiles of the electron temperature, electron density, floating potential, the intensity of carbon impurity radiation, the edge poloidal rotation varied significantly in the scrape off layer (SOL). After the excitation of the edge islands, the edge safety factor was decreased by increasing the net plasma toroidal current, so as to move the edge islands outwards to intersect with the divertor targets. The poloidal profiles of the floating potential measured at the target plates, varied during the outward movement of edge island, indicating that the edge island was opened by the divertor target, i.e. the establishment of the island divertor configuration. It has been found that the island divertor configuration is not only beneficial for spreading heat load on the divertor target, but also to provide effective screening of carbon impurities.

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Start-up runaway generation with neutral and low Z impurity reduced screening effects at the KSTAR Ohmic plasmas

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While runaway electron physics is a branch of tokamak research recently focusing on investigating, suppressing and mitigating it in the disruption phase, start-up runaways have been little interest after an early tokamak start-up study established. However, a recent ITER plasma initiation revision [1] indicated that ITER plasmas have a chance to produce the runaway electrons because of a low P plasma initiation condition constrained by a burn-through limit. ITER plasmas must avoid a runaways-dominant plasmas initiation, where runaway electrons carry most of plasma current, to prevent a harmful effect on the device by the energetic electrons. In fact, JET start-up runaway study reported that there is a case where the runaway current dominated the thermal current, which prohibited the thermal population from burning [2]. The runaway dominancy seems to arise from electrons density and electric field dynamics at an early stage.

Understanding of their formation and energy limit is necessary in order to predict how much they do the harm on the device. In this work, we only tackle the modelling of their formation process. We conducted a numerical analysis on a formation of runaway electrons at KSTAR Ohmic breakdown start up employing the gyro-averaged Fokker Planck solver [3] and the DYON [4].

An evaluation of a reduced screening effect on electron-ion elastic and electron-electron inelastic collision has been typically concentrating on high Z impurity because the high Z impurities like Ne and Ar were used for runaway mitigation [5-7]. However, a species is different at plasma initiation, i.g. C for KSTAR and Be for ITER, and thus low Z impurity's effect on deflection and slowing-down frequency should be revisited. We extended an investigation to relevant low-Z elements.

Before equilibrium reliably reconstructed, the plasma position cannot be located and thus pushing it inward is adopted to a position control strategy. In this process, impurities from the wall can penetrate into the plasma, which should affect electron density, electric field and impurity contents. The DYON code can capture this picture setting the sputtering coefficient as a function of time.

The well-known runaway generation mechanisms are the Dreicer mechanism, the avalanche mechanism and the hot-tail mechanism. The last one omitted in 0d modelling but the others cannot describe a time transient effect. Moreover, the formulas for 0d modelling were developed assuming fully-ionized plasmas and thus they are not applicable at an early stage of tokamak start-up. On the other hands, the gyro-averaged Fokker Planck solver can be applicable to weakly ionized plasmas and consider all mechanisms with neutral and impurity only if the maxwellian background assumption is valid. With the DYON and the gyro-averaged Fokker Planck solver, we modelled the formation of start-up runaways at KSTAR Ohmic plasma. We compared the Dreicer flow rate and the runaway current between the analytic expectation and the numerical computation.

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H-mode operation in Helium plasmas on TCV: access and pedestal characterisations

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In ITER, not only will fusion operation be performed in mixed deuterium-tritium (D-T) plasmas, but also the pre-fusion power operation will be performed in helium (He) plasmas. Therefore, it is important to understand not only the dependence of the H-mode power threshold, P_{L-H}, for Helium plasmas but also the pedestal properties for type-I ELMy H-modes.

In this contribution, we will report on recent experiments on TCV, unbaffled, conducted to document the properties of H-mode Helium plasmas and we will compare with Deuterium cases from the TCV pedestal database [1]. The plasma configuration features a lower single-null divertor with B_T=1.43T and I_p=240 kA (q_{95}=3.2, κ=1.6, δ=0.34). The plasmas were heated with NBI only either operated in Deuterium or Hydrogen, resulting in $n_{He}/n_e \sim 0.85$.

The L-H threshold was assessed with NB ramps and no significant differences was found between H and D beams. The power threshold agrees well with the ITPA scaling [2]. In particular, the density dependence is well reproduced in line with past experiments with ohmic heating only [3]. On JET, a significant upshift of the density at minimum P_{L-H} was observed in Helium [4]. This was not seen in our experiments.

The Type-I ELM regime was identified from a clear change in the ELM frequency dependence with NB power. In stationary-state conditions, a fuelling scan was performed. A preliminary analysis indicates that the pedestal pressure degrades faster with $n_{e,sep}$ as compared to D cases. No striking difference was seen between NBH-D and NBH-H driven ELMy H-mode plasmas. Pedestal stability w.r.t. peeling-ballooning boundaries will also be reported.

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[a] See appendix of "H. Reimerdes, Overview of the TCV experimental programme" to be published in Nuclear Fusion, 2022

Non-linear visco-resistive MHD modelling of reversed field-pinch fusion plasmas: viscosity coefficient studies

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Numerical simulations of non-linear visco-resistive magneto-hydrodynamics (MHD) represent a fundamental tool in modelling magnetically confined fusion plasmas. In the case of the reversed-field pinch (RFP) configuration, SpeCyl [1] simulations have successfully predicted the rise of quasi-periodical oscillating helical self-organized states jointly exploiting two features [2]: the visco-resistive dissipation, represented by the dimensionless Hartmann number [3], and the non-ideal magnetic field helical boundary conditions [4, 5].

This work is focused on the viscosity, which represents the momentum transport coefficient of the model. So far, no unique consensus on the plasma viscosity evaluation in RFP plasmas has been developed [6]: the experimental estimates carried on according to classical [7] or turbulent transport theory [8-10] display orders of magnitude differences. As consequence of it, only a uniform viscosity profile without self-consistent time evolution was considered in the previous modelling activity, reducing it to a constant scalar of the model.

On the contrary, in this work, we study the impact of non-uniform and time dependent viscosity. Firstly, we test the effect of different time-independent viscosity profiles, including the one derived according to the Braginskii formula of perpendicular viscosity [7], on both 2D and 3D numerical simulations. While not displaying important qualitative differences, such modification quantitatively modifies the tearing modes MHD activity and the plasma flow, suggesting a slight reduction of the magnetic field chaos for viscosities increasing towards the plasma edge. Secondly, we introduce (limited to the uniform profile case) a preliminary self-consistent time evolution of the Hartmann number. We express the latter as a function of the dominant mode magnetic energy: this allows mimicking the effect of increased magnetic order and plasma temperature, resulting in reduced visco-resistive dissipation and thus increased reconnection period in the RFP sawtooth activity. The results motivate further development of self-consistent viscosity and resistivity studies in 3D nonlinear MHD.

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Research on the effect of non-resonant magnetic perturbation on low-q limit in J-TEXT tokamak

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The disruption is one of the biggest challenges for the future fusion device and can occur for a variety of reasons. Among these are well known operating limits related to the plasma pressure and density, and with high plasma current or low edge safety factor (q_a) operation [1,2]. For the low edge q disruptions, they are avoided by rotation transform supplied by the stellarator coils on CTH [3]. And the experimental results on J-TEXT indicate that the applied resonant magnetic perturbations (RMPs) can lower the limit of the edge q. However, RMPs with too large amplitude leads to a higher q_a limit and an earlier disruption [4].

In this paper, we will present the low-q limit at different interval of the central line-averaged electron density. Furthermore, experiments have been carried out in J-TEXT tokamak to study the non-resonant magnetic perturbations (MPs) on low-q limit discharges with the constant density. The coils system is set to produce static non-resonant MPs, dominated by a m/n = -1/1 components. The results indicate that the -1/1 non-resonant MPs can lower the limit of the edge q from 2.7 to 2.06. Moreover, the removal of -1/1 non-resonant MP, is followed by fast precursor MHD instability and disruption.

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Self-consistent simulation of Magnum-PSI target in SOLPS-ITER with a Finite Element Wall model

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Accurate simulation of the plasma and neutral dynamics in front of Magnum-PSI's target [1] is of uttermost importance to understand the complex physical processes taking place in divertors with huge heat and particle loads as those expected at ITER. These simulations can aid to understand relevant Atomic & Molecular (A&M) processes taking place near the target [2]. Moreover, the addition of liquid metal (Li or Sn) targets, currently being analysed in Magnum-PSI, creates a much more complex scenario. Therefore, including the evolution of the target properties in a self-consistent way is of uttermost importance. This includes the surface temperature, evaporation flux of liquid metals, sputtering, outgassing and other relevant processes arising from the interaction of high temperature plasma and neutrals with the target.

A Finite Element wall model [3] to describe the target temperature evolution is currently being developed to work in combination with the well-known edge plasma code SOLPS-ITER [4, 5]. This strategy allows for an in-depth comparison with experimental data, which is useful for the validation of the code and also to translate the relevant A&M processes in the device to other machines.

In this work, the surface temperature of a simple tungsten target obtained self-consistently with the simulation of plasma and neutrals in Magnum-PSI is presented and its effects in the recycling of ions at the target is analysed. Simulations are compared with experimental measurements from Thompson Scattering near the target and temperatures of the target surface.

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Global stability and MHD dynamics in TCV negative triangularity plasmas

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Negative triangularity tokamak (NTT) plasmas are the subject of increasing interest both in existing experiments and in view of fusion demonstration reactors. Experimental results indicate that negative triangularity plasmas keep L-mode edge characteristics while achieving improved core performance and confinement with respect to positive triangularity. An L-mode edge implies absence of Edge Localized Modes, making the NTT reactor an appealing concept. On the TCV device negative triangularity is studied since the 1990s [1] and recent experiments have further characterized a variety of scenarios with record performance in terms of normalized β [2]. MHD activity not necessarily leading to discharge termination is observed, in many cases from initial phases and related to n=1 [neoclassical] tearing modes. Global MHD stability of these plasmas is investigated with parametric numerical studies, to confirm the experimental evidence suggesting that most of the disruptive shots terminate below the eventual β limit. The numerical analysis is carried out with the linear resistive MHD stability code MARS-F, to investigate the nature of instabilities appearing in both diverted and limited scenarios. Projections of the ideal β limit are made for positive and negative triangularity comparable cases.

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ECWC experiments and modeling on TCV

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During the first stage of ITER operation (PFPO-1), Electron Cyclotron Wall Conditioning (ECWC) will be the only available conditioning technique in the presence of a toroidal field. The limited experience with this technique calls for dedicated modeling and experiments to ensure that ECWC can be an efficient conditioning tool for ITER.

The TOMATOR 1D hydrogen helium plasma simulator numerically describes the evolution of currentless magnetized RF plasmas in a tokamak based on Braginskii's standard continuity and heat balance equations. This code was initially benchmarked with experimental data from TCV Helium plasmas to determine the transport coefficients used in the diffusion-convection-reaction equation of the simulation. The simulator is used to model the plasma parameters and particle fluxes in ECWC experiments in the presence of a vertical magnetic field [1].

Several ECWC experiments were performed in TCV to study the influence of the heating power, the magnetic field and the pressure on the plasma parameters and the particle fluxes to the wall. We observed that the magnetic field, hence the position of the electron cyclotron resonance layer, plays an important role in the location and the intensity of the particle fluxes, while the heating power and the pressure only affects the global amount of particles. The density profiles, measured with the Far Infrared Interferometer, and the particle fluxes, measured with Langmuir probes, are compared to the modeling with the TOMATOR 1D simulator to benchmark the code also for deuterium plasmas.

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Integrated core transport modeling of NSTX plasmas

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Reliable transport modeling is critical to enable performance assessment and design of future fusion machines. Such modeling should combine different models into a consistent solution and allows straightforward validation against experimental data. The integrated modeling approach described in this work is based on the OMFIT integrated modeling workflow [1]. The OMFIT workflow has been successfully applied on traditional larger aspect ratio tokamaks like DIII-D, and in this work, we demonstrate initial results of adapting this workflow to a tokamak plasma of low aspect ratio tokamak, NSTX. We show how the integrated workflow addresses tasks of kinetic profiles fitting and integrated with a transport code TRANSP [2,3] and EFIT to provide the self-consistent equilibrium reconstruction with kinetic constraints of total pressure, including beam pressure, and total current, including bootstrap current. The interpretive power balance calculations of TRANSP are further used in the the single-time-point TGYRO [4] solver for prediction of plasma profiles based on the combination of reduced turbulent model TGLF [5] and neoclassical code NEO [6]. We begin our study from a low beta L-mode NSTX plasma, where traditional electrostatic drift waves are expected to be dominant. This first investigation is devoted to identifying the sensitivity of profiles prediction to variations in the kinetic profiles fitting and equilibrium reconstruction on the initial steps of integrated transport analysis.

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Isotope effects on particle transport in TCV ohmic discharge

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Isotope effects of particle transport are an essential ingredient of fusion power generation in a future reactor. However, the isotope dependence of particle transport is less understood than the isotope dependence of energy transport. This is due to the difficulty of estimation of particle transport coefficients. In TCV ohmic plasmas with single null divertor configuration, the particle diffusion coefficients (D_{mod}) and convection velocities (V_{mod}) were estimated in Hydrogen (H) and Deuterium (D) plasma by density modulation experiments. Density was modulated at typically 5 Hz by external gas fuelling. The radial modulation amplitude and phase were evaluated from multi-channel far-infrared interferometer signals, and D_{mod} and V_{mod} were then evaluated by model fitting technique.

Figure 1 shows the density dependence of the global confinement time of the kinetic electron energy (τ_{Ee}). The transition from linear ohmic confinement (LOC), where τ_{Ee} increases with the line averaged density ($n_{e\ bar}$), to saturated ohmic confinement regime (SOC), with τ_{Ee} almost constant with density increase, was identified both in H and D plasmas. The ttransition density was lower in H plasma. As shown in Fig. 1(b), D_{mod} at $\rho = 0.75$ - 1.05 are comparable in the low density ($n_{e\ bar} < \sim 3\text{x}10^{19}\text{m}^{-3}$) LOC regime, however, at high density ($n_{e\ bar} > \sim 3\text{x}10^{19}\text{m}^{-3}$) in the SOC regime, D_{mod} is clearly lower in D plasma. The different isotope effects in the LOC and SOC regimes might be linked to the different ion scale instabilities in the two regimes. On the other hand, V_{mod} does not show a clear difference over uncertainty of the estimation in H and D plasma. Inwardly directed V_{mod} decreases with higher density in H and D plasma. This is against the characteristics of the neoclassical Ware pinch and suggests that the inward pinch is an anomalous process. The lower edge diffusion in D plasma is favourable for the confinement but unfavourable for plasma density control. Also, it is essential to confirm that the observed isotope effects were due to the difference of bulk ion species rather than other effects such as impurity density or radiation. Gyrokinetic modelling is now underway.

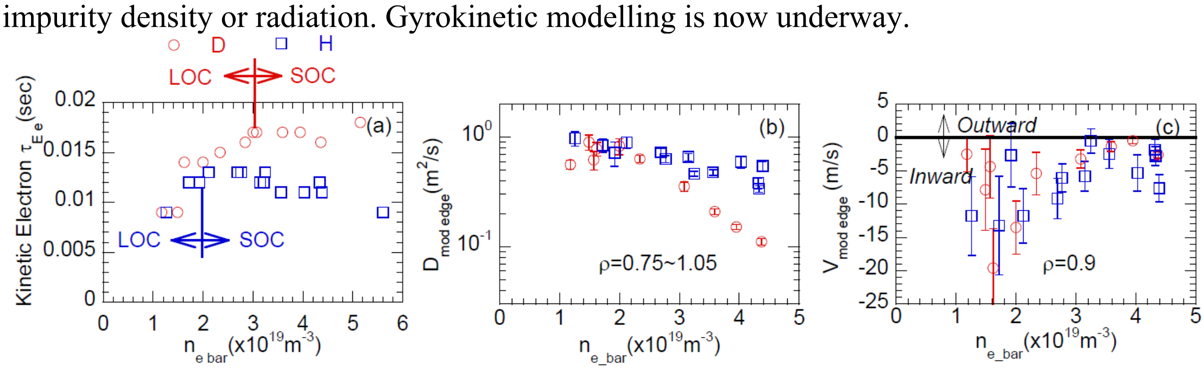

Fig.1 Density dependence, in ohmic discharge, of (a) kinetic electron confinement time, (b) particle diffusion coefficients and (c) convection velocities, for D and H.

Effects of the external current drive on three-dimensional magnetic islands in the CFQS quasi-axisymmetric stellarator

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Magnetic island physics is a major topic of interest for the Chinese First Quasi-axisymmetric Stellarator (CFQS) in case of high-β operation [1-3]. Electron cyclotron current drive (ECCD) can be one of the options for adjusting the rotational transform, and hence modifying magnetic islands in the CFQS [4]. This study focuses on the influence of the external current drive on the three-dimensional magnetic islands by the HINT code [5] for the CFQS. By applying toroidal magnetic field produced by the auxiliary toroidal field coil (TFC), of which coil current is 30 kA, m/n=5/2 magnetic islands are generated without the bootstrap current effect. It is found that the islands can be significantly suppressed by using the external flat or Gaussian current, depending the direction and amplitude of the current. Figs. 1(a) and (b) show the 5/2 islands without and with the external current, respectively. The region of the plasma pressure p/p_0>10 % is marked by the red line. The width of islands is reduced with increasing of external current as plotted in fig. 1(c), where the minus means the counter toroidal direction.

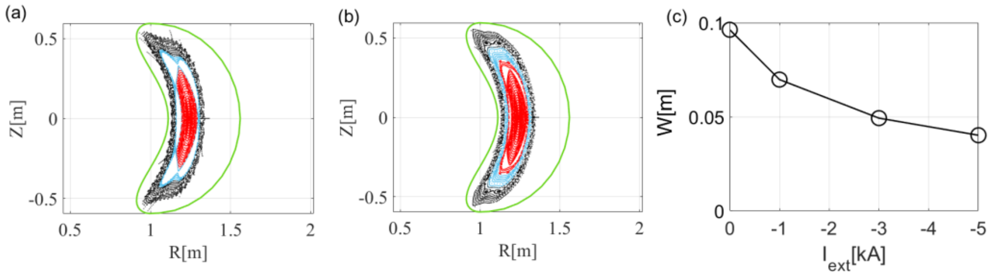

Figure 1 The poincaré plots of magnetic surfaces (a) without the external current (I_{ext}=0 kA), (b) with the Gaussian external current (I_{ext}=-5 kA), (c) The averaged width of magnetic islands (W) as a function of the Gaussian external current, where volume averaged beta is ~0.5 %. In all cases, toroidal magnetic field by TFC is applied to generate 5/2 islands.

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Performance assessment of a tightly baffled, long-legged divertor configuration in TCV with SOLPS-ITER simulations

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In future high power magnetic fusion devices such as ITER and DEMO, the heat flux deposited on the divertor target will exceed material limits if unmitigated. This has motivated the study of a variety of innovative divertor configurations that reduce target heat flux. Here, the SOLPS-ITER code package[1] is employed to explore the performance of a tightly baffled, long-legged divertor (LLD) geometry, which was inspired by LLD simulations for the ADX tokamak concept with UEDGE [2, 3] and is proposed for the next TCV divertor upgrade. L-mode TCV simulations, including carbon impurities, compare the tightly baffled LLD with the existing baffled and unbaffled divertors. For the same input power, the tightly baffled LLD shows a significant reduction in the power reaching the divertor target plates. An input power scan shows the power exhaust potential of the tightly baffled LLD, defined as the highest power where the peak outer target temperature remains below 5eV, exceeding that of both baffled and unbaffled cases by factors of 2.5 and 7, respectively.

This larger operation window of the detached tightly baffled LLD is mainly attributed to a higher target neutral compression. The tightly baffled LLD develops a gradient of neutral density along the divertor leg, which allows poloidal displacements of the detachment front location for a range of input powers. The detachment front location is controlled by a balance between the power entering the divertor leg, the target neutral pressure and losses to the divertor walls. A scan of the outer divertor width indicates that this stabilising feedback loop is only important for a sufficiently narrow divertor, and is limited by excessive radial power exhaust that may damage the divertor baffles. These results suggest that TCV with a tightly baffled, long-legged divertor configuration should be able to demonstrate substantially improved detachment access and a larger detachment window as a proof-of-principle of this new divertor concept for a reactor.

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Magnetic reconnection events in RFX-mod high current plasmas

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Magnetic reconnection is a basic process involving a topological rearrangement of the magnetic topology observed in almost all magnetized plasmas, including those relevant for controlled nuclear fusion experiments. The magnetic energy released during reconnection events can be converted into thermal or kinetic energy. The goal of this contribution is to investigate magnetic reconnection phenomenology associated to the partial or complete transition from a helical to an axisymmetric magnetic topology in high plasma current (I_p up to 2MA) reversed field pinch (RFP) configuration [1]. In particular the analyses here reported concern the RFX-mod experiment [2], which is at present the largest RFP experiment in operation, focusing in particular on: 1) the MHD activity and magnetic energy evolution, 2) the electron temperature dynamics and the energy released during these phenomena and 3) the corresponding ion heating.

By a power balance technique in axisymmetric approximation [3] it has been possible to compute, for several hydrogen discharges, the energy released during reconnection events which is generally in the range 5 – 180kJ at I_p = 1.2 - 2 MA. Experimental measurements from Neutral Particle Analyzer diagnostic have been used to estimate the corresponding changes in the ion temperature profile (T_i) which shows an increase of about 250eV in the core region (at I_p=1.3MA). The associated thermal energy variation computed from the whole T_i radial profile, of the order of 0.5-1kJ, is lower than the released magnetic energy, thus suggesting that suprathermal ion heating and electron acceleration might be dominant.

The analyses described above have been recently extended to deuterium plasmas too and preliminary results on magnetic activity, electron thermal energy variation and DD neutrons generation during reconnection events are here reported. Given the great relevance of ion heating during reconnection events in a reactorial perspective these issues will be further investigated with dedicated experiments and new diagnostics in RFX-mod2 [4], an upgrade of the present device currently under implementation.

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Bechmarking DIV1D on SOLPS-ITER simulations of TCV plasmas

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Future tokamak reactors will require real-time feedback control to handle the enormous heat and particle fluxes coming from the ignited plasma core to the wall in the heat exhaust called the divertor [1, 2]. Heat exhaust controllers should bring and maintain the divertor plasma in a detached regime, characterized by low plasma temperature and pressure, to reduce heat loads to the wall and stay within material limits. To minimize commissioning time and involved risks, controller designs should be guided by dynamic physics-based models. Although detached plasmas are simulated with increasing accuracy by large-scale physics-based models, excessive computation times for dynamic cases necessitate complimentary faster dynamic models for the design, verification and validation of heat exhaust controllers for future reactors.

In this contribution we benchmark DIV1D, a new 1D dynamic physics-based model of the divertor plasma [3], on SOLPS-ITER simulations of TCV plasmas. SOLPS-ITER is a large-scale model used to determine 2D edge and divertor plasma equilibria [4, 5]. We present a novel 1D interpretation of static 2D SOLPS-ITER divertor plasmas that captures the heat flux as it flows from a region near the X-point (upstream) to the divertor target wall. Using the 1D interpreted SOLPS-ITER profiles, we fit the heat flux profiles of DIV1D by modeling cross-field transport with an effective flux expansion factor. Additionally, a homogeneous neutral background is imposed to constrain the neutral density and improve the fit of the temperature profile. The benchmark of DIV1D shows reasonable to good agreement with 1D interpretations of SOLPS-ITER for low divertor plasma temperatures and serves as a basis to further develop DIV1D as a dynamic model to guide tokamak heat exhaust control efforts.

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Effect on the tearing mode by adding rotating resonant magnetic perturbation with different frequency in J-TEXT

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The external resonant magnetic perturbation (RMP) has been proved to be an effective method on controlling the 2/1 tearing mode (TM) in tokamaks. In J-TEXT tokamak, sets of in-vessel saddle coils generate rotating RMP to control the 2/1 TM as the TM is locked to the RMP and rotating with the RMP. The RMP with higher, equal or lower frequency than the natural frequency of TM is used respectively in experiments. And the experimental results show that, the width of the TM magnetic island decreases (increases) with the increase (decrease) of the frequency before and after mode locking.

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Systematic design and demonstration of a MIMO gas injection controller for the N-II emission front and line averaged electron density in TCV

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Unmitigated, the expected power fluxes impacting the divertor targets during reactor relevant operation will exceed present-day engineering limits. Real-time feedback control of *plasma detachment*, a regime characterized by a large reduction in plasma temperature and pressure at the divertor targets, is considered mandatory to achieve acceptable power fluxes. Controlling the divertor plasma in future reactors is inherently a multi-input multi-output (MIMO) control problem. Injection of multiple different gas species like deuterium, nitrogen and neon is envisioned for ITER. Each of these species will affect multiple output performance parameters, for example divertor radiation, neutral pressure and electron density. In control terminology, this is called *interaction*, and must be specifically dealt with in controller design [1].

In this contribution we show a systematic design of a MIMO controller that accounts for this interaction. We aim to individually control the N-II emission front position L_{pol} and the line averaged electron density $\bar{n}_e$ using a combination of D_2 and N_2 gas injection in TCV [2]. The designed MIMO controller uses a decoupling matrix as a pre-compensator to reduce interaction around the control loop bandwidth. The pre-compensator is based on an apt transfer function structure for gas injection response in TCV [3], and its parameters are identified using system identification experiments. The generalized Nyquist theorem is used to test the controller stability, which accounts for interaction. The N-II emission front position is tracked using a real-time image processing algorithm [4] applied to spectrally filtered images from the multi-spectral imaging diagnostic MANTIS [5]. We demonstrate the controllers ability to keep the N-II emission front at a desired position, and then keep it there while changing the line-averaged density.

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Effects of isotopes on pedestal structure in DIII-D

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Using a database of hydrogen and deuterium H-modes on DIII-D we examine how the isotope effect alters the fueling and transport of plasmas to change the pedestal stability and structure calculated by EPED [1]. The isotope effect is an empirical positive scaling of beneficial plasma parameters, such as confinement and decreased L-H transition power, with an increase in hydrogenic isotope mass. This empirical scaling conflicts with Bohm diffusion which predicts the opposite. The majority of this positive scaling originates from the edge pedestal region, raising the question if the isotope effect in part arises from a change of edge turbulence, transport, or fueling behavior. In this study, we compare hydrogen and deuterium discharges to predictions of the EPED model which uses MHD stability limits to calculate a scaling for pedestal pressure width and height. While the model uses the pressure profile, the individual differences in the temperature and density profiles often indicate the underlying physics of the pedestal. DIII-D hydrogen discharges, compared to similar deuterium shots, often exhibit an increased outward shift of the density profile relative to the temperature profile (Figure 1 bottom) which increases separatrix density and significantly alters the ballooning stability. Hydrogen discharges generally have narrower density pedestals compared to deuterium despite the increased neutral mean free path with lower isotope mass. We also compare transport and fueling relevant parameters such as $\eta_e = \frac{L_{n_e}}{L_{T_e}} = \frac{(n_e/\nabla n_e)}{(T_e/\nabla T_e)}$ (Figure 1 top) to explore the differences between experiment and the EPED model in hydrogen and deuterium. **Work supported by US DOE under DE-FC02-04ER54698 and DE-SC0019302.**

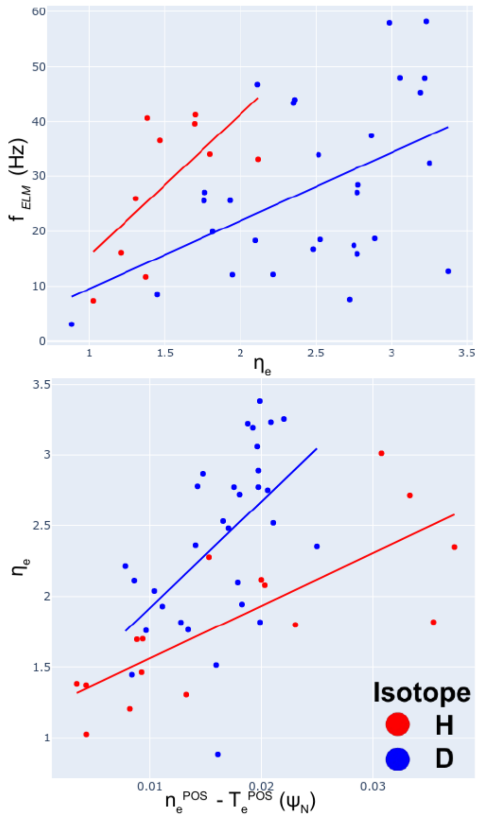

Figure 1: *(top) ELM frequency is correlated with η_e (transport driven) and (bottom) η_e is correlated with profile shift.*

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Numerical simulation of thermal quench triggered by density source in HL-2A

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Magnetic flux surfaces are abruptly destroyed and the plasma is no longer confined during thermal quench [1]. For a representative unmitigated disruption occurring in ITER with full deuterium-tritium performance, about 350 MJ of thermal energy and up to 1 GJ of magnetic energy may be released to the divertor and first-wall during several milli-seconds, leading to serious damage of the device [2]. Since occasional disruptions might probably be unavoidable in future fusion reactor, the realization of disruption mitigation is of crucial importance.

The mainstream methods of disruption mitigation system (DMS) include Shattered Pellet Injection (SPI) [3] or Massive Gas Injection (MGI) [4]. The location and uniformity of injected material deposition can affect the mitigation efficiency. To clarify the effect of MHD-modes-induced-transport on the injection penetration, we simulate the thermal quench (TQ) during the pre-disruption phase triggered by pure deuterium (D_2) injection at different fixed deposition location employing three-dimensional (3D) non-linear reduced MHD code JOREK. Results exhibit evidently different n=1 mode dynamics and variation of plasma density profiles, depending on the location of D_2 deposition (LoD) relative to the magnetic surface of q=2.

When LoD is outside the q=2 surface, the m/n=2/1 mode tends to be dominant and mainly couple with the m/n=3/1 mode. Magnetic stochasticity firstly happen in the m/n=2/1 island region and then expanding outwards. But when LoD is inside the q=2 surface, the m/n=1/1 mode tends to be dominant, and magnetic stochasticity firstly occur in the m/n=1/1 island region then the core plasma density greatly increases. The LoD is also found to be strongly linked to the growth rate and maximum dominant mode amplitude during the TQ, and consequently affects the TQ duration and the current spike amplitude.

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Study of the shattered pellet injection on runaway current dissipation in the J-TEXT tokamak

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Runaway electrons (REs), which is created during tokamak disruptions and may lead to runaway current, pose a threat to the reliable operation of future large tokamaks[1]. The SPI technology has been regarded as a primary method to mitigate the runaway current [2]. There are quasi symmetric dual SPI systems which have been developed to in J-TEXT used for disruption mitigation and runaway current dissipation. A series of experiments about runaway current dissipation by these two SPI systems have been carried out. The preliminary experimental results show that there is a positive correlation between the dissipation efficiency and the pellet velocity. Compared to Ar MGI, when the Ar pellet velocity is about 200 m/s, the runaway current dissipation rate is only about 12 MA/s, which is far lower than 22 MA/s in MGI shot. This difference may be caused by the low temperature of the runaway current in the J-TEXT, which makes it difficult to completely melt the fragments. As the pellet velocity increasing to 300 m/s, the dissipation rate increases to about 20 MA/s, which shows the Ar SPI has a similar dissipation effect than MGI. The similar results also have been found in Ne SPI experiments. With the increase of pellet velocity, the fragments are broken into smaller pieces. The larger contact area between the fragments and the runaway current makes the ablation more complete, thus improving the dissipation effect, which is proved by the increase of impurity assimilation rate.

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Measurement of the phase relationship of coupled $n = 1$ tearing modes in J-TEXT

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Tearing modes (TM) is a common magnetohydrodynamics instability in tokamaks. Coupled tearing modes with the same toroidal mode number and rotation frequency is observed by a poloidal array of Mirnov coils in J-TEXT. The poloidal variation of the perturbed magnetic field depends on the amplitudes and phase difference of coupled modes. Phase difference may lead to different evolutions of the coupled modes. This work develops a model for the phase relationship of the coupled modes in J-TEXT.

Based on the model for ASDEX-U [1, 2], a fitting model of magnetic measurements on J-TEXT is developed to determine the phase difference of 2/1 and 3/1 modes. The perturbed magnetic fields are considered to be generated by the force-free surface currents on the resonant surfaces. The surface currents are represented as filaments. The amplitude and phase of the perturbed surface currents at $q = 2$ and $q = 3$ surfaces can be obtained by least squares fitting.

The time evolutions of the amplitude and phase difference of the two modes are then obtained. The coupling of 2/1 and 3/1 modes is often observed to be in phase in the low field side (LFS) midplane. However, with the application of ECRH, the 2/1 and 3/1 modes are observed to be off phase in the LFS midplane. And the phase difference jumps from 180° to 0° once the ECRH is turned off, meanwhile the amplitudes of the two modes increase.

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High heat fluxes testing of tungsten materials with different microstructure under QSPA transient plasma impacts

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Accumulation and comparison data from a number of very different test facilities (electron, ion and plasma) could be a basis for choosing the material with much better properties for the armour of plasma facing components in the divertor region of fusion devices like ITER and DEMO [1]. From this reason, the main objective of this work is to study the features of macroscopic erosion of the pure tungsten (W) samples with different grain orientation irradiated by plasma streams in quasi-stationary plasma accelerator QSPA Kh-50 [2,3]. It is considered as important direction of experimental studies of damages of pure tungsten as major plasma facing material relevant to ITER and DEMO. The samples (with the longitudinal (L) and transversal (T) grain orientation and in the recrystallized (R)) have been irradiated with surface heat load of energy density up to 0.75 MJ/m^2 and the pulse duration of 0.25 ms. The plasma exposures were performed for the targets maintained at room temperature and preheated at 400 °C. The surface heat loads were either with no melting of W surface or above the melting threshold. The development of surface morphology of the exposed targets as well as cracking at the surface is discussed. Surface analysis was carried out with an SEM. Surface modification and development of cracks led to increases of roughness of exposed surfaces. X-ray diffraction (XRD) has been used to study the micro-structural evolution of the exposed targets [3]. Complexes of vacancies were annealed in course of plasma irradiation. Surface modification of re-solidified layer was registered at heat loads above melting threshold. Corrugation structure and inter granular crack of width up to several μm were also observed.

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Design of the calibration setup for VUV spectrometers using calibrated photo-diode detector in the wide range of VUV wavelength

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The primary role of VUV (vacuum ultra-violet) spectrometers in MCF (magnetically confined fusion) devices including future tokamak such as ITER is to measure the impurity species in plasmas. To perform the post analysis of the acquired VUV spectra from line integrated emission, it is necessary to calibrate the raw data using the intensity calibration curve as the first step. Therefore the absolute intensity calibration of VUV spectrometers has attained its importance by many researchers. However the calibration in VUV wavelength range in the laboratory scale is limited because available calibration light sources are limited, therefore the calibration of VUV spectrometer has been performed using the beam line of the large accelerator device. In the present study, thanks to the recently developed calibrated Si photodiode detector (VUV Si Detector, calibrated in NIST, McPherson 5 - 1000 nm), the calibration setup was designed also including a dedicated VUV spectrometer to select the specific wavelength to be calibrated. Two VUV light sources were employed for this calibration setup in the laboratory scale. A hollow cathode lamp with He, Ne, and Ar gases, which was developed in Hanover university, is used for the wavelength range from 23 nm to 160 nm. The other light source multiple anode SXR source (e-beam + target light source), Model 642-1 from McPherson Co. Ltd. is employed for wavelength range of 1 nm - 20 nm. The dedicated spectrometer was also designed to select the specific wavelength through aperture in the imaging plane, and the Laminar-type Replica Diffraction Gratings for Soft X-ray Region from Shimadzu Co. Ltd. was used for these full wavelength ranges of VUV light. By installing the docking system of the photodiode in the end of the spectrometer beam line, the input photon numbers to be entered into the VUV spectrometer to be calibrated can be measured *in-situ*.. The spectrometer to be calibrated is to be connected to the vacuum flange after this photo-diode docking system. By this design of the calibration setup, VUV spectrometers for the wide wavelength range of 1 nm - 160 nm are expected to be able to be calibrated.

On the effects of multi-pump Raman amplification of short laser pulses

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Beam combining is a promising concept for amplification of laser beam via crossing it with multiple pump beams. The ongoing experimental campaign at National Ignition Facility demonstrated the feasibility of generating a high power beam by crossing a seed beam with multiple identical pump beams, with the energy transfer mechanism being Brillouin scattering. Using coupled nonlinear Schrodinger equation model and 2D particle-in-cell simulations, we investigate the effects of resonant pulse amplification by pump energy redistributed between multiple pump beams, paying special attention to questions of energy transfer and focusability of the amplified seed. We show that the redistribution of the pump energy between multiple pumps and their optimal arrangement may help to improve seed energy gain and its focusability.

Modulating far-field properties of attosecond pulses based on relativistic plasma mirrors

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High-order harmonic generation driven by relativistic laser-plasma interaction is one of the most promising ways to realize table-top high-brightness attosecond sources, attracting a wide range of research interests for their broad applications. In the contribution, we report that the far-field properties of such attosecond pulses are greatly impacted by optically-formed parabolic-like relativistic plasma mirrors (PMs) [1]. Utilizing particle-in-cell codes and self-developed computation modules for the far field, we show that through adjusting the distance between foci of incident lasers and plasma targets, the divergences, waveforms and wavefront of far-field attosecond pulses can be efficiently adjusted.

An experimentally feasible proposal to obtain intense attosecond pulses in the far field without filters has been proposed recently [2], which can greatly improve intensities and useable spectrum width of attosecond pulses. With a proper defocusing distance, attosecond pulse trains with 65 times enhanced intensity and 50% decreased duration are obtained naturally in the far field due to suppressed divergences and locked peaks of harmonics. Besides, we also present a new method, named "divergence gating", to generate isolated attosecond pulses [3], where varying curvatures of defocused chirped lasers are used to modulate the focusing characteristics of the relativistic PM. Through making sure the most intense attosecond pulse generated at the peak cycle of lasers has the smallest divergence angle, isolated attosecond pulses can be obtained in the far field, confirmed by theoretical analysis and numerical simulations. Finally, what's more, the influence of PMs on the wavefront aberration of attosecond pulses will be discussed.

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Efficient high-order harmonic generation via surface plasma compression with lasers

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The efficiency of high-order harmonic generation from a relativistic laser interacting with solid targets depends greatly on surface plasma distribution. The usual method of enhancing efficiency involves tuning the plasma scale length carefully by improving the laser contrast [1,2]. Here, we experimentally demonstrate that efficient harmonics can be achieved directly by compressing large-scale surface plasma via the radiation pressure of a circularly polarized normally incident prepulse. The harmonic generation efficiency obtained by this method is comparable to that obtained with optimized plasma scale length by high-contrast lasers, and the harmonic spectrum plateaus at high orders. Our scheme does not rely on high-contrast lasers and is robust and easy to implement. Thus, it may pave a way for the development of intense extreme ultraviolet sources and future applications with high repetition rates. Moreover, our studies also reveal that the preplasma can be actively tailored into a curved surface using the radiation pressure of a normally incident prepulse. This may also be an efficient way to focus relativistic harmonics [3] or to produce high-order vortex harmonics [4].

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Generation of second-harmonic in focusing structured laser beams inside dielectrics

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Second-harmonic emission at a frequency that is twice the laser frequency is an important diagnostic for nonlinear laser-plasma interaction. It is forbidden for centrosymmetric materials such as the bulk of sapphire. The symmetry, however, can be broken by dielectric discontinuities as a result of laser-induced plasma inside a solid dielectric. Here, for the first time to our knowledge, we have experimentally measured second-harmonic from plasmas inside the bulk of sapphire. This is performed focusing single-shot 100 fs Bessel pulses inside sapphire. This configuration creates dense sub-wavelength plasmas (diam. $\approx$ 200 to 500 nm) which relaxation in the material is capable of creating Warm Dense Matter [1] and lately opening voids [2].

In our experiments, a single Bessel pulse at central wavelength 800 nm was focused in the bulk of sapphire at an intensity of 10^{14} W/cm^2, in conditions where voids can be opened [1, 2]. Second-harmonic emission was recorded in a single-shot mode in the far-field. To reproduce the experiments, we performed simulations using the massively parallel EPOCH particle-in-cell (PIC) code [3].

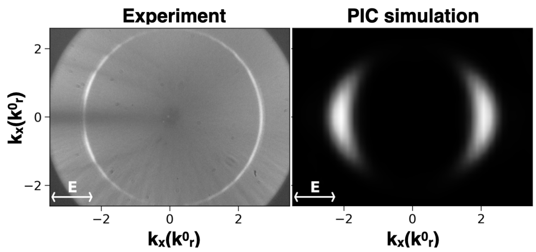

Figure 1: *Second-harmonic spatial spectrum from experiment versus simulation. $k_r^0 = k_0 \sin\theta$ where θ is the cone angle.*

We analyze how the efficiency of second-harmonic generation and its polarization depend on the plasma parameters. We find that the second-harmonic is generated either due to the coalescence of two surface electromagnetic waves or nonlinear interaction between the transverse electromagnetic wave and the electron plasma wave driven by linear mode conversion. Experimental results agree very well with the theoretical predictions [see Fig. (1)] and confirm the existence of over-critical plasma inside the sapphire that is essential for the resonance of plasma waves or excitation of surface plasmons.

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Electromagnetic emission via linear mode conversion mediated by stimulated Raman backscattering

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Linear mode conversion (LMC) in plasma is a process where the electrostatic and electromagnetic waves are converted into each other under certain conditions. Here we focus on the conversion Langmuir waves to electromagnetic waves, where the Langmuir waves are excited by stimulated Raman backscattering (SRBS) of incident lasers in underdense inhomogeneous plasma. The evolution of the wave vector of the Langmuir waves excited by SRBS is analyzed and the time when the wave vector approaches zero is estimated. Around this time, mode conversion from Langmuir waves to electromagnetic waves occurs. A series of particle-in-cell simulations has been carried out to confirm this. The effects of laser-plasma parameters on the conversion efficiency, including the laser intensity, the angle of incident laser, the laser pulse duration, the initial electrons temperature, and the plasma density scale length. As SRBS can be driven below the quarter critical density in inhomogeneous plasma, the corresponding Langmuir waves and the electromagnetic emission from the mode conversion can cover a frequency range from zero up to half of the incident laser frequency. This emission may provide a useful diagnosis of SRBS.

Superradiance from superluminal nonlinear plasma wakefields

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Bright tunable radiation has applications ranging from biomedical applications to fundamental processes of light-matter interaction. One of the experimental concepts that is most used today is the free-electron laser, an ultra-bright, frequency tunable synchrotron light source, that requires expensive and bulky hardware.

In this work, we propose a new superradiant radiation source using wakefield acceleration structures, driven by either ultra-short laser beams or highly energetic particle beams. In both cases the interaction with plasma leads to a highly nonlinear regime (called bubble/blowout regime), in which the plasma electrons are expelled from the axis, creating a nearly complete blowout. In such structures, radiation is typically produced by the betatron oscillations of electrons injected into the blowout bubble. However, the wakefield itself also radiates in the nonlinear regime: the back of this blowout bubble is characterized by an accumulation of relativistic electrons that can radiate well above the plasma frequency. A plasma density up-ramp forces the back of the bubble to travel superluminally. Even though individual electrons are subluminal, the collective motion at the back of the bubble is akin to a particle moving faster than c. The superluminal structure produces superradiant optical shock[1] at the Cherenkov angle.

We use the PIC code OSIRIS[2] and the Radiation Diagnostic for Osiris (RaDiO)[3] module to show that such superluminal structures lead to superradiant emission at the Cherenkov angle. First, we use 2D simulation data with a superluminal external field to showcase the method. Secondly, we use 3D simulations of both LWFA and PWFA that exhibit the desired behavior. We also describe the radiation spatiotemporally.

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Generation and control of internal-injected electron beams in plasma for cancer therapies

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The step-like plasma density profile produced by a shock wave is demonstrated to be promissing in the generation of very high-quality electron beam. This technology has been widely used in the application of Free Electron Lasers, where a 30 picocoulomb electron bunch with ~0.5% relative energy spread is required[1]. For the application of medical electron therapy for cancer one need a higher charge electron beam (~200 picocoulomb) in the range of 150-250MeV energy with low energy spread (<5% relative energy spread)[2]. In this research, the possibility to generate and control of such high-charge and high-quality beam with one-stage plasma accelrator is firstly explored. The relationship between shock profile and injected beam parameters are studied and it is understood that the beam charge and quality can be controlled and tailored by tuning shock position, shock height and the length of shock density downramps. An approximately 200 picocoulomb electron beam with over 200 MeV beam energy and less then 2% energy spread is shown to be able to obtained and applied to electron cancer therapies.

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High Frequency Incoherent and Coherent Radiation in SMILEI: application to XUV emission from electrons accelerated in surface waves

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Relativistic high-charge electron bunches can be produced by surface plasma waves (SPW) excited by ultra-high intensity fs lasers impinging on a solid-density target which strongly enhances the laser-plasma coupling. There is good evidence that SPW excitation survives in the ultra relativistic regime [1] and that the produced electron bunches experience strong acceleration, therefore emitting large amounts of electromagnetic radiation [2] with interesting characteristics (such as directionality, brightness, spectral range etc.).

In most numerical works performed with Particle-in-cell (PIC) codes, the treatment of radiation is either directly captured on the simulation grid (coherent radiation), or approximated by synchrotron emission or non-linear inverse Compton scattering (depending on the importance of quantum effects) for very high frequencies that can not be resolved on the simulation grid. In the later case, emission is usually assumed to be incoherent.

In this work, we propose the implementation of a diagnostic, based on the Lienard Wiechert potentials following the method of [3], complementing the pre-existing radiation modules in the open-source PIC code SMILEI [4, 5]. The implementation of this radiation treatment in SMILEI is not only interesting for the study of SPW excitation and electron acceleration in the ultra relativistic regime, but also for the investigation of betatron radiation and high harmonic generation among many others.

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Scanning the optical path of a tabletop vortex EUV beam

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The ability to control the properties of light beams has enabled the appearance of multiple technologies. In recent years the study of the manipulation of orbital angular momentum (OAM) of light has been an exciting topic of research. There are many promising applications in various fields using different light wavelengths from visible to x-rays, and even promising applications in plasma accelerators [1].

In the particular case of extreme ultraviolet (EUV) light, one of the most promising applications is the generation of skyrmionic defects which have been proposed for future magnetic memory devices [2]. Among the many different EUV sources available, high harmonic generation (HHG) in gases is an accessible, tabletop way to generate coherent EUV light with attosecond resolution.

In this work, we induced orbital angular momentum in a HHG EUV beam by using Spiral Zone Plates (SZP) [3] of different angular momentum - l. We scanned the beam near the focus of each one of the generated harmonics and recorded each beam profile with a lithium fluoride (LiF) crystal, a well characterized x-ray and EUV detector [4]. The different HHG wavelengths were spatially separated using a diffraction grid. As shown in Figure 1, we obtained high spatial resolution images of OAMs generated in the tabletop EUV source.

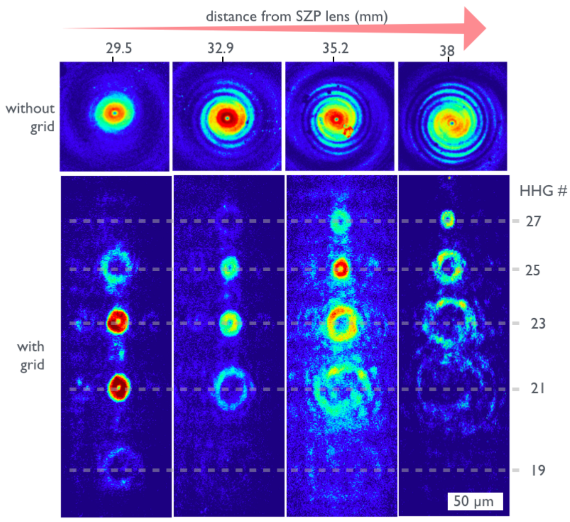

Figure 1: Photoluminescense images obtained on LiF of the EUV beam intensity distribution near the focus position of SZP with $l = 2$, without (*top*) and with (*bottom*) diffraction grid .

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Terahertz radiation emission from laser-induced plasmas inside dielectrics

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Electromagnetic radiation in the terahertz ($10^{11}-10^{13}$) frequency domain is particularly attractive for applications in remote sensing or in time-domain spectroscopy. The plasma is a promising medium to generate THz radiation. An ultrashort laser pulse can generate over-critical plasma inside dielectrics [1]. Here we show that the ponderomotive forces due to the intense resonantly driven fields at the critical surface are sufficient to create a large density difference between the ions and electrons which can lead to powerful THz radiation even at the moderate intensities that can be reached within the bulk of materials. The nonlinear current, in this case, can also lead to second-harmonic generation. In our experiments, a single 100 fs Bessel pulse at central wavelength 800 nm was focused inside transparent dielectrics at intensities of 10^{14} Wcm^{-2}, in conditions where over-critical plasma can be generated (diam. 200-500 nm). To reproduce the experiments, we performed simulations using the massively parallel EPOCH particle-in-cell (PIC) code [2].

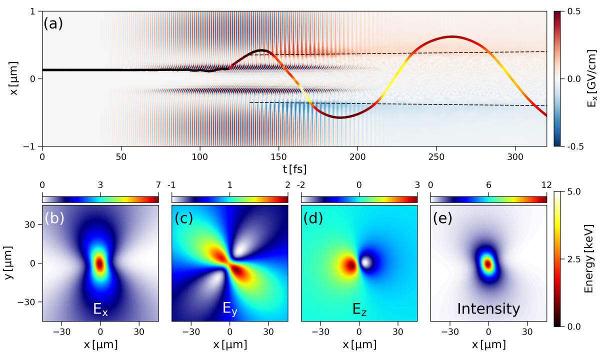

Figure 1: *Terahertz radiation from an electron trapped in the ambipolar electric fields.*

Figure 1(a) shows the time evolution of the E_x component, parallel to the plasma density gradient, and the trajectory of a representative electron. There are intense ambipolar fields due to the induced pressure difference between the electrons and ions (dashed lines). An ejected electron from the resonance region follows an arc trajectory in the ambipolar fields with a period of around 100 fs. During this motion, it radiates in the THz frequencies. Panels 1(b-e) show the electric fields and intensity radiated by the electron during the arc between 186-219 fs. The THz radiation is polarized in the x direction as the second-harmonic in the far-field. The emission pattern corresponds with an electron having acceleration mainly in the x direction and velocity in the z direction.

Using Bessel beams, it is possible to reach cm-scale over-critical plasmas inside solids which can be a promising candidate for generating THz radiation in the spectral range 1-30 THz.

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Decoupling of dust cloud and embedding plasma for high electron depletion in nanodusty plasmas

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Understanding how dust particles can grow in a reactive plasma discharge and change its behavior, is an interesting topic, since nanoparticles (nps) have become key technological products, e.g. as coatings with tunable optical gap in third generation solar cells, as nanocrystals for photonic applications, and as pharmaceutical nanocarriers.

We have been able, to characterize an argon discharge with embedded amorphous hydrocarbon nps of different size and density, using self excited dust density waves (DDW) as a diagnostic tool [1].

It is known from observations of spokes in Saturns rings [2] that electrons get captured on dust particles and can leave the plasma electron depleted. With comparably high dust density (high Havnes parameter *P*) such electron depletion in turn governs the charge of dust grains q_d, while the nps size has only a weak influence (fig. 1). The ion density and electric potential profile (fig. 2) are almost independent of both, dust size as well as dust density. This suggests, that the ion generation and the dust cloud coexist and the coupling of both is weak [3].

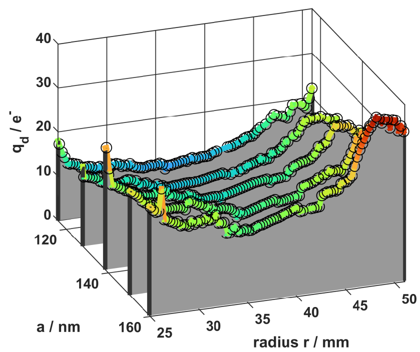

Figure 1: Grain charge q_d for sizes a of 117 nm to 158 nm is near constant compared to OML.

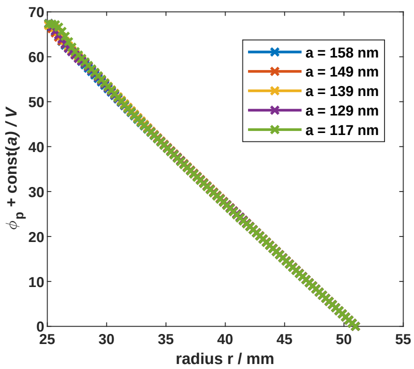

Figure 2: Plasma potential Φ_P is close to independent of the grain size.

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Acknowledgements

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Fractality and cumulative entropy of a magnetized plasma driven by fractional Brownian motion

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Shannon entropy of a probability distribution can be estimated directly by knowing the probabilities p_i of each state i. In the case of real time series, p_i can be derived from a binning of the possible values, a strategy that can give a bad estimate of S if the number of intervals is not properly chosen. To overcome this issue, Di Crescenzo *et al.* proposed an entropy based on the cumulative probability distribution (CDF), defined as

$$\mathrm{CE} = -\int F(x) \ln F(x)\, dx, \tag{1}$$

where $F(x)$ is the CDF of a random variable X. Recently [3], the fractality of a magnetohydrodynamic turbulence shell model has been studied. In particular, the GOY-type shell model described by the evolution equations for the velocity $u_n(t)$ and magnetic field $b_n(t)$ fluctuations corresponding to the eddy's scale of length $l \sim k_n^{-1}$. In Ref. [3], the forcing terms for the velocity and the magnetic field, f_n and g_n, were obtained from solar wind velocity and magnetic field data, representing the evolution of the Earth's magnetosphere under various levels of intermittency of solar wind forcing (as measured by its fractal dimension). Here, in order to systematically study this issue, the forcing is given by a fractional Brownian motion time series with various Hurst exponents. Thus, we investigate the possible correlations between the cumulative entropy of the dissipated magnetic energy time series and the fractal dimension of the forcing time series.

Acknowledgement

We thank the support of ANID, Chile, through FONDECYT Grant No. 1201967 (VM).

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Analyzing the solar activity using the horizontal visibility graph method

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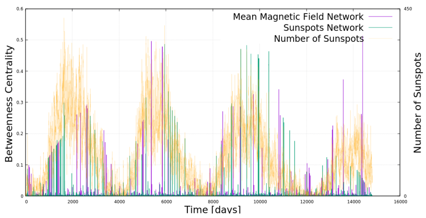
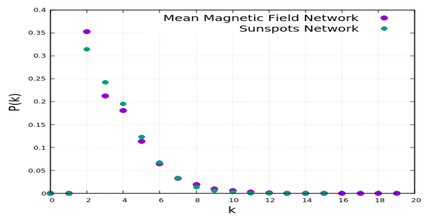
Various measures of complexity can provide relevant ways to study the complexity in the dynamics of magnetized plasma. In this case, the sun and its behavior will be studied through the use of complex networks. We take two time series associated with solar activity, namely total sunspot [1] and global mean magnetic field [2], taken from 1975 to 2015. Both time series will be analyzed through the Horizontal Visibility Graph (VG) technique [3]. Formally, given a series of data Y_N, it is said that each value of the time series correspond to a node, and two arbitrary nodes y_a and y_b "see" each other if for every node y_c the relation $y_a\,, y_b > y_c$ is satisfied. Then, once the HVG criteria is established, the method leads to a complex network, where the nodes correspond to the values of each time series. The HVG allows to study statistical properties of time series such as reversibility [4], and it has been successfully used to study a variety of physical systems [5]. Using this analysis, we observed a specific metric of the complex networks that is sensitive to the solar cycle, Betweenness Centrality (BC), which quantifies the frequency at which a node acts as a connecting bridge along the shortest path between any other two nodes. Furthermore, from the connections established within the networks, we also observed that they follow an exponential topology for their degree distribution, which is the fraction of nodes with k connections over the total amount of nodes, $P(k) = n_k/n$.



(a) Betweenness Centrality for both networks, it can be observed that the maxima of this metric match those of the solar cycle.



(b) Exponential topology for both degree distribution associated with the two time series employed.

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Solitary structures associated with parallel whistler field at magnetopause

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Abstract

In this study, we report the observations of solitary structures associated with whistler parallel field in magnetopause. The beam-driven whistler-mode dynamical equation has been put up with the expectation that it will expand from noise level due to beam energy to large amplitude and then localize due to nonlinear effects due to ponderomotive force. Thus, whistler waves will ultimately occur in a turbulent state. For this, the model contouring the dynamics of nonlinear interaction between the high-frequency whistler wave and low-frequency ion acoustic wave (IAW) dynamics in a magnetized plasma. The presence of IAW in the background is thought to be the source of whistler wave dynamics density perturbation. When the ponderomotive nonlinearities are included in the whistler dynamics, the model equations of whistler and IAW turn out to be a modified Zakharov system of equations. Numerical simulation has been carried out with the help of pseudospectral method and finite difference method to study the effect of nonlinear interaction between these waves which results in the formation of localized structures. The results of the numerical simulation show that the intense localized structure and power spectra are considered to be responsible for the heating and acceleration of plasma particles. The electric field power spectra exhibit the scaling $k^{-3/2}$ in the inertial range and $k^{-0.8}$ the dispersive range. The transverse scale size of the localized structure is of the order of electron inertial length.

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Kinetic models of solar wind current sheets

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Current sheets in the collisionless solar wind usually have kinetic spatial scales. In-situ measurements show that these current sheets are often approximately force-free, i.e. the directions of their current density and magnetic field are aligned, despite the fact that the plasma beta is found to be of the order of one. The measurements also often show systematic asymmetric spatial variations of the plasma density and temperature across the current sheets, whilst the plasma pressure is approximately uniform. Neukirch et al. (2020) found exact equilibrium models of force-free collisionless current sheets which allowed for asymmetric plasma density and temperature gradients. These models assumed that the form of the distribution function for electrons and ions is the same. In this contribution we generalise this approach to current sheets with static ions. As a consequence the force-free condition is only satisfied approximately and quasi-neutrality requires the presence of a nonvanishing electric potential.

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Alfvénic Transport in the Storm-time Magnetosphere

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In this presentation it is shown how measurements performed in Earth's magnetosphere during periods of disturbed space weather know as geomagnetic storms comprise a range of Alfvenic interactions with basic consequences for the near-Earth space environment. These interactions drive the formation of dynamic aurora and the modulation of energetic particle populations through this region of space. Here observations reported from a number of spacecraft are combined in a fluid-kinetic model to describe the energy transport and particle scattering/energisation evolution driven by these interactions. It is shown from simulations and a consideration of transport coefficients evaluated using the observations that these plasma processes are likely important drivers of the enigmatic evolution of this region of space during geomagnetic storms.