TORINO 2023
FUNDAMENTAL PLASMA PHYSICS

Book of Abstracts

Invited oral presentations

Wednesday 21 June

1

Overview of physics results from the deuterium-tritium DTE2 campaign on JET

Luca Garzotti on behalf of JET contributors* EUROfusion

At the end of 2021 the JET tokamak performed an experimental campaign denominated DTE2, operating plasmas with a 50-50 mixture of deuterium-tritium (D-T) for the first time since the previous D-T experiments in 1997 (DTE1). As a results of a series of upgrades, in DTE2 JET was equipped with a full beryllium/tungsten ITER-like wall, increased additional heating power and an expanded set of diagnostics with respect to the previous deuterium-tritium campaign.

DTE2 had several scientific objectives ranging from the development of plasma scenarios for high fusion performance to the study of specific plasma physics aspects underlying D-T operations. In particular, the campaign was focussed on the following points:

- Demonstrate fusion power in excess of 10 MW, sustained for 5 s,
- Demonstrate integrated radiative scenarios in plasma conditions relevant to ITER,
- Demonstrate clear alpha particle effects,
- Clarify isotope effects on energy and particle transport and explore consequences of mixed species plasma,
- Address key plasma-wall interaction issues,
- Demonstrate radio frequency (RF) schemes relevant to ITER D-T operation.

All the above aspects are interconnected and the high performance scenarios developed to maximize fusion power integrate the information and the results provided by different research areas.

In this paper we review the main physics results achieved in DTE2. In particular, we discuss the record plasma performance of 59 MJ of fusion power over 5 s, the new insights on particle and heat transport dependence on the isotopic composition of the plasma and alpha particle physics including their interaction with MHD activity. In addition, we put these results into perspective and discuss open issues and the needs for further fundamental research on the way to the realization of a burning plasma, which is the objective of the ITER experiment.

* See the author list of ‘Overview of JET results for optimising ITER operation’ by J. Mailloux et al. to be published in Nuclear Fusion Special issue: Overview and Summary Papers from the 28th Fusion Energy Conference (Nice, France, 10-15 May 2021)”

2

Laser plasma electron acceleration at ELI-Beamlines

G. M. Grittani
ELI Beamlines Facility, The Extreme Light Infrastructure ERIC, Dolni Brezany, 25241, Czech Republic.

The extremely high electric fields sustainable by a plasma make the Laser Wakefield Acceleration (LWFA) the most compact technique to generate very highly relativistic electron beams in the GeV regime. The limited repetition rate and low efficiency of this technology has, to date, prevented to unleash its full potential as a unique source for basic research, biomedical applications and high flux sources of secondary radiations as hard X-rays and Gamma-rays. In recent years a new direction emerged showing the possibility to accelerate electron beams at 1 kHz repetition rate. All these works are based on commercial lasers, requiring laser pulse compression to single cycle by fiber technology, having limits in terms of maximum available laser pulse energy and achievable electron beam energy.

Here I will show the generation of very collimated (2 mrad) relativistic quasi-monoenergetic electron beams accelerated to the highest energy (up to 50 MeV) ever reached up to date with a kHz laser. Said innovative results have been achieved in the new Laser Wakefield ALFA platform for user experiments developed at ELI-Beamlines. The driver for the accelerator is the in-house developed L1-Allegra 1 kHz multi-cycle (15 fs FWHM) laser system. The acceleration was driven by 1,7 TW pulses but, thanks to its modular OPCPA (Optical Parametric Chirped Pulse Amplification) design, the system is scalable to above 5 TW. On top of the experimental results, I will introduce both the laser system and the ALFA platform with available diagnostics.

The electron beams reported in this work are a step forward towards the development of in-demand high brilliance X-ray sources for medical imaging, high dose rate machines for radiotherapy based on high energy electrons, and to the future realization of a kHz 1 GeV electron beamline.

Moreover, I will present the recent developments on PW and multi-PW electron acceleration at ELI-Beamlines. These efforts are in the direction to enable nonlinear QED experiments (electron-laser collider) and GeV muon beam production.

3

Making a case for open-source codes: the example of the LisbOn KInetics tool

L.L. Alves - Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal

Software development and computational calculations are prominent research activities in low-temperature plasma science, but surprisingly the community has not been driven to define clear standards for the various steps of the workflow, including the publication of the codes used in computational calculations. Accessing the research software, as publicly available or open-source code, is not only desirable to ensure the quality standards of published material, but it can also accelerate and inspire advances in the scientific work, especially in a small community such as LTPs.

In this talk we will make a case for the development of open-source codes in LTPs [1], whenever possible, briefly reviewing the state-of-the-art of open-source and publicly available codes in the community; highlighting the benefits for research work, as well as the easier connection to data under FAIR principles; and proposing practical recommendations for code development. We will present as an example the roadmap defined in the development and the release of the LisbOn KInetics (LoKI) code [2], a simulation tool for plasma chemistry that couples a Boltzmann solver (LoKI-B) and a Chemical solver (LoKI-C). LoKI is currently under verification and should be released soon as open-source code.

[1] Alves, L.L. et al. 2023 “Foundations of Plasma Standards”, Plasma Sources Sci. Technol. 32 023001
[2] nprime.tecnico.ulisboa.pt/loki/

This work was supported by the Portuguese FCT -Fundação para a Ciência e a Tecnologia, under projects 2022.04128.PTDC, UIDB/50010/2020 and UIDP/50010/2020.

4

Magnetic and fluid instabilities effects on collisionless plasma turbulence

Daniela Grasso - Istituto dei Sistemi Complessi - CNR and Politecnico di Torino

The evolution of current and vorticity sheets is studied in the framework of collissionless turbulent plasmas, where magnetic and fluid instabilities coexist and play a role in determining their evolution. Thin current sheets may be prone to plasmoid or Kelvin-Helmholtz instabilities depending on the local values of the magnetic and velocity fields. The coexistence of these two instabilities not only influence how the current and vorticity sheets break, but also affect the energy cascade. In contrast to the resistive magnetohydrodynamic context, in collisionless plasmas the magnetic and kinetic spectra decouple.

5

Laser Plasma Physics for Fast Ignition

a. Kunioki Mima, b. Martin Matys, b. Sergei Bulanov, c. Naoki Higashi, a. Natsumi Iwata, a. Yasuhiko Sentoku, a. Hideo Nagatomo, a. Shinsuke Fujioka and a.Takayoshi Sano
a. Osaka University

Laser driven fast ignition consists of two processes. The first step is the compression of plasma and the second step is the heating of high density plasma. At ILE Osaka University, It is proposed to implode a solid density spherical DT fuel recently and it is investigated by simulation and experiments. The multiple spherical shocks concentrate at the center of the pellet to produce thousand times solid density plasma. On the other hand. the imploded plasma is heated by hole boring of intense laser pulse or by guiding high high energy electrons generated by B-field. In the magnetic guiding, It is found that the resistive heating by high return current plays important roles for the plasma heating with high energy electron injection. It is also proposed to guide ultra-intense laser pulse into over-dense plasma. When the ultra-relativistic laser pulse is injected into an over-dense plasma, it is converted into spiral pulse by the effects of deflection and self-generated magnetic field to propagate into the high plasma.

In this talk, the recent achievements at ILE Osaka University on the stable implosion of solid ball target, high energy electron magnetic guiding and the PIC simulations on the propagation of the heating laser pulse in over-dense plasma are reviewed.

6

Coherent structures from MHD to kinetic scales in solar wind turbulence at 0.17 and 1 au

O. Alexandrova (1), A. Vinogradov (1), A. Artemyev (2), P. Demoulin (1), M. Maksimovic (1), A. Mangeney (1), S. Bale (3)
(1) LESIA, Observatoire de Paris, Université PSL, CNRS, Sorbonne Université, Université Paris Cité, Meudon, France; (2) Institute of Geophysics and Planetary Physics, University of California, Los Angeles, USA; (3) Space Science Laboratory, Physics department, University of California, Berkeley, USA.

We study magnetic turbulence in the solar wind from MHD to kinetic plasma scales at 0.17 au, using Parker Solar Probe measurements during its first perihelion and using Cluster and Wind data at 1 au. One of the inherent properties of the turbulent cascade is intermittency which is due to coherent structures. Coherent structures are localized in space and characterised by high amplitudes of magnetic fluctuations. We show presence of embedded coherent structures from MHD down to kinetic scales. Statistical study at 0.17 au shows that Alfven vortices are dominant at all scales. Co-existance of magnetic vortices from MHD to sub-ion scales is shown here for the first time. Current sheets are rare. Further away from the Sun, at 1 au, magnetic holes appear in the slow wind streams, as well as magnetic solitons and shocks. In the fast wind, Alfven vortices are the dominant events as is observed closer to the Sun.

7

Towards a fundamental understanding of energy-efficient, plasma-based CO2 conversion

Omar Biondo(1,2), Gerard van Rooij(2,3), Annemie Bogaerts(1)
(1) Research Group PLASMANT, Department of Chemistry, University of Antwerp, Universiteitsplein 1, Wilrijk B-2610, Belgium (2) DIFFER, 5612AJ Eindhoven, The Netherlands (3) Faculty of Science and Engineering, Maastricht University, 6229 GS Maastricht, The Netherlands

Plasma-based CO2 conversion is worldwide gaining increasing interest. The aim of this work is to find potential pathways to improve the energy efficiency of plasma-based CO2 conversion beyond what is feasible in thermodynamic equilibrium. To do so, we use a combination of modeling and experiments to better understand the underlying mechanisms of CO2 conversion, ranging from non-thermal to thermal equilibrium conditions. Zero-dimensional (0D) chemical kinetics modelling, describing the detailed plasma chemistry, is developed to explore the vibrational kinetics of CO2, as the latter is known to play a crucial role in the energy efficient CO2 conversion [1,2]. The 0D model is successfully validated against pulsed CO2 glow discharge experiments [3], enabling the reconstruction of the complex dynamics underlying gas heating in a pure CO2 discharge, paving the way towards the study of gas heating in more complex gas mixtures, such as CO2 plasmas with high dissociation degrees. Since gas heating has a strong effect on vibrational excitation, this work represents a substantial step forward in the definition of the experimental conditions suitable for vibrationally-enhanced CO2 splitting in a plasma.

Energy-efficient, plasma-based CO2 conversion can also be obtained upon the addition of a reactive carbon bed in the post-discharge region [4,5]. The reaction between solid carbon and O2 to form CO allows to both reduce the separation costs and increase the selectivity towards CO, thus, increasing the energy efficiency of the overall conversion process. In this regard, a novel 0D model to infer the mechanism underlying the performance of the carbon bed over time is developed. The model outcome indicate that gas temperature and oxygen complexes formed at the surface of solid carbon play a fundamental and interdependent role. These findings open the way towards further optimization of the coupling between plasma and carbon bed, which proved very promising.

Experimentally, it has been demonstrated that “warm” plasmas (e.g. microwave or gliding arc plasmas) can yield very high energy efficiency for CO2 conversion, but typically only at reduced pressure [6]. For industrial application, it will be important to realize such good energy efficiency at atmospheric pressure as well. However, recent experiments illustrate that the microwave plasma at atmospheric pressure is too close to thermal conditions to achieve a high energy efficiency [7–9]. Hence, we use a comprehensive set of advanced diagnostics to characterize the plasma and the reactor performance, focusing on CO2 and CO2/CH4 microwave discharges. In particular, laser scattering is coupled with optical emission imaging to reconstruct the shape of the plasma and link it with the evolution of electron density and temperature, and gas temperature. The results lead to a deeper understanding of the mechanism of power concentration with increasing pressure, typical of plasmas in most gases, which is of great importance for model validation and understanding of reactor performance.

[1] A. Fridman, Plasma Chemistry, Cambridge: Cambridge University Press, 2008.
[2] T. Kozák, A. Bogaerts, Plasma Sources Sci. Technol. 23 (2014) 045004.
[3] B.L.M. Klarenaar, R. Engeln, D.C.M. van den Bekerom, M.C.M. van de Sanden, A.S. Morillo-Candas, O. Guaitella, Plasma Sources Sci. Technol. 26 (2017) 115008.
[4] P. Liu, X. Liu, J. Shen, Y. Yin, T. Yang, Q. Huang, D. Auerbach, A.W. Kleiyn, Plasma Sci. Technol. 21 (2019) 012001.
[5] H. Zhang, Q. Tan, Q. Huang, K. Wang, X. Tu, X. Zhao, C. Wu, J. Yan, X. Li, ACS Sustainable Chem. Eng. 10 (2022) 7712–7725.
[6] R. Snoeckx, A. Bogaerts, Chem. Soc. Rev. 46 (2017) 5805–5863.
[7] G.J. van Rooij, D.C.M. van den Bekerom, N. den Harder, T. Minea, G. Berden, W.A. Bongers, R. Engeln, M.F. Graswinckel, E. Zoethout, M.C.M. van de Sanden, Faraday Discuss. 183 (2015) 233–248.
[8] S. Heijkers, A. Bogaerts, J. Phys. Chem. C 121 (2017) 22644–22655.
[9] D.C.M. van den Bekerom, J.M.P. Lina

8

From kink instability to magnetic reconnection to oscillations in solar flares

Philippa Browning
Jodrell Bank Centre for Astrophysics, University of Manchester

Traditionally, ideal instabilities, reconnection and waves (or oscillations) are considered separately in plasma physics, but they interlink in many ways. Some connections which will be explored in this talk, focusing on solar flares and energy release in twisted magnetic flux ropes. Flares involve the release of stored magnetic energy in the solar corona through magnetic reconnection, leading to plasma heating and energetic particle acceleration. The ideal kink instability in a twisted magnetic flux rope generates many current sheets in its nonlinear phase, triggering magnetic reconnection which dissipates magnetic energy and accelerates particles. This has been modelled through a combination of 3D resistive magnetohydrodynamic simulations with test particles, which allows forward modelling of the observational signatures of this process in both thermal and non-thermal emission. Such energy release in twisted coronal loops produces oscillations in microwave emission, providing an explanation for the origin of Quasi Periodic Pulsations observed in flare emission. Furthermore, I will also show that magnetic reconnection arising due to the merger of two twisted magnetic flux ropes is oscillatory in nature, and this also leads to the generation of waves propagating away from the merger site.

9

Magnetic Nozzle: Plasma Acceleration and Detachment Scenario

Boris Breizman
Institute for Fusion Studies, The University of Texas at Austin, Austin, TX 78712

Some plasma propulsion concepts rely on a strong magnetic field to guide the plasma flow through the thruster nozzle, which raises the question of how the magnetically controlled plasma accelerates and detaches from the spacecraft. This talk will describe plasma acceleration under electron pressure and a magnetohydrodynamic detachment scenario in which the plasma stretches the magnetic field lines to infinity. A related theory demonstrates that the electrons detach from the plasma source in collisionless motion. They, therefore, expand adiabatically rather than isothermally. The adiabatic electrons cool down, which limits ion acceleration during plasma expansion. As plasma flows along the magnetic field lines, the originally subalfvénic flow becomes superalfvénic. This transition is like that in the solar wind. The ideal MHD equations have been solved analytically to model the plasma flow detachment from a slowly diverging nozzle. The solution exhibits a well-behaved transition from sub- to super- alfvénic flow inside the nozzle and a rarefaction wave at the edge of the outgoing flow. The envisioned detachment scenario has been tested in the Detachment Demonstration Experiment (DDEX) at NASA Marshall Space Flight Center.

10

Air-breathing electric propulsion and the BREATHE project

Tommaso Andreussi
Scuola Superiore Sant'Anna e Università di Pisa

Air-breathing Electric Rockets (AERs) can allow to lower the altitude of spacecraft operations below 400 km, in the Very Low Earth Orbits (VLEOs). Operations in VLEOs will give radical advantages in terms of payload performance, protection from radiations, and debris mitigation. Several AER realizations have been proposed, but the few end-to-end tests highlighted the need to improve the AER design and the representativeness of simulated atmospheric flows. The difficulty in recreating the VLEO environment on ground limits the data available to validate modelling efforts. This presentation will describe the status of R&D activities on AERs and introduce the BREATHE project. Funded by the European Research Council, BREATHE will focus on one hand, on the development of models and simulations to characterize atmospheric flows and low-temperature plasmas, on the other hand on the realization of a controlled environment to characterize technological solutions for an AER-based CubeSat platform.

11

Collective Dynamics in dusty plasma and dust particle clusters

Amita Das, Priya Deshwal, Mamta Yadav, and Srimanta Maity
IIT Delhi

Dusty plasma comprises electrons, ions, and heavier micron-sized dust particles which acquire very large negative charges. The large size, high charge and mass of the dust particles compared to electrons and ions ensures that the response time of the dust particles is considerably slow and its motion can be easily tracked with the naked eye. It is in fact a unique medium wherein simplicity of interactions at microscales leading to complex macro-scale phenomena can be observed with simple diagnostic tools. Furthermore, dusty plasma can be easily prepared (at room temperature and normal densities) to be in a strongly coupled state. Thus, when the physics community is grappling for a suitable description for a strongly coupled state of matter, dusty plasma offers a suitable test medium for such studies. In this talk, complex dynamical properties of small and medium-sized dust clusters observed with the help of Molecular Dynamics simulations will be presented. I would also talk about certain fluid instabilities, and the role of strong coupling on them, in the context of dusty plasma medium.

12

Simulations of turbulence and reconnection with a 2-field gyrofluid model

T. Passot, P.L. Sulem, E Tassi, D. Laveder, S. Cerri, C. Granier, G. Miloshevich*
Université Côte d’Azur, Observatoire de la Côte d’Azur
*** Laboratoire des Sciences du Climat et de l’Environnement, CEA-CNRS-UVSQ, IPSL & U Paris-Saclay**

This talk aims at presenting a short review of recent simulation results performed with a two-field Hamiltonian gyrofluid model retaining ion finite Larmor radius corrections, parallel magnetic field fluctuations and electron inertia [1,2]. This model describes the quasi-perpendicular dynamics of Alfvén and kinetic Alfvén waves and is suitable for studies of collisionless reconnection, the collisional regime being easily recovered when diffusive terms are added.

We shall first present 3D simulations of Alfvenic turbulent cascades, from the MHD to the sub-ion scales [3], focusing on the case of large imbalance between co- and contra-propagating waves. In addition to the energy, this model has another invariant, referred to as generalized cross-helicity (GCH), which identifies with the cross-helicity at the MHD scales and with the magnetic helicity at the sub-ion scales. Cross-helicity cascades to small scales and magnetic helicity to large scales [4], resulting in the presence of a “helicity barrier” at the ion scale, discussed in Meyrand et al. (J. Plasma Phys. 87, 535870301, 2021) in the case of strong magnetic fluctuations. Our simulations in the weak amplitude regime, show a significant decay of the perpendicular GCH flux past the ion scale, confirming the presence of a GCH barrier, and a steep spectral transition zone near the ion scale (as commonly observed in the solar wind). In contrast with the case of strong magnetic fluctuations, dissipation in the parallel direction remains weak. A phenomenological model suggests that the interactions between co-propagating waves present at the sub-ion scales can play a central role in the development of the transition zone in the presence of a helicity barrier at small amplitudes.

The strength of co- versus contra- propagating wave interactions is investigated in more detail in simulations of colliding wave packets. The setup of these simulations with varying degree of nonlinearity is convenient to investigate in 3D the existence of reconnection mediated ranges [5].

We shall finally present two-dimensional simulations of collisionless reconnection, with a varying ratio τ of ion to electron temperatures. When τ is large enough, turbulence develops at scales smaller than the electron skin depth and invades the domain outside the magnetic islands, with a magnetic energy spectrum exponent close to -11/3.

[1] Passot, T., Sulem, P.L. & Tassi, E. 2018 Gyrofluid modeling and phenomenology of low-β_e Alfvén wave turbulence, Phys. Plasmas 25, 042107.

[2] Passot, T. & Sulem, P.L. 2019 Imbalanced kinetic Alfvén wave turbulence: from weak turbulence theory to nonlinear diffusion models for the strong regime, J. Plasma Phys. 85, 905850301.

[3] Passot, T., Sulem, P.L. & Laveder, L. 2022 Direct kinetic Alfvén wave energy cascade in the presence of imbalance, J. Plasma Phys. 88, 905880312.

[4] Miloshevich, G., Laveder, D., Passot, T. & Sulem, P.L. 2021 Inverse cascade and magnetic vortices in kinetic Alfvén-wave turbulence, J. Plasma Phys. 87, 905870201.

[5] Cerri, SS., Passot, T., Laveder, D., Sulem, P.-L. & Kunz, M. W. 2022 Turbulent Regimes in Collisions of 3D Alfvén-wave Packets, Astrophys. J. 939, 36.

13

Evolution of space plasma turbulence in the inner heliosphere

Raffaele Marino (1), Raffaello Foldes (1), Emmanuel Lévêque (1), Daniele Telloni (2), Luca Sorriso-Valvo (3,4,5), Roberto Bruno (6), Raffaella D'Amicis (6)
1) Université de Lyon, CNRS, École Centrale de Lyon, INSA Lyon, Université Claude Bernard Lyon 1, Laboratoire de Mécanique des Fluides et d'Acoustique, France
2) National Institute for Astrophysics (INAF) – Astrophysical Observatory of Torino, Pino Torinese, Italy
3) Swedish Institute of Space Physics (IRF), Ångström Laboratory, Uppsala, Sweden
4) CNR, Istituto per la Scienza e la Tecnologia dei Plasmi, Bari, Italy
5) Space and Plasma Physics, School of Electrical Engineering and Computer Science, KTH Royal Institute of Technology, Stockholm, Sweden
6) National Institute for Astrophysics (INAF) – Institute for Space Astrophysics and Planetology (IAPS), Rome, Italy

The solar wind is a natural plasma in a highly turbulent state whose dynamics are driven by large-scale structures and motions of the Sun's corona as well as by local phenomena developing in the heliosphere, also in the proximity of the solar system planets. Features of turbulence in the solar wind do change as this space plasma expands from the solar corona. In order to characterize the evolution of solar wind turbulence in the inner heliosphere we analyzed dataset from past and ongoing space missions, complementing results stemming from observations with the output of direct numerical simulations of magnetohydrodynamic plasmas. In particular, we investigated turbulent cascades and spectral energy distributions in the solar wind by assessing second- and third-order statistics in the following frameworks: extended solar wind streams observed by the spacecraft Ulysses during periods of low solar activity (up to 4.5 au), at high heliolatitudes; solar wind samples originating from the same coronal hole, observed by Helios II at different distances from the Sun (from 0.3 to 0.9 au) in the ecliptic plane; and solar wind plasma parcels observed by Parker Solar Probe and Solar Orbiter (at 0.1 and 1 au, respectively) during the first radial alignment of these spacecraft. Our analysis provides an overall (though not exhaustive) picture of the evolution of main solar wind turbulent parameters in the inner heliosphere.

14

Beam-plasma interactions for particle acceleration and basic studies at AWAKE

Patric Muggli, AWAKE Collaboration
Max Planck Institute for Physics

When a relativistic, charged particle bunch travels in plasma it is subject to a number of instabilities depending on the parameters of the system. In the AWAKE experiments we seed the self-modulation of the 400GeV proton bunch to drive wakefields with large amplitudes (~1GV/m). We plan on externally injecting and accelerate electrons to high energies (~200GeV) for applications to particle physics. We measured many of the parameters of this instability. In particular, measurements with plasmas with different ion species suggest that plasma ion motion could play a role development of the instability. In addition, we observe the hose instability, an instability that could limit or prevent the acceleration of a particle with quality sufficient for applications. We also study the current filamentation instability, a relativistic version of the Weibel instability, as one of the mechanisms that could be at the origin of magnetic fields in the universe.

I will introduce the AWAKE experiment. I will show sample experimental results about the three instabilities, and I will describe plans for developing the self-modulated plasma wakefield accelerator scheme into a tool for particle physics.

Thursday 22 June

15

Multi-harmonic Rutherford island theory

Richard FITZPATRICK - Institute of Fusion Studies, University of Texas at Austin

Rutherford island theory, which governs the nonlinear evolution of tearing modes in tokamak plasmas, is generalized to take into account situations in which the conventional one-harmonic approximation is not valid. The analysis incorporates non-inductive currents driven by radio frequency (RF) electromagnetic waves injected into the plasma. A multi-harmonic tearing mode dispersion relation is derived that takes the form of a nonlinear inhomogeneous matrix eigenvalue problem. The dispersion relation is solved in the so-called two-harmonic approximation, in which only the principal Fourier harmonic of the perturbed magnetic flux and its first overtone are included in the calculation. In the absence of RF current drive, the nonlinear behavior of a tearing mode predicted in the two-harmonic approximation does not differ substantially from that predicted in the one-harmonic approximation. On the other hand, RF current drive that is sufficiently localized in the vicinity of the O-points of the mode's magnetic island chain is capable of triggering bifurcations of the O-points (which is impossible in the one-harmonic approximation). However, the current drive is incapable of triggering bifurcations of the island X-points. This finding is significant because Bardoczi and Evans [Phys. Rev. Lett. 126, 085003 (2021)] recently observed bifurcations of magnetic island chain O-points in the presence of RF current drive in the DIII-D tokamak but did not observe bifurcations of the X-points. Finally, the changes in the topology of the magnetic island flux-surfaces induced by RF current drive are found to facilitate the stabilization of the tearing mode.

16

High-Field Physics Related to LWFA on Dual-Beam Ultrafast High-Power Lasers

Wenchao Yan
Key Laboratory for Laser Plasmas (Ministry of Education), School of Physics and Astronomy, Shanghai Jiao Tong University, Shanghai 200240, China
Collaborative Innovation Center of IFSA (CICIFSA), Shanghai Jiao Tong University, Shanghai 200240, China

Electron–photon scattering is one of the most fundamental mechanisms in electrodynamics, underlying laboratory and astrophysical sources of high-energy X-rays. After a century of studies, it is only recently that sufficiently high electromagnetic field strengths have been available to experimentally study the nonlinear regime of the scattering in the laboratory. This can act as a new generation of accelerator-based hard X/γ-ray sources driven exclusively by laser light. One ultrahigh intense CPA laser pulses will act as two means: first used to accelerate electrons by laser driven wake field (LWFA) to hundreds MeV, and second, from split beam or LWFA-leftover energy reflected by plasma mirror, to collide on the electron for the generation of X/γ-rays. Such all-laser-driven X/γ source have recently been demonstrated to be energetic, tunable, narrow/broad in bandwidth, short pulsed and well collimated. Such characteristics, especially from a compact source, are highly advantageous for numerous advanced X-ray applications. Moreover, the scattering interaction can act a test bed for high-field QED study. Also, preliminary plan of laser wake-field accelerator and radiation source in two high-power laser facilities, 0.5PW in SJTU and 2.5PW in TDLI will be presented, both of the lasers include two independently compressed two beamlines.

17

Two-fluid solutions for Langmuir probes in collisionless and isothermal plasma, over all space and bias potential

Ph. Guittienne, A.A. Howling, I. Furno - Swiss Plasma Center Ecole Polytechnique Fédérale de Lausanne

Solving the fluid equations using the Lambert function allows the collisionless and isothermal plasma sheath problem to be reduced to the sole integration of Poisson's equation. This is achieved without the introduction of the usual approximations of negligible electron inertia and cold ions. In a 1D Cartesian geometry, the solution provides an analytical expression for Langmuir probe characteristics at any bias potentials. In cylindrical geometry, the model leads to semi-analytical solutions, such that iterative numerical integrations of Poisson's equation still have to be performed to determine the probe characteristics. The cylindrical solution predicts that the ion/electron currents do not saturate at large negative/positive probe bias, in contrast to the 1D Cartesian solution, and as expected from experiments. Many interesting results and questions arise from this exact solution, notably concerning the relevance of the Bohm criterion in radial geometries, and the value of the adsorbed flux density at the probe for repelled species, which is found to differ from the conventionally stated kinetic flux.

18

New approaches to connecting fluid and kinetic models based on implicit time discretization and machine learning

Giovanni LAPENTA - KULeuven, Department Wiskunde Celestijnenlaan – Leuven (Belgium)

We present a method that tries to overcome the dichotomy between particle-based (kinetic) and moment-based (fluid) approaches to plasma modelling. The two approaches, continuum and kinetic are usually considered as alternatives to one another. But this needs not be. Indeed, explicit PIC is radically alterative to fluid continuum methods because it treats all microscopic scales and cannot reach the large macroscopic scales. However, there is no fundamental reason why the kinetic approach cannot be used at large scales: we discuss here a kinetic algorithm that allow the user to select the range of scales resolved: the implicit particle in cell model.

If explicit PIC needs to resolve all small scales and the largest scale is determined simply by the available memory and computing speed, implicit PIC allows the user to select the maximum and minimum scale desired. The implicit PIC does not need to resolve all small scales. If the small scales are not resolved in explicit PIC, the method becomes numerically unstable and energy or momentum or both increase exponentially, loosing physical fidelity. Not so in implicit methods. If one is not interested in resolving some small scales, they can be ignored and the method remains stable, simply the scales captured are only those in the range considered. Of course, the smaller and larger scales not resolved are not part of the story. This is exactly what we need to bridge the gap between fluid models and kinetic models.

But implicit kinetic methods do not merely replace fluid models: they can be the key to augmenting fluid models with the information they miss. Fluid models reduce the 6D of phase space using 3D moments. There are infinite moments and in practice fluid models need to truncate their number at a manageable level. But what if we give the fluid methods artificial intelligence tools that can reconstruct the original 6D state looking at the 3D projection? We can train ML tools using implicit PIC simulations to supplement fluid models.

19

Highly Electronegative Plasmas Formed in a Negative Ion Source for NBI

**K. Tsumori1,2, H. Nakano1,3, S. Geng4, E. Rattanawongnara2, K. Ikeda1, Y. Takeiri1,
N. Nagaoka1,3, and M. Osakabe1,2.**
1 National Institute for Fusion Science, 322-1 Toki Oroshi Gifu 509-5292, Japan.
**2 The Graduate University for Advanced Studies, SOKENDAI, Shonan Village, Hayama,
Kanagawa 240-0193, Japan.**
3 Nagoya University, Furo-cho, Chikusa-ku, Nagoya, 464-8601, Japan.
4 Southwestern Institute of Physics, No. 5, Huangjing Road, Chengdu 610225, P. R. China.

Formation and Characteristics of highly electronegative plasma in a negative ion source are described. By introducing caesium vapour in the ion-source plasma, density of hydrogen negative ions (H-) increases gradually in the beam extraction region of the source. Electron density in the region decreases according to the increase of H- density and the plasma is finally formed mainly with hydrogen positive and H- ions. Electrons diffuse from plasma generation region through two different magnetic field, so-called filter magnetic and electron deflection magnetic fields, to the beam extraction region, and are reduced their density and energy due to collisions with charged particles and neutrals. In the NBI Test Stand (NBTS) at the National Institute for Fusion Science (NIFS), several diagnostic modules are installed to measure the characteristics of ion-source plasma and beam accelerated from the source in both situations with and without beam acceleration. Langmuir probe measurement made clear the distribution of the plasma potential that the highly electronegative plasma shows different response to applied electrostatic field from usual electron-positive ion plasmas, which plasma sheaths are formed with electron. Distribution of the H- ions were measured with a Cavity Ring-Down (CRD) method, and it was found that the H- ions emitted from the surface have flat distribution.

In this talk, we are going to present our experimental results such as H- temperature, H- flow map, which are measured with a directional photodetachment Langmuir probe, CRD and extracted H- density distribution measured with H⍰ CCD camera.

20

New Developments in Shock Acceleration Simulations and Theory

Damiano Caprioli
University of Chicago

I present some recent developments in the theory of shock acceleration that stemmed out of kinetic simulations. In particular, I discuss a novel channel of rapid acceleration at oblique, weakly magnetized shocks and the dynamical back-reaction of accelerated particles and self-amplified magnetic fields on the shock dynamics.

21

Gamma Ray Flash Generation in the Extreme Power Laser-Matter Interaction

S. V. Bulanov
ELI Beamlines Facility, The Extreme Light Infrastructure ERIC, Za Radnicí 835, Dolní Břežany 25241, Czech Republic

A theoretical study is made of the main regimes of interaction of relativistically strong electromagnetic waves with near critical density plasma under conditions in which the radiation from particles plays a dominant role. The discussion is focused on the electromagnetic wave dynamics in the case of the transverse and longitudinal mode nonlinear coupling. The radiation friction effects implemented into the theoretical model result in extremely fast, on the scale of few oscillation periods, decay of the wave with substantially high intensity. The consequences of the electromagnetic wave decay for the gamma-ray flash generation in laser-matter interaction are also discussed.

22

E-FISH: A Diagnostic for Spatially and Temporally Resolved E-Field Characterization in Low Temperature Plasma Discharges

Lorenzo Ibba
SPC – EPFL

Plasma-based biomedical applications have gained significant attention in recent years, with the characterization of plasma parameters being essential to understand the interaction between the biological target and the plasma. In direct plasma treatments, where the target is either inside or in contact with the plasma, the electric field (E-Field) controlled by the plasma dynamics plays a significant role. However, the E-Field is not uniform inside the plasma and is dependent on the experimental setup circuit, which changes depending on the application. Moreover, the biological target itself becomes part of the circuit, influencing the voltage waveform, plasma, and E-Field. The E-Field Induced Second Harmonic (E-FISH) generation is a diagnostic tool that enables in situ measurement of the E-Field with high spatial and temporal resolution. E-FISH offers multiple advantages compared to other commonly used techniques such as OES and E-Field probes. Specifically, E-FISH is a non-invasive approach that is easy to calibrate, not dependent on plasma emission, and provides spatially and temporally resolved measurements. Measurements of E-FISH in a nanosecond pulsed VDBD plasma discharge in humid air at atmospheric pressure will be discussed, explaining the characteristic processes of the ionization wave in air. Our results demonstrate the potential of E-FISH in characterizing the E-Field and understanding its role in the plasma interaction process, opening up new avenues for plasma-based biomedical applications.

23

Hydrodynamic Shock Modifications by the Heat Flux of Non-Thermal Particles

Colby C. Haggerty,1 Damiano Caprioli,2 Paul Cassak,3 M. Hasan Barbhuiya,3 Lynn Wilson III,4 and Drew Turner5
1: Institute for Astronomy, University of Hawaii, Manoa, 2680 Woodlawn Dr., Honolulu, HI 96822, USA
2: Department of Astronomy and Astrophysics, University of Chicago, 5640 S Ellis Ave, Chicago, IL 60637, USA
3: Department of Physics and Astronomy and the Center for KINETIC Plasma Physics, West Virginia University, Morgantown, West Virginia 26506, USA
4: NASA Goddard Space Flight Center, Heliophysics Science Division, Greenbelt, MD, USA
5: Johns Hopkins University Applied Physics Laboratory: Laurel, MD, USA

Collisionless plasma shocks are a common feature of many space and astrophysical systems and are sources of high-energy particles and non-thermal emission, channeling as much as 20% of the shock's energy into non-thermal particles. The generation and acceleration of these non-thermal particles have been extensively studied, however, how these particles feedback on the shock hydrodynamics has yet to be fully treated. This work presents the results of self-consistent, hybrid particle-in-cell simulations that show the effect of self-generated non-thermal particle populations on the nature of collisionless, quasi-parallel shocks, which contribute to a significant heat flux upstream of the shock. Non-thermal particles downstream of the shock leak into the upstream region, taking energy away from the shock. This increases the compression ratio, slows the shock, and flattens the non-thermal population's spectral index for lower Mach number shocks. We incorporate this into a revised theory for the jump conditions that include this effect and show excellent agreement with simulations. The results have the potential to explain discrepancies between predictions and observations in a wide range of systems, such as inaccuracies of the predicted arrival times of coronal mass ejections and the conflicting radio and x-ray observations of intracluster shocks. These effects will likely need to be included in fluid modeling to predict shock evolution accurately.

24

REGARDING THE GENERAL METRIPLECTIC FORMALISM FOR DESCRIBING DISSIPATION AND ITS COMPUTATIONAL USES

Philipp Morrison
The University of Texas at Austin.

Although an early generalization of Lagrangian mechanics to include dissipation was proposed by Rayleigh (1894) and subsequently various specific frameworks for dissipation have been given, e.g., for phase separation in Cahn-Hilliard (1958) and Ricci flows in Hamilton (1982), here we discuss bracket descriptions for dissipation that were motivated by the noncanonical Poisson bracket formulation of fluid and plasma models presented in e.g. [1–3]. Here the motivation was to place dissipation in a kind of bracket formalism that complements the nondissipative Poisson bracket formalism. First attempts were given in [3-7]. The axioms of the formalism presented in [6,7] were later in [8] called metriplectic dynamics. Subsequent aspects of metriplectic dynamics were described by the author and co-workers in [9-11].

The vector fields of metriplectic dynamical systems have the form $\{z, F\} + (z, F)$, where z represents the dynamical variable and $F = H + S$ is a free energy functional, composed of an energy H plus entropy S (a Lyapunov functional), that generates the dynamics. Here $\{\,,\}$ is a Poisson bracket while $(,)$ is a symmetric bilinear product on phase space functions that generates dissipative terms of the dynamical system. Because Casimir invariants are candidate entropies, $\{A,S\} = 0$ for all functionals A; similarly, $(A,H) = 0$ for all functionals A. These assumptions together with $(S, S) > 0$ guarantee that the first and second laws of thermodynamics are satisfied for a dynamical system.

Just as symplectic integrators preserve canonical Hamiltonian structure, with some advantages, there have been recent efforts to preserve non- canonical Hamiltonian structure (see e.g. [12,13]) and even metriplectic structure [14]. Our recent efforts are in [15,16]. Another kind of dissipative dynamics, double bracket dynamics, was proposed in [17,18]. Here energy serves as a Lyapunov function with all Casimir invariants being con- served. This formalism was proposed as a method for computation of equilibrium states, that was generalized and elevated to a practical method for fluid systems in [19,20] and plasma equilibria in [21-23].

To summarize, in this talk I will talk about general dissipative structures and their use for designing computational algorithms.

REFERENCES

[1] P.J.MorrisonandJ.M.Greene,Phys.Rev.Lett.,vol.45,pp.790,1980.
[2] P.J.Morrison,AIPConf.Proc.,vol.88,13,1982.
[3] P.J.MorrisonandR.D.Hazeltine,Phys.Fluids,vol.27,886,1984.
[4] A.N.KaufmanandP.J.Morrison,Phys.Lett.A,vol.88,405,1982.
[5] A.N.Kaufman,Phys.Lett.A,vol.100,419,1984.
[6] P.J.Morrison,Phys.Lett.A,vol.100,423,1984.
[7] P.J.Morrison,Tech.Rep.PAM–228,UniversityofCaliforniaatBerkeley,1984.
[8] P.J.Morrison,PhysicaD,vol.18,410,1986.
[9] P. J. Morrison, J. Physics: Conf. Ser., vol. 169, 012006, 2009.
[10] M.MaterassiandP.J.Morrison,J.CyberneticsandPhysics,vol.7,78,2015.
[11] B.CoquinotandP.J.Morrison,J.PlasmaPhys.,vol.86,835860302,2020.
[12] P.J.Morrison,Phys.Plasmas24,vol.055502,2017.
[13] B.Jayawardana,P.J.Morrison,andT.Ohsawa,J.Geom.Mech.,vol.14,635,2022.
[14] M.KrausandE.Hirvijok,Phys.Plasmas24,vol.102311,2017.
[15] C. Bressan, M. Kraus, P. J. Morrison, and O. Maj, J. Phys.: Conf. Series, vol. 1125, 012002, 2018.
[16] C. Bressan, Metriplectic Relaxation for Calculating Equilibria: Theory and Structure-Preserving Discretization, Ph.D. thesis, Technical University of Munich, Garching, Germany, 2023.
[17] R.W.Brockett,Proc.IEEE,vol.27,799,1988.
[18] G.K.Vallis,G.Carnevale,andW.R.Young,J.FluidMech.,vol.207,133,1989.
[19] G.R.FlierlandP.J.Morrison,PhysicaD240,vol.212,2011.
[20] G.R.Flierl,P.J.Morrison,andR.V.Swaminathan,Fluids,vol.4,104,2019.
[21] M.FurukawaandP.J.Morrison,PlasmaPhys.Control.Fusion,vol.59,054001,2017.
[22] M.Furukawa,T.Watanabe,P.J.Morrison,andK.Ichiguchi,Phys.Plasmas,vol.25,082506,2018.
[23] M.FurukawaandP.J.Morrison,Phys.Plasmas,vol.29,102504,2022.

25

Observation of fusion-born alpha particles in Joint European Torus

Vasili Kiptily and JET contributors
See the author list of ‘Overview of JET results for optimising ITER operation’ by J. Mailloux et al 2022 Nucl. Fusion 62 042026

The fusion-born alpha-particle heating in magnetically confined fusion machines is a high priority subject for study. A comprehensive set of diagnostics for both confined and lost α-particles was employed for studying their behaviour in D-3He, D-T and T-plasmas. To make such measurements at the high neutron and γ-ray fluxes in D-T experiments we used the enhanced neutron/γ-ray spectrometers, 2D neutron/γ-ray camera, two fast ion loss detectors – a scintillator probe with energy and pitch-angle resolution and an array of the lost α-particle collectors with poloidal, radial and an energy resolution. JET with Be-wall and W-divertor, improved energetic-particle diagnostic capabilities and enhanced auxiliary heating systems producing significant population of α-particles provided a great opportunity to study the α-particle behaviour giving a stepladder approach for modelling and extrapolating to ITER and burning plasma machines. In the talk the JET capabilities for measurements of α-particles are shown and selected results of the fast-ion and fusion -particle measurements in D-3He, D-T and T-plasmas are highlighted.

The D-3He, T-T and D-T α-particle losses have been observed in hybrid and baseline scenarios as well as in a novel heating scheme – 3-ion ICRF heating of Be-impurity (could be used in ITER). It was found that α-particles losses related to MHD instabilities are correlated with fishbones and long-lasting modes in both the baseline and the hybrid scenario discharges. In the baseline scenario, significant changes in -particle losses were observed to be associated with L–H confinement transitions in the plasma. Anomalous D-T α-particle losses have been observed in the 3-ion ICRF heating of Be-impurity.

One of the important results – the first direct evidence of α-particle heating obtained in the high-performance NBI afterglow discharges will be presented. It was found that D-T α-particles continue transferring their kinetic energy to plasma electrons during slowing-down after the NBI power cut. The transport modelling of the relevant D-T and reference deuterium discharges is consistent with the alpha-particle heating observation.

In conclusion, importance of the JET α-particle observations for future fusion reactors will be highlighted.

26

Low-temperature plasma technology for Cultural Heritage safeguard

S. Grassini, E. Angelini
Dipartimento di Scienza Applicata e Tecnologia (DISAT) - Politecnico di Torino

The preservation of tangible Cultural Heritage is of outstanding importance for safeguarding this fascinating witness of the mankind art and creativity. In the case of metallic artefacts, curators and restorers always face the never-ending problem of corrosion of artefacts of archaeological and historic interest. They have to choose the correct strategy both for cleaning the artefacts and stopping or slowing down the surface degradation phenomena in order to avoid further damages.

Taking into account that the restoration procedures have to be non-destructive, reversible, as well as preservers of the aesthetic appearance of the artefact, low-temperature plasmas, the so-called cold plasmas, exhibit some major advantages that suit perfectly their application in Cultural Heritage field. They can be applied directly on the exterior or the interior of complex shapes; plasma etching can be controllable and selective at nanoscale; plasma deposition can produce very thin coatings with customizable structure with a minimal effect on the appearance of the surface, and very good corrosion protection characteristics.

The Plasma Enhanced Chemical Vapour Deposition (PECVD) technique, due to its possibility of depositing a wide variety of void-free, well-adherent thin films (10-1000 nm) has been chosen for the treatment of the artefacts made of iron, copper and silver-based alloys. The PECVD deposition has been carried out using silicon containing organic compounds, as hexamethyldisiloxane (HMDS) or tetraethoxysilane (TEOS) , thus obtaining SiO2-like thin films that definitely improve the corrosion resistance of metallic artefacts in the environment.

Some applications will be presented on metallic artefacts of different ages and different provenance: bronze artefacts from Ayanis fortress of the Urartian Kingdom, Lake of Van, Turkey, 600 B.C.; copper and silver coins of the Phoenician-Punic and Roman Age, 200 A.D.; iron nails of medioeval age, Piedmont, Italy, 1500 A.D..

Friday 23 June

27

Nanosecond pulsed plasma: kinetics and applications

Svetlana Starikovskaia
Laboratory for Plasma Physics, Ecole Polytechnique, Palaiseau, France

Recent progress in solid-state high power electronics is a reason for increased interest to nanosecond discharges. Modern companies suggest compact and reliable high voltage nanosecond generators allowing operation both in laboratories and in the extreme conditions of industrial applications. High-voltage pulses 5-50 kV in amplitude and a few tens of nanoseconds in duration are capable to produce highly nonequilibrium low temperature plasma in a wide pressure range, from mbar to tens of bar. The fact that nanosecond discharges are uniform at low and moderate gas densities, and are naturally synchronized within 0.1 ns in time in the case of a multi-streamer configuration at high gas densities, is extremely attractive for laboratory-scale research. Depending on the specific purpose of the experiment, it is sometimes possible to choose a discharge geometry in which the specific input energy is a predetermined quantity. In other cases, it is necessary to take into account the self-organization of the discharge under given experimental conditions and the change in plasma parameters. A brief review of plasma parameters in nanosecond discharges, from fast ionization waves (FIWs) at low pressure to filamentary nanosecond surface dielectric barrier discharges (nSDBDs) at tens of bars will be given. Possible modifications of discharge leading to high specific energy deposited to plasma (SED) will be discussed. Consequences of developed chemistry of excited species for plasma diagnostics and necessary precautions when treating the data will be presented. Potential applications will be discussed.

28

Streaming instabilities in Yang Mills system

V Ravishankar*, Subramanya Bhat*, Bhooshan Paradkar, Amita Das***
***Department of Physics, IIT Delhi, New Delhi, 110016, India ** Centre of excellence in basic sciences, University of Mumbai, Mumbai, 400098, India**

As a natural generalisation of Electrodynamics, Yang Mills dynamics is governed by non abelian gauge covariance. As a consequence, the field equations become non linear -- leading to new and rich physics. As an example, in this talk, the streaming instabilities associated with the color dynamics of Yang Mills system will be presented. In particular, the emergence of an additional unstable mode entirely dependent on color fields will be shown.

29

On the physics and modelling of the interaction between RF waves and resonating ions in tokamaks

Lars-Göran Eriksson (1) and Thomas Jonsson (2) - (1) Chalmers University of Technology, Gothenburg, Sweden (2) Royal Institute of Technology, Stocholm. Sweden

The presentation reviews key physics aspects of the interaction and between RF waves and resonant ions in a tokamak, especially Ion Cyclotron Resonance Frequency (ICRF) Heating (ICRF). In order to model ICRF heating, it is necessary to combine self-consistently a wave propagation code with a Fokker-Planck code for the resonant ion distribution function. This is a complex problem and experimental results pointing to the necessity of such self-consistent calculations will be discussed. The Fokker-Planck modelling of the resonant ion distribution function must take into account, among other things, finite orbit width effects and wave induced transport in real space. Experimental evidence for the importance of such effects will be shown. It is possible to model the resonating ion distribution function with orbit following Monte Carlo codes, and a two-step Monte Carlo algorithm for such codes is briefly described, including subtle effects that are normally not accounted for.

30

The numerical support to the Plasma Observatory ESA M7 candidate mission.

Francesco Valentini and PO Science Team
Dipartimento di Fisica, Università della Calabria

Plasma energization and energy transport are central in space plasma physics research, with important implications for space weather science as well as for the understanding of distant astrophysical plasmas, and are strictly interconnected with important processes such as shocks, magnetic reconnection, turbulence and waves, plasma jets and their combination. The Earth's Magnetospheric System is the complex and highly dynamic plasma environment where the strongest particle energization and energy transport occur in the near-Earth space.

Plasma Observatory (PO) multi-scale space mission is one of the five ESA M7 candidates for a launch in 2037 and is currently undergoing a competitive Phase 0 at ESA, for further downselection to Phase A at the end of 2023. The mission concept is tailored to study plasma energization and energy transport in the Earth's Magnetospheric System, simultaneously at both fluid and ion scales, at which the largest amount of electromagnetic energy is converted into energized particles and energy is transported. PO baseline mission includes one mothercraft and six identical smallsat daughtercraft, covering all the key regions of the Magnetospheric System.

PO Numerical Simulation Working Group (NSWG) provides support to the development of the mission concept during all phases of mission design, not only from the scientific point of view but also for the definition of the payload, as well as for the optimization of the configuration of the spacecraft constellation.

Here, we discuss the concept of the PO space mission and the role of the NSWG, focusing specifically on the complex interaction between shocks and plasma turbulence and presenting a novel combination of magnetohydrodynamic (MHD) and small-scale, hybrid kinetic simulations, where a shock is propagating in a turbulent medium. Finally, we put our modelling effort in the context of spacecraft observations, elucidating the role of cross-scale, multi-spacecraft simultaneous measurements in resolving shock front irregularities at different scales.

31

Relativistic wave-particle interaction under a strong magnetic field

Takayoshi Sano
Osaka University

The ultimate goal of fusion science is to heat ions to the high enough temperature to promote fusion reactions. In the laser-driven inertial confinement fusion scheme, the laser energy should be converted to the ion energy of fuels as much as possible through various laser-plasma interactions. However, there is a fundamental problem that electrons take away most of the laser energy at the first step of the interaction. Therefore, the development of direct energy transfer from electromagnetic waves to ions has a valuable meaning that overcomes the essential difficulty. A possible mechanism of ion heating proposed recently is caused by collapsing standing whistler waves. Thanks to the no-cutoff nature of the whistler wave, the laser energy is delivered to the inside of over-dense plasmas, which enables the direct interaction of the electromagnetic waves and ions there.

We investigate thermal fusion plasmas initiated by standing whistler waves numerically by multi-dimensional Particle-in-Cell simulations. When a standing whistler wave collapses due to the wave breaking of ion plasma waves, the energy of the electromagnetic waves transfers directly to the ion kinetic energy. We find that the ion heating by the standing whistler wave is operational even in multi-dimensional simulations of multi-ion species targets, such as deuterium-tritium ices and solid ammonia borane. The energy conversion efficiency to ions becomes as high as 15 % of the injected laser energy, which depends significantly on the target thickness and laser pulse duration. The ion temperature could reach a few tens of keV or much higher if appropriate laser-plasma conditions are selected. The standing whistler wave heating would expand the experimental possibility for an alternative ignition design of magnetically confined laser fusion, and also for more difficult fusion reactions including the aneutronic proton-boron reaction.

32

Multi-scales physics of magnetic reconnection in hot plasmas

M. Muraglia 1 O. Agullo 1 N. Dubuit 1 X. Garbet 2 + 3
1. Aix-Marseille Universit\'e, CNRS, PIIM UMR 7345, Marseille, France
2. CEA, IRFM, F-13108, Saint-Paul-Lez-Durance, France
3. School of Physical and Mathematical Sciences, Nanyang Technological University, 637371 Singapore

Magnetic reconnection consists in a modification of magnetic field topology leading to the formation of island-shaped magnetic structures. Magnetic reconnection is ubiquitous in magnetized plasmas. It is found in space plasmas (with the well-known example of sunspots of the solar flares[1]) as well as in fusion plasmas on earth[2]. The idea of the non-conservation of magnetic connectivity during the movement of a plasma emerged over the years[3]. Since then, many works based on theoretical and/or numerical models have given estimates of the growth rate of reconnected structures in disagreement with experimental observations (in space plasma in particular). In fusion plasmas, it is commonly accepted that the collisionality is too low to explain the existence of magnetic reconnection phenomena at large-scales[4] and at small-scales[5].

Thus, magnetic reconnection still raises many open questions. The work presented here falls within the context of hot fusion plasmas and aims to improve the fundamental knowledge about "the life of a magnetic island".

In the literature, studies mainly focus on how a reconnected structure (magnetic island) can grow, the phenomenon at the origin of magnetic reconnection being not distinguished from the phenomenon of growth. This leads generally to the disagreement between theory and experiences. However, there is no fundamental reason that the non-ideal mechanism at the origin of the reconnection is also the one that will allow the island to grow.

Here, in the light of the many works of the last 70 years, a new paradigm for understanding and studying the magnetic reconnection in fusion plasmas is proposed. The life of a magnetic island (whatever its scale) follows 3 phases : the origin, the growth and the saturation. The possible physical mechanisms at play in these 3 phases will be investigated from ionic Larmor radius scale to the large MHD scale. First, for the island origin, typical time scales in link with magnetic reconnection will be computed for 3 tokamaks of different sizes (TCV, WEST and JET) in order to check if magnetic reconnection is such an unexplained phenomenon in fusion plasmas. Second, for the island drive, the richness of possible mechanisms leading to "rapid" magnetic island growth will be presented from small[6] to large scales[7]. Third, comes the island saturation step. Results on the prediction of a large island size at saturation and its impact on transport will be presented.

References

[1] R.G. Giovanelli, Nat 158, 81-82 (1946).

[2] J.C. Minjun et al., Nat Commun 12, 375 (2021).

[3] J.W. Dungey, Phil. Mag. 44, 725 (1953).

[4] O. Sauter et al., Plasma Phys. Control. Fusion, 52, 025002, (2010). [5] D.R. Hatch et al., Nucl. Fusion 56, 104003 (2016).

[6] M. Hamed et al., Phys. Plasmas 26, 092506 (2019).

[7] M. Muraglia et al., Phys. Rev. Lett. 107, 095003 (2011).

33

Compressible theory of unmagnetized islands in inhomogeneous plasma

F.L. Waelbroeck,[1] S. Cancino,[2] J. Martinell [2] and R. Fitzpatrick [1]
[1] Institute for Fusion Studies, University of Texas at Austin
[2] Instituto de Ciencias Nucleares (UNAM), Mexico D.F., Mexico

Plasma inhomogeneity can create magnetic islands through instabilities such as the classical, micro-tearing and neoclassical tearing modes (TM, MTM and NTM). Plasma inhomogeneity also affects how the plasma responds to applied resonant perturbations, such as those used for ELM control in tokamaks and for creating island divertors in stellarators. The IslET fluid model (Island Equilibrium and Transport) [1] that describes islands in inhomogeneous plasma has been extended to account for ion compressibility, which allows island chains to couple to drift-acoustic waves. The compressible IslET model completes the equilibrium solution of Smolyakov et al. [2] by specifying the relaxed form of the profiles (density, velocity and current) and in particular the degree to which they are flattened in the island. Analytic solutions of the IslET model will be presented in the “unmagnetized” regime. This regime (also called the « supersonic » regime [3]) is such that islands are wider than the width of the current channel found in linear theory but narrower than the ion-acoustic gyro-radius. The new solutions extend a previous analysis [3] by lifting the assumption that the phase velocity of the island is close to the electron drift velocity.

[1] F.L. Waelbroeck, Phys. Rev. Lett. 95, 035002 (2005).

[2] A. I. Smolyakov, H. R. Wilson, M. Ottaviani, and F. Porcelli, Plasma Phys. Control. Fusion 46, L1 (2004).

[3] R Fitzpatrick and FL Waelbroeck, Phys. Plasmas 15, 012502 (2008).

This research was funded by the U.S. Department of Energy under Grant DE-FG02-04ER54742 and by PAPIIT-IN110021 and CONACyT A1-S-25157.

34

The interaction of ultraintense short laser pulse with nanostructured target

Jian Fuh ONG
Extreme Light Infrastructure Nuclear Physics (ELI-NP)

The interactions of ultra-intense lasers with solid targets with nanowires received a lot of attention because they appear to show the potential to increase the laser light absorption rate. Laser-nanowire interactions open up various applications such as attosecond bunch generation, enhanced x-ray generation, brilliance gamma-ray yield, as well as efficient micro fusion. Despite many studies on this topic, either numerically or experimentally, the electron dynamics under the action of a strong laser field across the nanowire remain an open question. We discuss our observation of the electron transport inside the nanowire when irradiated by the intense laser pulse. We found that a plasma wakefield is excited by the double-frequency electron bunches. These fast electron bunches are generated by the J X B heating of the linearly polarized laser pulse at the tip of the nanowire. This wakefield has an amplitude of the order of TV/m, oscillating at the plasma frequency, and propagates into the nanowire. In addition, we also observed that the plasma undergoes stable density modulation inside the laser field with a pressure of more than 10 Tbar when the plasma is relativistically transparent to the laser field. When the plasma is transparent, the magnetic instabilities associated with z-pinch are no longer relevant. The forward and backward photon emission at different stages of laser irradiation is also discussed.

35

Study on the ion velocity distribution function in the magnetized plasma of electric thrusters

Stéphane MAZOUFFRE- CNRS - ICARE laboratory Orleans, France

Electric Propulsion is an efficient way of moving a spacecraft. In short, EP relies upon the ejection of ions into the vacuum of space to generate a net momentum, therefore a thrust. The large ejection velocity of ions achieved by electrostatic or electromagnetic acceleration makes EP much more efficient than chemical propulsion from a propellant consumption viewpoint, hence the interest and the high demand for the new satellite generations whatever the size, the orbit and the mission. In this contribution, after a brief introduction to EP fundamentals, transport properties of ions and atoms in various plasma thrusters will be discussed in light of recent series of Laser-Induced Fluorescence spectroscopy experiments. We will mostly focus on the magnetic nozzle of Helicon thrusters and electron cyclotron resonance thrusters as well as on Hall effect thrusters and variants. We will notably demonstrate the usefulness of continuous-wave LIF spectroscopy combined with a comprehensive fluorescence lineshape model to capture the local velocity distribution function of particles and extract quantities like temperature and bulk velocity essential for transport phenomena investigation.

36

Fast and furious: reconnection-powered emission in black hole jets and coronae

Lorenzo Sironi
Columbia University

In the most extreme astrophysical sources, dissipation of the dominant magnetic energy via magnetic reconnection—a process by which opposite field lines annihilate, releasing their energy to the plasma — leads to efficient particle acceleration and powerful emission. In black hole jets and coronae, reconnection operates in the "relativistic" regime, where the magnetic field energy exceeds even the rest-mass energy of the plasma. With radiative particle-in-cell (PIC) simulations and analytical theory, I will show that particle acceleration by reconnection can resolve a number of puzzling observations. In particular, I demonstrate that reconnection can naturally explain the limb-brightened radio emission of AGN jets, and it likely is the hidden engine powering the mysterious hard X-ray "coronal" emission of X-ray binaries.

37

Non-equilibrium Plasma for a Green Process Industry

G.J. van Rooij
Maastricht University, faculty of science and engineering, department of circular chemical engineering.

A carbon neutral and circular economy requires utilization of waste materials and biomass as feedstock for the production of new materials. Moreover, the energy input must be of zero carbon footprint, which currently implies that it concerns electric energy input that is intermittently available. Plasma technology carries distinct advantages and/or promises that make it suitable to make an impact in the transition to a circular economy such as compatibility with (intermittent) sustainable energy and unique opportunities for efficiency and/or selectivity in reactions with CO2, N2, and CH4.

Vibrational excitation effects were invoked to explain the very high energy efficiencies reported in the 80s and are still being embraced by the research community as key to success. This work invokes vibrational laser excitation to determine the limits of CO2 dissociation by vibrational excitation alone. In situ plasma temperature and species measurements in dynamic experiments confirm short timescales for the vibrational non-equilibrium. The main opportunity that we recognize for vibrational excitation enhanced CO2 dissociation occurs due to excitation transport to the plasma edges and recombination with oxygen atoms. These results are extrapolated to opportunities for industrial application of plasma that are currently researched in the context of the Brightsite consortium, the knowledge center aiding the transition of the process industry at Chemelot in the southeast of the Netherlands.

38

Ultrahigh Charge Electron Acceleration for Nuclear Applications

Liming Chen, Jie Feng, Wenchao Yan, Yaojun Li, WenZhao Wang, Jie Zhang
School of Physics and Astronomy, Shanghai Jiao Tong University

The laser plasma acceleration is not only suitable for advance accelerator, but also possess great potential for plasma exciter or collider. At present, main research topics focus on the quality improvement of accelerated electrons. On the other hand, the laser plasma accelerator also has extremely high electron charge which will produce high brightness gamma ray source and intense neutron source, resulting in powerful tool for nuclear physics research.

Recently, our team has carried out systematic studies on electron acceleration with large charge. For example, we used a solid target to realize relativistic electron acceleration of 100 nC [1] with very small divergence angle; And achieved stable acceleration of ~ 20 nC and electron energy of tens MeV in high-density gas targets through a novel efficient injection that the atom inner shell electrons are ionized and continuously injected into multiple plasma bubbles [2].

Based on new results of electron acceleration obtained, we have carried out the research of "laser-plasma exciter". Firstly, a high brightness neutron source [3] is obtained by driving a solid target with an electron beam. And then, using the nonlinear resonance of Kr clusters excited by intense laser, the 83Kr isomeric state is achieved experimentally with peak efficiency 2x10^15 p/s [4]. And also, with optimized high charge electron beam driven (γ,n) reaction, the peak flux of neutron source reaches to 10^21 n/cm^2/s, which is comparable to Supernova [5].

In order to carry out the experimental verification of laser "plasma exciter" and extremely strong field QED, we are constructing the "laboratory astrophysics research platform" (LAP) in TsungDao Lee Institute, for the nuclear astrophysics research in relativistic.

Poster contributions
Poster session on 22 June

P1

Particle Drifts in the background of Classical Yang-Mills Fields

Subramanya Bhat K N*, V Ravishankar*, Bhooshan Paradkar, and Amita Das***
*** Department of Physics, Indian Institute of Technology Delhi, Hauz Khas, New Delhi India. ** Center of Excellence in Basic Sciences, University of Mumbai, Mumbai - 400098, India.**

Yang-Mills theory helps us understand the behaviour of quark-gluon plasma. This plasma is produced in relativistic heavy ion collisions. It is also believed that the universe passed through this phase of matter soon after the big bang. Yang-Mills dynamics is inherently non-linear due to the non-abelian nature of gauge transformations, giving rise to new solutions for both field equations and the test particle motion. In this poster, we study some examples of a test particle in external fields and present some counter-intuitive results.

P2

Asymmetries in Tokamak's boundary plasmas and divertor design

Fulvio Militello, David Moulton, Lingyan Xiang, Qian Xia, Ryoko Osawa
UKAEA

Divertor design for future reactors is machine defining and requires reliable models to assess the energy flux reaching the targets. An important element of this is the evaluation of the asymmetries in the power deposition between the different divertor legs, both in single (two legs) and double null (four legs). This paper provides a theoretical, numerical and experimental analysis of the subject, using novel models and results from MAST-U. It will be shown that in low recycling regimes, the SOL collisionality and the machine geometry plays a major role in determining the in/out asymmetries, with conduction limited regimes showing temperature differences between inner and outer target and SOL currents flowing between the two (from the cold to the hot target). It will be shown that changes in the sheath transmission coefficient tend to mitigate the asymmetry growth, which are instead enhanced by the SOL currents. In detachment, neutral and radiation physics becomes dominant and analysing asymmetries requires numerical codes and a precise definition of the divertor geometry. It will be shown that the concentration of the impurities in different regions of the divertor can play an important role in this case. Finally, in double null conditions, we have carried out numerical simulations with multifluid and 3D turbulence codes, both showing that the in-out asymmetry is quite marked in spherical tokamaks (10%-90% or 20%-80%), in double null, single null and intermediate configurations (disconnected double null). These results have been compared with MAST and MAST-U experimental results, showing good agreement, thus validating the models and increasing confidence in the results.

P3

Cleaning and protection by plasma technology of Portuguese oolitic limestone of Batalha Monastery in Portugal

L. Es Sebar *, Y. Ding °, E. Angelini*, S. Grassini*, N. Schiavon°
*** Dipartimento di Scienza Applicata e Tecnologia (DISAT) - Politecnico di Torino, Torino, Italy**
° Hercules Laboratory for the Study and Conservation of Cultural Heritage , University of Evora, Evora, Portugal

Stones present in buildings and monuments may suffer noteworthy decay as a consequence of anthropic activities in urban areas. An example is the Batalha Monastery, located in Portugal’s central region near the city of Leira, officially named “Mosteiro de Santa Maria da Vitoria”, built in the 14th century and UNESCO World Heritage site from 1983. Unfortunately over a century after a large-scale restoration campaign, the Monastery shows a high degree of stone decay, mainly due to biodeterioration processes, which play an ever-increasing role in stone decay both in urban and rural environments.

In order to safeguard the stones, their surfaces were coated by means of PECVD (Plasma Enhanced Chemical Vapour Deposition) of a thin SiOx layer starting from tetraethoxysilane (TEOS) as the reaction precursor and deposited via a capacitively coupled parallel-plate plasma reactor. The optimization of the deposition parameters was performed on Si wafers and on stone samples coming from five limestone quarries (Pidiogo, Valinho do Rei, Reguengo do Fetal, Cabeco do Roxo, Outreiro de Sebastiao) in the middle of Portugal from which the stones were extracted for the construction and restoration of the Batalha Monastery. The characterizations of the deposited film were carried out by Raman spectrometry and scanning electron microscopy (SEM+EDS). The protective effectiveness of the SiOx film was evaluated by means of laboratory accelerated tests and natural aging tests. Acid rain attack simulation showed that the SiOx layer, due to its good barrier effect, was able to isolate the stone from the aggressive solution, thus reducing the possible damage. Moreover natural aging tests proved that SiOx thin film inhibits to a high extent bio-colonization and prevents the stone from darkening.

P4

Plasma technology for corrosion protection of metals

L. Iannucci, S. Grassini, E. Angelini
Dipartimento di Scienza Applicata e Tecnologia (DISAT) - Politecnico di Torino

The thin film technology concerning a large variety of non-equilibrium processes for leading-edge surface modifications of materials gained in recent years increasing popularity, because it allows the design of substrate of a material by means of the deposition of thin films in a versatile and environmentally friendly way, employing low pressure plasmas. Plasma Enhanced Chemical Vapour Deposition (PECVD) is one of the most important result of thin film technology and was applied for the deposition of silicon containing organic compounds (i.e. organosilicons) to mild steels, magnesium alloys and silver alloys, in order to increase their corrosion resistance.

PECVD was performed, in a capacitively-coupled parallel-plate-reactor with an asymmetric electrode configuration, constituted by a stainless steel vacuum chamber, a powered electrode connected to a 13,56 MHz RF power supply. Gas and organosilicon vapour flow rates are controlled by mass-flow and vapour source controllers, while a turbomolecular pump backed by a rotary pump, a throttle valve, a pressure gauge keeping the pressure at selected values (1.0.10-3- 1.0 Torr). The film deposition was performed igniting a glow discharge with a gas mixture with Ar and/or O2. HMDS and TEOS were employed for coating deposition, the effect of the input power was investigated between 50-250W.

The corrosion protection properties of SiOx thin films on different metals and alloys may be modulated with the plasma process parameters: (i) a marked increase in the protective effectiveness is obtained with the increase of the discharge input power, which leads to the formation of more inorganic films; (ii) plasma pre-treatment processes, in oxygen or hydrogen, remove the surface contamination, thereby reducing the defectiveness degree of the coating and enhancing its adhesion to the substrate; (iii) the deposition process carried out in oxygen-rich plasma allows to attain a further increase of the protective effectiveness.

P5

The distribution of halo current using the Hodge decomposition of eddy currents on the Keda Torus eXperiment device

Zheng Chen,Hong Li,Adil Yolbarsop,Yuan Zhang,Wentan Yan,Xianhao Rao,Shuchen Song,Zhen Tao,Shunrong Ren,Furen Tian,Wenzhe Mao,Zian Wei,Zixi Liu,Chu Zhou,Adi Liu,Tao Lan,Jinlin Xie,Haiyang Zhou,Xiaohui Wen,Hai Wang,Ge Zhuang,Weixing Ding and Wandong Liu
KTX Laboratory and Department of Plasma Physics and Fusion Engineering, University of Science and Technology of China

During the plasma discharge, eddy currents induced in the metallic wall that contains the plasma can be categorized into two main types: (1) inductive currents, which are driven by vortex electric fields and have streamlines that are entirely confined within the shell; and (2) halo currents, which consist of part of the circuit on the shell and the remainder in the plasma. Halo currents play a crucial role in investigating the thermal load on the wall and electromagnetic forces during disruptions in plasmas. Additionally, understanding halo currents is essential for improving existing methodologies that aim to remove their effects on equilibrium reconstructions and instability analyses based on boundary magnetic probe data. Nonetheless, accurately measuring all radial halo currents flowing into the wall and distinguishing inductive currents and halo currents on the shell are simultaneously two challenging tasks.

Fortunately, the eddy current diagnostic system on the Keda Torus eXperiment (KTX), measuring all the tangent eddy currents on the shell, and the mathematical tools such as Hodge decomposition enable the unique decomposition as
\begin{equation}
\vec{\alpha} = \nabla\times\Gamma\quad\Vec{e}_n-\nabla\Phi + \vec{\gamma}, \label{eq:1}
\end{equation}
where Γ describes the inductive current's stream function, Φ describes the potential function of the halo current, and $\vec{\gamma}$ represents the harmonic current. During minor disruptions, the radial current density of the halo current can be estimated using $j_r=\delta_w \nabla^2 \Phi$ to locate wetting zones. Experimental results show that the halo current appears before the minor disruption during the development of the (1,1) resistive wall mode (RWM), and the phase difference between $\Phi^{(1,1)}$ and $\Gamma^{(1,1)}$ is approximate π, while the ratio $\epsilon=|\Phi^{(1,1)}/\Gamma^{(1,1)}|\sim0.3$. Moreover, the self-helicity of the eddy currents can be conveniently calculated by decoupling inductive and halo currents.

For devices lacking the capability to measure the two-dimensional eddy current distribution along the entire boundary, we propose a method to estimate inductive and halo currents using only a set of eddy currents along the toroidal direction. This technique is demonstrated on the KTX device and provides an overall good approximation of the inductive and halo current distribution.

P6

Axi-symmetric modes in Straight Tokamak

D. Banerjee1, T. Barberis1, C. C. Kim3, F. Porcelli1 A. Yolbarsop2
1 Polytechnic University of Turin, Torino 10129, Italy
2 University of Science and Technology of China, Hefei, Anhui 230022, China
3 SLS2 Consulting, San Diego, California 92107, USA

The stability of the axi-symmetric mode has been studied both analytically and numerically considering a model mhd equilibrium devised for straight tokamak. In linear ideal MHD theory [1,2], it is found that the n=0 axi-symmetric mode may have three different stability conditions – unstable, marginally stable and oscillatory – depending on the locations of X-points relative to the ideal (perfectly conducting) wall position. The same characteristics is confirmed via linear simulation with the initial value extended MHD code NIMROD [3]. The agreement in results between our analytic calculation and NIMROD simulation is satisfactory both qualitatively and quantitatively [4]. The resonance between the X-points and the axi-symmetric perturbation may act to stabilize the n=0 mode by forming a current sheet around X-points, as found in our ideal MHD analytic theory [1]. In simulation, we also have observed current sheet formation around X-points in agreement with our theory. When X-points lie outside the ideal wall, the n=0 mode becomes stable and the plasma oscillates vertically with an Alfvénic oscillation frequency. As discussed in [5], due to its frequency this oscillatory mode can resonate with fast ions of energy around 1MeV, leading to a new kind of fast ion instability. The overall results from our study of the n=0 mode will be presented in detail – the verification of analytic results with simulation, the role of X-point current to the stability of the axi-symmetric mode and the effect of fast ions.

[1] A. Yolbarsop et al., Nucl. Fusion 61, 114003 (2021).
[2] A. Yolbarsop et al., Plasma Phys. Contr. Fusion 64, 105002 (2022).
[3] NIMROD team webpage ~ https://nimrodteam.org.
[4] D. Banerjee et al., under review in Physics of Plasmas.
[5] T. Barberis et al., Nucl. Fusion 62, 064002 (2022).

P7

Low-temperature plasmas for biological applications

I. Furno, R. Agus, F. Avino, L. Ibba, B. Meyers, A. Waskow
Ecole Polytechnique Federale de Lausanne

The most recent frontier in low temperature plasmas is their use for biological applications. A variety of fields, ranging from plasma medicine to plasma agriculture, are presently being explored with a focus on both the development of industrial applications and the fundamental understanding of the interaction processes between plasmas and biological organisms. At the Swiss Plasma Center (SPC) at EPFL, we recently created a laboratory, dubbed “bio-plasmas laboratory”, to investigate biological applications of plasmas. I will review the main diagnostics and plasma sources available in the bio-plasmas laboratory and present a few highlights of our activities, including the use of plasma-activated water for sterilization, and plasma treatment to enhance seed germination.

P8

Fast particle acceleration in 3D hybrid simulations of quasi-perpendicular shocks

Luca Orusa, Damiano Caprioli
Università degli Studi di Torino
University of Chicago

We use hybrid (kinetic ions---fluid electrons) kinetic simulations to investigate particle acceleration and magnetic field amplification at non-relativistic, weakly magnetized, quasi-perpendicular shocks. Unlike 2D simulations, 3D runs show that protons develop a non-thermal tail spontaneously (i.e., from the thermal bath and without pre-existing magnetic turbulence). They are rapidly accelerated via shock drift acceleration up to a maximum energy determined by their escape upstream.

P9

Electron dynamics and coherent structures in stochastic magnetic reconnection

Dario Borgogno, Anna Perona, Daniela Grasso
Istituto dei Sistemi Complessi - CNR and Politecnico di Torino

In the framework of the studies on magnetic reconnection, a relevant role is represented by fluid models based on the magnetohydrodynamical equations. Thanks to the enhancement of the computational tools, the complexity of the magnetic field topology can now be represented by three-dimensional descriptions, which allow for the observation of the magnetic stochasticity caused by the nonlinear interaction of multiple perturbations in the reconnection regions. Previous investigations of collisionless magnetic reconnection configurations highlighted the coexistence in the chaotic magnetic sea of structures, such as invariant Kolmogorov-Arnold-Moser (KAM) flux surfaces, broken KAM surfaces (cantori), stable and unstable manifolds and ridges (i.e., structures identified by gradient lines normal to the direction of the minimum curvature of the structures themselves), which can effectively limit the diffusion of the magnetic field lines across the chaotic regions. In our work, we focus on the electron dynamics in such an environment, with the aim of understanding whether and how the magnetic structures hidden by the chaotic sea affect the particle behavior in the reconnection region. By means of a test-particle approach interfacing a fluid plasma description, we show the effects produced on the spatial distribution of the electrons by the evolving topology of the magnetic reconnection fields and discuss the relationship between the fluid fields and the electron energies. Our results complete at the kinetic level the fluid plasma description at the macroscopic scale and contribute to the overall picture of the collisionless magnetic reconnection process.

P10

Runaway Electron driven Magnetic reconnection

Lovepreet Singh (1)(2), Dario Borgogno (1), Daniela Grasso (1)

(1) Istituto dei Sistemi Complessi—CNR and Dipartimento di Energia, Politecnico di Torino, Torino
(2) NEMO Group, Dipartimento Energia, Politecnico di Torino, Torino, Italy

Runaway electrons (RE) generated during disruption represent a serious threat to the future Tokamaks. In fact, RE can cause unrecoverable damages to the plasma-facing components once they reach the plasma edge. In order to mitigate the RE, it is vital to understand their interactions with the core plasma where the characteristics of RE current are defined. The goal of this work is to study the mutual interaction of the RE with the magnetic reconnection instability in a weakly collisional plasma where the current is completely carried by runaway electrons. Here we present the numerical results that reproduce recent analytical studies in the linear regime [1] along with the new results obtained in the nonlinear regime. In addition, preliminary results concerning the contribution of non-collisional effects on the evolution of the magnetic reconnection driven by a RE current are shown.

[1] Liu, C., Zhao, C., Jardin, S. C., Bhattacharjee, A., Brennan, D. P., & Ferraro, N. M. (2020). Structure and overstability of resistive modes with runaway electrons. Physics of Plasmas, 27(9), 092507.

P11

Protection of Silver-based Alloys from Tarnishing by means of PECVD Coating

I. Sannino, L. Es Sebar, L. Iannucci, S. Grassini, E. Angelini

Politecnico di Torino

Silver is a metal used since ancient times in the fabrication of decorative and functional objects due to its working properties and pleasing colour and shine: silver, pure or alloyed with other metals as copper, may be shaped by hammering, embellished by engraving, or inserted with gems or plated with gold. The alloy surface, although highly lustrous when just polished, darken easily during air exposure, mainly because of the reaction with sulphur-containing compounds, thus also artistic and archaeological artefacts are subjected to a gradual discolouration, called tarnishing. The removal of tarnished film usually requires the use of chemicals to convert the silver sulphide dark layer into soluble compounds, and/or the use of abrasives, to remove mechanically the dark layer. All these methods do not last long and may damage of the artefacts. At present the never-ending problem of cleaning and protecting silver artefacts has not yet found a satisfactory solution Thus, aim of this research is to evaluate the possible application of SiOx-like thin films deposited by Plasma Enhanced Chemical Vapour Deposition (PECVD) processes as an innovative conservation treatment because of their low gas permeability, high chemical stability and optical transparency, reversibility in hydrogen plasma. Thus, this process fits the specific requirements of cultural heritage conservators and in particular preventing further tarnishing of restored silver and silver-based alloys artefacts.