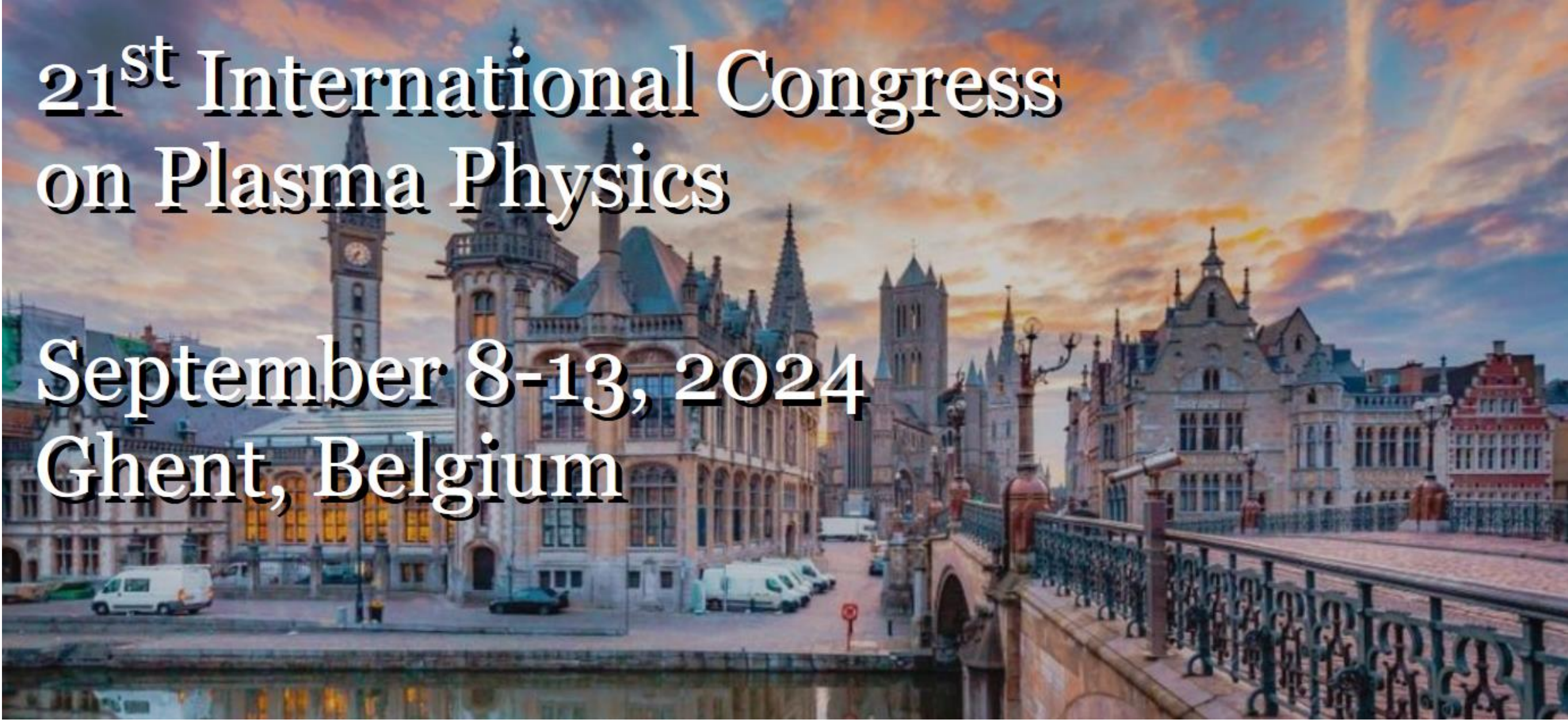

Program
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Abstracts

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Foreword

Dear Colleagues,

On behalf of the Local Organizing Committee, the Program Committee, and the International Advisory Committee, we sincerely welcome you to the 21st International Congress on Plasma Physics (ICPP 2024), in Ghent. The event is organized by the Research Unit Nuclear Fusion (infusion) and the Research Unit Plasma Technology (RUPT) in the department of Applied Physics at the faculty of Engineering and Architecture of Ghent University (UGent).

We are very pleased to welcome a large number of distinguished presenters who will address a wide range of topics in the field of plasma physics. With participants hailing from 30 different countries all over the world, the conference will be a forum for discussion of cutting-edge research in fundamental plasma physics, fusion plasmas, laser-plasma interaction, plasma accelerators, astrophysical and space plasmas, applications of plasmas and plasma technology, complex plasmas, high energy density plasmas and quantum plasmas.

In addition, we are proud to offer you a plenary session on Public-Private Partnerships in Fusion Energy Development (Monday, September 9), in the form of a panel discussion among experts in the field. Furthermore, there will be an informal interest-group meeting regarding community engagement in repository and management of materials fundamental data for (fusion) plasma physics (Thursday, September 12). We invite all interested conference participants to attend these sessions.

We are deeply saddened by the premature decease of Prof. Robert (Bob) Dewar (Australian National University), who made an immense contribution to the field of theoretical plasma physics. Bob also had a significant presence at the ICPP and, in recognition of this service and commitment, a plenary memorial session celebrating his accomplishments will be held on Tuesday morning, September 10.

Finally, we hope that you take the occasion to explore Ghent as a vibrant city with an extensive historical center and an abundant architectural and cultural patrimony.

We welcome you here, to enjoy with us the conference, the many enchanting sights and the rich culinary tradition of the region!

Geert Verdoolaege
Chair of LOC
Professor, Ghent University

Bob Bingham
Chair of PC
Professor, Science and Technology Facilities Council (STFC)

Sponsoring

ICPP 2024 gratefully acknowledges its sponsors.

The International Union of Pure and Applied Physics (IUPAP) is the only international physics organization that is organized and run by the physics community itself. Its members are identified physics communities in countries or regions around the world.
To secure IUPAP sponsorship, the organizers have provided assurance that ICPP 2024 will be conducted in accordance with IUPAP principles as stated in the IUPAP resolution passed by the General Assembly in 2008 and 2011. In particular, no bona fide scientist will be excluded from participation on the grounds of national origin, nationality, or political considerations unrelated to science.

The Research Foundation Flanders (FWO) offers researchers in Flanders the opportunity to create knowledge. The FWO provides financial support for individual researchers, programmes and projects, and research infrastructure.

We are also very grateful to Prof. Hyeon K. Park and the other members of the local organizing committee of the ICPP 2022 conference, for the generous additional support.

Code of conduct

Free circulation of scientists

The principle of the Universality of Science is fundamental to scientific progress. This principle embodies freedom of movement, association, expression and communication for scientists, as well as equitable access to data, information and research materials.

In pursuing its objectives with respect to the rights and responsibilities of scientists, the International Union of Pure and Applied Physics (IUPAP) actively upholds this principle, and, in so doing, opposes any discrimination on the basis of such factors as ethnic origin, religion, citizenship, language, political stance, gender, or age. IUPAP should only sponsor conferences and events at institutions and in countries that uphold this principle. If scientists are excluded from attending IUPAP-sponsored international conferences by a host institution or country on the basis of any of these factors, IUPAP should register its concern at the highest level of that institution or country, and should not sponsor any future events in that country until such exclusions have been eliminated.

Harassment

It is the policy of the International Union of Pure and Applied Physics (IUPAP) that all participants in Union activities will enjoy an environment which encourages the free expression and exchange of scientific ideas, and is free from all forms of discrimination, harassment, and retaliation. The conference organisers have named an advisor who will consult with those who have suffered from harassment and who will suggest ways of redressing their problems, and an advisor who will counsel those accused of harassment. The conference organisers may, after due consideration, take such action they deem appropriate.

Committees

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Local Organizing Committee

The Local Organizing Committee is chaired by Prof. Geert Verdoolaege and consists of the members of the Research Unit Nuclear Fusion (infusion) and the Research Unit Plasma Technology (RUPT) in the Department of Applied Physics at Ghent University.

Locations

Conference locations

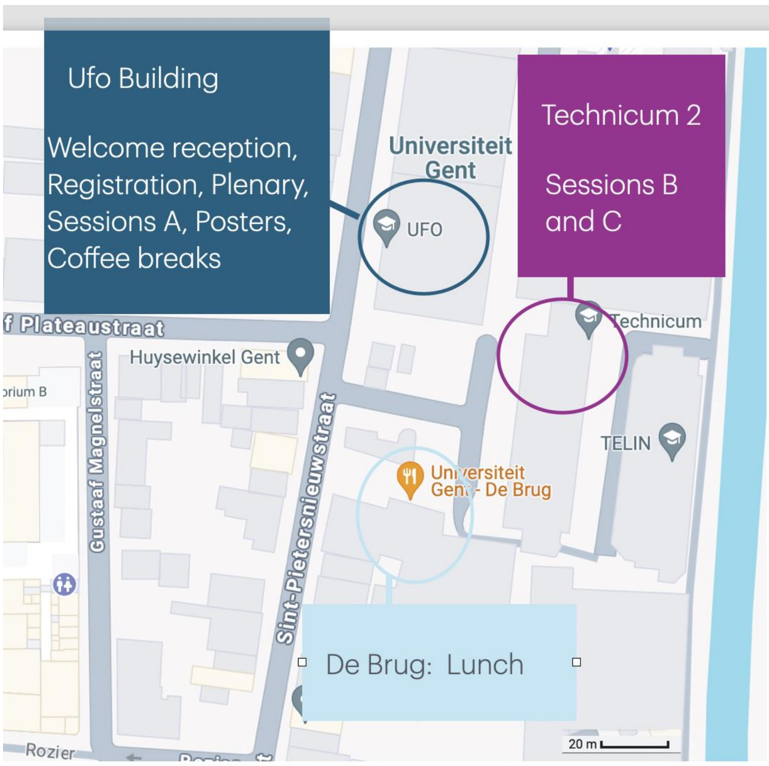
Registration, coffee breaks and welcome reception: Ufo building, Foyer
Sint-Pietersnieuwstraat 33

Plenary sessions: Ufo building, Aud. 1 "Leon De Meyer"
Sint-Pietersnieuwstraat 33

Sessions A: Ufo, Aud. 1 "Leon De Meyer" Sint-Pietersnieuwstraat 33	Sessions B: Technicum building 2 (T2), floor 3 Aud. H Sint-Pietersnieuwstraat 33	Sessions C: Technicum building 2 (T2), floor -3 Aud. A "Jean-Norbert Cloquet" Sint-Pietersnieuwstraat 33

Poster sessions: Ufo building, Foyer
Sint-Pietersnieuwstraat 33

Lunch: student restaurant "De Brug"
Sint-Pietersnieuwstraat 45



Internet

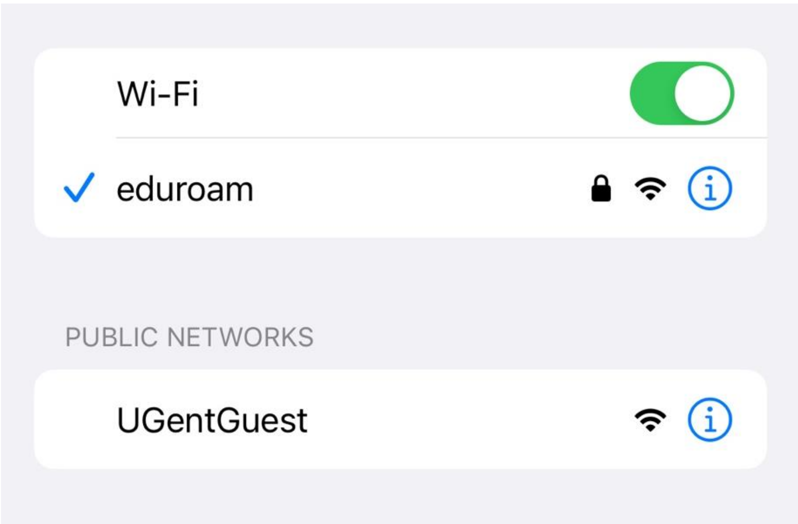
Wi-Fi internet connection is available at the venue. The credentials are:

Network: UGentGuest

Username: guestlcpp24

Password: gVmU8Lvg

The attendees may also connect via **Eduroam** using the credentials provided by their respective institutes.



Program overview

Sunday, September 8

13:00 - 18:00	Registration
18:00 - 20:00	**Welcome reception**

Monday, September 9

08:00 - 08:45	Registration		
08:45 - 09:00	Opening Ceremony		
09:00 - 09:40	[Mo.P.1] Frank Jenko, Towards Digital Twins of Fusion Systems		
09:40 - 10:20	[Mo.P.2] Rahul Pandit, The Solar Wind and Statistical Properties of Three-Dimensional Hall Magnetohydrodynamics Turbulence		
10:20 - 10:50	**Coffee break**		
10:50 - 11:30	[Mo.P.3] Jozef Ongena, Overview and Initial Results of the ICRH Antenna for the Optimized Stellarator Wendelstein 7-X		
11:30 - 11:40	**Short break**		
11:40 - 12:30	[Mo1.A] Instabilities in Fusion Plasmas	[Mo1.B] Modelling for Plasma Processing Applications	[Mo1.C] Magnetic Reconnection in Space and Astrophysical Plasmas
	[Mo1.A.I1] Hao Wang	[Mo1.B.I1] Igor Kaganovich	[Mo1.C.I1] Dmitri Uzdensky
	[Mo1.A.O1] Alodie Grondin-Exbrayat	[Mo1.B.O1] Sunil Swami [remote]	[Mo1.C.O1] Kuldeep Singh
12:30 - 14:00	**Lunch**		
14:00 - 15:30	[Mo2.A] Fusion Plasma Modelling	[Mo2.B] Technological Applications of Plasmas	[Mo2.C] Solar Wind and Solar Physics
	[Mo2.A.I1] Hideo Sugama	[Mo2.B.I1] Rony Snyders	[Mo2.C.O1] Sebastián Echeverría-Veras [remote]
	[Mo2.A.O1] Richard Sydora	[Mo2.B.O1] Leopoldo Soto	[Mo2.C.O2] Victor Muñoz
	[Mo2.A.O2] W. Guo	[Mo2.B.O2] Jasna-Tinea Jelinek	
	[Mo2.A.O3] Arzoo Malwal [remote]	[Mo2.B.O3] Manis Chaudhuri	
15:30 - 16:00	**Coffee break**		
16:00 - 17:40	[Mo3.A] Energetic Particles and Plasma Heating	[Mo3.B] Plasma Applications in Environmental and Agricultural Sciences	[Mo3.C] Numerical Methods and Plasma Modelling I
	[Mo3.A.I1] Yevgen Kazakov	[Mo3.B.I1] Alan Mašláni	[Mo3.C.O1] Supratik Banerjee
	[Mo3.A.I2] Kenji Imadera	[Mo3.B.O1] Alexandr Ustimenko	[Mo3.C.O2] Arijit Halder
	[Mo3.A.O1] Julio Martinell	[Mo3.B.O2] Toshiro Kaneko	[Mo3.C.O3] Mario Imbrogno
	[Mo3.A.O2] Kohnosuke Sato		[Mo3.C.O4] Xudong Ke Lin
17:40 - 17:50	**Short break**		
17:50 - 18:50	[Mo.P.4] Public-Private Partnerships in Fusion Energy Development		

Tuesday, September 10

08:00 - 09:00	Registration			
09:00 - 09:40	[Tu.P.1] Nicholas Dubuit, Complex Interplay of Magnetic Islands and Turbulence in Fusion Plasmas			
09:40 - 10:20	[Tu.P.2] Christopher Deeney, Pioneering High-Energy-Density Plasma Physics at the Laboratory for Laser Energetics			
10:20 - 10:40	**Coffee break**			
10:40 - 12:30	[Tu1.A] Bob Dewar Memorial Session			
	[Tu1.A.I1] Matthew Hole			
	[Tu1.A.O1] Ben McMillan			
	[Tu1.A.O2] Robert MacKay			
	[Tu1.A.O3] Mark Koepke			
	[Tu1.A.O4] Hideo Sugama			
12:30 - 14:00	**Lunch**			
14:40 - 15:40	[Tu2.A] Magnetic Reconnection in Fusion Plasmas	[Tu2.B] Plasma Accelerators I	[Tu2.C] Numerical Methods and Plasma Modelling II	**Poster Session 1** 14:00 - 16:00
	[Tu2.A.I1] Yasushi Ono	[Tu2.B.I1] Colin Whyte	[Tu2.C.O1] Takayuki Umeda	
	[Tu2.A.I2] Hiroshi Tanabe	[Tu2.B.O1] Devki Nandan Gupta	[Tu2.C.O2] Harune Sekido	
15:40 - 16:00	**Coffee break**			
16:00 - 17:20	[Tu3.A] Spherical Tokamaks	[Tu3.B] Laser-Plasma Interaction I	[Tu3.C] Nonextensive Plasma Physics	
	[Tu3.A.I1] Daniel Kennedy	[Tu3.B.I1] Robert Babjak	[Tu3.C.O1] Victor Muñoz	
	[Tu3.A.I2] Kazuaki Hanada	[Tu3.B.I2] Dominika Maslarova	[Tu3.C.O2] Sebastian Saldivia [remote]	
		[Tu3.B.O1] Ravina		

Wednesday, September 11

08:00 - 09:00	Registration		
09:00 - 09:40	[We.P.1] Didier Mazon, Developing Numerical Tools for Tungsten Profile Measurement from X-Ray Diagnostics in WEST Plasmas		
09:40 - 10:20	[We.P.2] Eve Stenson, Highlights From the Path Toward Confined e+e- Pair Plasmas		
10:20 - 10:50	**Coffee break**		
10:50 - 11:30	[We.P.3] Emilia R. Solano, JET Isotope Studies and the L-H Transition		
11:30 - 11:40	**Short break**		
11:40 - 12:30	[We1.A] Data-Driven Plasma Science I	[We1.B] Laser-Plasma Interaction II	[We1.C] Astrophysical Plasmas I
	[We1.A.I1] Zetao Lin	[We1.B.I1] Sylvie Depierreux	[We1.C.I1] Turlough Downes
	[We1.A.O1] Hao Wu	[We1.B.O1] Vladimir Kocharovsky	[We1.C.O1] Nicolas Brughmans
12:30 - 14:00	**Lunch**		

14:30 - 17:30	**Excursion**

Thursday, September 12

08:00 - 09:00	Registration		
09:00 - 09:40	[Th.P.1] Tammy Ma, Ignition Achieved: Next Steps in the Path toward an Inertial Fusion Energy Future		
09:40 - 10:20	[Th.P.2] Victor Malka, Laser Plasma Accelerators: Manipulating Relativistic Electrons with Intense Lasers		
10:20 - 10:50	**Coffee break**		
10:50 - 11:30	[Th.P.3] Osamu Sakai, Design of Plasma Shapes for Metamaterials, Chemical Filters, and Maze-Solvers		
11:30 - 11:40	**Short break**		
11:40 - 12:40	[Th1.A] Plasma-Wall Interaction and Plasma-Facing Components	[Th1.B] Laser Applications	[Th1.C] Astrophysical Plasmas II
	[Th1.A.I1] Renaud Dejarnac	[Th1.B.I1] Jessica Shaw	[Th1.C.I1] Vinicius Duarte (IUPAP Early Career Scientist Prize)
	[Th1.A.I2] Henri Kumpulainen	[Th1.B.O1] Minsup Hur	[Th1.C.O1] Anoop Singh
12:40 - 14:00	**Lunch**		

14:40 - 15:30	[Th2.A] Edge-Localized Modes	[Th2.B] Materials Applications	[Th2.C] Data-Driven Plasma Science II	**Poster Session 2** 14:00 - 16:00
	[Th2.A.O1] Jaehyun Lee	[Th2.B.I1] Mark Koepke	[Th2.C.I1] E. Paulo Alves	
	[Th2.A.O2] Tridip Kumar Borthakur	[Th2.B.O1] Noriyasu Ohno	[Th2.C.O1] Maria Jose Quezada Roco	
15:30 - 16:00	**Coffee break**			
16:00 - 17:30	[Th3.A] Tokamak Scenarios and Ignition	[Th3.B] Laser-Plasma Interaction III	[Th3.C] Dusty Plasmas	
	[Th3.A.I1] Luca Garzotti	[Th3.B.I1] Thales Silva	[Th3.C.I1] Hubertus M. Thomas	
	[Th3.A.I2] Eun-Jin Kim	[Th3.B.O1] Amit Dattatraya Lad	[Th3.C.O1] Ram Prasad Prajapati [remote]	
	[Th3.A.I3] Hyeon Park	[Th3.B.O2] Rohit Juneja	[Th3.C.O2] Sven Van Loo	
17:30 - 17:40	**Short break**			
17:40 - 18:30	[Th.P.4] RM3FD Interest-Group Meeting			

19:00 - 23:00	**Conference banquet**

Friday, September 13

09:00 - 09:40	Registration		
09:40 - 10:20	[Fr.P.1] G. Ravindra Kumar, 10^4-Fold Field Amplification and Control of Relativistic Mega-Ampere Electron Beams in a Modest, Static Magnetic Solid		
10:20 - 10:50	**Coffee break**		
10:50 - 11:30	[Fr.P.2] Gianluca Gregori, Suppression of Pair Beam Instabilities in a Laboratory Analogue of Blazar Pair Cascades		
11:30 - 11:40	**Short break**		
11:40 - 12:30	[Fr1.A] Tokamak Physics	[Fr1.B] Plasma Accelerators II and Laser-Plasma Interaction IV	[Fr1.C] Ionospheric Plasmas
	[Fr1.A.O1] Ankit Kumar	[Fr1.B.I1] Krishnamurthy Manchikanti	[Fr1.C.O1] Arash Tavassoli
		[Fr1.B.O1] Ankit Dulat	[Fr1.C.O2] Ioannis Kourakis
12:30 - 12:45	Closing Ceremony		
12:45 - 14:00	**Lunch**		

Session chairs

Monday, September 9			
Session	Start time	Chair	Location
Opening Ceremony	08:45	G. Verdoolaege	Ufo, Aud. 1 "Leon De Meyer"
[Mo.P.1] Plenary 1	09:00	S. Mohamed-Benkadda	
[Mo.P.2] Plenary 2	09:40	S. Mohamed-Benkadda	
[Mo.P.3] Plenary 3	10:50	G. Verdoolaege	
[Mo1.A] Instabilities in Fusion Plasmas	11:40	A. Das	Ufo, Aud. 1 "Leon De Meyer"
[Mo2.A] Fusion Plasma Modelling	14:00	Y. Ono	
[Mo3.A] Energetic Particles and Plasma Heating	16:00	L. Soto	
[Mo1.B] Modelling for Plasma Processing Applications	11:40	C. Leys	Technicum building 2 (T2), Aud. H
[Mo2.B] Technological Applications of Plasmas	14:00	A. Nikiforov	
[Mo3.B] Plasma Applications in Environmental and Agricultural Sciences	16:00	T. Kaneko M. Gromov	
[Mo1.C] Magnetic Reconnection in Space and Astrophysical Plasmas	11:40	R. Sydora	Technicum building 2 (T2), Aud. A "Jean-Norbert Cloquet"
[Mo2.C] Solar Wind and Solar Physics	14:00	S. Van Loo	
[Mo3.C] Numerical Methods and Plasma Modelling I	16:00	L. Soto	
[Mo.P.4] Public-Private Partnerships in Fusion Energy Development	17:50	M. Koepke	Ufo, Aud. 1 "Leon De Meyer"

Tuesday, September 10			
Session	Start time	Chair	Location
[Tu.P.1] Plenary 4	09:00	J. Martinell	Ufo, Aud. 1 "Leon De Meyer"
[Tu.P.2] Plenary 5	09:40	J. Martinell	
[Tu1.A] Bob Dewar Memorial Session	10:40	R. Mackay M. Hole	Ufo, Aud. 1 "Leon De Meyer"
[Tu2.A] Magnetic Reconnection in Fusion Plasmas	14:40	R. Sydora	
[Tu3.A] Spherical Tokamaks	16:00	N. Ohno	
[Tu2.B] Plasma Accelerators I	14:40	B. Bingham	Technicum building 2 (T2), Aud. H
[Tu3.B] Laser-Plasma Interaction I	16:00	K. Sato	
[Tu2.C] Numerical Methods and Plasma Modelling II	14:40	S. Mohamed-Benkadda	Technicum building 2 (T2), Aud. A "Jean-Norbert Cloquet"
[Tu3.C] Nonextensive Plasma Physics	16:00	F. Verheest	
Poster Session 1	14:00	Y. Zhang	Ufo, Foyer

Wednesday, September 11			
Session	Start time	Chair	Location
[We.P.1] Plenary 6	09:00	G. Verdoolaege	Ufo, Aud. 1 "Leon De Meyer"
[We.P.2] Plenary 7	09:40	G. Verdoolaege	
[We.P.3] Plenary 8	10:50	G. Verdoolaege	
[We1.A] Data-Driven Plasma Science I	11:40	M. Hole	Ufo, Aud. 1 "Leon De Meyer"
[We1.B] Laser-Plasma Interaction II	11:40	T. Kaneko	Technicum building 2 (T2), Aud. H
[We1.C] Astrophysical Plasmas I	11:40	S. Van Loo	Technicum building 2 (T2), Aud. A "Jean-Norbert Cloquet"
Excursion	14:30	G. Verdoolaege	

Thursday, September 12			
Session	Start time	Chair	Location
[Th.P.1] Plenary 9	09:00	B. Bingham	Ufo, Aud. 1 "Leon De Meyer"
[Th.P.2] Plenary 10	09:40	B. Bingham	
[Th.P.3] Plenary 11	10:50	M. Narimisa	
[Th1.A] Plasma-Wall Interaction and Plasma-Facing Components	11:40	N. Ohno	Ufo, Aud. 1 "Leon De Meyer"
[Th2.A] Edge-Localized Modes	14:40	K. Sato	
[Th3.A]Tokamak Scenarios and Ignition	16:00	M. Hole	
[Th1.B] Laser Applications	11:40	C. Leys	Technicum building 2 (T2), Aud. H
[Th2.B] Materials Applications	14:40	R. Ghobeira	
[Th3.B] Laser-Plasma Interaction III	16:00	J. Martinell	
[Th1.C] Astrophysical Plasmas II	11:40	A. Das	Technicum building 2 (T2), Aud. A "Jean-Norbert Cloquet"
[Th2.C] Data-Driven Plasma Science II	14:40	G. Verdoolaege	
[Th3.C] Dusty Plasmas	16:00	F. Verheest	
Poster Session 2	14:00	Y. Zhang	Ufo, Foyer
[Th.P.4] RM3FD Interest-Group Meeting	17:40	M. Koepke	Ufo, Aud. 1 "Leon De Meyer"
Conference banquet	19:00	A. Das	Oude Vismijn (Sint-Veerleplein 5)

Friday, September 13			
Session	Start time	Chair	Location
[Fr.P.1] Plenary 12	09:40	Y. Ono	Ufo, Aud. 1 "Leon De Meyer"
[Fr.P.2] Plenary 13	10:50	Y. Ono	
[Fr1.A] Tokamak Physics	11:40	Y. Zhang	Ufo, Aud. 1 "Leon De Meyer"
[Fr1.B] Plasma Accelerators II and Laser-Plasma Interaction IV	11:40	K. Sato	Technicum building 2 (T2), Aud. H
[Fr1.C] Ionospheric Plasmas	11:40	S. Van Loo	Technicum building 2 (T2), Aud. A "Jean-Norbert Cloquet"
Closing Ceremony	12:30	B. Bingham	Ufo, Aud. 1 "Leon De Meyer"

Special session Monday:
Public-Private Partnerships in Fusion Energy Development

Public-private partnerships (PPP) allow large-scale government projects, such as roads, bridges, or hospitals, to be completed with private funding. These partnerships work well when private-sector technology and innovation combine with public-sector incentives to complete work on time and within budget.

A recent rapid increase in private-sector involvement in fusion R&D is a growing global trend with private funding being invested into companies based in Canada, UK, EU, China, Japan, and Australia.

This ICPP 2024 special session on Public-Private Partnerships in Fusion Energy Development takes place on **Monday 9 September 2024**, **17:50-18:50 CEST** in the **plenary room** (Ufo, Aud. 1). PPP programs now exist having the following guiding principles:

- Public- and private-sector organizations must be able to fulfill their own institutional missions while also collaborating in a public-private partnership;
- Promote diversity in science & technology approaches to fusion energy;
- Government acts similar to an investor by selecting a portfolio that diversifies both technical and commercial risk;
- All applicants must devote a meaningful fraction of the total project cost from non-governmental funding sources;
- Flexibilities in contracting terms (including but not limited to intellectual property, data protection, etc.) and reduced reporting and cost accounting requirements.

The assembled panel is populated with subject matter experts who will share perspectives on present and future steps worth considering when capitalizing on the PPP approach.

Start 17:50 CEST

1. Welcome – Mark Koepke, West Virginia University
2. PPP's federal framework and goals – Colleen Nehl, U.S. Department of Energy [remote]
3. PPP's realization and impact within the fusion community's private sector – Andrew Holland, CEO, Fusion Industry Association [remote]
4. PPP plan and promise – Ambrogio Fasoli, Programme Manager, EUROfusion [remote]
5. PPP role in roadmapping high-gain inertial fusion energy development – Peter Norreys, Professor of Inertial Fusion Science, University of Oxford [remote or in-person]
6. PPP for collaboration and innovation benefit – Chris Deeney, Director, Laboratory for Laser Energetics, University of Rochester
7. PPP vision for success in inertial fusion energy – Tammy Ma, Lead for the LLNL Inertial Fusion Energy Institutional Initiative
8. Aspirational highlights, targeted metrics of PPP – Open question
9. Question and answer opportunity

End 18:50 CEST

Special session Thursday: RM3FD Interest-Group Meeting

This ICPP 2024 special session will consist of an informal interest-group meeting to facilitate community engagement, coordinate communication efforts, and build trust among stakeholders in the area of materials for the fusion energy community. It will be held on **Thursday 12 September 2024**, **17:40-18:30 CEST** in the **plenary room** (Ufo, Aud. 1). This session precedes the 19h conference banquet (walking to the banquet involves a 20-minute walk from the Ufo building).

The aim of this open meeting is the recruitment of users, partners, databases, and facilities. This cooperation and/or collaboration will focus on enabling the fusion research community in accelerating the development of fusion energy through the repository, curation, management of materials fundamental data and the effective development and deployment of data-driven methodologies and cutting-edge computational resources.

The desired overall outcome is the creation of a comprehensive data infrastructure, within 3-4 years, that supports fusion energy research by providing federated access to heterogeneous data sources, advanced data processing tools, and integrated workflows for simulation, experimental, and engineering data.

The scope of the fusion data resource includes:

- Development and implementation of a comprehensive network of users and data providers;
- Productive coordination with conference organizers, journal editors, and international programs;
- Two-way communication to customize functionality and minimize response time for users;
- Monitor and report on best practices of tested or adopted methodologies;
- Evolve and refine the infrastructure as the data ecosystem expands and results are interpreted.

We seek a cross-cutting platform and hub aimed at accelerating the transfer of foundational open-science research into fusion energy solutions. Specifically, we want to enable the fusion energy mission by providing community-based solutions for the timely and efficient sharing of information, data, models and workflows between government lab scientists, individuals in academia, and commercialization-oriented teams in private industry.

The resource should (a) provide the data infrastructure and standards that will serve as the "community commons" for the efficient sharing of data, models, workflows and metadata, (b) provide the tools for the rapid discoverability of shared information, including capabilities for data aggregation, curation, analysis and visualization, and (c) provide the application interfaces for the seamless integration of data into user-defined workflows.

Start 17:40 CEST

1. Welcome – Mark Koepke, West Virginia University (FEDER Co-PI)
2. Data Ecosystem and Repository management – Raffi Nazikian, General Atomics (FEDER PI) [remote]
3. Building and operating the Data Ecosystem and Repository – Brian Sammuli, General Atomics (FEDER Co-PI) [remote]
4. Challenges in operating the Data Ecosystem and Repository – Frank Wuerthwein, San Diego Supercomputer Center at University of California-San Diego (FEDER facility partner) [remote]
5. Important features desired by the data community – Open question
6. Aspirational highlights, targeted metrics & foreseen impact within plasma physics – Open question
7. Question and answer opportunity

End 18:30 CEST

Social program

Welcome reception: Sunday, Sept. 8, 18:00 – 20:00

The reception will take place in the Foyer of the main conference building Ufo (Sint-Pietersnieuwstraat 33).

Excursion: Wednesday, Sept. 11, 14:30 – 17:30

Join us for a guided walking tour through the historical city center of Ghent, followed by a boat tour on the rivers and canals.

We will depart from the main conference building Ufo (Sint-Pietersnieuwstraat 33). Please check your badge for your group numbers.

Conference banquet: Thursday, Sept. 12, 19:00 – 23:00

The conference banquet will be held at the “Oude Vismijn” (old fish market), Sint-Veerleplein 5.
Please bring your badge.

Abstracts

Monday
September 9

09:00-09:40. [Mo.P.1] Plenary 1

Towards Digital Twins of Fusion Systems

Frank Jenko (Max Planck Institute for Plasma Physics).

Abstract

With the world's energy needs expected to rise by a factor of at least 4-5 until the end of the 21st century, and all existing options to cover these demands known to be subject to various disadvantages and limitations, fusion energy provides an attractive additional opportunity. As we edge closer to realizing practical fusion power, the integration of advanced computational tools becomes essential. This talk will explore the concept and development of digital twins in the context of fusion systems, highlighting their potential to revolutionize the design, optimization, and operation of fusion reactors.

Digital twins – virtual replicas of physical systems – enable real-time monitoring and simulation, providing a dynamic and predictive insight into system behavior under various conditions. For fusion systems, digital twins can simulate plasma behavior, reactor materials, and subsystems, facilitating enhanced plasma operation and control strategies, thus significantly reducing downtime and operational costs.

The talk will cover the foundational elements required to develop digital twins for fusion systems, including multi-fidelity modeling, data integration, and advanced algorithms for real-time data processing and decision-making. Emphasis will be placed on the challenges unique to fusion systems, such as the complex and highly nonlinear nature of plasma dynamics. Case studies of ongoing projects and collaborations in the fusion research community will be presented to illustrate the practical applications and benefits of digital twins.

The talk will also address future directions, emphasizing the role of artificial intelligence and machine learning in enhancing the predictive capabilities of digital twins. By leveraging these technologies, we can accelerate the path to achieving reliable and economically viable fusion energy.

09:40-10:20. [Mo.P.2] Plenary 2

The Solar Wind and Statistical Properties of Three-Dimensional Hall Magnetohydrodynamics Turbulence

Rahul Pandit (Department of Physics, Indian Institute of Science), Sharad Kumar Yadav (Department of Physics, Sardar Vallabhbhai National Institute of Technology) and Hideaki Miura (National Institute for Fusion Science).

Abstract

The characterization of the statistical properties of solar-wind turbulence is a major challenge in solar plasma physics. Satellite observations have shown that solar-wind-plasma turbulence displays a fluid energy spectrum with an inertial range with a scaling exponent that is consistent with -5/3, which follows from the Kolmogorov hypotheses of 1941 (henceforth K41). By contrast, the magnetic-energy spectrum displays two different scaling ranges (the first and second inertial ranges): (i) the first inertial range is consistent with the K41 power; (ii) the second inertial range is characterised by an exponent that lies in the range[-4,-1]. Furthermore, solar-wind-turbulence has also been analyzed to uncover (a) intermittency and multiscaling of velocity and magnetic-field structure functions and (b) the alignment of velocity and magnetic-field fluctuations. One study has found structure-function multiscaling (simple scaling), in the first (second) inertial range. We examine the statistical properties of three-dimensional (3D) Hall magnetohydrodynamics (HMHD) turbulence by carrying out high-resolution pseudospectral direct numerical simulations. We explore the dependence of 3D HMHD turbulence on the Reynolds number Re and the ion-inertial scale. We present several statistical properties of 3D HMHD turbulence, which we also compare with their counterparts for 3D MHD turbulence and solar-wind turbulence by calculating (a) the temporal evolution of the energy-dissipation rates and the energy, (b) the wave-number dependence of fluid and magnetic spectra, (c) the probability distribution functions of the cosines of the angles between various pairs of vectors, such as the velocity and the magnetic field, and (d) various measures of the intermittency in 3D HMHD turbulence.

Overview and Initial Results of the ICRH Antenna for the Optimized Stellarator Wendelstein 7-X

Jozef Ongena (LPP-ERM/KMS), Ye. O Kzakov (LPP-ERM/KMS), K. Crombé (LPP-ERM/KMS Brussels, Ghent University), D. Hartmann (Max-Planck-Institut für Plasmaphysik), D. Castaño-Bardawil (LPP-ERM/KMS), D. Lopez-Rodriguez (LPP-ERM/KMS, Ghent University), I. Stepanov (LPP-ERM/KMS), M. Verstraeten (LPP-ERM/KMS), M. Vervier (LPP-ERM/KMS), B. Schweer (LPP-ERM/KMS), A. Dinklage (Max-Planck-Institut für Plasmaphysik), T. Fornal (Institute of Plasma Physics and Laser Microfusion), D. Gradic (Max-Planck-Institut für Plasmaphysik), M. Gruca (Institute of Plasma Physics and Laser Microfusion), K. P. Hollfeld (Zentral Institut für Engineering, Elektronik and Analytik-Engineering und Technologie), J. P. Kallmeyer (Max-Planck-Institut für Plasmaphysik), I. Ksiazek (Institute of Physics, Opole University), A. Krämer-Flecken (Institut für Energie-und Klimatforschung/Plasmaphysik), M. Kubkowska (Institute of Plasma Physics and Laser Microfusion), Ch. Linsmeier (Institut für Energie-und Klimatforschung/Plasmaphysik), F. Louche (LPP-ERM/KMS), O. Neubauer (Institut für Energie-und Klimatforschung/Plasmaphysik), D. Nicolai (Institut für Energie-und Klimatforschung/Plasmaphysik), G. Offermanns (Zentral Institut für Engineering, Elektronik and Analytik-Engineering und Technologie), G. Satheeswaran (Institut für Energie-und Klimatforschung/Plasmaphysik), L. Syrocki (Institute of Plasma Physics and Laser Microfusion), M. Van Schoor (LPP-ERM/KMS), R. C. Wolf (Max-Planck-Institut für Plasmaphysik), the TEC team (LPP-ERM/KMS, Institut für Energie-und Klimatforschung/Plasmaphysik), and W7-X team (See author list Sunn Pedersen et al. Nucl. Fusion 62 (2022) 04202).

Abstract

The superconducting stellarator Wendelstein 7-X (W7-X) at the Max-Planck-Institutein Greifswald began operation in 2015. To demonstrate efficient confinement of energetic alpha particles, which will be essential for a future Helias fusion reactor, W7-X requires a population of fast ions with energies ranging from 80 to 100 keV in the core of high-density plasmas. This can be achieved with Ion Cyclotron Resonance Heating (ICRH) using minority heating of H in ^{4}He and D plasmas, as well as the three-ion scenarios of ^{4}He-(^{3}He)-H and D-(^{3}He)-H.

The ICRH antenna for W7-X consists of two poloidal straps. Each strap is terminated by a pre-matching capacitor at one end and short-circuited at the other, with RF power fed at an intermediate position along the straps. The antenna's shape is tailored to match the 3D shape of the Last Closed Magnetic Surface (LCMS) in the standard magnetic field configuration of W7-X, resulting in variable curvature in both toroidal and poloidal directions over the plasma-facing surface [1]. The antenna can also be moved radially up to 35 cm, and a gas puffing system is incorporated to inject gas in the region between the scrape-off layer (SOL) and the LCMS to locally improve coupling. The full system was commissioned on W7-X plasmas in February and March of 2023. During these experiments, only one of the two straps was powered due to a faulty pre-matching capacitor and vacuum feedthrough, resulting in operation with k|| ~0.

Two significant milestones were achieved: operation at high power levels (up to 700kW) and the generation of a target plasma using ICRH alone at magnetic fields below the usual 2.5 T, where the 140 GHz ECRH system is not resonant. In these experiments, the standard magnetic configuration in W7-X was used, the LCMS was positioned 17 cm from the first wall, and the distance between the antenna and the LCMS ranged from 3 to 10 cm. Despite the unfavourable heating conditions, $k_{||}$~0, there was a clear increase in the plasma stored energy at constant electron density, consistent with an increase in ion temperature. The Faraday screen is omitted in this antenna design, based on extensive experience with TEXTOR [2]. No edge interaction was observed. Small levels of Cu and C impurities where observed with VUV and Soft X-ray diagnostics. In plasma start-up experiments at 1.7T, plasmas were sustained for the full duration of the ICRH pulse with approximately 300 kW RF power.

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11:40-12:10 [Mo1.A.I1] Nonlinear Excitation of Energetic-Particle-Driven Geodesic Acoustic Mode by Resonance Overlap with Alfven Eigenmode

Hao Wang (National Institute for Fusion Science), Philipp Lauber (Max-Planck-Institute for Plasma Physics), Yasushi Todo (National Institute for Fusion Science), Yasuhiro Suzuki (Hiroshima University), Hanzheng Li (National Institute for Fusion Science), Jialei Wang (National Institute for Fusion Science), Malik Idouakass (National Institute for Fusion Science) and Panith Adulsiriswad (National Institutes for Quantum Science and Technology).

Abstract

The Alfvén instability nonlinearly excited the energetic-particle-driven geodesic acoustic mode on the ASDEX-Upgrade tokamak, as demonstrated experimentally [1-5]. The mechanism of the energetic-particle-driven geodesic acoustic mode excitation and the mode nonlinear evolution is not yet fully understood. In the present work, a first-principles simulation using the MEGA code [6] investigated the mode properties in both the linear growth and nonlinear saturated phases [7,8]. The simulation parameters and the equilibrium data are based on the realistic experiment, that is shot #34924 of ASDEX-Upgrade at t = 1.9 s. Here we show that the simulation successfully reproduced the excitation and coexistence of these two modes, and agreed with the experimental results well. The mode frequencies of these two modes are about 100 kHz and 50 kHz, respectively. In addition, the simulation reveals a radially inward energetic particle redistribution during mode activities, consistent with the experimental findings. Conclusive evidence showed that the resonance overlap is the excitation mechanism of the energetic-particle-driven geodesic acoustic mode. In the linear growth phase, energetic particles that satisfied different resonance conditions excited the Alfvén instability, which then caused energetic particle redistribution in phase space. These redistributed energetic particles caused resonance overlap, exciting the energetic-particle-driven geodesic acoustic mode in the nonlinear phase. The above process was demonstrated in toroidal canonical momentum P_ϕ and energy E phase space, and the time evolution of energetic particle distribution f_{total} and δf are investigated in detail.

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12:10-12:30 [Mo1.A.O1] Numerical Investigation of Fishbone Instability in Tokamak Plasmas

Alodie Grondin-Exbrayat (Aix-Marseille Université, CNRS), Matteo Faganello (Aix-Marseille Université, CNRS), Nicolas Dubuit (Aix-Marseille Université, CNRS) and Alexandre Poye (Aix-Marseille Université, CNRS).

Abstract

Understanding the transport and losses of particles in tokamaks is crucial for operating future fusion reactors in particular for energetics particles, as they can be expelled before being able to deposit their energy in the tokamak core. Focusing on energetic trapped particles, they can destabilize the so called fishbone instability[1, 2, 3] that finally induces their transport. Indeed, the resonant interaction between the toroidal precessional motion of particles and the low-frequency kink mode [2, 4] leads to a growing fishbone instability in the core of the tokamak. Those energetic particles can be generated by heating systems in D-D experiments, for instance, or correspond to the population of particles with a velocity mainly perpendicular to the ambient magnetic field in D-T experiments. In this work, we first present a model coupling a reduced MagnetoHydroDynamics model in cylindrical geometry, for the thermal plasma, with a kinetic description for the trapped energetic particles. The numerical work takes advantage of reduced MagnetoHydroDynamic code, AMON [5], developed at the PIIM laboratory, to which we added a gyro- and bounce-averaged Vlasov equation for the energetics particles. We ran linear simulations, using a small resistivity and different amounts of energetic particles for investigating the development of the fishbone instability close and far to the threshold [6], checking for the correct growth rate of the mode and the eigenfunction profiles. Non-linear simulations have been performed focusing on the saturation of the fishbone instability and the induced transport, by checking the phase space dynamics of the energetics particles.

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11:40-12:30. [Mo1.B] Modelling for Plasma Processing Applications

11:40-12:10 [Mo1.B.I1] Modelling of Modern Plasma Processing Reactors: Plasma Physics and Surface Chemistry

Igor Kaganovich (Princeton Plasma Physics Laboratory), Yury Barsukov (Princeton Plasma Physics Laboratory), Kallol Bera (Applied Materials, Inc, Santa Clara, USA), Jian Chen (Sun Yat-sen University, Zhuhai, China), Stephane Ethier (Princeton Plasma Physics Laboratory), Sathya Ganta (Applied Materials, Inc, Santa Clara, USA), Sierra Jubin (Princeton Plasma Physics Laboratory), Alexander Khrabrov (Princeton Plasma Physics Laboratory), Andrew Tasman Powis (Princeton Plasma Physics Laboratory), Shahid Rauf (Applied Materials, Inc, Santa Clara, USA), Dmytro Sydorenko (University of Alberta), Haomin Sun (École Polytechnique Fédérale de Lausanne (EPFL)), Sarveshwar Sharma (Institute for Plasma Research, Ahmedabad, India), Liang Xu (Soochow University, Suzhou, China), Abishek Verma (Applied Materials, Inc, Santa Clara, USA), Willca Villafana (Princeton Plasma Physics Laboratory) and Michael Tendler (KTH Royal Institute of Technology, Stockholm).

Abstract

For modern plasma processing, there is a need to perform kinetic simulations of large plasma devices using the particle-in-cell (PIC) technique due to relative ease of implementing the method, and that it can be parallelized effectively over many processors and accelerated on GPUs. At PPPL we have developed two codes EDIPIC-2D and LTP-PIC-3D. EDIPIC-2D is an open-source code that includes features for simulations of practical devices and has been used for modelling of several plasma devices. LTP-PIC-3D is a high-performance scalable PIC code which incorporates best programming practices and multi-level parallelism. This code was upgraded to operate efficiently on the latest CPU/GPU architectures for additional performance improvements. Energy conserving or implicit methods were implemented to speed up simulations [1]. Effects of numerical noise in simulations using PIC code need to be analysed and considered [2]. These codes have been applied to study plasma processing applications, such as capacitively coupled plasmas [3], electron beam produced plasmas [4], inductively coupled plasmas, and hollow cathode discharges. To model surface processes we used a combination of quantum chemistry methods and molecular dynamics [5].

Acknowledgments Supported by the US Department of Fusion Energy Science.

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12.10-12:30 [Mo1.B.O1] Optimization of Electron Cyclotron Resonance (ECR) Plasma Parameters for Enhanced Material Processing Applications

Sunil Swami (Department of Physics, Savitribai Phule Pune University, India), Vikas Mathe (Department of Physics, Savitribai Phule Pune University, India), Sudha Bhoraskar (Department of Physics, Savitribai Phule Pune University, India), Premkumar S. (Armament Research and Development Establishment, India), Supriya More (Research Unit Plasma Technology, Ghent University) and Rino Morent (Research Unit Plasma Technology, Ghent University).

Abstract

Surface modification of polymers is essential for tuning their surface properties, opening a myriad of applications across various technological areas. ECR plasma is one of the technologies used for surface treatment of polymers. However, various ECR plasma system parameters affect the plasma behavior and the plasma energy required to tune the surface of polymers. Therefore, in this study, COMSOL Multiphysics-based Finite Element Analysis [1,2] was utilized to investigate various crucial plasma parameters as a function of microwave power, pressure, and magnetic field strength. Variations in the resonance zone and properties such as ionization rate, electron mobility, mean plasma electrical conductivity, electron temperature, electron density, etc., were predicted. Further, the parameters were experimentally measured [3] and validated. The results demonstrated good agreement with experimental data. This study provides valuable insights for optimizing plasma parameters for various applications of ECR plasma, such as polymer surface modification, surface grafting, and applications in space and biomedical fields.

Acknowledgments I would like to express my sincere gratitude to Mahatma Jyotiba Phule Research and Training Institute, Nagpur, India for their Financial support. Their assistance was crucial in enabling the progress and completion of this work.

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11:40-12:30. [Mo1.C] Magnetic reconnection in Space and Astrophysical Plasmas

11:40-12:10 [Mo1.C.I1] Radiative Relativistic Magnetic Reconnection in Astrophysical Plasmas

Dmitri Uzdensky (University of Colorado Boulder and University of Oxford).

Abstract

Magnetic reconnection – a fundamental collective plasma process of violent reorganization of the magnetic-field topology and associated rapid release of magnetic energy– is ubiquitous in many space and astrophysical plasma environments, powering intense high-energy flares. However, under the extreme physical conditions encountered around neutron stars and black holes, reconnection takes place in an exotic radiative relativistic regime, where particles energized by magnetic-energy release to relativistic energies emit copious amounts of synchrotron and/or inverse-Compton radiation. The resulting radiative losses feedback on the reconnection process, altering its dynamics and energetics and suppressing nonthermal particle acceleration. Under even more extreme conditions, QED processes like pair creation come into play, leading to a nontrivial self-regulating regime where the reconnection layer creates its own plasma. In this talk I will review the recent advances in our understanding of this fascinating radiative relativistic reconnection regime made possible by novel first-principles radiative-QED particle-in-cell numerical simulations in combination with analytical theory.

12:10-12:30 [Mo1.C.O1] Subsonic Shock Waves in Reconnection Jets

Kuldeep Singh (Khalifa University of Science & Technology, Abu Dhabi), Frank Verheest (Sterrenkundig Observatorium, Ghent University) and Ioannis Kourakis (Khalifa University of Science & Technology, Abu Dhabi).

Abstract

The Magnetospheric Multiscale Spacecraft (MMS) identified electrostatic solitary wave (ESW) signatures associated with localized bipolar electric field pulses in there connection jet region located in Earth's magnetotail [1]. Those observations unveiled the presence of two counter streaming ion (proton) beams and hot electrons [1], thus suggesting a possible link between the generation of nonlinear waves and counterpropagating cold ion beams within the jet. ESW observed in the magnetosphere [2] are known to be affected by energetic particles, a common occurrence in various Space environments and in particular in the solar wind, associated with long-tailed non-Maxwellian distributions [3].

Inspired by the above observations [1] and following up on subsequent studies [4-5],we have developed a three-component plasma model consisting of two counterstreaming proton beams and suprathermal electrons, in order to investigate the occurrence of electrostatic waves in the Earth's reconnection jet region. A thorough study reveals a number of possibilities, including predictions of subsonic pulse-shaped solitary waves -associated with the slow ion-acoustic mode- occurring only at a certain threshold in the beam speed (value)[6]. Subsonic shock-shaped structures have also been shown to exist in the presence of weak dissipation [7]. Subsonic electrostatic excitations are not possible in the absence of a beam.

Acknowledgments Authors KS and IK acknowledge financial support from Khalifa University's Space and Planetary Science Center under grant No. KU-SPSC-8474000336. KS and IK also thank KU for support via grant CIRA-2021-064/8474000412.

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14:00-14:30 [Mo2.A.I1] Momentum Balance and Energy Exchange in Gyrokinetic Turbulent Systems

Hideo Sugama (National Institute for Fusion Science), Tetsuji Kato (Graduate School of Frontier Science, The University of Tokyo) and Tomo-Hiko Watanabe (Department of Physics, Nagoya University).

Abstract

Gyrokinetics is a powerful theoretical framework based on which a large number of analytical and numerical studies on microinstabilities and turbulent processes in magnetized plasmas have been done. This work consists of two parts of our recent theoretical and simulation studies on gyrokinetic turbulence. In the first part, a variational principle is used to derive governing equations of electromagnetic turbulent gyrokinetic plasma systems with conservation properties favorable for long-time global gyrokinetic transport simulation of high beta plasmas. Then, the invariance of the Lagrangian of the system under an arbitrary spatial coordinate transformation is used to derive the local momentum balance equation in which effects of collision and source terms are included [1]. In a way analogous to the derivation of the energy-momentum tensor in the theory of general relativity, the variational derivative of the Lagrangian density with respect to the metric tensor is taken to directly obtain the symmetric pressure tensor which describes both collisional and turbulent momentum transport processes. The derived symmetric pressure tensor is useful for treating momentum conservation in symmetric magnetic configurations. In the second part, the effects of turbulence on energy exchange between electrons and ions are investigated. Although the effect of turbulent energy exchange has not been considered significant in previous studies, it is anticipated to have a greater impact than collisional energy exchange in low collisional plasmas such as those in future fusion reactors. It is shown from gyrokinetic simulations that the energy exchange due to the ion temperature gradient (ITG) turbulence mainly consists of the cooling of ions in the grad B-curvature drift motion and the heating of electrons streaming along a field line [2]. The ITG turbulence transfers energy from ions to electrons regardless of whether ions or electrons are hotter, which is in marked contrast to the energy transfer by Coulomb collisions. This implies that the ITG turbulence should be suppressed from the viewpoint of sustaining the high ion temperature required for fusion reactions since it prevents energy transfer from alpha-heated electrons to ions as well as enhancing ion heat transport toward the outside of the reactor. Furthermore, linear and nonlinear simulation analyses confirm the feasibility of quasilinear modeling for predicting the turbulent energy exchange in addition to the particle and heat fluxes.

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14:30-14:50 [Mo2.A.O1] Magnetized Plasma Experiment on Layering and Inhomogeneous Mixing in an Evolving Vortex Lattice: Melting Staircases

Richard Sydora (University of Alberta, Canada), Thomas Simala-Grant (University of Alberta, Canada), Fredy Ramirez (University of California, San Diego), Patrick Diamond (University of California, San Diego) and Shreekrishna Tripathi (University of California, Los Angeles).

Abstract

The phenomena of layering in turbulent mixing processes is observed in a variety of physical systems, including magnetically confined plasmas. In this case, layering is connected with the so-called **E**x**B** staircase, which is a series of mixing zones interspersed by shear layer mini-barriers. Staircase formation can result from inhomogeneous mixing. This basic experiment addresses some of the key questions in layering and staircase dynamics, such as deviation from marginality and the percolation of density and thermal mixing.

In this work, we investigate layering and staircase dynamics using a melting vortex lattice (or fluctuating cellular array), which intrinsically drives inhomogeneous mixing [1]. To accomplish this, a vortex array is created in a large linear magnetized plasma device (LAPD) that is designed to have a system of tangent eddies, thus forming a staircase structure which can exhibit "melting" through the interaction of neighboring cells in the lattice. To create the vortex lattice in the LAPD experiment, a smaller lanthanum hexaboride (LaB6) cathode source is placed at the opposite end of the device relative to the main discharge large area LaB6 cathode. A carbon mask containing a patterned array of holes is placed in front of this smaller cathode. When this smaller cathode is biased to a mesh anode in front of the main discharge cathode, a stream of electrons flows through the lattice of holes in the mask and current channels are created in the pattern of the mask. The lattice of filaments that form has finite axial extent and the filament length is controlled by adjusting the magnitude of the biasing voltage. The initial experiments were carried out using a 3x3 square lattice of cells. Langmuir probes were used to make cross-field planes of density, temperature, and plasma potential.

The results indicate the establishment of a dynamical vortex lattice with local and global vortical azimuthal and axial flows. In the near field region of the lattice, the local plasma potential forms a well, which induces **E**x**B** differential rotation of the lattice resulting in azimuthally symmetric inhomogeneous boundary layers that are on the scale of the gaps in the initial lattice structure. A series of mixing layers is interspersed with the boundary layers and cross-field diffusion begins to reduce the gradients. A spectral analysis of the gradient-driven fluctuations and their relation to the diffusivity, as well as the coupling of this spinning lattice structure to the background plasma will be presented.

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14:50-15-10 [Mo2.A.O2] Developments and Preliminary Applications of Tokamak Magnetohydrodynamic Codes

W Guo (ASIPP).

Abstract

MHD instabilities are of considerable fundamental and practical importance for magnetic fusion plasmas, since they are believed to set limits on the achievable plasma pressure and current density, sometimes even leading to the termination of the plasma discharge. An eigenvalue and an initial value MHD codes in toroidal geometry have been developed to facilitate the related numerical investigations in understanding MHD stability in tokamak plasmas, since the exact solutions are impossible to analytically obtain due to the complexity of toroidal geometry.

A new full MHD eigenvalue code SCELT (Symbolic Computation aided Eigenvalue and Linear code for Tokamak) has been constructed by utilizing the symbolic computation technique for the first time [1]. A symbolic vector analysis module is first developed to conduct the automatic derivation of the tedious linearized full MHD equations in the magnetic flux coordinate system. And an automatic numerical discretization module is developed to implement the automatic numerical discretization. The reliability of the new full MHD eigenvalue code developed with help of these two modules is verified by the internal kink mode and tearing mode tests. This new method has the advantage to dramatically reduce the manpower and to avoid possible errors in code development. The feasibility and advantage of the methodology also has been further demonstrated by solving the more difficult challenge of MHD continua, i.e. global Geodesic Acoustic Modes (GAM), which ordinarily come with spatial singularities [2].

Also, a new initial value full MHD code using discontinuous Galerkin (DG) and Weighted Essentially Non-Oscillatory (WENO) methods has been developed to solve the conservative perturbed MHD equations in toroidal geometry [3]. A triangular mesh based on the flux of the fixed boundary equilibrium in the poloidal plane and a uniformly division in toroidal direction were adopted during the code development. The code was linearly tested by performing the linear calculations of the internal kink mode and tearing mode. Nonlinear simulations of the resistive internal kink mode and tearing mode are also carried out.

Acknowledgments This work is supported by the National Natural Science Foundation of China under Grant Nos. 12075282 and 11775268. The numerical calculations in this paper were performed on ShenMa High Performance Computing Cluster in Institute of Plasma Physics, Chinese Academy of Sciences and Hefei Advanced Computing Center.

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15:10-15:30 [Mo2.A.O3] Plasma Boundary Simulations of Limiter Ramp-up Phase of ITER

Arzoo Malwal (Institute for Plasma Research), Devendra Sharma (Institute for Plasma Research) and Richard A. Pitts (ITER Organization).

Abstract

The vast majority of ITER plasma boundary simulations have focused on the divertor phase since it is under these conditions that the principal plasma performance objectives will be achieved. However, as in all tokamaks, every ITER plasma pulse will have to pass through a current ramp-up phase, which, in common with many devices will take place in ITER in limiter configuration on the central column[1]. As for the rest of the main chamber first wall (FW), the central column will consist of FW panels (FWP) protecting the blanket shield blocks, with each panel shaped toroidally to ensure protection of leading edges between adjacent panels. This shaping leads to localized power deposition due to magnetic field line shadowing. Analysis based on 3D field line tracing coupled with a very simple, non-dissipative description of the scrape-off layer (SOL) parallel heat flow profile, $q_{||}(r)$ has shown that under some conditions (depending on plasma current, heating power and the degree of radial misalignment between FWP's), heat loads during the limiter ramp-up can approach, or even exceed the stationary values for which the panels are rated.

Given the potential for FWP power flux overload, it is important to assess the degree of conservatism introduced by the simplified SOL model employed in field line tracing study. A first step in such an assessment is reported here in which a 3D plasma transport study is performed using the coupled plasma-neutral transport code EMC3-Eirene, taking into account the full 3D FW CAD geometry from which an appropriate EMC3-Eirene numerical grid is constructed and a large enough portion of the full torus is simulated to fully capture all shadowing effects. Radial profiles of transport coefficients are chosen such that $q_{||}(r)$ at the outside midplane (OMP) closely follows the double exponential profile used to determine the optimum FWP toroidal shaping [1,2]. First simulations are reported for a fixed, slightly elongated magnetic equilibrium at I_p~2 MA, B_T= 5.3 T with varying SOL input power and OMP separatrix density, chosen on the basis of DINA code ramp-up simulations. These are similar parameter sets to those chosen for a companion 2D SOLPS-ITER study of ITER limiter start-up, though this latter work includes impurity evolution from the limiter surface, while there the focus is on pure hydrogen simulations. The key first conclusion from this work is that at the low densities (and hence high SOL Te) required for limiter start-up on ITER, dissipation due to hydrogenic radiation alone is negligible and the EMC3-Eirene deposited power distributions are similar to those obtained from the simple field line tracing approach. To provide a more quantitative assessment of the real reduction in power loading to be expected compared with the simple engineering treatment will require impurity release and transport to be included.

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14:00-14:30 [Mo2.B.I1] Study of an Atmospheric Gliding Arc Discharge for Sustainable Nitrogen Fixation into NOx

Rony Snyders (University of Mons).

Abstract

Nowadays, plasma-assisted nitrogen fixation (NF) processes have been demonstrated as a highly promising alternative to the environmentally impacting Haber-Bosch process. Therefore, the community develops numerous attempts to optimize these processes in term of energy cost and yield. Among the various plasma technologies, atmospheric gliding arc plasmas (GAP) is found to suit well thanks to their warm feature and the significant molecular vibrational excitation they allow. In this contribution, we overview our recent experimental efforts to contribute towards a better understanding of this plasma technology for nitrogen fixation into NO_x.

In this context, the present work will specifically evaluate a gliding arc plasma operating with $N_2$and O_2at atmospheric pressure and more precisely on the study of the electrical (arc) stability of the process, and on the resultant benchmarking of the plasma-based nitrogen fixation process from a techno-economic perspective.

Considering the electrical stability of the studied process, the conventional approach of introducing external resistors to stabilize the arc is challenged by studying both the performance and the stability of the plasma replacing the external resistor with an inductor. From this work, we conclude that similar stabilization results can be obtained while significantly lowering the overall energy cost, which decreased from up to a maximum of 7.9 MJ/mol N to 3 MJ/mol N. Then, considering these results, we evaluate to which extent a hypothetical small-scale fertilizer production facility based on a rotating gliding arc plasma for nitrogen fixation can be a local competitive alternative for the Haber-Bosch process. This is done by proposing a comparative model to understand how capital expenditures, gas price, CO2 allowances, levelized cost of energy, and transport costs affect the fertilizer production costs. The model highlights how, with the current best available technology, plasma-based nitrogen fixation, while being an interesting alternative for the synthesis of NO_x, still requires a more efficient use of $H_2$for a direct production of NH_3.

Acknowledgments This research is supported by the FNRS project “NITROPLASM”, EOS O005118F.

14:30-14:50 [Mo2.B.O1] Impulse Measurements in a Pulsed Micro-Energy Propulsion System for Nanosatellites

Leopoldo Soto (Chilean Nuclear Energy Commission), Camilo Vásquez-Wilson (Universidad Adolfo Ibáñez), Cristian Pavez (Chilean Nuclear Energy Commission), José Moreno (Chilean Nuclear Energy Commission), Jalaj Jain (Chilean Nuclear Energy Commission), Biswajit Bora (Chilean Nuclear Energy Commission), Marcos Díaz (Universidad de Chile), Felipe Asenjo (Universidad Adolfo Ibáñez) and Luis Altamirano (Dicontek Ltda.).

Abstract

In this work, miniaturized Plasma Focus (PF) technology, based on scaling laws for PF devices, is utilized to design and construct a pulsed plasma thruster for CubeSat nanosatellites. After the pinch phase in PF devices, a plasma shock appears, traveling at speeds of approximately 10^5m/s, independent of the energy of the device. The ejected mass scales with the energy of the device; for a device operating at 400 J, the ejected mass is approximately 10^{-10} kg [1].Theoretical estimations suggest that a pulsed plasma thruster (PPT) based on PF technology, operating at 1 J, will generate impulses ranging from fractions of μNs to several μNs per pulse [2].

It is important to note that while PF devices operate at millibar pressures, a PPT operates in orbit under vacuum conditions, where plasma is generated through the ablation of insulating material, typically PTFE.

A pulsed plasma thruster was constructed using a small capacitor of 1.5 μF, 2 kV (3 J stored energy), with dimensions of 50 mm x 45 mm x 30 mm and a weight of 115 g. This capacitor is charged using a voltage multiplier rated at 6 W, Vin = 12 V, Vout = 2 kV, with dimensions of 57mm x 28 mm x 12 mm and a weight of 37 g. The plasma gun weighs approximately 2 g. Consequently, the total weight and volume of the PPT system are around 150 g and 100 cm^3. To measure the impulse, a new thrust stand based on a single-point load cell was developed. The calibration of the load cell, along with the associated electrical signals and PPT assembly, is analyzed.

Acknowledgments This work is supported by ANID FONDECYT Regular 1211695.

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14:50-15:10 [Mo2.B.O2] Synthesis of Polystyrene Nanoparticles via a Gas Aggregation Cluster Source

Jasna-Tinea Jelinek (Ghent University), Maryam Nilkar (Ghent University), Zdeněk Krtouš (Charles University), Ondřej Kylián (Charles University), Rino Morent (Ghent University) and Nathalie De Geyter (Ghent University).

Abstract

Due to their unique properties, polymer nanoparticles (PNPs) have found their application in photonics, drug delivery, sensing, environmental remediation, and more. Numerous chemical methods have been developed for their synthesis, which normally require the use of solvents, are time-consuming, and costly. Therefore, there is still a need for environmentally sustainable, efficient, and time-saving methods for the synthesis of PNPs [1]. One such method is magnetron sputtering, a quite straight-forward process with high deposition rates, yielding nanoparticles of very high purity, and allowing the tailoring of particle size distributions [2]. However, despite the high potential of this method in developing PNPs, most existing studies have primarily focused on the production of metal nanoparticles. To address this gap, we present, for the first time, the solvent-free synthesis of polystyrene (PS) nanoparticles via a radiofrequency (RF) magnetron-based gas aggregation cluster source (GAS).

A PS target with a 81 mm diameter and 4 mm thickness is bombarded by high-energy plasma species, mainly ions, leading to the ejection of atoms, molecules, or molecular fragments from the target. The ejected species then travel and condense onto surrounding surfaces [2]. The PNPs were synthesized under constant pressure of 164 Pa in the aggregation chamber and a constant flow of 40 sccm of argon with a reaction time of 30 minutes. The effect of power on the PNPs' characteristics was investigated across a range of power levels: 40, 60,and 80 W. The PNPs synthesized at lower power (40 W) exhibited spherical morphology with a diameter of approximately 100 nm, while higher powers (60 and 80 W) led to a cauliflower-like morphology marginally larger than the 40 W particles. Despite variations in morphology, Fourier-transform infrared (FT-IR) spectroscopy revealed a consistent preservation of the aromatic structure, evidenced by characteristic vibrational modes of the styrene ring with the out-of-plane bending vibration at 669 cm-1, C-C in-plane stretching [3], and various vibration bands associated with symmetric C-H stretching vibration of the methyl group (-CH3) at 2871and 2958 cm^{-1}, indicating substantial branching of the polymer [4]. For further comprehensive analysis, X-ray photoelectron spectroscopy (XPS) will be employed to provide insight into the elemental composition of the PNPs. Due to particles appearing transparent in the images obtained from scanning electron microscopy (SEM), ultraviolet-visible (UV-VIS) spectroscopy will also be performed to elucidate optical properties and the potential application of the synthesized PNPs in optoelectronic devices.

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15:10-15:30 [Mo2.B.O3] Population Dynamics of Charged Particles in EUV and EUV Induced Plasma

Manis Chaudhuri (ASML), Luuk Heijmans (ASML), Andrei Yakunin (ASML) and Mark Van de Kerkhof (ASML).

Abstract

Particle contamination control for particles down to submicron sizes is a crucial aspect of semiconductor processing and etching technologies. In recent times this aspect has also become crucial for the lithographic patterning process with the introduction of extreme ultraviolet (EUV) lithography which uses highly energetic EUV photons (13.5 nm, 92 eV). One of the side effects of this development is the generation of EUV-induced plasma due to the interactions of highly energetic EUV photons with low pressure (1–10 Pa) background hydrogen gas. The lithography machines operate in pulsed mode with EUV pulses of < 100 ns in every 20 µs. The spatial and temporal evolution of the EUV induced plasmas has been investigated using 3D particle-in-cell (PIC) model. This shows the EUV light beam creating the plasma in < 100 ns (Fig.1a), whereafter it spreads and decays in the remaining 19.9 µs afterglow (Fig. 1b). This also impacts the particle contaminants: they become positive within the EUV beam due to the photoelectric effect and they become negative outside and after the beam passage due to EUV-induced plasma. The location of charged particles during the EUV pulse and in the afterglow is shown below in Fig. 1(c-d) . The multi-pulse population dynamics of charged particles is shown in Fig. 1e. This shows a peaked increase in positive particle population during every EUV pulse and a steady increase of negative particle population during multiple afterglows.

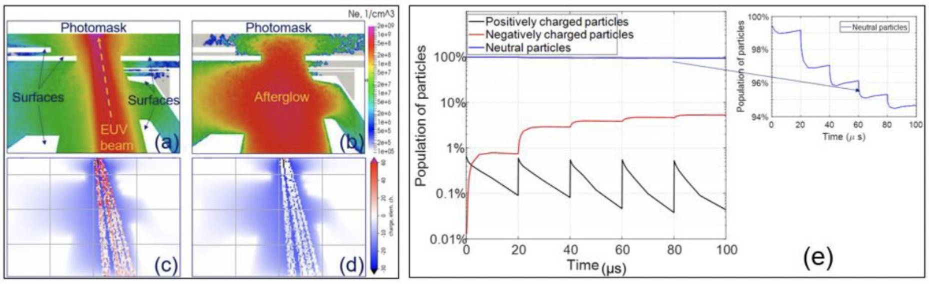

Figure 1 Spatial distribution profile of electron density at Reticle Mini-Environment within ASML lithography machine is shown (a) within EUV pulse (< 100 ns) and (b) after pulse (100 ns - 20 µs) in the afterglow condition.(c-d) The typical population characteristics of 100 nm charged (positive: red and negative: blue) particles are shown in the two regimes mentioned in (a-b). For multi-pulse scenario, the population dynamics of charged and neutral particles are shown in (e). The population of neutral particle decreases over time at the expense of negatively charged particle generation. However, the population of positively charged particle remains steady over time.

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14:00-14:20 [Mo2.C.O1] Quantifying the Expanding and Cooling Effects into the CGL Evolution Through the Expanding Box Model [online]

Sebastián Echeverría-Veas (Universidad de Chile), Pablo S. Moya (Universidad de Chile), Marian Lazar (KU Leuven & Ruhr University Bochum), Stefaan Poedts (KU Leuven & University of Maria Curie-Skłodowska) and Felipe Asenjo (Universidad Adolfo Ibáñez).

Abstract

One of the fundamental problems in space physics is the solar wind expansion and its interaction with different physical processes, e.g., collisions, wave turbulence or self-generated instabilities, conditioning the plasma dynamics. The expansion of the solar wind has been commonly described by the double adiabatic invariants or CGL theory [1], including the approach with the so-called Expanding Box Model (EBM) [2,3]. Despite the contributions made in the last decades, much remains to be understood and a realistically model, which includes plasma cooling and heating effects due to expansion concurring with other physical processes, is still an open problem. Our study introduces a new theoretical formalism to solve the CGL equations in an expanding framework, a significant step towards understanding what the expansion of the plasma entails but also what it implies. Our primary objective is to isolate the expanding effects and how they affect the conservation of double adiabatic invariants, the key aspect of the CGL theory.

To address the plasma expansion, we employed the Expanding Box Model transformations coupled with the ideal-MHD formalism used for CGL theory. This model provides a unique system of reference co-moving with the solar wind, allowing for the incorporation of transverse expansion into the double adiabatic equations. By following the same approximations and assumptions as in EBM and CGL theory, we developed a CGL-like description in which the expansion modifies the conservation of the double adiabatic invariants. Our results show that the double adiabatic equations are no longer conserved if plasma cooling is introduced through the EBM, with explicit dependence on expanding parameters, magnetic field profiles, and velocity gradients. Solving the equations for different magnetic field and density profiles (obtained self-consistently through the equations), we compute the evolution of anisotropy and plasma beta, which deviates from CGL predictions and empirical observations [4]. This deviation is attributed to the plasma cooling effect induced by the Expanding Box Model. Results suggest that heating mechanisms play an even major role in counteracting plasma cooling during expansion.

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14:20-14:40 [Mo2.C.O2] A 22-Year Cycle of the Network Topology for Solar Active Regions

Alejandro Zamorano (Universidad de Chile), Eduardo Flández (Universidad de Chile) and Victor Muñoz (Universidad de Chile).

Abstract

In this work solar cycles 21 to 24 were studied using complex network analysis. A network was constructed for each of the four solar cycles, where the nodes correspond to the active regions of the Sun that emanate flares, and on the other side, the connections correspond to the time sequence of solar flares. A similar network construction method is found in Ref. [1], following previous analyses for earthquake networks [2, 3]. In this way, we have constructed a directed network where we have also allowed self-connections. We calculate the incoming degree for each node, and subsequently the degree distribution, finding that for each solar cycle, the degree distribution obeys a power law, suggesting a preference of flares to appear in correlated active zones. Additionally, we found a variation in the characteristic exponent for each cycle, being higher in the even cycles than in the odd cycles. By means of a more detailed analysis based on moving 11-year networks, we find that the characteristic exponent varies with a period of approximately 22 years [4], which suggests that complex networks may provide information about the Hale cycle [5].

Acknowledgments This research was funded by FONDECyT grant number 1242013 (V.M.), and supported by ANID PhD grant number 21210996 (E.F.) and ANID PhD grant number 21231335 (A.Z). We are grateful to SDO Data supplied courtesy of the SDO/HMI consortia. We also thank to Space Physics Data Facility, NASA/Goddard Space Flight Center.

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16:00-17:40. [Mo3.A] Energetic Particles and Plasma Heating

16:00-16:30 [Mo3.A.I1] Alpha-Particle Physics Studies in D-3He Plasmas at JET and JT-60SA in Support of ITER Rebaseline

Yevgen Kazakov (LPP-ERM/KMS), Jeronimo Garcia (CEA, IRFM), Massimo Nocente (Dipartimento di Fisica, Università di Milano-Bicocca), Rui Coelho (Instituto de Plasmas e Fusão Nuclear, Lisbon), Shunsuke Ide (National Institutes for Quantum Science and Technology (QST), Naka Fusion Institute), Vasily Kiptily (United Kingdom Atomic Energy Agency, CCFE), Jef Ongena (LPP-ERM/KMS), Hajime Urano (United Kingdom Atomic Energy Agency, CCFE), Maiko Yoshida (United Kingdom Atomic Energy Agency, CCFE), JET contributors (See author list of Maggi et al. to be published in Nuclear Fusion Special Issue from the 29th Fusion Energy Conference) and the EUROfusion Tokamak Exploitation Team (See author list of Joffrin et al. to be published in Nuclear Fusion Special Issue from the 29th Fusion Energy Conference).

Abstract

Mixed D-^{3}He plasmas provide an opportunity to generate alpha particles with birth energies of 3.6 MeV without using tritium in a fusion device. The cross-section of the D-^{3}He fusion reaction peaks at deuterium energies of ~450 keV. Recently, in preparation for alpha particle diagnostics in the DTE2 and DTE3 campaigns, dedicated alpha particle experiments were conducted at JET [1]. These experiments utilized a combination of ICRF and NBI heating systems to generate the necessary high-energy deuterons. The resulting alpha production rate of ~1-2x$10^{16}s^{-1}$enabled not only high-quality measurements of alpha particles [2], but also the observation of plasma instabilities driven by fusion-born alphas [3].

JT-60SA, the world-largest superconducting tokamak, will play a crucial role in supporting ITER and DEMO. It is equipped with a powerful NBI system, including both P-NBI and N-NBI, capable to deliver fast deuterons with energies up to 500 keV [4]. These characteristics make JT-60SA ideal for alpha-particle experiments in D-^{3}He plasmas(there will be no tritium in JT-60SA to explore D-T fusion-born alphas), similar to those conducted at JET with a combination of P-NBI and ICRF systems. Following the closure of JET, JT-60SA is currently a unique tokamak for experimental studies of MeV-range fast ions and their impact on plasma confinement in large-scale tokamaks.

This proposed talk will first discuss recent JET experiments in D-^{3}He plasmas, designed to prepare for future comparison experiments at JT-60SA. Specifically, in some of JET pulses discussed in this contribution, fast ions were deliberately generated off-axis, simulating the conditions expected with N-NBI ions at JT-60SA. We will proceed with discussing modeling results for a dedicated fast-ion scenario for alpha-particle studies in JT-60SA plasmas. The modeling shows that an alpha production rate of approximately 2-3x$10^{16}s^{-1}$can be achieved with the high-power N-NBI system on JT-60SA at moderate ^{3}He concentrations of 10-15%, surpassing the alpha production rate observed in D-^{3}He plasmas on JET. The talk will conclude with a discussion on how future fast-ion experiments at JT-60SA can support the ITER rebaseline [5], particularly the development of alpha-particle diagnostics. This is a complex task, as most efforts have focused on exploiting alpha particle measurements using nuclear reactions between alpha particles and ^{9}Be impurities. Due to the recent ITER decision to use a full-W wall, a new technique must be developed. We will present a proposed solution and explain how JT-60SA can contribute to this development.

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16:30-17:00 [Mo3.A.I2] Fuel Supply and Helium Ash Exhaust in Gyrokinetic Flux-Driven ITG/TEM Turbulence

Kenji Imadera (Kyoto University), Mikiya Muto (Kyoto University), Masatoshi Yagi (National Institutes for Quantum Science and Technology), Yasuaki Kishimoto (Kyoto University) and Akihiro Ishizawa (Kyoto University).

Abstract

Establishment of a refuelling method is an important issue for controlling nuclear fusion reactors. But, in DEMO-class high-temperature plasmas, a pellet injection reaches only up to 80-90% of the minor radius so that the central density peaking depends on particle pinch, making the prediction difficult. While turbulent particle transport has been studied based on local gyrokinetic models, it is also important to study global physics including the mean flow and the related neoclassical process. The global simulation is also meaningful to investigate impurity transport [1, 2] such as core Helium ash exhaust and edge impurity accumulation.

Based on this motivation, we perform flux-driven ITG/TEM simulations in the presence of ion/electron heating by means of the full-*f* electrostatic version of our global gyrokinetic code GKNET with a hybrid kinetic electron model [3]. This version enables us to precisely consider the self-consistent mean E_r determined by the radial force balance with the pressure and poloidal/toroidal flow profiles controlled by external source and sink. The global gyrokinetic ambipolarity condition can be also precisely treated so that we can investigate the physical mechanism of particle transport caused not only by non-axisymmetric ***ExB*** drift but also by axisymmetric ***ExB*** and magnetic drifts which is responsible for the interactions between turbulent and neoclassical transport.

It is found that ion heating can drive turbulent ion particle pinch by ***ExB*** drift ($n\neq 0$) because the negative thermo-diffusion term becomes dominant. Turbulent electron particle pinch is also driven in the case with electron heating. Such an electron particle pinch can trigger an ambipolar field, leading to up-down asymmetric density perturbations and resultant ion particle pinch by not only magnetic drift but also ***ExB*** drift ($n= 0$) [4]. It suggests that a density peaking of bulk ions due to turbulent fluctuations can be achieved by sufficiently strong both ion and electron heating. It also implies that a scale separation between neoclassical and turbulent transport process is not satisfied and their interactions become essential, when the macroscopic structure changes on a turbulence time scale shorter than a collision time scale. We also perform flux-driven ITG/TEM simulation for deuterium, helium, electron and find that both helium ash exhaust and fuel supply can be achieved simultaneously by the similar mechanism discussed above.

In this talk, we will report the heating condition as well as the interaction between helium and bulk ion and electron transport in details.

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17:00-17:20 [Mo3.A.O1] Alpha Particle Confinement with Magnetic Perturbations from Guiding Center and Full Orbit Simulations

Julio Martinell (Institute For Nuclear Sciences, National Autonomous University of Mexico) and Leopoldo Carbajal (Type One Energy).

Abstract

Fusion-produced alpha particles have to be well confined in order to maintain the plasma at thermonuclear temperatures. But the presence of magnetic perturbations which can be produced by instabilities of various kinds, modify the magnetic structure of the confinement device and hence the transport properties of fast particles. In previous works we have analyzed the transport of fast ions across the region where a magnetic island is present comparing the predictions from a guiding center description and the full orbit ion trajectory [1]. That study was limited to the ion energies in the range of NBI heating, from 10 to 50 keV and it was found that the full orbit outflows are larger than those predicted by guiding center transport [2]. In this work we study the transport of alpha particles with birth energies in the MeV range. The alphas are born in the plasma center and cross an island chain located at about the mid-radius. The analysis is done using a guiding center code (GCAF) and the full orbit code (KORC) for the case of a mid-size tokamak. Resonance effects are found to be important for the particles to cross the island region, regarding the island width and the particle Larmor radius. In addition, for rotating islands, the rotation frequency has a resonant effect on the particle flow when it is of the order of the transit frequency or the trapping frequency. The study with the guiding center code is also applied to the case of a stellarator with single helicity in order to estimate the non-axisymmetric effects on the transport.

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17:20-17:40 [Mo3.A.O2] Development and Basic Studies on the Cs-Free Negative Hydrogen Ion Source TPDsheet-U

Kohnosuke Sato (Tokai University), Kaito Miura (Tokai University), Naonori Okada (Tokai University) and Akira Tonegawa (Tokai University).

Abstract

The progress has been reported [1-3] toward realizing a high-performance caesium (Cs)-free negative-ion source based on volume production in the magnetized sheet plasma device TPDsheet-U. In the experiments, H−ions have been successfully extracted from sheet plasma by using single-aperture grids when argon gas is added to hydrogen plasma at the external magnetic field strength of 38 mT. The experimental results with the single-aperture grid show that the performance of negative hydrogen ion current density (JC(H-)) of Cs-free H− ion beam in TPD sheet-U is about one-fourth of that of Cs-containing H− ion sources in the negative-ion neutral-beam injector for ITER (NNBI) [4]. (i) The JC(H-) was ~7.5 mA/cm2 at an extraction voltage of 10 kV, a discharge current Id of 90 A, and a gas pressure of 0.3 Pa without argon. (ii) Co-extracted electrons JEG(e) are successfully suppressed by setting a soft magnetic filter (SMF) on plasma grid. The JEG(e)/JC(H-) ratio has been reduced to below 1.0 for a single-aperture grid with the SMF.

The basic studies have been carried out extensively in order to understand the mechanisms of volume production of H−ions in the magnetized sheet plasma and its dependences on gas pressure, magnetic field strength and grid structures.

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16:00-17:10. [Mo3.B] Plasma Applications in Environmental and Agricultural Sciences

16:00-16:30 [Mo3.B.I1] Steam Thermal Plasma for Turquoise Hydrogen Production

Alan Maslani (Institute of Plasma Physics of the Czech Academy of Sciences), Jafar Fathi (Institute of Plasma Physics of the Czech Academy of Sciences), Michal Hlina (Institute of Plasma Physics of the Czech Academy of Sciences), Vineet Sikarwar (Institute of Plasma Physics of the Czech Academy of Sciences) and Maksym Buryi (Institute of Plasma Physics of the Czech Academy of Sciences).

Abstract

Thermal plasma offers great opportunity for processing of wide range of materials. For instance, different wastes can be efficiently decomposed into individual elements and as a result, valuable products can be obtained. One of such products is hydrogen, which is abundant in principle everywhere, its efficient large-scale production is inevitable for industry or as a fuel, but at the same time hydrogen production is still considered as a challenge. Indeed, hydrogen technologies are a very rapidly evolving field and there is a great demand for alternative methods of hydrogen production. At present, most hydrogen is produced with CO_2as a by-product, namely by fossil fuels reforming. The fossil reserves of hydrocarbons/methane/natural gas are still huge, but their processing by currently used methods is apparently unsustainable. Research teams and petrochemical companies around the world are working intensively on this issue, and new technological solutions can be expected in the near future. In general, we can see in every day's life that the way in which energy is produced and used changes fundamentally.

This contribution presents the overview of the research related to the production of hydrogen from methane (or natural gas) and other hydrocarbons using thermal plasma. The hydrogen produced this way is categorized as a turquoise hydrogen and can be considered as a complementary to the well-known green and blue hydrogen production ways [1]. Produced hydrogen is characterized by high purity and at the same time we address the possibility of using the residual solid carbon, which can have a wide range of parameters. This is clearly the critical issue connected with turquoise hydrogen production, because once the produced solid carbon finds reasonable market, then the hydrogen produced this way becomes meaningful and competitive to other technologies. As an example from our laboratory research, we present the steam thermal plasma with very high enthalpy and low mass flow rate produced in the direct current arc discharge, which is in direct contact with water vortex surrounding the arc column[2, 3]. This thermal plasma source is attached to the reactor with internal volume 200 l, where interaction of the hydrocarbon flow with the plasma takes place. Results include characterization of the gaseous and solid product of the reaction. Both hydrogen and carbon are analysed with the intent of wide range of different applications and at the same time, almost zero CO2 (or other greenhouse gases) production.

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16:30-16:50 [Mo3.B.O1] Plasma Application in Agricultural Waste Processing: a Thermodynamic and Experimental Study

Vladimir Messerle (The Institute of Combustion Problems), Alexandr Ustimenko (The Institute of Combustion Problems) and Oleg Lavrichshev (Al-Farabi Kazakh National University).

Abstract

A large amount of manure and its irrational use negatively affect the environment. By using plasma processing of manure, it is possible to enhance the process of obtaining synthesis gas (CO+H2) and increase plant productivity by 150–200 times over biomass fermentation. Plasma processes are characterized by high temperatures, which greatly reduce waste processing time. This paper examines the plasma processing of biomass using the example of dried mixed animal manure (dung with a moisture content of 30%). Characteristic composition of dung, wt.%: H2O – 30, C – 29.07, H – 4.06, O – 32.08, S – 0.26, N – 1.22, P2O5 – 0.61, K2O– 1.47, CaO – 0.86, MgO – 0.37.

The thermodynamic code TERRA was used to analyze the plasma gasification and pyrolysis of dung. The calculations were conducted in the temperature range of 300 to 3,000K and pressure 0.1 MPa for the following thermodynamic systems: 100% dung + 25% air (plasma gasification) and 100% dung + 25% nitrogen (plasma pyrolysis). At a temperature of 1,500 K, which provides complete gasification of dung carbon, the maximum yield of combustible components, and decomposition of toxic furan, dioxin, and benz(a)pyrene, the following composition of gas was obtained, vol.%: CO – 29.6, H2 – 35.6, CO2 – 5.7, N2 – 10.6,H2O – 17.9 (gasification); CO – 30.2, H2 – 38.3, CO2 – 4.1, N2 – 13.3, H2O – 13.6 (pyrolysis). Gasification and pyrolysis of dung require 1.28 and 1.33 kWh/kg of specific energy, respectively.

A reactor with a capacity of 50 kg/h with a 100 kW plasma torch was used to process dung experimentally. The dung was gasified in an air (or nitrogen during pyrolysis) plasma jet, which provided a mass-average temperature in the reactor volume of at least 1,600 K. Organic matter was gasified, and inorganic matter was melted. For pyrolysis and gasification of dung, the specific energy consumption was 1.5 kWh/kg and 1.4 kWh/kg, respectively. The maximum temperature in the reactor reached 1,887 K. A gas of the following composition was obtained, vol.%: CO – 25.9, H2 – 32.9, CO2 – 3.5, N2 – 37.3 (pyrolysis in nitrogen plasma); CO – 32.6,H2 – 24.1, CO2 – 5.7, N2 – 35.8 (air plasma gasification). The specific heat of combustion of the combustible gas formed during pyrolysis and plasma-air gasification of agricultural waste was 10,500 and 10,340 kJ/kg, respectively. Comparison of the integral indicators of dung plasma processing showed satisfactory agreement between the calculation and experiment.

16:50-17:10 [Mo3.B.O2] Precise Measurements of Short-Lived Reactive Species in Gas-Liquid Interfacial Plasmas with High-Speed Liquid-Column Flow

Toshiro Kaneko (Graduate School of Engineering, Tohoku University), Kazuki Takeda (Graduate School of Engineering, Tohoku University) and Shota Sasaki (Graduate School of Engineering, Tohoku University).

Abstract

Atmospheric pressure plasmas (APPs) in contact with liquid, which are defined as "gas-liquid interfacial plasmas (GLIPs)", are widely used in chemical [1], medical [2], agricultural[3,4], and public health fields [5]. In these applications of GLIPs, the reactive species generated by the plasma in the gas and liquid phases, especially those with short lifetimes, are considered to play an important role.

The purpose of this study is to control the generation of short-lived reactive species using several lab-made GLIP devices, to measure them precisely, and to elucidate their chemical reaction mechanisms [6,7]. For this purpose, GLIP experiments using high-speed liquid-column flow [8] are conducted to investigate in detail the spatio-temporal dynamics of the short-lived reactive species in the liquid phase irradiated by a helium plasma. As a result, very fast decay (a half-life of ~ 0.1 msec) of OH radical was detected for the first time and explained with a numerical model assuming surface-localization of OH radical.

Furthermore, we are trying to measure not only OH radicals but also short-lived reactive nitrogen species (RNS). To achieve this purpose, we attempted to measure short-lived RNS, which are precursors of long-lived RNS such as nitrate and nitrite, using the GLIP system equipped with the high-speed liquid column flow. As a result, we have successfully measured the time decay of precursors of RNS using the reagent p-HPA (p-hydroxyphenylacetic acid), a scavenger of nitrite and nitrate precursors. The nitrite precursors were detected whereas nitrate precursors were below the detection limit, and the half-life of nitrite precursors was approximately 3 ms, which is obviously longer than 0.1 ms of OH. The results, such as the fact that only the precursor of nitrite decayed with time, led to the conclusion that the precursor of the reactive nitrogen species detected in the present study was N_2O_3. These findings will contribute to the fully controlled generation of short-lived reactive species at the plasma-liquid interface, and the resulting selectively generated short-lived reactive species will be extended to a wide range of applications in environmental science, plant science, drug discovery science, material science, and other fields.

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16:00-16:20 [Mo3.C.O1] Universal Energy Cascade and Relaxation for Electron Magnetohydrodynamic Turbulence

Supratik Banerjee (Indian Institute of Technology Kanpur), Arijit Halder (Indian Institute of Technology Kanpur) and Amita Das (Indian Institute of Technology Delhi).

Abstract

The understanding of plasma turbulence is pivotal to describe several interesting features in both laboratory and space plasmas. For fluctuation length scales sufficiently larger than the ion inertial length scale, a plasma is described by magnetohydrodynamics (MHD), which is the simplest mono fluid model of plasma. However, space plasmas are often weakly collisional with sufficiently high thermal pressure and hence are associated with fluctuations with length scales sufficiently smaller than the ion inertial length scales. The corresponding fluctuations time scale is subsequently much smaller than the ion gyroperiod. In such a regime, the ions are practically immobile and the plasma can be described using electron magnetohydrodynamics (EMHD) where the electron fluid is primarily carrying both the inertia and the current while colliding with neutralizing medium of immobile ions.

Since the ion fluid velocity is negligible, the current (**J**) and the electron fluid velocity ($\mathbf{v}_e$) are related as $\mathbf{J} = -ne\mathbf{v}_e$. In addition, the electron fluid is assumed to be incompressible such that $\nabla \cdot \mathbf{v}_e = 0$. Similar to ordinary magnetohydrodynamics, here too we neglect the displacement current ($\partial\mathbf{E}/\partial t$) assuming non-relativistic fluid velocities and the resulting governing equation for inviscid electron MHD becomes [1] $\frac{\partial}{\partial t}(d_e^2\nabla^2 B - B) = \nabla \times [v_e \times (d_e^2\nabla^2 B - B)]$ which is simply a frozen-in field equation for $(d_e^2\nabla^2 B - B)$ in the electron fluid with velocity $\mathbf{v}_e$ with $d_e = c/\omega_{pe} = (m_e/\mu_0 n_e^2)^{1/2}$ being the electron inertial length. The total energy E, the sum of the kinetic energy of the electron fluid and the magnetic energy i.e. $E = \int \left(\frac{1}{2}\rho_e v_e^2 + \frac{B^2}{2\mu_0}\right) d\tau$, is an inviscid invariant of EMHD and hence is expected to show universal turbulent cascade.

In this work, we derive a compact exact relation where we express the average energy cascade rate ε in terms of two point increments of field variables and is written as $\langle \delta [\mathbf{v}_e \times (\rho_e\omega_e - ne\mathbf{B})] \cdot \delta v_e \rangle = 2\varepsilon$, (2) where ω is the electron fluid vorticity. By using the condition of vanishing cascade [2], it has been shown that the flow relaxes towards a pressure-balanced relaxed state given by $\mathbf{v}_e \times (\rho_e\omega_e - neB) = \nabla p_e$. The universal cascade and the relaxation are also numerically studied by the help of direct numerical simulations.

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16:20-16:40 [Mo3.C.O2] Non-Locality in Scale-to-Scale Energy Transfer in Hall Magnetohydrodynamic Turbulence

Arijit Halder (Indian Institute of Technology Kanpur), Supratik Banerjee (Indian Institute of Technology Kanpur), Manohar Kumar Sharma (LEGI, University of Grenoble Alpes) and Pablo D. Mininni (Departamento de Fisica, FCEN, UBA, Argentina).

Abstract

Hall magnetohydrodynamics (HMHD) is a single fluid plasma model often employed to study sub-ion scale plasma dynamics. Unlike ordinary MHD, HMHD system allows a finite difference between ion and electron fluid velocities. The Hall effect is modelled in the induction equation by adding a nonlinear term $-d_i\nabla \times (j \times b)$ where d_i is the ion inertial length, **b** is the magnetic field (normalized to a velocity) and **j** = ∇ × **b**. Therefore the Hall effect becomes important for length scales comparable or smaller than di.

In a turbulent plasma, the Hall effect plays a pivotal role by introducing a novel backscatter of magnetic energy which is found to be important for dynamo growth of magnetic field. By decomposing the Hall term in two parts namely d_i(**j** · ∇)**b** and $-d_i$(**b** ·∇) **j** one can separately measure the contributions of **b** and **j**-field to the dynamo action [1]. Along with the backscatter, the Hall effect is believed to introduce non-locality in the scale-to-scale energy transfer process [2]. In our current work [3], using data from simulation with 5123 grid points, we numerically investigate the locality of the energy transfer for two parts of the Hall term separately.

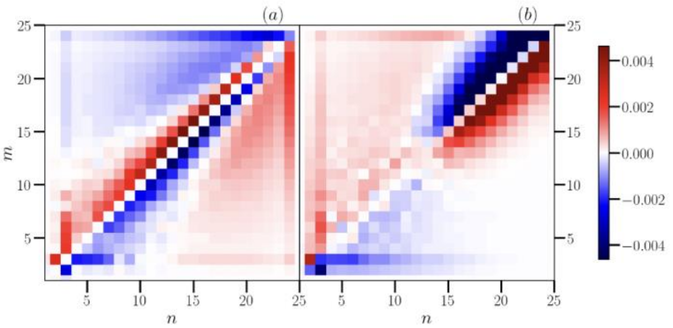

Figure 1 Shell-to-shell transfer rates for b-to-b (left panel) and j-to-b (right panel) transfers.

Fig. (1) shows the shell-to-shell transfers rates for the two parts mentioned before where $T^{x,y}_{m,n}$ signifies net transfer rate from shell n of y-field to shell m of x-field. For all the shells, it is found that **b**-to-**b** channel shows strong local inverse cascade and weak non-local forward cascade (Fig. 1a). In contrast, for scales greater than d_i (corresponding to shell number 11) **j**-to-**b** channel shows weak inverse cascade both locally and nonlocally (Fig. 1b). However, for length scales smaller than d_i, the **j**-to-**b** transfer become strongly local and forward in nature. A phenomenological explanation is also provided based on the power spectra of **b** and **j**.

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16:40-17:00 [Mo3.C.O3] Long-Living Equilibria in Kinetic Plasma Turbulence

Mario Imbrogno (Dipartimento di Fisica, Università della Calabria), Claudio Meringolo (Institut für Theoretische Physik, Goethe Universität), Sergio Servidio (Dipartimento di Fisica, Università della Calabria), Alejandro Cruz-Osorio (Instituto de Astronomía, Universidad Nacional Autónoma de México), Benoît Cerutti (Université Grenoble Alpes, CNRS) and Francesco Pegoraro (Dipartimento di Fisica "Enrico Fermi", Università di Pisa, Pisa, 56122, IT).

Abstract

In classical fluids, turbulence is characterized by long-lasting patterns emerging from the chaotic environment. We use high-resolution, direct numerical simulations in two spatial dimensions to study the equivalent mechanism in fully kinetic plasma turbulence. We observe the creation of long-lived vortices whose profile is characteristic of macroscopic force-free states dominated by magnetic fields. We describe these metastable solutions with a self-consistent kinetic model in a cylindrical coordinate system centered on a representative vortex, inspired by the Harris pinch model for inhomogeneous equilibria, beginning with an explicit form of the particle velocity distribution function. These novel equilibria can be reduced to a modified force-free state of the Gold-Hoyle solution [1]. Long-lived structures facilitate turbulence, which is accompanied by transients when these vortices combine to generate self-similarly new metastable equilibria. Understanding this process can help shed light on several astrophysical events, such as the production of plasmoids around massive compact objects or the appearance of coherent structures in the heliosphere.

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17:00-17:20 [Mo3.C.O4] Novel Algorithms for the Accurate and Fast Solution of the Five-Moment Two-Fluid Plasma Equations

Xudong Ke Lin (University of Cambridge), Stephen Millmore (University of Cambridge) and Nikos Nikiforakis (University of Cambridge).

Abstract

The disparate time- and length-scales associated with the physics of magnetically confined fusion necessitate the deployment of a variety of simulation strategies, ranging from magnetohydrodynamic (MHD) to particle-based models. Single-fluid MHD, though computationally efficient, is invalid in regimes with small length and time scales, whilst particle-based methods are computationally expensive in simulations of full-domain phenomena, due to their high dimensionality. Five moment two-fluid plasma models offer an attractive compromise between the two approaches, by significantly reducing the dimensionality of the problem, but retaining important physics lost by standard MHD models. This work is concerned with the numerical solution of the two-fluid model by means of a finite volume approach and this work presents new innovations to improve the simulation efficiency. The cost of the calculation is reduced by relaxing the time step restrictions from the speed of light constraint with an implicit Maxwell solver and further improvement of the efficiency of the solution is achieved by using a locally implicit treatment of the stiff source terms. In this study, the multi-physics approach is extended in an attempt to capture the plasma-wall interaction. This is achieved through the implementation of a rigid body ghost fluid method, which allows the simultaneous consideration of both materials within the same computational domain. The algorithms are implemented in a highly parallelized software framework, and are validated against benchmarks from the open literature. It is shown that the new algorithms considerably reduce the computational times compared to traditional fully explicit methods.

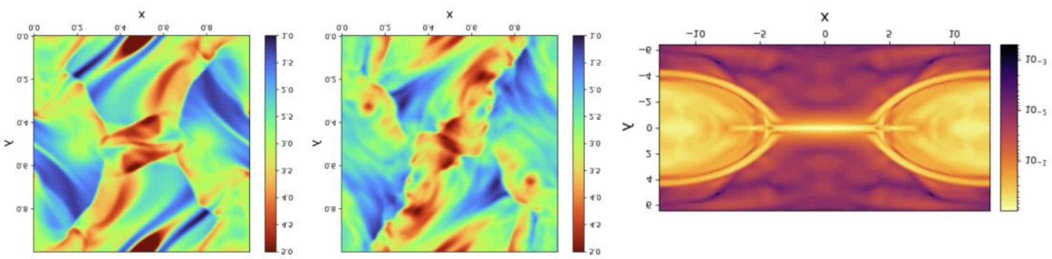

Figure 1 Validation test cases for both small and large length and time scales. From left to right - ideal MHD Orszag-Tang vortex, two-fluid Orszag-Tang vortex, GEM magnetic reconnection challenge.

17:50-18:50. [Mo.P.4] Public-Private Partnerships in Fusion Energy Development

1. Welcome – Mark Koepke, West Virginia University
2. PPP's federal framework and goals – Colleen Nehl, U.S. Department of Energy [remote]
3. PPP's realization and impact within the fusion community's private sector – Andrew Holland, CEO, Fusion Industry Association [remote]
4. PPP plan and promise – Ambrogio Fasoli, Programme Manager, EUROfusion [remote]
5. PPP role in roadmapping high-gain inertial fusion energy development – Peter Norreys, Professor of Inertial Fusion Science, University of Oxford [remote or in-person]
6. PPP for collaboration and innovation benefit – Chris Deeney, Director, Laboratory for Laser Energetics, University of Rochester
7. PPP vision for success in inertial fusion energy – Tammy Ma, Lead for the LLNL Inertial Fusion Energy Institutional Initiative
8. Aspirational highlights, targeted metrics of PPP – Open question
9. Question and answer opportunity

Tuesday September 10

09:00-09:40. [Tu.P.1] Plenary 4

Complex Interplay of Magnetic Islands and Turbulence in Fusion Plasmas

Nicolas Dubuit (Aix-Marseille Université, CNRS), Daniele Villa (Aix-Marseille Université, CNRS), Bojana Stefanoska (Aix-Marseille Université, CNRS), Olivier Agullo (Aix-Marseille Université, CNRS), Magali Muraglia (Aix-Marseille Université, CNRS) and Xavier Garbet (CEA, IRFM).

Abstract

Magnetic islands are regions of reconnected magnetic field that appear frequently in magnetized fusion plasmas as well as in astrophysical plasmas. While they can be directly created by the current-driven "tearing" instability, in tokamak plasmas they frequently appear in situations where the tearing mode is stable. Therefore, the ubiquity of micro turbulence in tokamaks plasmas has prompted many studies seeking to clarify the possible mechanisms through which turbulence may generate magnetic island. In the meantime, magnetic islands (regardless of their origin) perturb heat and particle transport, because they connect field lines across equilibrium magnetic surfaces. In addition to the associated degradation of confinement, this can lead to the explosive growth of so-called Neoclassical Tearing Modes. However, while the effect on collisional transport of single tearing-driven islands in simple MHD models is rather well understood, the situation with more detailed models, turbulence and/or multiple islands is another matter. Therefore, a consistent view of turbulence, transport and magnetic islands together is necessary.

Several different processes, discovered in the last decade, allow turbulence at small scales to drive large-scale magnetic islands. First, we show how the competition between those processes determines the size and shape of the generated large-scale magnetic islands, depending on the thermal power injected into the plasma [1]. Next, with use a 6-feld model [2, 3] to present a newly identified mechanism whereby the turbulence-generated "zonal" mean flows nonlinearly change the parity of the turbulent modes and, after a zonal flow-mediated coalescence process, drives large-scale islands. While this process depends on terms that are usually neglected in usual 2- or 3-field MHD models, it is dominant in the low-shear high-β regime of interest to advanced tokamak operation scenarios.

Next, we turn to the related issue of transport in magnetic islands. Even in the 2D mono-helicity geometry, the effect of magnetic islands can be much more complex than a flattening (or lack thereof) of the pressure gradient, in particular exhibiting self-heating [3] and/or several distinct flattened regions separated by sharp gradients. On top of this, the 3D multi helicity geometry enables the complex issue of stochastic regions of the magnetic field. Indeed, while such regions look deceptively uniform in Poincare plots, they feature complex local variations: in addition to sticky regions around islands, particular manifolds called Lagrangian Coherent Structures (LCS) which have been touted as possible transport barriers. However, the complex cohabitation of turbulence and turbulence-driven magnetic islands raises several questions which we address in this work: is stochasticity dominated by the small-scale magnetic flutter, or by the coupling of large-scale islands? Are the large-scale generated LCS resilient to the presence of small-scale turbulence?

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09:40-10:20. [Tu.P.2] Plenary 5

Pioneering High-Energy-Density Plasma Physics at the Laboratory for Laser Energetics

Christopher Deeney (Laboratory for Laser Energetics, University of Rochester).

Abstract

The pursuit of inertial confinement fusion created advanced pulsed-power and laser systems for five decades, culminating in the world's largest laser, the National Ignition Facility, demonstrating a target gain of more than 1 in 2022. In this journey, the laser systems, which deliver high-energy pulses in nanoseconds, have facilitated many other areas of high-energy-density science from studying materials at planetary conditions to simulating many aspects of astrophysics. The laser technology also advanced, including the development of chirped-pulsed amplification (CPA), to create picosecond pulses at petawatt levels of power. LLE is the home of two tens-of-kilojoule laser systems and one petawatt-class laser. The facilities support 2000 experiments per year for hundreds of users. In this presentation we will review the significant advances in fusion and high-energy-density science being conducted at LLE. This ranges from measuring fundamental plasma parameters like distribution functions to integrated experiments to study the role of magnetic fields in galaxy formation. In addition, the entire realm of short-pulse laser science, enabled by CPA, is expanding into advanced accelerator, THz radiation production, and intense x-ray sources. We will also discuss advances in short-pulse laser physics and a vision for 25-PW lasers to meet the scientific goals outlines in the recent international Multi-Petawatt Prioritization workshop.

Acknowledgments This material is based upon work supported by the Department of Energy [National Nuclear Security Administration] University of Rochester "National Inertial Confinement Fusion Program" under Award Number DE-NA0004144.

10:40-12:30. [Tu1.A] Bob Dewar Memorial Session

10:40-11:10 [Tu1.A.I1] Plasma Equilibria, Stability and Nonlinear Dynamics – a Celebration of the Contributions of Prof. Robert Dewar

Matthew Hole (Mathematical Sciences Institute, Australian National University), Arash Tavassoli (Mathematical Sciences Institute, Australian National University), Amitava Bhattacharjee (Princeton University), Stuart Hudson (Princeton Plasma Physics Laboratory), Adelle Wright (University of Wisconsin – Madison) and Zhisong Qu (Nanyang Technological University).

Abstract

Em/Prof. Robert (Bob) Leith Dewar, FAA, FAPS, FAIP (1944 – 2024) was a giant in the field of theoretical plasma physics, with important contributions in Magnetohydrodynamics (MHD) and in dynamical systems. These include MHD equilibrium and stability, MHD ballooning modes, Taylor relaxation and Hamiltonian maps. Bob worked closely with computer simulation and with experimentalists and has made important contributions to toroidal magnetic fusion research and to astrophysics. Over the last decade he had been instrumental in the development of a multiple region relaxed MHD model to describe general stellarator fields, and he was presently working on a generalization of such models to systems that preserve magnetic helicity with a weak ideal Ohm's law constraint. [1] Perhaps most importantly, he has left a legacy in both research and teaching, spanning 5 postdocs, 16 PhD, and many Masters and Honours students. Many of these now hold prominent positions in the field. Bob has also had a strong service contribution to the ICPP community, serving on the International Advisory Committee for decades, Chairing the 2002 ICPP meeting in Sydney, and was the architect of the ICPP statutes. In this proposed talk I will overview Bob's major contributions to the field, and focus on his work to describe magnetic fields in toroidally asymmetric configurations with flux surfaces, islands and chaos.

References

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11:10-11:30 [Tu1.A.O1] Tokamak Turbulence: a Pathway via a Series of Bifurcations.

Ben McMillan (University of Warwick), Chris Pringle (Coventry University) and Olly Smith (University of Warwick).

Abstract

Turbulence is often thought of as being constituted of a collection of interacting wave modes, but at the outset of classical fluid dynamics, was seen to arise as a series of increasingly complex structures that saturate and became successively unstable. We show that gyrokinetic tokamak turbulence follows this paradigm. The case of interest is subcritical turbulence that arises when there is both a driving gradient and a sheared background flow; this is known do give rise to isolated radially-propagating structures, and the formation and destabilisation of these structures is the pathway to turbulence in this system. Not only can we observe this in initial value simulations, it is possible to directly determine these structures via a nonlinear root-finding technique. These relative periodic orbits (RPOs) are turbulence states that repeat after some time, modulo some symmetry operation like translation; direct numerical solution allows us to determine these states even when they are unstable and to examine the bifurcation pathway as simple translation transitions via Hopf bifurcations into more complex nonlinear oscillations and finally space-filling turbulence.

11:30-11:50 [Tu1.A.O2] SPEculations (on Stepped Pressure Equilibria)

Robert MacKay (The University of Warwick).

Abstract

Extending work by Berk et al [1] on the case with a single interface, Bruno and Laurence [2] used KAM theory to make near axisymmetric magnetohydrostatic (MHS) fields with an arbitrary finite number of zones of constant pressure. The field is Beltrami in each zone and has a current sheet at each interface between zones, at which the pressure has a jump. Bob Dewar had the good idea, and the computationally expert team, to implement this strategy numerically [3]. The resulting stepped pressure equilibrium code (SPEC) is a hugely valuable tool in the search for suitable stellarator fields for confined nuclear fusion. In 2005, I began a discussion with Bob, in which I put the view that there could be limiting cases with infinitely many zones of constant pressure but for which the pressure is continuous, thereby eliminating the non-physicality of current sheets. The pressure gradient would be an L1 function supported on a fat Cantor set of flux surfaces. The same would hold for the current density. Such solutions would fit with Grad's hunch that most nonaxisymmetric MHS fields are pathological [4]. Bob was keen on the idea, but we never reached a conclusion. Here, I will present what I can on the proposal.

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11:50-12:10 [Tu1.A.O3] Periodic Nonlinear Phenomena (PNP) in Plasma Dynamics

Mark Koepke (West Virginia University).

Abstract

The basic elements (e.g., equivalent inductance and equivalent capacitance) of distributed-parameter and lumped-parameter characteristics will be described in a qualitative examination of multiple periodic nonlinear systems that are important as phenomenological models for demonstrating the salient features of the behavior of PNP that are encountered across a wide spectrum of discovery plasma science and beyond. This paper contains mostly theory but also contains many experimental examples from laboratory experiments.

- Basic, physical, and mathematical descriptions of PNP
- Prototype PNP systems
- Topological, analytical, variational, and perturbative methods
- Specific nonlinear characteristics of PNP
- Amplitude-frequency-phase relations and harmonic generation in PNP
- Experimental examples of PNP
- Coupled first-order systems
- Stabilization methods

Acknowledgments Seminal contributions from H. Lashinsky (deceased) and collaborative contributions from R. Majeski, D. Hartley, K.D. Weltmann, P. Miller, T. Klinger,and N. Brenning are greatly appreciated.

12:10-12:30 [Tu1.A.O4] Tribute to the Late Professor Robert Dewar

Hideo Sugama (National Institute for Fusion Science).

Abstract

Professor Robert Dewar was a great theoretical plasma physicist who made many important contributions to the development of research in magnetic fusion and astrophysics. The first part of this talk highlights one of his great achievements: his theory on ballooning representation of instabilities in toroidal magnetic configurations [1]. He presented an elegant formulation of ballooning representation to efficiently investigate pressure-driven MHD instabilities in tokamaks and nonaxisymmetric systems such as stellarators and heliotrons. His work had a significant impact not only on analyses of MHD modes but also on studies of microinstabilities and turbulence through gyrofluid and gyrokinetic theory and simulation, in which his ballooning formalism is used as a standard helpful tool. The second half of the talk will touch on Professor Dewar's interactions with Japanese researchers. Professor Dewar has often visited Japan, sometimes for long periods of time, and has conducted many joint research projects. This talk will forward some messages from Japanese collaborators. It is also remembered that he participated in the AAPPS-DPP2023 in Nagoya last November and played very active roles as the program committee member, the plenary session chair, and the invited speaker. After the conference, he also visited NIFS and gave a seminar on plasma relaxation models, where he had a lively discussion and showed his energy. Therefore, we were even more shocked and saddened by the news of his sudden passing. We will never forget his great achievements and warm personality.

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14:40-15:10 [Tu2.A.I1] High Power Ion Heating of Magnetic Reconnection in Two Merging Tokamak Plasmas

Yasushi Ono (University of Tokyo), Hiroshi Tanabe (University of Tokyo), Michiaki Inomoto (University of Tokyo) and Chio-Zong Cheng (Princeton Plasma Physics Laboratory).

Abstract

We have been developing high-power ion heating of magnetic reconnection using two merging tokamak plasma with high guide field $B_t \gg B_p$(poloidal field)[1, 2]. The heated ion energy by magnetic reconnection scales with the reconnecting magnetic field component energy ($B_{rec}^2/2\mu_0$) where $B_{rec} \sim B_p$. The B_{rec}^2-scaling of ion heating energy by reconnection can be understood by the fact that in the reconnection downstream the ion energy is mainly in the form of outflow kinetic energy before ions are thermalized in further downstream. The ion outflow velocity is produced mainly by the large $\boldsymbol{E}\times\boldsymbol{B}$ drift velocity associated with large poloidal electric field E_z, resulting from the formation of quadrupolar electrostatic potential structure in the downstream region and E_z depends linearly on $B_t B_p$ as observed in the experiments. Hence, the outflow velocity scales with B_{rec}, and thus the ion heating energy scales with B_{rec}^2. High power ion heating with about 40-50% of $B_{rec}^2/2\mu_0$converted into the heated ion energy can only be achieved when the reconnection current sheet thickness d is compressed to thinner than the ion gyroradius r_i. The B_{rec}^2-scaling of high power reconnection ion heating provides an efficient way to produce burning plasmas with T_i > 10keV by increasing B_{rec} to 0.6T (for $n_e \sim 1.5\times10^{19}$m^{-3}) without using any auxiliary heating methods like neutral beam injection (NBI). If $d \gg r_i$, the magnetic reconnection converts only 5-10% of $B_{rec}^2/2\mu_0$ into ion energy. This operation is suitable for magnetic helicity injection (current drive) of tokamak with small heating loss.

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15:10-15:40 [Tu2.A.I2] Ion and Electron Heating Characteristics During Magnetic Reconnection in ST40 and TS-6 Plasma Merging Experiments

Hiroshi Tanabe (University of Tokyo), Ryo Someya (University of Tokyo), Yunhan Cai (University of Tokyo), Tara Ahmadi (University of Tokyo), Mikhail Gryaznevich (Tokamak Energy Ltd.), Dmitry Osin (Tokamak Energy Ltd.), Hannah Willet (Tokamak Energy Ltd.), Hazel Lowe (Tokamak Energy Ltd.), Chio-Zong Cheng (Princeton Plasma Physics Laboratory), Michiaki Inomoto (University of Tokyo) and Yasushi Ono (University of Tokyo).

Abstract

Here we report ion and electron heating characteristics of magnetic reconnection under the influence of high guide field in ST40 and TS-6 plasma merging experiments using 96CH/320CH 2D ion Doppler tomography and Thomson scattering diagnostics. In addition to the extension of ion heating scaling $\Delta T_i \propto B_{rec}^2$ in keV range as demonstrated in MAST and ST40, our recent experiments explored the following 3 new findings using 2D ion Doppler tomography and Thomson scattering diagnostics: (1) formation of poloidally asymmetric global ion heating structure in TS-6 and highly localized electron heating around the X-point in ST40 via parallel electric field acceleration, (2) update of the heating scaling with $\Delta U_i \propto B_{rec}^2$ to 10kJ/m^3 by including the contribution of electron density in collaboration with Thomson scattering measurement in ST40 from 2023 (the increment of ion thermal energy ΔU_i in the downstream region is ~30% of the upstream magnetic energy of reconnecting field B_{rec}), and (3) exploration of further electron heating via magnetic reconnection under the influence of high guide field in the keV range in ST40.

The poloidally asymmetric ion heating structure depends on the polarity of toroidal field B_t and the fine structure gets flipped when the guide field direction is reversed. Under the influence of high guide field, ***E***×***B*** drift is mainly driven by in-plane/poloidal electric field E_p from the quadruple potential structure, while parallel electric field $E_{//}$ is mainly driven by reconnection electric field E_{rec} (spontaneously formed toroidal electric field E_t around X-point) and higher T_i appears where plasma potential is positive, while high T_e mainly appears around the X-point. The portion of toroidal electric field E_t for parallel electric field $E_{//}$ is higher for high guide field condition ($B_t > 3B_{rec}$) and the peaked electron heating structure around the X-point becomes clearer when higher guide field is applied. Under the influence of toroidal effect to have higher guide field in the inboard side of outflow direction ($B_t \propto 1/r$), downstream heating also forms poloidally asymmetric structure, and more heating appears in the high field side. Perpendicular heat conduction in the outflow region is strongly suppressed by high guide field $\kappa^i_{//}/\kappa^i_{\perp} \sim 2(\omega_{ci}\tau_{ii})^2 \gg 1$ and the field-aligned transport process leads to the formation of poloidally ring-like characteristic fine structure after merging.

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14:40-15:30. [Tu2.B] Plasma Accelerators I

14:40-15:10 [Tu2.B.I1] The Laser-Hybrid Accelerator for Radiobiological Applications (LhARA)

Colin Whyte (University of Strathclyde) and The Lhara Collaboration The Lhara Collaboration (STFC).

Abstract

The "Laser-hybrid Accelerator for Radiobiological Applications", LhARA, is being developed to serve the Ion Therapy Research Facility (ITRF). ITRF/LhARA will be a novel, uniquely flexible facility dedicated to the study of the biological impact of proton and ion beams. LhARA will combine laser ion acceleration, plasma lens with conventional accelerator technologies, to accelerate ions to 10's of MeV energies by using a high power laser focussed onto a thin target (target normal sheath acceleration). These ions, are captured and focussed by a non-neutral plasma lens known as a Gabor lens. The technologies can transform the clinical practice of proton and ion beam therapy (PBT) by creating a fully automated, highly flexible laser-driven system to:

- Deliver multi-ion PBT in completely new regimens at ultra-high dose rate in novel temporal-, spatial- and spectral fractionation schemes; and
- Make PBT widely available by integrating dose-deposition imaging with real-time treatment planning in an automatic, triggerable system.

The status of the ITRF/LhARA project will be described along with the collaboration's vision for the development of a transformative proton- and ion-beam system.

15:10-15:30 [Tu2.B.O1] Chaperoning Propagation of Laser Pulses and Laser Wakefield Accelerations in Plasmas

Devki Nandan Gupta (Department of Physics and Astrophysics, University of Delhi).

Abstract

The laser-plasma accelerator has advanced to the stage where control of beam parameters and stability are the main development challenges [1,2]. Achieving high quality electron beams in laser wakefield accelerators requires stable guiding of the driving laser pulse, which is challenging because of mode mismatching due to relativistic self-focusing. Here we show how an intense pre-pulse can be used to prepare the phase-space distribution of plasma electrons encountered by a trailing driver pulse so that it produces its own well-matched guiding channel that minimises wakefield evolution. We present a unique double-pulse scheme that creates a stable plasma channel waveguide intrinsically aligned with the trailing driver pulse. The plasma momentum distribution and electrostatic field are prepared by an intense, short duration pre-pulse that precedes the arrival of a second, co-propagating pulse. The time delay between the two pulses is chosen to be slightly less than the plasma period and the moderately intense leading, or chaperone, pre-pulse excites a weakly-nonlinear plasma wave that is below the threshold for wave breaking and self-injection. The pre-pulse does not directly produce a guiding structure for the trailing driver pulse, but rather its wake prepares the plasma by driving converging streams of electrons that are subsequently deflected by the ponderomotive force of the (trailing) driver pulse to produce a narrow, well-defined parabolic plasma channel. This acts as a self-aligned waveguide accompanying the driver over extended propagation lengths. The driver pulse initially undergoes relativistic self-focusing so that it matches the narrow density channel, which ensures high coupling efficiency. The chaperone pre-pulse stimulates guiding of the driver pulse, providing control over its evolution and enhancing the stability of the resulting wakefield [3].

Controlling high intensity driver pulses is an essential step in developing useful wakefield accelerators and compact radiation sources. Stable channels are necessary for developing next generation compact plasma undulators for compact synchrotron sources and free-electron lasers. Wide availability of ultra-compact accelerators and radiation sources could transform the way science is done.

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14:40-15:20. [Tu2.C] Numerical Methods and Plasma Modelling II

14:40-15:00 [Tu2.C.O1] New Integrator for Relativistic Equations of Motion for Charged Particles

Takayuki Umeda (Information Initiative Center, Hokkaido University), Eiichiro Mizoguchi (Institute for Space-Earth Environmental Research, Nagoya University) and Riku Ozaki (Institute for Space-Earth Environmental Research, Nagoya University).

Abstract

Numerical methods for solving the relativistic motion of charged particles with a higher accuracy is an issue for scientific computing in various fields including plasma physics. The classic fourth-order Runge-Kutta method (RK4) has been used over many years for tracking charged particle motions, although RK4 does not satisfy any conservation law. However, the Boris method [1] has been used over a half century in particle-in-cell plasma simulations because of its property of the energy conservation during the gyro motion.

Recently, a new method for solving relativistic charged particle motions has been developed, which conserves the boosted Lorentz factor during the E-cross-B motion [2]. The new integrator has the second-order accuracy in time and is less accurate than RK4. Then, new integrator is extended to the fourth-order accuracy in time by combining RK4 [3]. However, it is not easy to implement the new fourth-order integrator into PIC codes, because the new method with RK4 adopted co-located time stepping for position and velocity vectors, which is not compatible with the charge conservation method.

In this paper, the two new relativistic integrators are reviewed. Then, a new leap-frog integrator with fourth-order accuracy in time is developed, which adopts staggered time stepping for position and velocity vectors.

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15:00-15:20 [Tu2.C.O2] Relaxation of the Courant Condition and Reduction of Numerical Errors in the Explicit Finite-Difference Time-Domain Method for Plasma Kinetic Simulations

Harune Sekido (Institute for Space-Earth Environmental Research, Nagoya University), Takayuki Umeda (Information Initiative Center, Hokkaido University) and Yoshizumi Miyoshi (Institute for Space-Earth Environmental Research, Nagoya University).

Abstract

This study provides a new numerical method for relaxation of the Courant condition and correction of numerical errors in the Finite-Difference Time-Domain (FDTD) method with the time-development equations using higher-degree difference terms. The FDTD method [1] is a numerical method for solving the time development of electromagnetic fields by approximating Maxwell's equations in both space and time with the finite difference of the second-order accuracy, which is widely used in plasma kinetic simulations. A staggered grid system is adopted in the spatial differences, in which Gauss's law is always satisfied. The FDTD method has a disadvantage that numerical oscillations occur due to the error between the numerical phase velocity and the theoretical phase velocity. The FDTD (2,4) method [2, 3],which uses the fourth-order spatial difference, is proposed for reduction of the numerical errors. However, the Courant condition becomes more restricted by using higher-order finite differences in space and a larger number of dimensions.

Recently, a numerical method has been developed by adding third-degree difference terms to the time-development equations of FDTD(2,4) [4]. Although the new method relaxes the Courant condition, there exist large numerical errors with large Courant numbers. In the present study, a new explicit and non-dissipative FDTD method is proposed with two types of the higher-degree difference operators for relaxation of the Courant condition and reduction of numerical errors. First, the one-dimensional third- and fifth-degree difference terms are added to the time-development equations of FDTD(2,6) [5]. Second, the third-degree difference terms including Laplacian are added to those of FDTD(2,4) [6]. The results of the test simulations show that numerical oscillations are not reduced so much with the one-dimensional difference operator, whereas the Laplacian operator suppresses an anisotropy in the waveforms and reduces the numerical oscillations. Furthermore, numerical instability is suppressed with large Courant numbers up to 1, which reduces the computational time of plasma kinetic simulations significantly.

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16:00-16:30 [Tu3.A.I1] Electromagnetic Instabilities in Spherical Tokamaks

Daniel Kennedy (United Kingdom Atomic Energy Authority), Maurizio Giacomin (Dipartimento di Fisica “G. Galilei”, Università degli Studi di Padova), Plamen Ivanov (Rudolf Peierls Centre for Theoretical Physics, University of Oxford), Toby Adkins (Department of Physics, University of Otago), Facundo Sheffield (Max Planck Institute for Plasma Physics), Tobias Görler (Max Planck Institute for Plasma Physics), Arka Bokshi (York Plasma Institute, University of York), David Dickinson (York Plasma Institute), Harry Dudding (United Kingdom Atomic Energy Authority), Bhavin Patel (United Kingdom Atomic Energy Authority) and Colin Roach (United Kingdom Atomic Energy Authority).

Abstract

Electromagnetic micro instabilities are likely to limit performance in future advanced steady state tokamak plasmas and are expected to dominate transport in high β next generation spherical tokamaks (STs) such as STEP [1]. While gyrokinetic (GK) simulations have thus far proven to be a very accurate tool in modelling turbulent transport in predominantly electrostatic regimes, obtaining saturated nonlinear simulations in higher β plasmas with unstable kinetic ballooning modes (KBMs) and microtearing modes (MTMs) has proven computationally challenging (see e.g. [2]). Recent simulations of STEP-relevant equilibria that retain only MTMs and exclude KBMs (by neglecting compressional perturbations) saturate cleanly at very modest electron heat flux. However, local GK simulations find that including $\delta B_{\parallel}$ in such plasmas can unleash a hybrid KBM-like (hKBM) instability which drives very large heat fluxes (orders of magnitude greater than the available heating power) in the absence of strong equilibrium shear flows [3, 4]. These simulations underscore that understanding and mitigating hKBM-induced turbulence will be essential for the development of consistent flat-top operating regimes for future high performance ST devices.

In this talk we will present recent advances in our understanding of electromagnetic turbulence and discuss hKBM-driven turbulence in high β STs, with a particular focus on avoiding the high-transport state. We will present: (i) linear and nonlinear local simulations of hKBM turbulence, exploring the sensitivity of the turbulence and its associated transport to local parameters as well as different saturation mechanisms; (ii) a quasi-linear inspired reduced transport model for the hKBM turbulence; (iii) first flux-driven simulations for a high β ST that support the existence of a transport steady state in STEP with a fusion power comparable to that in the burning flat top of the conceptual design; and (iv) the first global nonlinear electromagnetic simulations of STEP to include $\delta B_{\parallel}$. These first-of-their-kind global simulations support the conclusions drawn from local GK simulations by: confirming that high-transport states in some equilibrium conditions are a robust prediction of GK and not simply an artefact of the local approximation; and tentatively supporting, in simulations that are currently running, the existence of a transport steady state in the vicinity of the conceptual STEP flat top. We will also discuss the most pressing priorities to be addressed in future work.

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16:30-17:00 [Tu3.A.I2] Experimental Progress and Future Plan on Spherical Tokamak, QUEST

Kazuaki Hanada (Kyushu University), Hiroshi Idei (Kyushu University), Takeshi Ido (Kyushu University), Ryuya Ikezoe (Kyushu University), Yoshihiko Nagashima (Kyushu University), Makoto Hasegawa (Kyushu University), Takumi Onchi (Kyushu University), Toshiki Kinoshita (Kyushu University), Kengo Kuroda (Japan Coast Guard Academy), Makoto Oya (Kyushu University), Kazuo Nakamura (Kyushu University), Naoaki Yoshida (Kyushu University), Takahiro Nagata (Kyushu University), Aki Higashijima (Kyushu University), Shun Shimabukuro (Kyushu University), Ichiro Niiya (Kyushu University), Izumi Sekiya (Kyushu University), Kaori Kono (Kyushu University), Shoji Kawasaki (Kyushu University), Akira Ejiri (University of Tokyo), Sadayoshi Murakami (Kyoto University), Rojor Raman (University of Washington) and Masayuki Ono (Princeton Plasma Physics Laboratory, Princeton University).

Abstract

Spherical tokamak (ST) is a type of tokamak with low aspect ratio (A) that is the ratio of major radius (R) to minor radius (a) of torus and is intensively studied as a candidate for a cost-effective fusion power plant. Taking advantage of better MHD stability, higher bootstrap current fraction, and favorable confinement trend with magnetic field than traditional tokamaks (TTs), several designs of ST based fusion power plant have been proposed. But, the intrinsic natures of STs give rise to issues that need to be resolved. In particular, since the magnetic flux available for inductive plasma current generation is less than in TTs, it is important to develop methods to start and maintain the plasma current and to increase the toroidal magnetic field, BT. Recently, a small- sized ST, ST-40 developed in a private company (Tokamak Energy Ltd.) in UK achieved 10keV of ion temperature for several tens ms at B_T=2.2T. The machine size of ST-40 (R=0.4m, a=0.25m) is significantly smaller than TTs that obtained more than 10 keV that is need to cause a DT nuclear fusion reaction. This proves a high potential of STs.

QUEST is a medium sized spherical tokamak with R=0.64m, a=0.4m, and B_T<0.25T at R=0.64m. The QUEST aims at effective plasma current start up and stable maintenance of plasma discharge. To resolve the ST specific issues mentioned above, electron cyclotron current drive (ECCD) and coaxial helicity injection (CHI) are introduced on QUEST. An efficient ECCD could be achieved owing to energetic electrons (EEs), but the excess fraction of EEs may limit the application of toroidal electric field to drive plasma current to avoid a significant damage on the vacuum vessel due to local heat load caused by EEs. The methods we developed are to control the number of EEs with the assistance of control of injection refractive index to the magnetic field, $N_{//}$of electron cyclotron wave (ECW) and/or to apply negative toroidal electric field using center solenoid. The combination of both methods could drive the bulk electron temperature up to 1keV. Another non-inductive start-up tool, the Transient coaxial helicity injection (T-CHI) has been succesfully used in NSTX and a new electrode configuration is applied on QUEST. The electrode has been installed on lower divertor plates and electrically insulated by ceramic plates, and a plasma discharge between the electrode and the vacuum vessel is generated to supply magnetic helicity. The discharge develops in a force-free manner and magnetic reconnection drives a production of closed flux surface. The plasma induced by CHI is high density up to 1020 m^{-3}, but the temperature is still 10 eV. For long pulse operations on QUEST, it is impeded frequently due to particle imbalance. To resolve the issue, QUEST equipped a temperature controllable plasma facing wall (PFW) called hot wall. With help of the hot wall, 6 h discharges were obtained. In particular, the plasma duration of 40 min at 673K could be extended to more than 3 h through the temperature control of the hot wall.

Augmentation of B_T up to 0.5T and a CW gyrotron of 28GHz will be prepared as future plans of QUEST. Long pulse operations with higher plasma parameters will be expected.

16:00-17:20. [Tu3.B] Laser-Plasma Interaction I

16:00-16:30 [Tu3.B.I1] Optimised Direct Laser Acceleration of Electrons - Towards High-Brilliance Gamma-Ray Sources

Robert Babjak (GoLP - Institute for Plasmas and Nuclear Fusion).

Abstract

The pursuit of high-charge, high-density electron bunches driven by multi-petawatt lasers is essential for applications such as neutron generation, bright synchrotron radiation, and laboratory studies of electron-positron plasmas. Experiments have proven that at the hundred-terawatt scale, the OMEGA-EP facility can achieve electron energies of several hundred MeV and total charge over one hundred nanocoulombs via direct laser acceleration [1]. We push the acceleration mechanism towards multi-PW laser facilities to obtain electrons with energies surpassing GeV level and keeping the important property of high total charge. Our analytical scaling shows the dependence of an electron energy on laser intensity, and plasma density, and we provide a pathway to optimize this acceleration process for both existing and future facilities [2]. By precisely guiding a laser pulse over an appropriate distance, we can produce a wide Maxwellian spectrum of electrons with energies reaching several GeV and laser-to-electron conversion efficiencies in the tens of percent.

This presentation the nonlinear trade-off between the laser intensity and laser spot size will be explained. Understanding this balance provides insight into maximizing the transfer of laser energy to electrons, thus achieving the highest possible electron energies for a given laser power. We will compare our analytical scaling with Quasi-3D particle-in-cell simulations using the OSIRIS framework. Furthermore, we will discuss the theoretical aspects of plasma interactions under varying density conditions [3], crucial for understanding interactions in the preplasma of thin foils for ion acceleration. This analysis is necessary for experiments where the density profile of a gas jet varies along the laser propagation. In the end, we will highlight the potential of these electron bunches to emit high-brightness radiation at energies >100 MeV.

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16:30-17:00. [Tu3.B.I2] Scheme for Injecting Breit-Wheeler Positrons into a Plasma Channel Using Multi-PW Lasers

Dominika Maslarova (Department of Physics, Chalmers University of Technology), Bertrand Martinez (GoLP/Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, University of Lisbon) and Marija Vranic (GoLP/Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, University of Lisbon).

Abstract

Positron acceleration in plasmas has gained great interest due to its promising future applications, such as multi-TeV electron-positron colliders [1]. The challenge of this endeavor is greater for positrons than for electrons because self-generated fields from laser-plasma interactions are usually not well-suited for positron focusing and on-axis guiding. Additionally, an external positron source is required, while electrons are naturally available in the plasma. Here, we study electron-positron pair generation by an orthogonal collision of a multi-PW laser pulse and a GeV electron beam via the nonlinear Breit-Wheeler process [2].

We examine conditions favorable for positron deflection in the direction of the laser pulse propagation, facilitating injection into the plasma for further acceleration [3]. Using the OSIRIS particle-in-cell framework, we demonstrate that the radiation reaction triggered by ultra-high laser intensity plays a crucial role in positron injection by suppressing the initial transverse momentum gained from the Breit-Wheeler process. For the parameters used in our work, an intensity threshold is required to inject more than 1% of the created positrons, with the injection percentage rapidly increasing above this threshold.

Additionally, subsequent direct laser acceleration of positrons in the plasma channel using the same laser pulse can boost the final positron energy by a factor of two. The positron focusing and on-axis guiding are provided by significant electron beam loading, altering the internal structure of the channel fields. This study highlights the robustness and potential of this scheme for future applications.

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17:00-17:20. [Tu3.B.O1] Laser Wakefield Acceleration of Electrons in Double-Gas System

Ravina (University of Delhi) and D.N. Gupta (University of Delhi).

Abstract

The number of particles in an electron beam from laser wakefield acceleration is determined at the moment of trapping of background electrons. The longitudinal and transverse wave-breaking initiates the electron trapping. After some time, the trapping stops because of the repulsive force by the trapped particles. From many simulations and experiments, it has been well known that trapping of the background electrons begins much below the longitudinal wave-breaking limit [1,2]. This is related with transverse motion of the electrons. As an ultra-intense laser pulse propagates through a plasma, it pushes out the background plasma electrons and leaves behind a periodically-repeated bubble-like region. Inside the bubble, the electron density is very low, while the electron density at the rim of the bubble is very high. Highly energetic electrons make their trajectories along the rim of the bubble. Though many of such electrons turn around the rim and leave the bubble, some of those electrons are trapped in the transverse direction when their kinetic energies are lower than the depth of the potential well of the bubble [3].

The idea suggested in this paper is to use the double-gas system for electron injection. Based on the ionization of higher atomic number gas, enhanced injection has been estimated through particle-in-cell (PIC) simulations. The laser ionizes a lower atomic number gas to facilitate the laser wakefield via ponderomotive push of the electrons. However, the electron injection is weak in this case. The inclusion of higher atomic number gas (such as nitrogen) can enhance the electron injection via gas ionization. The advantage of this technique is to obtain the control of the beam charge in the laser-plasma accelerators, while keeping other parameters unmodified. Though the required gas ionization should be controlled via various parameters. A systematic bunch optimization is estimated in this work for future course of compact accelerator development.

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16:00-16:20 [Tu3.C.O1] Parametric Decays of Electromagnetic Waves in Electron-Positron Nonextensive Plasmas

Victor Muñoz (Departamento de Fisica, Facultad de Ciencias, Universidad de Chile), Gabriel Medel (Departamento de Fisica, Facultad de Ciencias, Universidad de Chile) and Roberto Navarro (Departamento de Fisica, Facultad de Ciencias Fisicas y Matematicas, Universidad de Chile).

Abstract

Wave propagation in relativistic plasmas is a subject of interest in many astrophysical and space systems, where electromagnetic fields may accelerate particles up to relativistic velocities, which in turn modifies the physics of wave propagation. Besides, kinetic effects further modify the dispersion properties of waves and their nonlinear interactions with the plasma particles. Thus, it is of interest to study wave propagation, and its nonlinear decays, considering both relativistic and kinetic effects.

However, the traditional approach of equilibrium statistics, where kinetic effects are described by Maxwellian velocity distributions, is not satisfactory in several environments where long range correlations, or memory effects, may lead the distributions to deviate from the Maxwellian case. Here, the proposal to describe plasma distribution functions in terms of nonextensive distribution functions, either of the Tsallis (where deviation from the Maxwellian case is given by a parameter q) [3] or the kappa type (where deviations are parametrized by a κ factor), [4, 5] allows to extend the traditional formalisms, to study wave linear and nonlinear propagation for systems out of thermodynamical equilibrium.

Following these ideas, in this work, parametric decays of an electromagnetic wave in an electron-positron plasma are studied. Kinetic effects are considered by means of the collisionless Vlasov equation, which is coupled to Maxwell equations. Relativistic effects on the particle motion are also taken into account. [6]

In the weakly relativistic case, although some of the instabilities involve strongly damped, electroacoustic pseudomodes, instabilities found using fluid theory are present as well in the kinetic regime. [1, 2] We study in detail the dependence on κ of the dispersion relation, the growth rate, and the phase velocity of the waves. As expected, results reduce to the Boltzmann-Gibbs statistics for $\kappa \to \infty$ ($q \to 1$).

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16:20-16:40 [Tu3.C.O2] Using Visibility Graphs to Characterize Non-Maxwellian Turbulent Plasmas [online]

Sebastian Saldivia (Universidad de Chile), Pablo Moya (Universidad de Chile) and Denisse Pastén (Universidad de Chile).

Abstract

The Visibility Graph, a technique for mapping time series into complex networks, is employed to research underlying physical mechanisms in collisionless, turbulent plasmas. We analyze four distinct time series of magnetic field fluctuations obtained from Particle in Cell (PIC) simulations, initialized varying the κ parameter of its particle velocity distributions to explore departures from thermodynamic equilibrium. All studied cases exhibit a power law behavior in the degree distribution of the nodes. The critical exponent of this distribution unveils information about network properties, including particle correlations and heterogeneity. We compute the γ exponent for the degree distribution of the scale-free network and observe its evolution according to κ, peaking at κ = 3. This trend suggests that long-range correlations are more prominent in plasmas far from thermal equilibrium, while short-range correlations dominate in thermal plasmas following a Maxwellian distribution. These findings align with previous non-collisional plasma studies. Additionally, we investigate the μ and ν exponents associated with the slopes of power spectra of the magnetic fluctuations, obtaining insights into the energy dissipation and temporal persistence of the time series. Our findings reveal that low-frequency fluctuations exhibit the sharpest energy dissipation in thermal equilibrium environments, while high-frequency fluctuations dominate in systems described by velocity distributions with small κ. When comparing the correlation between these exponents and γ as a function of κ, we find a direct correlation for the exponent ν associated with high-frequencies, and an anticorrelation for the low-frequencies exponent μ.This finding underscores the connection between long- and short-range correlations and the Debye sphere of the plasma, revealing that the γ metric of the Visibility Graph is only able to see the smaller scales of a time series.

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Wednesday September 11

Developing Numerical Tools for Tungsten Profile Measurement from X-Ray Diagnostics in WEST Plasmas

Didier Mazon (CEA), Y. Peysson (CEA), A. Jardin (Institute of Nuclear Physics, Polish Academy of Science), Gerenton (…). G. Verdoolaege (Ghent University), H. Wu (Ghent University, Southwestern Institute of Physics, CNNC, Chengdu), M. Chernyshova (Institute of Plasma Physics and Laser Microfusion), A. Wojenski (Warsaw University of Technology), J. Colnel (CEA), D. Guibert (CEA), T. Czarski (Institute of Plasma Physics and Laser Microfusion), K. Malinowski (Institute of Plasma Physics and Laser Microfusion), P. Linczuk (Warsaw University of Technology), D. Colette (ITER Organization), G. Kasprowicz (Warsaw University of Technology), K. T. Poźniak (Warsaw University of Technology), M. Walsh (ITER Organization) and the WEST team (http://west.cea.fr/WESTteam)

Abstract

In modern tokamaks like ITER—International Thermonuclear Experimental Reactor, or WEST – Tungsten (W) Environment in Steady-State Tokamak in Cadarache, the choice of W instead of traditional carbon as the main plasma facing material, to minimize tritium retention in the walls, has raised the essential issue of heavy impurity radiation. Monitoring and control of W concentration below 0.01% in the plasma core will be indeed necessary to avoid significant cooling of the plasma by impurity radiation, in particular in the soft X-ray(SXR) energy range of 0.1–20 keV.

In fusion devices, SXR plasma emissivity contains rich information not only about impurity transport, but also about the magnetohydrodynamic activity, magnetic equilibrium, plasma density and temperature. Since the radial impurity transport can be impacted by their poloidal distribution, SXR tomographic tools are valuable to infer the 2D impurity distribution and select adequate mitigation strategies.

In this context, this paper describes different efficient numerical tools, including artificial intelligence, neural network and Bayesian techniques for tungsten and/or electron temperature profiles evaluation in WEST plasmas based on experimental data from X-Ray measurements [1] and modelling tools [2], including synthetic diagnostics.

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Highlights from the path toward confined e+e- pair plasmas

E. V. Stenson (Max Planck Institute for Plasma Physics) representing the APEX Collaboration including V. C. Bayer (Max Planck Institute for Plasma Physics, Technische Universität München), E. Buglione-Ceresa (Technische Universität München), A. Card (Technische Universität München), J. R. Danielson (University of Calfornia San Diego), A. Deller (Max Planck Institute for Plasma Physics, University of Calfornia San Diego), P. Gil (Max Planck Institute for Plasma Physics), C. P. Hugenschmidt (Technische Universität München), P. Huslage (Max Planck Institute for Plasma Physics), J. von der Linden (Max Planck Institute for Plasma Physics), D. Mendoça (Technische Universität München), S. Nißl (Max Planck Institute for Plasma Physics), D. Orona (Massachusetts Institute of Technology), H. Saitoh (University of Tokyo), D. Schmeling (Colombia University), E. von Schoenberg (Concordia University), L. Schweikhard (University of Greifswald), M. Singer (Max Planck Institute for Plasma Physics, University of Greifswald), J. Smoniewski (Max Planck Institute for Plasma Physics), P. Steinbrunner (Max Planck Institute for Plasma Physics, University of Greifswald), M. R. Stoneking (Lawrence University), C. M. Surko (University of Calfornia San Diego) and A. Zetti (Lawrence University).

Abstract

The creation and study of confined, long-lived, electron-positron plasma in the laboratory is the grand challenge of the APEX (A Positron-Electron eXperiment) Collaboration. Conducting experiments with this unique hybrid of matter and antimatter will enable comparisons to fundamental plasma physics predictions for this uncommonly symmetric system. Ideally, these can in turn contribute to our understanding of positrons and/or pair plasmas in astrophysics --- or even the early universe. As part of striving towards this goal, we are employing, validating, combining, and advancing diverse, state-of-the-art science and technology [1]. This talk will give an overview of recent highlights --- including novel techniques in the areas of non-neutral plasmas [2], positron beams, and gamma diagnostics [3] --- as well as the progress on our two, complementary, table top-sized, pair-plasma traps: a levitated dipole and an optimized stellarator, both based on small, non-insulated, HTS (high-temperature superconducting) coils. Finally, it will summarize our roadmap for the next few years, when we will put all of these elements together.

Acknowledgments We gratefully acknowledge funding from the Helmholtz Association; the Deutsche Forschungsgemeinschaft (DFG); the Alexander von Humboldt Foundation; the UC San Diego Foundation; the Deutscher Akademischer Austauschdienst (DAAD) RISE program; the United States Department of Energy; the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme; the Japan Society for the Promotion of Science (JSPS); and the National Institute for Fusion Science (NIFS).

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10:50-11:30. [We.P.3] Plenary 8

JET Isotope Studies and the L-H Transition

Emilia R Solano (Laboratorio Nacional de Fusión, CIEMAT), for the JET L2H Team (See author list of E. R. Solano et al. Nucl. Fusion 63 112011 (2023)), and JET contributors (See author list of C. F. Maggi et al. Nucl. Fusion 63 110201).

Abstract

The transition between L and H-mode has fascinated plasma physicists since its discovery [1]. It is a clear phase transition between plasma confinement regimes, which takes place when the plasma is sufficiently heated. Here we present and discuss results from recent dedicated L-H transition experiments at JET [2]. Uniquely, we studied the power threshold (PLH) in plasmas composed of pure Tritium, to be compared with Hydrogen and Deuterium plasmas, D+T mixtures, and H+T mixtures [3]. We show that critical pressure profiles are required for the L-H transition to occur, and such critical profiles are independent of plasma content, but the power threshold itself depends strongly on isotopic content. PLH is in fact determined by the plasma transport characteristics in L-mode. We also show that an analysis of Doppler reflectometer measurements of the edge perpendicular velocity in D and He plasmas and observe that there are no critical radial electric field value or critical $\boldsymbol{v}_{ExB}$ rotation before the L-H transition [4]. Instead, there appears to a $\boldsymbol{v}_{ExB}$ profile that is characteristic of the L-mode. The diamagnetic velocity, proportional to ∇p, is a better indicator of proximity to the L-H transition. Together, these results enable us to challenge the widely accepted model of the L-H transition being associated to the stabilisation of electrostatic turbulence by sufficient $\mathbf{v}_{ExB}$ shear. An alternate model of the L-H transition is briefly discussed, based on a magnetisation transition of the plasma.

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11:40-12:30. [We1.A] Data-Driven Plasma Science I

11:40-12:10 [We1.A.I1] Data-Driven Insights into Heavy Impurity Dynamics in Drift-Wave Turbulence

Zetao Lin (Aix-Marseille University), T. Maurel-Oujia (Aix-Marseille University), B. Kadoch (Aix-Marseille University), S. Benkadda (Aix-Marseille University) and K. Schneider (Aix-Marseille University).

Abstract

Confinement quality in fusion plasma is significantly influenced by the presence of heavy impurities, which can lead to radiative heat loss and reduced confinement. This study explores the clustering of heavy impurity, i.e., Tungsten in edge plasma of tokamaks. The two-dimensional Hasagawa-Wakatani model of drift-wave turbulence is used as a paradigm to describe edge tokamak turbulence. To this end high-resolution direct numerical simulations of the Hasegawa-Wakatani equations are carried out with millions of charged inertial particles. We use Stokes number to quantify the inertia of impurity particles. It is found that particle inertia will cause spatial intermittency in particle distribution and the formation of large-scale structures, i.e., the clustering of impurity particles. The degrees of clustering are influenced by Stokes number [1]. To quantify these observations, we apply a modified Voronoi tessellation method, which assigns specific volumes to impurity particles [2]. By determining time changes of these volumes, the impurity velocity divergence can be calculated, where negative values indicate cluster formation while positive values correspond to cluster destruction. Thus the clustering dynamics can be assessed. Additionally, Lagrangian statistics are used to provide further insights into the dynamics of heavy impurity behavior in the edge plasma.

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12:10-12:30 [We1.A.O1] Integrated Data Analysis of the Tungsten Concentration Profiles at WEST Using Soft X-Ray and Bolometer Diagnostics

Hao Wu (Ghent University), Axel Jardin (Institute of Nuclear Physics, Polish Academy of Sciences), Tianbo Wang (ITER Organization), Didier Mazon (Institute for Magnetic Fusion Research, CEA) and Geert Verdoolaege (Ghent University).

Abstract

Tungsten (W) has been selected as the divertor and first wall material for the International Thermonuclear Experimental Reactor (ITER) project [1, 2]. The tungsten divertor technology of ITER is tested on several devices, including the W Environment in Steady-state Tokamak (WEST) located at Cadarache. Despite the high melting point and low erosion rate of W, the interactions between the edge plasma and the plasma-facing components are an important source of tungsten impurities in the plasma. The accumulation of heavy impurities like tungsten in the plasma core of fusion devices poses a major risk to the core performance through strong radiative cooling. Therefore, reliable estimates of impurity concentrations in fusion devices are of vital importance. The soft X-ray (SXR) diagnostic system at WEST records the line-integrated SXR emissivity from impurities as well as the bulk plasma [2]. The two-dimensional SXR emissivity profile in a poloidal cross section can be reconstructed through Bayesian inference with a nonstationary Gaussian process prior, resulting in a closed-form expression for the posterior distribution [3]. Combined with density and temperature measurements, the tungsten concentration profile can be directly inferred from the reconstructed emissivity profile. However, such sequential analysis does not take into account the various sources of uncertainty from the individual diagnostic systems. Instead, we use Bayesian probability theory to jointly estimate the density, temperature and tungsten concentration profiles from their joint posterior distribution. This approach is called integrated data analysis (IDA) in the fusion community [4]. The IDA approach enables reliable uncertainty estimates without explicit error propagation analysis and allows exploiting the diagnostics' interdependencies. The high-dimensional joint posterior distribution of the quantities of interest can be explored by a Markov chain Monte Carlo (MCMC) sampler. Tests on synthetic data suggest large uncertainty on the inferred tungsten concentration near the plasma edge, due to the weak SXR signal from low ionization states of tungsten at low electron temperature. Therefore, to improve the edge inference we also investigate the possibility of including additional diagnostics, like bolometry. First results using synthetic data show that this is a promising approach.

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11:40-12:10 [We1.B.I1] Experimental Investigation of Laser Plasma Interaction in the Context of Inertial Confinement Fusion on the Laser MéGajoule Facility

Sylvie Depierreux (CEA), Véronique Tassin (CEA) and Marion Lafon (CEA).

Abstract

Since the end of 2021, the Laser Mégajoule (LMJ) at CEA in France can be operated in a symmetric configuration with 10 laser chains [80 beams distributed into 2 upper hemisphere cones (polar angle 33° and 49°) and 2 lower hemisphere cones (147° and 131°)] giving up to ~270 kJ delivered at 351 nm. LMJ presently offers more than 14 plasma diagnostics operating in the visible-UV wavelengths ranges and in multiple hard and soft x-ray ranges as well as particles diagnostics (neutrons, electrons and ions). Notably, Laser Plasma Interaction (LPI) is characterized on LMJ with (i) backscattering measurements (time-resolved spectra end energy) on one inner quadruplet and (ii) near backscattering [1] covering polar angles from 20° to 65° over ~1/5 of the azimuth of the LMJ target chamber.

In the indirect-drive configuration to ICF, the laser energy is converted into a bath of x-rays inside a high-Z enclosure (a hohlraum) that further implode the capsule (containing the fuel), its symmetry of irradiation being adjusted through the energy balance between inner and outer cones of beams. A specific "rugby-ball shaped" hohlraum design (in contrast to the regular cylinder shape) is well suited to the LMJ energy partition with its ½-½ power balance. However, this particular prolate spheroid hohlraum shape introduces challenges in the control of the inner beams propagation. Namely, the significant expansion of the gold holhraum wall into the path of the inners can give rise to significant Stimulated Brillouin Scattering (SBS). The latter involves the coupling of the incident laser with ion acoustic waves thus amplifying scattered electromagnetic waves. Large amounts of SBS may be expected for inner beams propagating in the high-Z mm scale gold bubble plasma.

In the direct-drive configuration to ICF, the laser beams irradiate the capsule in a spherical geometry giving rise to an expanding exponential density profile plasma. The coupling of the laser beams with such a plasma at the relevant scale (laser intensity, plasma temperature, density scale length) had been studied with a planar geometry. The unique angular coverage of the LMJ LPI diagnostics recently allowed to investigate the Raman scattering mechanisms responsible for the hot electrons generation in direct-drive ICF experiments thanks to this planar target platform. We will report on the first indirect-drive experiments performed on LMJ in rugby ball-shaped gas-filled hohlraums with laser pulses duration up to 9 ns. We will illustrate the challenges of getting a round implosion while mastering the LPI mechanisms. The configuration and preliminary results of the planar direct-drive experiments will also be presented.

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12:10-12:30 [We1.B.O1] Filamentation of Currents and Generation of Strong Magnetic Fields Due to Electron Weibel Instability in an Expanding Collisionless Plasma

Vladimir Kocharovsky (A.V. Gaponov-Grekhov Institute of Applied Physics, Russian Academy of Sciences), Anton Nechaev (A.V. Gaponov-Grekhov Institute of Applied Physics, Russian Academy of Sciences) and Mikhail Garasev (A.V. Gaponov-Grekhov Institute of Applied Physics, Russian Academy of Sciences).

Abstract

The talk aims at the classical problem of the decay of a strong plasma discontinuity and a similar problem of the injection of a plasma with hot electrons into a vacuum or a rarefied cold plasma with a magnetic field in the absence of significant particle collisions. The main goal is to elucidate the transient phenomena of the formation of an anisotropic electron velocity distribution leading to quasi-magnetostatic turbulence associated with Weibel-type instabilities. We focus mainly on the formation and decay of current filaments and sheets and review the theoretical and numerical results on this account obtained previously for space and laser plasmas.

We describe and analyze in detail the original results of particle-in-cell modeling of a collisionless expansion of an anisotropic plasma cloud with hot electrons from a flat surface into a background magnetoactive plasma in different settings entailing [1] (i) a hot-electron spot of a circular or cylindrical form within an initial-value problem or a finite-time injection of electrons from the surface, (ii) an external magnetic field with three orthogonal orientations: perpendicular to the surface or along it, directed either across or parallel to a long axis of the hot-electron spot, and (iii) inhomogeneous layers of cold background plasma of different spatial scales and densities.

Bearing in mind typical laser-plasma experiments, we outline the development of the principal structures of currents and highly inhomogeneous magnetic fields linked with distinct forms of the anisotropic electron velocity distribution and sophisticated dynamics of the instability process for diverse sets of attributes (i)–(iii). Strong magnetic fields generated at the main transition stage are turbulent in nature, can reach, in typical laser experiments, mega-Gauss and higher values, and modify interaction between charged particles notably. In particular, according to the analytical estimates, numerical simulations and laser ablation experiments, the magnetic fields of self-consistent currents of cold and hot electrons quickly lead to the spatial separation of particle counter flows and suppress the beam instability of plasma (Langmuir) waves. This situation is qualitatively different from the well-studied decay of a weak plasma discontinuity, where the electrons obey a Boltzmann distribution and the formation of magnetic turbulence is replaced with the generation of ion-acoustic solitons. We discuss applications of the obtained results to the analysis of laboratory and space plasma problems involving an explosive development of the small-scale magnetic turbulence due to the filamentation of electric currents.

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11:40-12:10 [We1.C.I1] Dissipative Structures In Non-Ideal MHD Turbulence: The Hall Effect Unveiled

Turlough Downes (Dublin City University) and A. Kinsella (Dublin City University).

Abstract

Turbulence involves the transport of energy from large scales to the small scales at which it is dissipated. The properties of the structures which dissipate the magnetohydrodynamic (MHD) turbulence in star forming regions are important in determining the conditions within which stars and planets form. In MHD turbulence a significant fraction of energy is dissipated in current sheets which are formed as magnetic field lines are pressed together. In planet-forming discs these current sheets influence the chemistry and even the ionisation fraction, and thus the dynamics, of the plasma thereby potentially influencing star and planet formation.

Dissipation of energy in current sheets has been studied in the context of compressible and incompressible non-ideal MHD incorporating the effects of both Ohmic and ambipolar resistivity [1, 2]. However, these studies have not incorporated the Hall effect which is thought to be important during gravitational collapse (in molecular clouds) and certain parts of planet-forming discs.

In this work we report, for the first time, on the impact of the Hall effect on dissipative structures in MHD turbulence. We use the multi-fluid MHD code HYDRA [3, 4] to simulate driven, multi-fluid MHD turbulence and show that the size distribution of current sheets is changed, resulting in energy being dissipated equally across current sheets of all sizes, in contrast to previous results without the Hall effect and similar to previously published results for ideal MHD [5].

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12:10-12:30 [We1.C.O1] Non-Axisymmetric Accretion Disk Instabilities: New Possibilities Beyond the Magnetorotational Instability

Nicolas Brughmans (CmPA, KU Leuven), Rony Keppens (CmPA, KU Leuven) and Hans Goedbloed (DIFFER).

Abstract

Black hole accretion disks are assumed to be turbulent as they are highly unstable to magnetic instabilities driven by shear flow, resulting in angular momentum transport and an effective turbulent viscosity. The axisymmetric, weak-field magnetorotational instability (MRI) and its derivation through local WKB approximations has been the topic of many studies [1]. In contrast, its non-axisymmetric counterparts have received relatively little attention as they require the full power of magnetohydrodynamic (MHD) spectroscopy for a general description of the eigenspectrum of waves and instabilities [2]. This is essential for global cylindrical disk models, where the influence singularities from the overlapping MHD continua complicates the analysis. Recently, rigorous MHD spectroscopy identified a new type of ultra-localised, non-axisymmetric instability in global cylindrical disks with super-Alfvénic flow [3]. These super-Alfvénic rotational instabilities (SARIs) make up 2D unstable regions in the complex eigenfrequency plane with (near-eigen)modes that corotate at the local Doppler velocity and are radially localised between Alfvénic resonances, utterly insensitive to inner/outer radial disk boundaries.

Here, we independently confirm the existence of these unprecedented modes using the novel spectral MHD code Legolas (https://legolas.science/), reproducing and extending our earlier study with detailed eigenspectra and eigenfunctions [4]. We also compare growth rates of the discrete SARIs and MRI in a variety of disk equilibria, highlighting the impact of field strength and orientation, as well as compressibility in suprathermal fields. We show that non-axisymmetric modes can significantly extend instability regimes at high mode numbers, with instability determined by the Alfvén frequency and maximal growth rates comparable to the MRI. Furthermore, we explicitly show the existence of modes that are highly localised in all directions, with possible applications to global and shearing box simulations. A visualisation in the time and space domain of MRI/SARI modes highlights their differences and similarities and gives further indication that the onset instability in accretion disks could very well be governed by localised non-axisymmetric SARI modes.

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Thursday September 12

09:00-09:40. [Th.P.1] Plenary 9

Ignition Achieved: next Steps in the Path Toward an Inertial Fusion Energy Future

Tammy Ma (Lawrence Livermore National Laboratory), Mariann Albrecht (Lawrence Livermore National Laboratory), M. John Edwards (Lawrence Livermore National Laboratory), Justin Galbraith (Lawrence Livermore National Laboratory), Clement Goyon (Lawrence Livermore National Laboratory), Thomas Lynch (Lawrence Livermore National Laboratory), Veronika Kruse (Lawrence Livermore National Laboratory), James McCarrick (Lawrence Livermore National Laboratory), Vincent Tang (Lawrence Livermore National Laboratory) and G. Jackson Williams (Lawrence Livermore National Laboratory).

Abstract

The achievement of ignition on the National Ignition Facility in 2022 demonstrated the fundamental feasibility of controlled thermonuclear fusion in the laboratory for energy gain, and was the first major hurdle in efficiently harvesting fusion energy through inertial fusion energy (IFE). Excitement has been growing worldwide, with notable activity in the public and private sectors. To make IFE commercially viable, however, there are still significant scientific, engineering, workforce, and economic hurdles. This talk will review the advancements that made the ignition breakthrough possible, provide an overview of the international IFE landscape, and describe the remaining gaps and challenges that must be solved to realize IFE laser inertial fusion as a path for clean energy and energy security.

09:40-10:20. [Th.P.2] Plenary 10

Laser Plasma Accelerators: Manipulating Relativistic Electrons with Intense Lasers

Victor Malka (Weizmann Institute of Science).

Abstract

Laser-plasma-based wakefield accelerators are changing the scientific landscape bringing on new hopes for high energy physics, compact light sources, and societal applications. Many of these applications critically require the precise characterization of the plasma wakefield that largely affects the bunch's quality they provide. Advanced diagnostics of such highly transient, microscopic bunch and field structures, however, remains very challenging. After introducing the context and the status of this research, I will shortly explain the physical processes that are involved in plasma accelerators, I then will report on recent major results that demonstrate for the first time the real-time visualization of laser-driven nonlinear relativistic plasma wave[1], its transition to electron-driven wakefield [2] and the femtosecond microscopy of relativistic electron bunch [3].

This will be followed by a short review of the most mature applications including the status of our EIC project ebeam4therapy [4].

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10:50-11:30. [Th.P.3] Plenary 11

Design of Plasma Shapes for Metamaterials, Chemical Filters, and Maze-Solvers

Osamu Sakai (The University of Shiga Prefecture).

Abstract

Plasma in a gas phase forms in a free space or in a container, and its shapes and motions have attracted much scientific attentions for decades. In the outer space, it exists magnetohydrodynamically in rich forms in the background of the external magnetic fields. Fusion plasma in a reactor is produced in a large vacuum vessel to configure its form to maximize its energy output, keeping its stability. Low-temperature plasmas, which are industrial tools as well as fundamental scientific models, have been reported in many shapes under elaborate controls since they play various roles with specific aims in non-equilibrium states, such as light sources, material processing, and medical treatments. For instance, we reported plasma photonic crystals and plasma metamaterials, which have spatial periodic structure and work as microwave regulators [1,2]. In another study, a filter-like thin plasma sheet is equivalent to a controllable chemical filter [3]. Although they are deliberately designed to optimize their functional outputs, in some cases we have no ideas on scientific principles in its spatial design since they are fixed after simple trial-and-error procedures.

In this study, using our previous research results [1-4] and other relevant scientific achievements, we revisit relationships between functions of low-temperature plasmas and their shapes. Recently, we experimentally developed a maze-solver based on plasma channel expansion [4] and examined such phenomena using Boltzmann-Gibbs (thermodynamical) and Shannon (information) entropies. From this point of view, we can reconsider functions of plasma shapes in our previous research results such as plasma metamaterials and plasma chemical filters, both of which possessed designed shapes for specific purposes in non-equilibrium states. A clue to overall understanding of functions and shapes may be given by entropy estimation, and low-entropy states will be of benefit to improved functions.

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11:40-12:10 [Th1.A.I1] Physics Drivers for the Plasma-Facing Components Design of the COMPASS-U Tokamak

Renaud Dejarnac (Institute of Plasma Physics of the Czech Academy of Sciences), Jakub Caloud (Institute of Plasma Physics of the Czech Academy of Sciences), Ekaterina Matveeva (Institute of Plasma Physics of the Czech Academy of Sciences), Jonathan Gerardin (Institute of Plasma Physics of the Czech Academy of Sciences), Jozef Havlicek (Institute of Plasma Physics of the Czech Academy of Sciences), Jakub Hromadka (Institute of Plasma Physics of the Czech Academy of Sciences), Martin Imrisek (Institute of Plasma Physics of the Czech Academy of Sciences), Fabien Jaulmes (Institute of Plasma Physics of the Czech Academy of Sciences) and Matej Peterka (Institute of Plasma Physics of the Czech Academy of Sciences).

Abstract

COMPASS-U is a new tokamak which is currently under construction at the Institute of Plasma Physics of the Czech Academy of Sciences in Prague [1]. Its relatively small size (R = 0.9 m, a = 0.27 m), compared to other existing or planned tokamaks, combined to a high magnetic field (5 T) and a high plasma current (2 MA) makes it very challenging to design, especially its plasma-facing components. Indeed, the thermal energy confined in the plasma needs to be extracted on a limited area in the divertor yielding extremely high energy flux densities, few times higher than the ones met at the surface of the Sun. The large magnetic pressure needed to keep the hot plasma far away from the wall can be, in case of a sudden loss of confinement so-called 'disruptions', accidentally transferred to in-vessel components in a fraction of millisecond, yielding large electromagnetic (EM) ***J***x***B*** forces, ranging from several tens of kN on some tiles up to 4 MN on the vacuum vessel [2]. COMPASS-U being a unique new machine, these loads cannot be estimated from previous experiments and need to be determined.

This contribution describes how plasma physics considerations are used for engineering purposes in order to design the plasma-facing components of a tokamak. Design requirements are driven by the physics to be investigated. The large variety of foreseen plasma scenarios and magnetic equilibria, for investigating different types of physics, adds to the challenge as a single first wall configuration must cope with abroad range of completely different constraints. The different loads are estimated from scaling laws derived from multi-machine databases, simulations and extrapolation from existing devices. As an example, heat loads at the divertor targets follow the Eich's law and profiles [3]. It yields for COMPASS-U a power fall-off length in the edge plasma close to the wall of λ_q^{omp} ~1 mm and consequently steady-state energy flux densities up to 100 MW/m^2if no mitigation is applied. Other type of thermal loads, more transient but more powerful, have to be also considered, e.g., runaway electrons with energy in the range 100-300 kJ or edge localized modes, adding to the risk of melting the tungsten tiles. During disruptions, the different currents induced (eddy) and flowing (halo) into the structures due to the temporal variation of magnetic field, caused by vertical displacements and by the plasma current quench, are determined using an EM model based on finite element modeling and multi-machine databases created for ITER under the International Tokamak Physics Activity [4].

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12:10-12:40 [Th1.A.I2] Impact of Co-Dependent Energy and Angular Atomic Impact Spectra on Tungsten Erosion in JET

Henri Kumpulainen (Forschungszentrum Jülich), Detlev Reiter (Heinrich-Heine-Universität Düsseldorf), Sebastijan Brezinsek (Forschungszentrum Jülich), Mathias Groth (Aalto University), Juri Romazanov (Forschungszentrum Jülich) and Sven Wiesen (Dutch Institute for Fundamental Energy Research).

Abstract

The erosion of tungsten (W) by fast deuterium (D) atoms from charge-exchange reactions, predicted to be the dominant cause of the observed W radiation in most JET ITER-like-wall plasmas [1], is determined by the co-dependent energy and angular distributions and the flux of incident D atoms. Monte Carlo simulations using conventional histogram binning methods compromise between high resolution and low stochastic noise. In contrast, tallying functional expansion coefficients of the angular spectrum for each energy bin provides both arbitrarily high angular resolution and reduced Monte Carlo noise compared to angular histogram binning.

EIRENE simulations of JET L-mode and H-mode plasmas using newly implemented functional expansion tallies with a Legendre polynomial basis indicate that the most common D impact angles near the JET low-field side divertor entrance are in the range of 60° to 85° to the surface normal at impact energies (E) of 100 to 700 eV and 30° to 50° at E > 1 keV. The predicted W sputtering due to atoms and the W density in the core plasma is increased by up to one-third due to the energy-resolved angular spectra, compared to the total energy-independent angular spectrum and to earlier simulations [1] which assumed a constant impact angle of 60°. As the atomic D flux density decreases with higher impact energy, the increased W sputtering yield due to larger impact angles at 250 eV < E < 700 eV is more significant than the reduced W yield due to more perpendicular angles at E > 1 keV.

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11:40-12:30. [Th1.B] Laser Applications

11:40-12:10 [Th1.B.I1] Raman Amplification with a 1 X 10^15 W/Cm^2 Seed

Jessica Shaw (University of Rochester Laboratory for Laser Energetics), Manfred Virgil Ambat (University of Rochester Laboratory for Laser Energetics), Kyle McMillen (University of Rochester Laboratory for Laser Energetics), Jeremy Pigeon (University of Rochester Laboratory for Laser Energetics), Sara Bucht (University of Rochester Laboratory for Laser Energetics), Isabelle LaBelle (University of Rochester Laboratory for Laser Energetics), Hans Rinderknecht (University of Rochester Laboratory for Laser Energetics), Dan Haberberger (University of Rochester Laboratory for Laser Energetics), Kassie Moczulski (University of Rochester), Petros Tzeferacos (University of Rochester), John Palastro (University of Rochester Laboratory for Laser Energetics), Adam Sefkow (University of Rochester) and Dustin Froula (University of Rochester Laboratory for Laser Energetics).

Abstract

We present experimental results from the Raman Amplification experimental platform at the University of Rochester's Laboratory for Laser Energetics (LLE). This platform explores Raman amplification in a unique parameter space which includes a multi-joule pump and an adjustable-energy seed with intensities exceeding 1 x 10^{15} W/cm^2. Initial experiments have demonstrated single-pass Raman amplification in multiple focal configurations with energy gain factors as high as 30x and record efficiencies as high as 11.7%. Amplification factor and efficiency scalings with plasma density, focal geometry, pump energy, and seed energy are presented. The impact of propagation of both the pump and seed lasers on the amplification process is explored.

Acknowledgments This material is based upon work supported by the Department of Energy [National Nuclear Security Administration] University of Rochester "National Inertial Confinement Fusion Program" under Award Number DE-NA0004144, the U.S. Department of Energy under Awards DE-SC0021057 and DE-SC0016253.

12:10-12:30. [Th1.B.O1] Plasma Optics for Compression of Ultraintense Laser Pulses

Minsup Hur (UNIST).

Abstract

Exawatt or zettawatt laser pulses can be groundbreaking scientific tools for uncovering the mysteries of our universe. These high-power laser pulses enable experimental studies of phenomena such as vacuum boiling and pair-production, Hawking radiation, and quantum gravity, holding great potential for advancing our understanding of nature. However, the currently available CPA technology is stuck at petawatt level, mainly due to the material breakdown of compression gratings and alternative solutions are yet to come from conventional optics. Plasma, being in a state of matter already broken down, can endure highly intense laser fields without damage. Its resilience to strong fields, coupled with its optically dispersive properties, makes plasma an ideal medium for manipulating high-power laser pulses. In this presentation, I will present a recently devised novel concept for pulse compression using a density gradient, high density plasma. The point of the new idea is generating reflection path difference of photons of a chirped pulse using a near-critical, gradient density plasma. As the higher frequency photons take longer reflection path deeper into the plasma, the photons in the tail of a negatively chirped pulse can catch up those in the pulse front, resulting in concentration of the photons into a narrow region. So far this idea is still in theoretical and modelling level, but it has been already published to Nature Photonics in 2023 [1], and experimental proof-of-principle is in progress. In theoretical point of view, combining different plasma optics ideas with the original density gradient idea is being studied. Here I present the status of the research and future vision of this innovative concept, providing comparison of characteristics of previous plasma-based schemes such as Raman, Brillouin and plasma gratings. These advancements can be crucial steps toward realizing compact, exawatt, or zettawatt laser pulses.

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11:40-12:10 [Th1.C.I1] Relaxation of Energetic Particles in Plasmas and Dark Matter in Galaxies Through a Common Resonance-Broadened Kinetic Theory [IUPAP Early Career Scientist Prize]

Vinicius Duarte (Princeton Plasma Physics Laboratory).

Abstract

A quasilinear plasma transport theory that incorporates Fokker-Planck dynamical friction (drag) and pitch angle scattering is self-consistently derived from first principles for an isolated, marginally-unstable mode resonating with an energetic minority species. It is found that drag fundamentally changes the structure of the wave-particle resonance, breaking its symmetry and leading to the shifting and splitting of resonance lines. In contrast, scattering broadens the resonance in a symmetric fashion. Comparison with fully nonlinear simulations shows that the proposed quasilinear system preserves the exact instability saturation amplitude and the corresponding particle redistribution of the fully nonlinear theory. Even in situations in which drag leads to a relatively small resonance shift, it still underpins major changes in there distribution of resonant particles. This novel influence of drag is equally important in plasmas and self-gravitating systems. In fusion plasmas, the effects are especially pronounced for fast-ion-driven instabilities in tokamaks with low aspect ratio or negative triangularity, as evidenced by past observations. The same theory directly maps to the resonant dynamics of the rotating galactic bar and massive bodies in its orbit, providing new techniques for analyzing galactic dynamics and for constraining candidates of dark matter particles.

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12:10-12:30 [Th1.C.O1] One-Dimensional Model for Plasma-Flow from the Accretion Disk Towards the Neutron-Star Poles

Anoop Singh (Institute for Plasma Research), Mrityunjay Kundu (Institute for Plasma Research) and Shishir P. Deshpande (Institute for Plasma Research).

Abstract

Accreting neutron stars (ANS) are unique cosmic laboratories for studying the exotic plasma phenomena. ANS are characterised by strong surface gravity ~10^{14}cm/$s^2$and a wide range of strong dipole magnetic fields ~10^8-10^{14}Gauss and have a binary companion that feeds the ANS with matter, often creating the accretion disk (AD) [1]. We consider the simplest case of steady-state mass accretion and find intriguing solutions by applying the well-known MHD model.

The large magnetic field causes the ions and electrons to flow along the field lines, given in this case by the dipole approximation [2]. A slowly rotating ANS is considered, with its magnetic axis aligned with the rotation axis for simplicity. We show that for a given accretion rate, the conservation laws define boundaries of parameter-space where meaningful solutions can be found. It is also seen that the region near the poles, where the plasma gets concentrated, has an incredibly small thickness in the θ-direction. As the highly conducting plasma, attached to the converging magnetic field lines of increasing strengths, is channelled to the polar region of the neutron star acquires remarkably high densities and, in most cases ,remains sub-alfvenic [3]. As the plasma continues to move further towards the ANS poles, the gravity and the magnetic field topology causes a compression of the plasma [2]. Diamagnetic effects due to a sharp radial pressure gradient cause a toroidal sheet to form on the outer and inner sides of the envelope defined by field lines binding the accretion disk. A weak electrical resistivity is enough to drive a significant poloidal current in the ANS magnetosphere. Finally, the conditions that may mark the onset of ideal and resistive MHD instabilities are delineated.

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14:40-15:20. [Th2.A] Edge-Localized Modes

14:40-15:00 [Th2.A.O1] High-Frequency Observation of Pedestal Turbulence and Its Impact on ELM Dynamics in KSTAR

Jaehyun Lee (Korea Institute of Fusion Energy (KFE)), Minho Kim (Korea Institute of Fusion Energy (KFE)), Gunsu Yun (Pohang University of Science and Technology (POSTECH)), Minwoo Kim (Korea Institute of Fusion Energy (KFE)), Jae-Min Kwon (Korea Institute of Fusion Energy (KFE)), Juhyung Kim (Korea Institute of Fusion Energy (KFE)), Sumin Yi (Korea Institute of Fusion Energy (KFE)) and Sehoon Ko (Korea Institute of Fusion Energy (KFE)).

Abstract

Pedestal turbulence manifests as electron temperature fluctuations while the electron transport barrier remains intact until an edge-localized mode (ELM) crash occurs. Considering the crucial role of pedestal turbulence in the evolution and collapse of the pedestal, this study investigates the microscopic spatial structure and dynamics of these temperature fluctuations to elucidate the role of pedestal turbulence in the electron transport barrier [1,2]. We comprehensively compared electron temperature fluctuations observed during pedestal evolution under various instability conditions, explaining the role of pedestal turbulence in both the evolution and collapse phases. A novel diagnostic method was employed to enhance the turbulence characteristics in the KSTAR pedestal [3]. Utilizing a newly developed high-speed digitizer, we measured broadband electron cyclotron emission (ECE) to precisely observe high-frequency pedestal turbulence during both inter-ELM crash and resonant magnetic perturbation (RMP)-driven ELM suppression. Detailed comparisons with the characteristics of various instabilities revealed that the micro-tearing mode is associated with pedestal evolution and collapse. Conversely, the turbulence characteristics during ELM suppression align more closely with interchange modes, suggesting that turbulence-driven transport can induce distinct pedestal structures and ELM dynamics. To evaluate the impact of these turbulent fluctuations on pedestal evolution and collapse, we calculated the quadratic transfer function (QTF) [4]. The QTF results indicate that during the inter-ELM crash period, pedestal energy in nonlinearly transferred from turbulent eddies to magnetohydrodynamic (MHD) modes, causing the mode structure to expand radially. However, during RMP-driven ELM suppression, dominant modes do not grow due to energy exchange among turbulent eddies within the pedestal.

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15:00-15:20 [Th2.A.O2] Pulsed Hydrogen Plasma Stream Interaction on Tungsten Substrate

Tridip Kumar Borthakur (Centre of Plasma Physics Institute for Plasma Research), Azmirah Ahmed (Centre of Plasma Physics Institute for Plasma Research), Sumit Singha (Centre of Plasma Physics Institute for Plasma Research), Pallabi Baruah (Centre of Plasma Physics Institute for Plasma Research), Pradipta Prakash Kalita (Centre of Plasma Physics Institute for Plasma Research) and Nirod Kumar Neog (Centre of Plasma Physics Institute for Plasma Research).

Abstract

A Pulsed Plasma Accelerator (PPA) with coaxial electrodes system, is being used to produce ahigh speed (several km/s), high density (~ $10^{20}/m^3$) Hydrogen plasma stream by applying power from a 200 kJ Pulsed Power System (PPS). The PPS, which consists of two modules capacitor banks, can be charged up to 15 kV to achieve 200 kJ of energy. This PPS generates a peak discharge current of 100 kA for a half time period of 500 µs. A gas injection valve is used to supply the requisite gas during the application of high voltage discharge pulse in between the two electrodes. The high voltage thus applied breaks down the gaseous medium in between the electrodes to form plasma sheet which is driven by the JxB force towards the open end of the electrodes to form a high-density plasma stream. In this work, the high speed Hydrogen plasma stream is allowed to fall on Tungsten substrates placed at a distance of 10 cm from the end of the electrodes. The measured heat energy density of the Hydrogen stream at this position is 0.205 MJ/m^2while it increases up to 0.224 MJ/m^2under an influence of 0.1 Tesla external magnetic field. The plasma matter interaction at this condition creates blister formation to the surface of Tungsten material for single exposure. However minor and major cracks, displacement of cracked surface, dust formation, re-deposition are observed in scanning electron micrograph for surface exposed for 15 times to the same plasma stream. The interaction due to the heat energy density of plasma stream on Tungsten material in this work resembles either a mitigated or lower energy type-I Edge Localized Mode (ELM) [1] and the reported results are highly relevant for fusion reactor.

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14:40-15:30. [Th2.B] Materials Applications

14:40-15:10 [Th2.B.I1] Developing Community Engagement for RM3FD: Repository, Management, and Modeling for Materials Fundamental Data

Mark Koepke (West Virginia Univ and Tokamak Energy).

Abstract

Taking the lead in developing, collecting, curating, modeling, and making accessible online a repository for fundamental data characterizing novel materials that can with stand enormous heat and neutron exposure is important for controlled fusion energy and the design basis for a fusion pilot plant (FPP). The RM3FD is envisioned as a partnership for open access of high-value, high-effort, fully referenced, intellectual property for mutually shared, straightforward to implement, and as a benefit toward commercial fusion energy development.

We are motivated to form an association for the repository, management, and modeling of materials fundamental data to address the recognized need for such a community data archive both for modeling consistency and for improved transparency in interpreting experiments. Resources of the envisaged RM3FD association could include annual membership dues, public or private donations and grants, and income from services rendered by the association. One model for this endeavor is the LXCat endeavor [1] (www.lxcat.net) for the low-temperature plasma science community. The objective of this presentation is to recruit interest in facilitating the exchange of data and numerical tools for modeling Plasma-Materials Interfaces in Advanced Materials and Fusion Nuclear Science, Engineering, & Technology. Interested partners are welcome to join the effort as stakeholders (users, contributors, advisors, and leaders within the association.in advancing a proposal to government agencies.

Notional objectives:

-- Encourage the exchange and the open access of fundamental data via the internet.

-- Develop tools to facilitate the exchange of on-line data.

-- Contribute to the collection and evaluation of data.

-- Communicate with international fusion-materials community.

-- Appeal to the Modeling for Fusion Materials Fundamental Data Network/Forum.

-- Encourage open access of numerical tools for predictive modeling & analysis.

-- Contribute to the standardization of formats for storing of and exchanging of data

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15:10-15:30 [Th2.B.O1] Experimental and Modeling Studies of EIR and MAR Processes on Detached Plasmas Using the Linear Plasma Device NAGDIS-II

Noriyasu Ohno (Nagoya University), Ryoji Mano (Nagoya University), Yuta Uematsu (Nagoya University), Hiroki Natsume (Tokai University), Hirohiko Tanaka (Nagoya University), Yuki Hayashi (the University of Tokyo), Shin Kajita (the University of Tokyo), Jielin Shi (Dalian University of Technology) and Keiji Sawada (Shinshu University).

Abstract

Reducing the heat load on divertor plates is crucial for the development of a magnetic confinement plasma fusion power reactor. To achieve this goal, the formation of detached plasma through plasma-gas interaction is a promising method, and accurate modeling of detached plasmas is essential for designing DEMO reactors. In this study, we constructed a digital twin by comparing detached plasma experiments conducted using a linear plasma machine with simulations integrating calculation codes for plasma transport, neutral transport, and collisional radiative processes. This presentation describes the results of both the experiments and simulations on linear detached plasma.

The linear plasma machine NAGDIS-II is used for the experiments [1]. This device can produce steady and high-density plasmas exceeding $10^{19}m^{-3}$using DC discharges. Laser Thomson scattering measurements are installed in the upstream and downstream regions [2], and a 2D-driven spectroscopic and electrostatic measurement system is located downstream. The importance of the role of volume recombination as a particle loss process in detached recombining plasmas has been experimentally demonstrated, mainly using helium plasmas. The two-dimensional (2D) spatial structure of detached recombining plasmas, where the electron-ion recombination (EIR) is dominant, has also been clarified [3]. Furthermore, in the recombining region, the increase in plasma fluctuation and the associated increase in radial transport and structural changes have been revealed by time-space resolved 4D tomography using an electrostatic probe and a high-speed camera[4].

For hydrogen isotope plasmas, the competing processes of molecular assisted recombination (MAR) associated with excited hydrogen molecules and EIR have been investigated in detail. In deuterium plasmas, a transition from MAR to EIR is observed with increasing gas pressure [5]. Furthermore, comparative experiments between hydrogen and deuterium plasmas have been carried out, and isotope effects have been observed in which MAR is dominant in hydrogen plasmas compared to deuterium plasmas. To reproduce the above experimental results, a simulation code (DISCOVER: Detached plasma Integrated Simulation COde with Various Elastic/ inelastic Reactions), which integrates fluid, neutral and collisional radiative codes (including atomic and molecular species), has been developed by considering the transport of excited atoms and molecules generated by volume recombination and wall recycling.

Acknowledgments This work was supported by JSPS KAKENHI Grant Numbers (20H00138, 22H01203, 24H00201)

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14:40-15:30.   [Th2.C] Data-Driven Plasma Science II

14:40-15:10 [Th2.C.I1] Ab Initio Kinetic Simulations Meet Machine Learning: Opportunities in Plasma Physics

E. Paulo Alves (University of California, Los Angeles).

Abstract

First-principles kinetic simulations have long been indispensable tools for advancing our understanding of plasma physics. With the advent of increasing computational power, these simulations can now tackle larger and more complex problems than ever before. However, as the size of these simulations grows, so too does the volume of data they generate, presenting new challenges in data analysis and interpretation. Scientific Machine learning (SciML) is emerging as a powerful solution to these challenges, offering new ways to harness and analyze the vast datasets produced by fully kinetic simulations. Beyond data analysis, the computational underpinnings of SciML also present new opportunities to innovate in the way we tackle computational problems in plasma physics.

In this talk, I will explore some of the avenues my group is pursuing at the intersection of kinetic simulations and SciML. First, I will discuss how SciML can be employed to derive accurate yet simplified dynamical models of plasmas directly from the data of first-principles particle-in-cell simulations. These approaches hold the potential to create new theoretical frameworks and computationally efficient simulation models of plasmas. Additionally, I will discuss how computational methods from SciML, such as physics-informed neural networks, can be applied to solve complex inverse problems in plasma physics, including the full state reconstruction of plasmas from partial measurements/observations. Here, first-principles kinetic simulations serve as numerical experiments, providing the data necessary to understand both the potential and limitations of these innovative computational techniques, and to guide their development for plasma physics.

15:10-15:30 [Th2.C.O1] Iterated Vs One-Step Optimized System Science Models for Dst Index with Neural Networks

Maria Jose Quezada Roco (University of Chile), Juan Alejandro Valdivia (University of Chile), Jose Rogan (University of Chile), Sylvain Blunier (European Astronaut Center, European Space Agency) and Max Ramírez (University of Chile).

Abstract

The Earth's magnetic field undergoes constant perturbations caused by the solar wind, a stream of ions and electrons originating from the Sun. Understanding the dynamics of the solar wind driven magnetosphere is crucial, particularly as our modern society becomes increasingly dependent on technology that is susceptible to these phenomena. With the approach of the peak of the current solar cycle, it becomes imperative to anticipate potential disruptions to our magnetosphere and take precautionary measures to mitigate potential damage to our technologies.

In an effort to characterize the dynamics of the solar wind-magnetosphere-ionosphere system (SWMI), numerous geomagnetic indices (GI) have been introduced. One noteworthy index, DST, has been constructed to characterize the magnetic field fluctuations in the equatorial regions at the Earth's surface, aiming to capture the effects of the ring current at ground level with an hourly temporal resolution.

In this context, we adapt a machine learning approach [1] designed specifically as a system science discovery technique to study this system. First, given that the magnetosphere is a high dimensional system driven by a turbulent solar wind, we take advance of the complexity of the SWMI interaction to construct an ensemble of neural net models, starting from a diverse set of seeds. Second, we optimize the models in terms of the iterated error, instead of the standard one step error. In addition, we try to identify what are the Robust Solar Wind Drivers that affect the system. By combining these strategies, we are able to construct diverse system science models that intend to concentrate on the relevant dynamics and drivers of the system. It unveils interesting insights into how to achieve an enhanced adaptability across distinct stages of a storm. For example, our results indicate that iterated models show improvements when employing iterative optimization compared to the one-step approach.

Additionally, the construction of a diverse set of models that consider robust solar wind drivers suggest that this approach could be used to study the magnetosphere as a dynamically driven multi scale system with interconnected subsystems, and how to forecast their behavior. Additionally, it introduces an innovative interdisciplinary approach that provides valuable clues about the inner workings of neural networks.

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16:00-16:30 [Th3.A.I1] JET Experiments in Support of JT-60SA Scenario Development

Luca Garzotti (UKAEA), F. P. Orsitto (ENEA C. R. Frascati), G. Pucella (ENEA C. R. Frascati), S. Gabrielllini (Università di Roma La Sapienza), F. Auriemma (CNR ISTP, Milano), M. Baruzzo (ENEA C. R. Frascati), J. Bernardo (CNR IST, Lisboa), A. Burckhart (IPP Garching), C. Haliis (UKAEA), R. Dumont (CEA Cadarache), N. Hawkes (UKAEA), D. Kelling (UKAEA), D. King (UKAEA), J. Mailloux (UKAEA), A. Patel (UKAEA), C. Piron (ENEA C. R. Frascati), C. Sozzi (CNR IST, Lisboa), V. K. Zotta (Università di Roma La Sapienza), JET Conttributors (See author list of C. F. Maggi et al. 2024 Nucl. Fusion) and the EUROfusion Tokamak Exploitation Team (See author list of E. H. Joffrin et al. 2024 Nucl. Fusion).

Abstract

The integrated commissioning of JT-60SA tokamak was successfully completed in 2023 and the initial research phase of the machine is foreseen to start in 2026. The different operational scenarios envisaged for the extended research phase include a high current (5.5 MA / 2.25 T) inductive scenario, an advanced inductive scenario (3.5 MA / 2.28 T) and a fully non-inductive, high β_N scenario for advanced tokamak operation (2.3 MA / 1.72 T) and they will be developed progressively starting from lower plasma currents.

In support of the scenario development activity to be carried out on JT-60SA, and based on previous exploration of the hybrid and advanced tokamak scenarios, JET has performed experiments aiming at establishing a scenario with dimensionless parameters between the JT-60SA advanced inductive and fully non-inductive scenarios.

In particular, deuterium plasmas were realized at toroidal magnetic field B_T= 1.7, 2.0 and 2.4T, plasma current I_p= 1.4 MA, elongation k= 1.6, triangularity $\delta \approx 0.4$, q_{95}=3.5-4.5, and $q_0$at the start of the main heating phase >1.2, with NBI power P_{NBI}= 16-25 MW. A small subset of the deuterium plasmas obtained was replicated also in deuterium and tritium during the DTE3 experimental campaign to explore possible isotope effects.

Emphasis was placed to obtain plasmas with the highest possible β_N, while maintaining a mild MHD activity not to dramatically affect the confinement and guarantee the possibility of studying these plasmas from the transport point of view.

Main characteristics of the scenario developed on JET were: good confinement properties and relatively high β_N values for input NBI power of 20 MW (β_N>3.5 for1.7 T / 1.4 MA); good control of $q_0$at the beginning of the main heating phase by tuning the NBI starting time $t_{0,NBI}$ depending on the toroidal magnetic field value, as investigated in JET hybrid and advanced scenarios; maximum $\beta_N \approx$ 2.5-2.7 with relatively mild/stable MHD in the hybrid-advanced scenario at B_T= 2.4 T and q_0>1.

In this talk we review some aspects of the JT-60SA research plan, especially from the scenario development point of view, and present the main experimental results in support of the JT-60SA experimental exploitation showing that the scenarios developed on JET can approach theJT-60SA parameter space (especially in the initial operation phase) and some initial transport analysis showing that existing transport models such as Bohm/gyro-Bohm, QuaLiKiZ and CDBM can reproduce reasonably well the JET experiments.

16:30-17:00 [Th3.A.I2] Stochastic Theory of Plasma Bifurcations and Advanced Operations

Eun-jin Kim (Coventry University & Seoul National University).

Abstract

A key challenge in magnetically confined fusion of high-temperature plasmas is that plasmas tend to be unstable and become turbulent, causing anomalous transport and confinement degradation. However, novel plasma self-organization can emerge spontaneously, playing a vital role in plasma confinement and advanced scenarios. For instance, when a heating input power exceeds a critical power threshold, the transition from a low-confinement mode (L-mode) to a high-confinement mode (H-mode) occurs spontaneously, where plasmas organize themselves into an 'ordered', high-confinement state. While reproduced in different fusion devices, its triggering mechanisms and causality relations are not fully understood. Furthermore, turbulence characteristics in the L and H modes are very variable, often with highly time-varying RMS values of fluctuating density and turbulence velocity. On the other hand, the H-mode is subject to quasi-periodic edge-localized modes (ELMs), which can potentially cause significant damage to wall-facing materials. Despite successful experiments of ELM suppression and mitigation, e.g., by using resonant magnetic perturbations (RMPs), what is necessary for successful control is not fully understood.

To address this, I discuss a statistical analysis method [1-4] to shed light on fundamental mechanisms involved in accessing high-confinement or other advanced improved confinement states. I show the limitations of a naïve picture of bifurcation in a deterministic system based on a mean-field type theory and elucidate how plasma statistical properties change over the L-H transition. In particular, stochastic noises produce random trajectories and phase mixing, leading to uncertainty in power threshold [1] and ELM suppression [2]. I elucidate self-regulation and causal relations by information geometry [3,4] that works better than other popular entropy-based methods (e.g., transfer entropy). Some of the theoretical findings are supported from the L-H transition experimental data analysis [5]. We discuss implications for understanding other advanced operation scenarios.

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17:00-17:30 [Th3.A.I3] Most Probable Ignition Approach for Magnetic Fusion Plasmas

Hyeon Park (UNIST).

Abstract

New aspects of fusion plasma physics such as role of magnetic configuration for edge confinement and heating effects in core confinement will be a basis for the test of ignition in magnetic fusion. Performance data ($n\tau_E T_i$) and confinement scaling (τ_E) in the past half a century is discussed through critical analysis. These new findings are used to project the most probable ignition test device (tokamak device with V_p~200m^3) with the presently available engineering to demonstrate sustainment of $T_i \gg$10keV fusion plasma through sufficient α-particle heating.

16:00-16:30 [Th3.B.I1] Generation of Unstable Plasmas Leveraging Laser-Matter Interactions in Unmagnetized and Magnetized Regimes

Thales Silva (Instituto Superior Técnico).

Abstract

The study of plasma instabilities is essential for understanding various astrophysical phenomena and advancing laboratory astrophysics. This presentation focuses on recent advancements in using lasers to generate unstable plasma conditions, both in non-magnetized and magnetized scenarios, leveraging anisotropic heating in laser-plasma interactions and the generation of ring-shaped momentum distribution functions during laser-ionization of a neutral gas.

We first delve into the generation of anisotropic momentum distributions due to stimulated Raman scattering (SRS) in laser-plasma interactions [1]. We use a combination of theoretical predictions and particle-in-cell (PIC) simulations to explore regimes in which SRS will cause strong anisotropies due to trapping and wave breaking of the small wavelength plasma waves resulting from the SRS near back-scattered modes. This anisotropy is a source for the Weibel instability [2]. We show how this configuration may help to better understand the long-time evolution of the generated magnetic field filaments.

The second part is dedicated to the electron cyclotron maser (ECM) instability in laser-ionized magnetized plasmas [3]. Recent results have shown that laser ionization can also generate plasmas unstable to the Weibel instability [4]. Here, we extend this approach by using circularly polarized lasers to ionize plasmas in the presence of a guiding field, creating long-lived ring-shaped momentum distributions. This configuration allows the growth of the ECM in a controlled laboratory environment, simulating conditions found in space and astrophysical plasmas. This is a very timely topic, as ring-shaped momentum distributions have been recently discovered to be a general feature of the Vlasov dynamics in regimes where radiation cooling is relevant [5-6].

By bridging these two studies, we aim to provide a comprehensive overview of our recent work in the generation and study of unstable plasmas.

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16:30-16:50 [Th3.B.O1] Time-Resolved Two-Dimensional Velocity Mapping of the Hot-Dense Relativistic-Laser-Produced Plasmas

Amit Dattatraya Lad (Tata Institute of Fundamental Research), Kamalesh Jana (Tata Institute of Fundamental Research), Sagar Dam (Tata Institute of Fundamental Research), S. K. Rakeeb (Tata Institute of Fundamental Research), Yash Ved (Tata Institute of Fundamental Research), Ankit Dulat (Tata Institute of Fundamental Research), C. Aparajit (Tata Institute of Fundamental Research), Anandam Choudhary (Tata Institute of Fundamental Research), Alex Robinson (Rutherford-Appleton Laboratory), John Pasley (University of York) and G. Ravindra Kumar (Tata Institute of Fundamental Research).

Abstract

Ultra-intense, femtosecond laser pulses can produce hot, dense plasma and thereby generate intense shock waves. In the present study, we use extreme contrast pulses exhibiting an interesting consequence as the cold target is nanometric close to the probe critical surface. The cold target explodes under the influence of the intense pump pulse, driving a strong shock outward into the plasma, where it is witnessed by changes in the probe reflectivity and Doppler shift [1-3].

A detailed understanding of the critical surface motion of high intensity laser produced plasma is a very crucial parameter for understanding the interaction [1]. Experimentally resolving the ultrafast dynamics of high intensity laser driven plasma at both the relevant length scales and timescales simultaneously is challenging mainly due to the lack of diagnostic approach. Here, we present a novel technique based on pump-probe Doppler spectrometry to map spatially and temporally the ultrafast dynamics of hot-dense plasma generated by femtosecond, relativistic laser pulses [2,3]. Our technique offers hundreds of femtoseconds time resolution simultaneously with a few micrometers spatial resolution across the transverse length of the plasma. The experiment was carried out using the TIFR150 TW laser system. The extreme contrast laser pulses are generated by converting the main laser pulses to second harmonic (400 nm) with peak intensity of [4]. A normally incident time-delayed probe pulse reflected from its critical layer experiences a change in its wavelength due to the motion of the critical layer. Measuring the time dependent Doppler shifts at different locations across the probe pulse, we obtain two-dimensional velocity maps of the probe-critical plasma layer at ultrafast timescales [Fig. 1].The time and spatial resolution offered by the proposed technique could be improved using ashort duration probe pulse and increasing number of detection channels respectively. Early time measurements using this technique provide very important information about shockwave generation and propagation in dense medium [2,3].

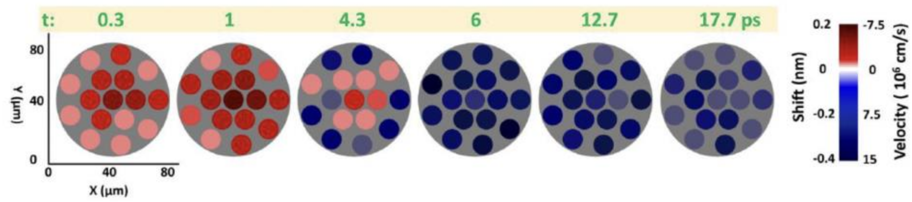

Figure 1: Spatially resolved Doppler shifts and corresponding velocity maps.

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16:50-17:10 [Th3.B.O2] Energy Absorption by Plasma Ions Under Inhomogeneous External Magnetic Field

Rohit Juneja (Indian Institute of Technology Delhi) and Amita Das (Indian Institute of Technology Delhi).

Abstract

Particle-In-Cell (PIC) simulations using the OSIRIS4.0 platform have been carried out to study the interaction of the laser pulse with an overdense plasma threaded by an inhomogeneous external magnetic field. The external magnetic field orientation is chosen to be along the laser magnetic field. The strength of the magnetic field at the plasma edge is such that the EM wave frequency lies inside the pass band, where the group velocity has a significant value. It enables the wave to enter the bulk plasma. The external magnetic field is then spatially tailored appropriately to have the LH resonance at a desired spatial location inside the plasma. This study demonstrates that the EM wave pulse comes to a standstill at the location of the resonance. The wave pulse is observed to break down subsequently, and the energy consequently goes dominantly to the local plasma ions. The absorption is significantly enhanced compared to the case in which the magnetic field profile was homogeneous [1, 2]. The dependence of absorption on the choice of magnetic field profile, the laser intensity, etc., will also be presented.

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16:00-17:10. [Th3.C] Dusty Plasmas

16:00-16:30 [Th3.C.I1] 30 Years of Plasma Crystal Research

Hubertus M Thomas (DLR-Institute of Materials Physics in Space).

Abstract

In 1994 the research field of dusty plasmas changed fundamentally due to the discovery of the crystallization of dusty plasmas in the laboratory [1-3]. Before, dusty plasmas where mainly discussed theoretically concerning the interaction of dust particles with plasma in space, including interstellar clouds, circumstellar and protoplanetary accretion discs, nova ejecta, and planetary magnetospheres. In the late 80ies and early 90ies of the last century laboratory research in low-temperature plasmas started since dust particle growth became one of the leading problems in plasma processing industry. With the discovery of the so-called plasma crystals a new research field in classical condensed matter physics was born – a topic merging plasma and solid-state physics. One of the main properties of this new state of matter is the investigation of fluid and solid processes on the most fundamental – the kinetic – level due to the individual observation of the dust particles forming liquid and crystalline structures.

Gravity strongly affects micron-sized dust particles and leads to their sedimentation. In Earth-bound labs 2-dimensional plasma crystals can be formed and investigated by e.g. levitating the charged dust particles in the sheath electric field. For the formation of large 3-dimensional systems microgravity experiments are necessary and have been performed in parabolic flights, sounding rockets and onboard the International Space Station ISS. The latter generated a longstanding program on the ISS over more than 20 years up to now. In this presentation I will review the research over the last 30 years by showing some of the highlight topics of plasma crystal research.

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16:30-16:50 [Th3.C.O1] Galactic Cosmic Rays Driven MHD Waves and Gravitational Instability Dusty Molecular Clouds [online]

Ram Prasad Prajapati (Jawaharlal Nehru University New Delhi).

Abstract

In this work, the impact of galactic cosmic rays (CRs) in terms of CR pressure and parallel CR diffusion is studied on the low-frequency magnetohydrodynamic (MHD) waves and linear gravitational instability in the typical dusty plasma environment of molecular clouds (MCs). The dusty fluid model is formulated by combining the equations of the magnetized electrons/ions and dust particles, including the CR effects. The interactions between CR fluid and gravitating magnetized dusty plasma have been studied with the help of modified dispersion properties of the MHD waves and instabilities using the hydrodynamic fluid–fluid (CR–plasma) approach. CR diffusion affects the coupling of CR pressure-driven mode with dust-Alfvén MHD mode and causes damping in the MHD waves. It persists in its effect along the direction of the magnetic field and is diminished across the magnetic field. The phase-speed diagram shows that for super-Alfvénic wave, the slow mode becomes the intermediate Alfvén mode.

The fundamental Jeans instability criterion remains unaffected due to CR effects, but in the absence of CR diffusion, the effects of dust-acoustic speed and CR pressure-driven wave speed are observed in the instability criterion. It is found that CR pressure stabilizes while CR diffusion destabilizes the growth rates of Jeans instability and significantly affects the gravitational collapse of dusty MCs. The charged dust grains play a dominant role in the sub-Alfvénic and super-Alfvénic MHD waves and the collapse of MCs, triggering gravitational instability. The consequences have been discussed to understand the gravitational instability in the dense photodissociation regions of dusty MCs [2].

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16:50-17:10. [Th3.C.O2] Sputtering and Grain-Grain Collisions in Weakly-Ionised Plasmas Using Grain Size Distribution Functions.

Sven Van Loo (Ghent University).

Abstract

Shocks in the interstellar medium occur as a result of a variety of phenomena, e.g. protostellar outflows, supernovae and cloud-cloud collisions. In dense, molecular clouds the ionisation fraction of the plasma is low and the magnetic fields threading the clouds can be significant. This results in the shocks from the bipolar outflows of young stellar objects being C-type, meaning there is a smoothing effect on the discontinuities in the fluid parameters through the shock. These shocks are important for the generation of molecules such as SiO which are otherwise heavily depleted into dust grains in these regions. The destruction of dust grains in shocks can occur due to gas-grain sputtering and grain-grain collisions, in which the grains undergo shattering and vaporisation. These processes can be modelled in a MHD code by taking different sizes of grains to be individual fluids. However, it is more realistic to incorporate the grain size distribution which is then followed through the shock. The novelty of the method presented here is that the distribution within each bin is taken into account, either using a piecewise linear or power law approach. Numerical tests show that the results closely follow the analytic solutions even for small numbers of size bins when using the power law approach. The piecewise linear method is accurate for large numbers of bins, but is inadequate in comparison to the power law method for small numbers of bins. This method can be implemented into any HD/MHD code in which changes in the dust grain size distribution occur.

17:40-18:30. [Th.P.4] RM3FD Interest-Group Meeting

1. Welcome – Mark Koepke, West Virginia University (FEDER Co-PI)
2. Data Ecosystem and Repository management – Raffi Nazikian, General Atomics (FEDER PI) [remote]
3. Building and operating the Data Ecosystem and Repository – Brian Sammuli, General Atomics (FEDER Co-PI) [remote]
4. Challenges in operating the Data Ecosystem and Repository – Frank Wuerthwein, San Diego Supercomputer Center at University of California-San Diego (FEDER facility partner) [remote]
5. Important features desired by the data community – Open question
6. Aspirational highlights, targeted metrics & foreseen impact within plasma physics – Open question
7. Question and answer opportunity

Friday
September 13

10^4-Fold Field Amplification and Control of Relativistic Mega-Ampere Electron Beams in a Modest, Static Magnetic Solid

G. Ravindra Kumar (Tata Institute of Fundamental Research), Anandam Chaudhary (Tata Institute of Fundamental Research), Amit Dattatraya Lad (Tata Institute of Fundamental Research), Trishul Dhalia (Indian Institute of Technology Delhi), Aparajit Chandrasekaran (Tata Institute of Fundamental Research), Ankit Dulat (Tata Institute of Fundamental Research), Rohit Juneja (Indian Institute of Technology), Laxman Goswami (Indian Institute of Technology), Yash M Ved (Tata Institute of Fundamental Research) and Amita Das (Indian Institute of Technology).

Abstract

Generating a powerful and quasistatic magnetic field within the confines of a tabletop laboratory experiment has proven to be a persistent challenge. Magnetized high energy density physics through such experiments presents significant opportunities for exploring and studying several terrestrial as well as astrophysical phenomena, apart from controlling relativistic electron transport, directly relevant for fusion schemes.

Here we demonstrate that the modest magnetic field (0.1 tesla) in a common, readily available Neodymium magnet excited by an ultra-intense, femtosecond laser pulse leads to the generation and amplification of axial quasistatic magnetic field to megagauss levels lasting a few picoseconds. The experimental findings are strongly supported by particle-in-cell simulations, which not only validate the observations but also unveil a potential dynamo mechanism responsible for the enhancement and amplification of the axial magnetic field [1].

We also experimentally demonstrate that this modest (0.1 Tesla), static magnetic field guides 100s keV-MeV energy, mega-ampere electron pulses over macroscopic distances. These pulses, driven by an ultrahigh intensity, femtosecond laser, propagate like a beam a distance as large as 5 mm in a high Z target (neodymium), their collimation improved, and flux density enhanced nearly by a factor of 3 [2]. Unlike the previous studies that used 100s Tesla or kilotesla fields [3,4], our studies may prove more amenable for fast electron beam-driven radiation sources, fast ignition of laser fusion, and laboratory astrophysics.

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10:50-11:30. [Fr.P.2] Plenary 13

Suppression of Pair Beam Instabilities in a Laboratory Analogue of Blazar Pair Cascades

Gianluca Gregori (University of Oxford).

Abstract

Relativistic electron-positron plasmas are ubiquitous in extreme astrophysical environments such as black-hole and neutron-star magnetospheres, where accretion-powered jets and pulsar winds are expected to be enriched with electron-positron pairs. Their role in the dynamics of such environments is in many cases believed to be fundamental, but their behaviour differs significantly from typical electron-ion plasmas due to the matter-antimatter symmetry of the charged components. So far, our experimental inability to produce large yields of positrons in quasi-neutral beams has restricted the understanding of electron-positron pair plasmas to simple numerical and analytical studies, which are rather limited. Here we present the first experimental results confirming the generation of high-density, quasi-neutral, relativistic electron-positron pair beams using the 440 GeV/c beam at CERN's Super Proton Synchrotron (SPS) accelerator. We show that the characteristic scales necessary for collective plasma behaviour, such as the Debye length and the collisionless skin depth, are exceeded by the measured size of the produced pair beams. In the first application of this experimental platform, the stability of the pair beam is studied as it propagates through a meter-length plasma, analogous to TeV γ-ray induced pair cascades in the intergalactic medium. It has been argued that pair beam instabilities disrupt the cascade, thus accounting for the observed lack of reprocessed GeV emission from TeV blazars. If true this would remove the need for a moderate strength intergalactic magnetic field to explain the observations. We find that the pair beam instability is suppressed if the beam is not perfectly collimated or monochromatic, hence the lower limit to the intergalactic magnetic field inferred from γ-ray observations of blazars is robust.

11:40-12:00 [Fr1.A.O1] Isotopic Effect on Intrinsic Toroidal Rotation in ADITYA-U Tokamak

Ankit Kumar (Institute for Plasma Research), Joydeep Gosh (Institute for Plasma Research, Homi Bahabha National Institute), M. B. Chowdhuri (Institute for Plasma Research), Aman Gauttam (Institute for Plasma Research), N. Ramaiya (Institute for Plasma Research), Bharat Hedge (Institute for Plasma Research, Homi Bahabha National Institute), Kaushlender Singh (Institute for Plasma Research, Homi Bahabha National Institute), Suman Dolui (Institute for Plasma Research, Homi Bahabha National Institute), Ashok Kumawat (Institute for Plasma Research, Homi Bahabha National Institute), Dipexa Modi (Pandit Deendayal Petroleum University), Soumitra Banarjee (Institute for Plasma Research, Homi Bahabha National Institute), Injamul Houqe (Institute for Plasma Research, Homi Bahabha National Institute), Komal (Institute for Plasma Research, Homi Bahabha National Institute), Harshita Raj (Institute for Plasma Research, Homi Bahabha National Institute), K. A. Jadeja (Institute for Plasma Research), Ankit Patel (Institute for Plasma Research), Pramila Gautam (Institute for Plasma Research), Utsav (Institute for Plasma Research), K. Shah (Princeton Plasma Physics Laboratory), G. Shukla (Institute for Plasma Research), N. Yadava (Oak Ridge Associated Universities), Tanmay Macwan (University of California Los Angeles), S. Patel (Pandit Deendayal Petroleum University), Laxikanta Padhan (Institute for Plasma Research), Suman Aich (Institute for Plasma Research), A. Kanik (University of Petroleum and Energy Studies), Rohit Kumar (Institute for Plasma Research, Homi Bahabha National Institute), Priyanka Verma (Institute for Plasma Research), K. M. Patel (Institute for Plasma Research), Kalpesh Gadoliya (Institute for Plasma Research) and R. L. Tanna (Institute for Plasma Research).

Abstract

In both Hydrogen & Deuterium discharges, intrinsic toroidal rotation has been observed using Doppler shifts in spectral lines of the main impurity ions (C5+ ions, emitting at 529.05nm) in ADITYA-U tokamak without applying any external torque to the plasma. In purely Hydrogen discharges, intrinsic toroidal rotation reverses its direction from counter-current to co-current on increasing the plasma current beyond a certain threshold value. However, this intrinsic toroidal rotation (measured in the edge region) is observed to damp to zero as soon as the edge electron density is increased [1]. In Hydrogen discharges, ***E***×***B*** drift velocity is found to drive the observed intrinsic toroidal rotation in the edge region of ADITYA-U. A recent and a new study of the isotopic effect is performed on the intrinsic toroidal rotation in ADITYA-U tokamak, which will be discussed in this paper.

References

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11:40-12:10 [Fr1.B.I1] Laser Driven Microdroplet for Efficient Electron Acceleration

Krishnamurthy Manchikanti (TIFR Hyderabad).

Abstract

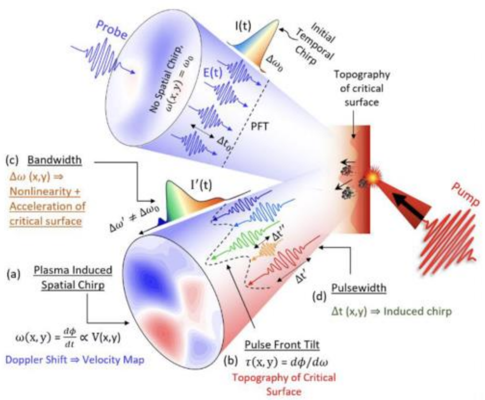
Intense ultrashort pulse lasers generate relativistic electrons when the intensity reaches relativistic scales, 10^{18}Wcm^{-2}for 800nm pulses. This requires Terra watt class lasers that are complex, cumbersome, expensive and deliver typically 10 pulses per second. While the electron/x-rays/proton beams generated from such system have shown a lot of promise, developing applications on such systems is very challenging. I will talk about experiments where even at a 1/100th of laser intensity, it is feasible to generate relativistic electron beam of 1 MeV energy with multi kHz few mJ/pulse lasers. We show that plasma wave instabilities generated and manipulated with suitable targetry is the underlying mechanism. The source size of the short pulse electron beam is amenable for x-ray radiography and shadowgraphy.

12:10-12:30 [Fr1.B.O1] Single-Shot, Spatio-Temporal Metrology of Relativistic Plasma Optics

Ankit Dulat (Tata Institute of Fundamental Research), Amit Lad (Tata Institute of Fundamental Research), C. Aparajit (Tata Institute of Fundamental Research), Anandam Choudhary (Tata Institute of Fundamental Research), Yash Ved (Tata Institute of Fundamental Research), Laszlo Veisz (Umea University) and G. Ravindra Kumar (Tata Institute of Fundamental Research).

Abstract

Plasma optics are promising new tools to guide, shape, or even amplify ultrahigh-power, ultrashort laser pulses [1]. They have the unique potential to liberate ultrafast laser technology from the strong limitations posed by optical damage in conventional optical elements and so further increase the peak power of state-of-the-art lasers. However, the plasma is inherently dynamic, highly complex, and challenging to control, so it can easily degrade the spatio-temporal structure of the optical pulse. Therefore, to design and operate plasma optics, a precise characterization of the complex spatio-temporal and spatio-spectral profile of the laser pulse and the instantaneous dynamics of the plasma surface is highly desired. Furthermore, as ultra high-power laser systems have a low repetition rate down to single-shot operation, this spatio-temporal characterization is mandatory on a single-shot basis. This was not demonstrated before, so it represents a serious gap.



Here, we present three-dimensional (3D) spatio-temporal measurements of such pulses based on spectral interferometry [2,3]. We measure the complex space-time distortions induced in the laser pulses by relativistic plasma while simultaneously capturing the underlying plasma dynamics, all in a single shot. This all-optical technique can capture 3D spatio-temporal couplings within pulses at ultra-high peak powers, enabling further progress in ultra-high-intensity laser and plasma technologies.

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11:40-12:20. [Fr1.C] Ionospheric Plasmas

11:40-12:00 [Fr1.C.O1] Inverse Cascade Processes in the Development of Electrojet Plasma Instabilities in Ionospheric E Region

Arash Tavassoli (Department of Physics and Engineering Physics, University of Saskatchewan), Andrei Smolyakov (Department of Physics and Engineering Physics, University of Saskatchewan), Sasha Koustov (Department of Physics and Engineering Physics, University of Saskatchewan) and Raymond Spiteri (Department of Computer Science, University of Saskatchewan).

Abstract

In this work, we use two-fluid simulations to investigate the nonlinear regime of the electrojet plasma instabilities responsible for the formation of electron density irregularities in the ionospheric E region [1]. We employ a 2-D model of partially ionized plasma, originally developed in [2] for studying E×B plasma discharges. The model unifies closely related plasma instabilities, such as the Simon-Hoh/gradient-drift, Farley-Buneman and lower-hybrid instabilities, and captures multiscale effects, including electron inertia and finite-Larmor-radius effects. We report on the development of secondary nonlinear instabilities and formation of large-scale plasma structures (the inverse cascade processes) leading to the nonlinear saturated state. We demonstrate that these large-scale structures play a crucial role in the development of the electrojet plasma turbulence. A comparison of computational results with experimental data is provided.

Acknowledgments This work is partially supported by funding from the Natural Sciences and Engineering Council of Canada (NSERC), University of Saskatchewan Research grant 421980 to AVK, computational resources from the Digital Research Alliance of Canada, and Simons Collaboration on Hidden Symmetries and Fusion Energy.

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12:00-12:20 [Fr1.C.O2] Emergence of Electrostatic Solitary Waves in Titan's Ionospheric Plasma

Steffy Sara Varghese (Khalifa University of Science and Technology), Kuldeep Singh (Khalifa University of Science and Technology), Frank Verheest (Ghent University) and Ioannis Kourakis (Khalifa University of Science and Technology).

Abstract

Observations conducted in Titan's ionosphere have unveiled the presence of various ions possessing either positive or negative charge [1] along with different blends of electron populations (at different altitudes) practically following a Maxwell-Boltzmann distribution[2]. From a fundamental (theoretical) point of view, it is well established that the coexistence of ions with opposite charges leads to novel phenomena, notably including the possibility of polarity reversal in localized modes, such as electrostatic solitary waves.

In this work, we shall thoroughly investigate the potential occurrence of ion-acoustic solitary waves in the ionospheric plasma of Titan. A bi-ion plasma-fluid model with two electron populations (with different temperatures) in the background has been adopted as a starting point to explore the nonlinear propagation features of ionic scale electrostatic solitary waves that may occur in Titan’s ionosphere from first principles. We have employed nonlinear (multiscale) perturbation techniques, in an effort to reduce the fluid model to a nonlinear evolution equation governing the electrostatic potential. Considering different plasma compositions, including critical configurations where the nature of nonlinearity is known to change [3], different partial-differential equations have been obtained, incorporating quadratic or cubic nonlinearity as well as combinations thereof, thus describing diverse scenarios for the solitary wave propagation characteristics. The parametric influence of the plasma composition, in terms of the relative electron concentration (cool-to-hot electron density) and the relative (negative-to-positive) ion density, on the solitary wave features has been investigated. Different possibilities have been predicted, including positive and negative polarity pulses and double layers, whose characteristics (amplitude, width, polarity) depend on the plasma configuration.

Our theoretical findings should provide valuable insight into the criteria for existence and the dynamics of electrostatic solitary wave structures occurring in Titan's ionosphere, with an ambition to contribute to the prediction and interpretation of future observations.

Acknowledgments The authors acknowledge financial support from Khalifa University’s Space and Planetary Science Center under grant No. KU-SPSC-8474000336. IK also thanks KU for support via grant CIRA-2021-064/8474000412.

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Poster sessions

[Tu.Po.1] A Simulation Study of Impurity Radiation Excitation and Driven Tearing Mode

Zhiwei Ma (Zhejiang University) and Yiming Zu (Zhejiang University).

Abstract

Tearing modes excited and driven by impurity radiation are investigated by using three-dimensional toroidal MHD code with the impurity module (CLT). Various types of impurities applied at the boundary under an equilibrium condition where the tearing mode is stable. It is observed that impurity radiation-induced plasma contraction results in a current gradient that excites the tearing mode at the resonance surface. Through a scan of the initial atomic number (Z) and impurity concentrations, it is found that impurities with different Z values exhibit similar behaviors in the radiation-driven tearing mode. The impurity radiation can drive tearing mode growth through temperature cooling near the resonance surface, and there exists a linear relationship between the temperature perturbation caused by impurity radiation and the linear growth rate of the tearing mode. Additionally, the impurity can promote the growth of magnetic islands through the cooling inside the magnetic island, and there exists a correlation between the initial parameters of impurity and the width of the saturated magnetic island.

[Tu.Po.2] GKNET-X, a Global Gyrokinetic Code for Turbulence Simulations in Core and Edge Regions of Tokamak Plasmas

Shuhei Okuda (Kyoto University), Kenji Imadera (Kyoto University), Haruki Seto (National Institutes for Quantum Science and Technology) and Akihiro Ishizawa (Kyoto University).

Abstract

Turbulent fluctuations play an important role in predicting the confinement of plasmas at the edge region as well as the core region. Namely, understanding the fluctuations in the outer core region connecting to the SOL/divertor region is important for predicting fuel supply, impurity pumping, divertor heat load control, and L-H transition of tokamak plasmas. These issues are particularly important for predicting the confinement of future fusion devices like JA-DEMO [1]. Although gyrokinetic simulation is an essential tool for studying these issues based on the first principles of magnetized plasmas, it is still challenging to apply it to the edge region due to high q values and complex magnetic surface geometries that are not present in the inner core region. To address these issues, a core global gyrokinetic simulation code GKNET [2] has been extended to GKNET-FAC [3] by introducing a field-aligned coordinate system [4] with a shifted metric technique [5] and numerical MHD equilibria. The field-aligned coordinate can reduce computational costs for turbulence in the outer core region significantly. For calculating drift-wave instabilities with a high toroidal mode number in a JT-60SA plasma, GKNET-FAC requires only 1/94 smaller the number of grid points than that for GKNET.

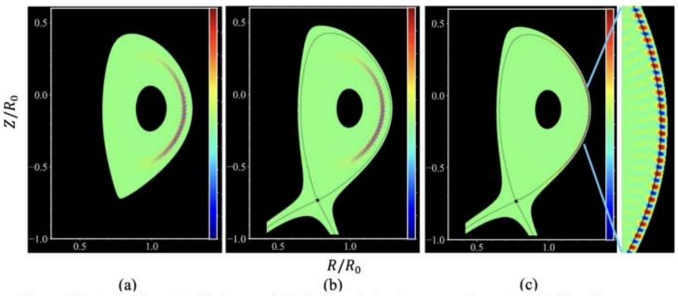

Figure. Electrostatic potential $\phi_{n=60}$ of the ITG mode in the core region calculated by (a) GKNET-FAC and by (b) GKNET-X. (c) $\phi_{n=60}$ of the ITG mode at the separatrix by GKENT-X.

In this study, we have extended GKNET-FAC to GKNET-X handling plasma turbulence in the edge region consisting of both the inside and outside of separatrix. Figures(a) and (b) show that the eigenfunction of the ion temperature gradient (ITG) mode calculated by GKNET-X is in good agreement with that by GKNET-FAC for a toroidal mode number n= 60. In addition, we successfully calculate the ITG mode excited at the separatrix between the closed surface core region and the open surface SOL region as shown in Fig. (c). We will also present some nonlinear simulation results by GKNET-X in the conference.

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[Tu.Po.3] Estimation of the Optical Reflection Property of Plasma Facing Surfaces from Topography Measurements

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Abstract

In the spectroscopic measurement of fusion reactors, the reflected light from the plasma-facing surface has a significant effect on the measurement signal [1]. Therefore, to obtain accurate spectroscopic measurements, it is necessary to quantitatively assess the influence of the reflected light, which can be done by ray tracing calculations [2]. The accuracy of this assessment depends on the precision of the Bidirectional Reflectance Distribution Function (BRDF) of the reflecting surface used in the ray tracing calculations. Since the interaction between the plasma and the wall can change the surface condition, the BRDF of the plasma-facing surface will also change. Therefore, without the development of a method to measure this BRDF in situ, reliable spectroscopic measurements cannot be achieved, potentially leading to significant misunderstandings in spectroscopic diagnostics.

The aim of this study is to investigate the relationship between the surface geometry of plasma-facing materials and optical reflection models, and to clarify the possibility of in-situ estimation of the BRDF based on the surface topography. Among the plasma-facing components of ITER, the divertor surface will be made of tungsten, which may vary due to plasma-wall interactions, while the blanket surface will be made of beryllium, which has a large surface area and raises concerns about its substantial impact on optical diagnostics. Therefore, this study has conducted an analysis of BRDF for both tungsten and beryllium with various topographies.

Fitting was performed to optimize the free parameters in the optical reflection model. The topographic parameters were determined from the surface three-dimensional measured with a laser microscope. The relationship between the parameter (kd) defining the diffuse reflection in the optical reflection model (Phong model), and the topographic parameters showed that kd increased monotonically with increasing topographic parameters. In addition, topographic parameters using the slope of the surface geometry showed a higher coefficient of determination (R2). Furthermore, the relationship between the parameter (ks) defining the magnitude of the specular reflection in the Phong model and the topographic parameters did not show as strong a correlation as kd. This is because the specular reflectance model does not accurately reproduce the measured BRDF, especially at the feet of the specular lobe where the BRDF is often underestimated, suggesting the need to investigate more accurate specular reflectance models. However, the topographic parameters that account for surface slope showed a certain correlation with ks. Therefore, this indicates the potential to directly assess BRDF from measurements of surface geometry inside fusion reactors using tools such as laser interferometers, and to accurately assess the effect of reflected light in spectroscopic measurements.

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[Tu.Po.4] 2D-Emission Intensity Measurement of Hydrogen/Deuterium Plasma Detachment with ICR Heating on TPDsheet-ICR

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Abstract

It is expected that the heat flux reaching the divertor region of the future reactor such as DEMO will be several times higher than that of ITER. To sufficiently reduce this heat flux, a fully detached plasma must be maintained while preventing X-point MARFE. In large fusion devices, conducting fundamental research focused on detailed divertor plasma physics is challenging due to port limitations and machine time, and other factors. Therefore, it is efficient to use a small linear divertor simulator that can generate steady-state detached plasmas and can be flexibly connected to various measurement devices.

A common issue with the general linear divertor simulator is that the ion temperature of the generated plasma is as low as several eV, which is one order of magnitude lower than that of fusion divertor plasmas. The ion temperature of fusion divertor plasmas is several tens of eV, which is close to or higher than the electron temperature (~10 eV). Therefore, it is required to increase the ion temperature from several eV to about 20 eV to study reaction processes in detached plasmas.

In this study, to investigate the transition process of detached plasma in detail, high-density sheet plasma (~10^{18}-$10^{19}m^{-3}$) was generated using the linear divertor simulator TPD sheet-ICR [1,2]. Hydrogen or deuterium was used as the discharge gas. Additionally, ions in the sheet plasma were heated by ion cyclotron resonance heating (ICRH) using parallel-plate electrodes. We performed the Langumuir probe measurement of plasma parameters (electron density and temperature) of the detached plasma outflowing into the divergent magnetic field region. Futhermore, two-dimensional distribution measurements of Balmer series emission (Hα, Dα, Fulcher, Hγ and Dγ) were performed using a fast-framing camera equipped with an Arbaa prism. When both hydrogen and deuterium plasmas transition from the attached plasma state to the detached plasma state, the Fulcher band emission intensity decreases, while the Hγ and Dγ emission intensity increases. Further, it is evidenced that the increase in the ion temperature by increasing the applied power of ICRH from 0 to 500 W (Ti: 2.4 to 6.5 eV) leads to rise in the electron temperature, resulting in a decrease in the emission from highly excited atoms such as Hγ and Dγ in the Balmer series.

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[Tu.Po.5] Optimisation of EBW Power Deposition and Current Drive in Spherical Tokamaks by Numerical Simulation and Resonance Condition Analysis

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Abstract

Auxiliary plasma heating and current drive (HCD) in the Spherical Tokamak for Energy Production (STEP) fusion reactor will be achieved by utilising a large number of high power microwave sources with a power of the order 1MW each. A combination of electron-cyclotron (EC) and electron Bernstein wave (EBW) HCD will be employed. In addition to the well-understood EC HCD method, the use of EBWs is considered due to their high efficiency current drive and ability to propagate in overdense plasmas. The proposed method to generate EBWs is by launching an O mode polarised microwave from the low field side at an optimal angle to the magnetic field. The O mode undergoes conversion to a slow X mode wave and finally to an EBW that can propagate into the overdense plasma interior. To obtain the most efficient power deposition and current drive, controllable access and power deposition of EBWs to all regions of the ST plasma is required. By employing GENRAY ray-tracing and CQL3D Fokker-Planck simulations, varying of the launch position and scaling the plasma parameters for a set of STEP Prototype Reactor (SPR) scenarios, we are able to optimise the propagation of the EBW and the locations of power deposition to achieve high levels of current drive. Analytical models have concurrently been developed through consideration of energy conservation and the fundamental resonance condition which give insight into the wave-plasma interaction. We also show how coupling of EBWs to Doppler-shifted electron cyclotron harmonics can impact the current drive through the excitation of oppositely directed currents.

[Tu.Po.6] Development of a Linear Divertor Plasma Simulator Based on Magnetic Mirror Device at KAIST

Donggeun Oh (Korea Advanced Institute of Science and Technology), Gwangwoon Baek (Korea Advanced Institute of Science and Technology), Dongha Kim (Korea Advanced Institute of Science and Technology), Yeono Jung (Korea Advanced Institute of Science and Technology), Kyu-Dong Lee (Korea Institute of Fusion Energy), Hyunyeong Lee (Korea Institute of Fusion Energy), Bong-Ki Jung (Q-BEAM SOLUTION), Kyoung-Jae Chung (Seoul National University) and Choongki Sung (Korea Advanced Institute of Science and Technology).

Abstract

It is crucial to understand physics of the edge region in fusion plasmas, since reducing heat flux at the divertor plate and reaching the thermo-mechanical engineering limit of the plasma facing materials are essential for the fusion energy development. Leveraging low construction and operation costs and simple geometry, linear devices have been utilized as a divertor simulator to investigate the edge plasma physics in closed magnetic field systems, including tokamaks [1–2]. This presentation will highlight the ongoing progress in developing a divertor plasma simulator using the magnetic mirror device at KAIST, KAIMIR [3]. The vacuum chamber of the device comprises three sub-chambers: source, center, and expander. We have modified the expander chamber as a divertor region of the tokamak to simulate the radiative divertor conditions and analyze their characteristics. To control the neutral pressure of the divertor chamber independently, we implemented a differential pumping system, allowing for a pressure difference of over 20 times between source and divertor chambers through the use of a skimmer structure. The gas injection valve, originally a piezoelectric valve (with a flow rate < 0.53 slm), has been replaced with a solenoid valve (with a flow rate ~ 17.8slm) to enhance neutral pressure control capability at the source chamber. We also developed additional diagnostics, such as probes and a mm-wave interferometer system to understand the physics relevant to the divertor region, complementing existing diagnostics (spectroscopy, diamagnetic loops, and probes) in the center chamber. Future plans involve the integration of an Electron Bernstein wave (EBW) heating system to regulate the temperature of the incoming plasma flow to the divertor region and mitigate plasma pressure degradation along the axis. Further details on the experimental setup and results will be discussed.

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[Tu.Po.7] Innovative Magnetic Confinement Method for Fusion Plasmas Based on an Overlooked Historical Discovery

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Abstract

In the late 1960s, the American physicists Eugene Parker and Ian Lerche studied a simplified model of the flow of the solar wind around Earth's magnetic field, focusing on the region where the flow is parallel to the field lines (shown in red in the Figure 1). They discovered that, in the thin boundary layer between the plasma and the field, a secondary magnetic field arises, which is stronger than the primary field. Under certain circumstances, this effect causes the boundary layer to become unstable [1].

A decade later, Owen Storey and Laurent Cairó demonstrated that this effect, which they named "Parker's Effect", also occurs when a magnetic field encloses and confines a supersonically flowing plasma. However, in this scenario, it reinforces the confinement of the plasma which remains, in the bulk, field-free and current-free. They demonstrated analytically that a simple confinement system based on this effect would be intrinsically MHD-stable and have a global beta significantly higher than most magnetic confinement devices currently under investigation. They suggested that Parker's Effect may have applications to fusion and outlined a toroidal device exploiting it [2]. To date, Parker's Effect has not been observed experimentally or in simulation, mainly because it has not been sought.

Our research group has been reviewing these investigations and developing a full simulation model of a module of the device (figure 2), using an open-source software framework running on modern supercomputers. In this presentation, we will explain Parker's discovery, the insights contributed by Storey and Cairó, and the main device they proposed. We will mention our team's recent research efforts, share preliminary results and findings, and highlight potential avenues for collaboration.

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[Tu.Po.8] Potential Research Programme for JET with a Tungsten Wall and ECRH

Jozef Ongena (LPP-ERM/KMS Brussels), Emilia Solano (Laboratorio Nacional de Fusion, CIEMAT, Madrid) and JET petition contributors (Petition to extend JET beyond 2023).

Writing as independent, not necessarily representing the views of our institutions

Abstract

We propose a research program for the continued operation of the JET facilities over the next 10-15 years, thereby making optimal use of JET's unique capabilities (especially operation with Deuterium-Tritium mixtures) by integrating the ITER re-baselining decisions within JET. The primary objective is to transition JET to a phase with a tungsten wall and 10 MW of Electron Cyclotron Resonance Heating (ECRH) using 170GHz gyrotrons in addition to the existing additional heating systems, thereby aligning with the goals of both STEP and ITER.

Enhancing JET as proposed, would allow to increase the fusion performance for Baseline and Hybrid scenarios, and to test their compatibility with a Tungsten wall, aiming at steady conditions with equal electron and ion temperatures. Synergies between Electron Cyclotron (EC), Ion Cyclotron (IC), Neutral Beam Injection (NBI), and alpha heating could be investigated in detail. Investigations in the ion temperature clamping effect seen on smaller machines with dominant electron heating (and methods to avoid it) would now become possible in a device with a size and under operational conditions as close as possible to ITER. The compatibility of Boronization with high performance plasmas in the presence of a high-Z wall can be investigated in detail. Control, mitigation and suppression techniques for Edge Localized Modes (ELMs) could be tested in more fusion-relevant situations, and the effect of controlled impurity seeding with Ar and Ne on plasma wall interaction and confinement could be explored. DT campaigns in the enhanced JET would also uniquely enable to develop advanced fusion diagnostics, including precise neutron measurements and γ-ray imaging to detect alpha-particles (from D+T or B^+4He reactions),providing a unique opportunity to prepare necessary diagnostics for the rebaselined ITER. Preparing for ITER's DT campaigns (presently planned to begin in 2039) implies training the next generation of scientists, technicians, and engineers within a large fusion facility. Extending JET's operation as proposed offers a unique opportunity to sustain and enhance the expertise of fusion researchers globally, thereby accelerating progress in the world-wide quest for fusion energy.

[Tu.Po.9] Terahertz to near-Infrared Radiation Generation Using Two-Color Laser Pulses in Plasma

Dinkar Mishra (University of Lucknow) and Bhupesh Kumar (University of Lucknow).

Abstract

The generation of intense and coherent THz radiation has been a subject of intense research, with numerous methods developed to harness its potential. One of the promising techniques that has emerged is the generation of THz radiation using laser-induced plasma. This method utilizes the unique properties of ultrafast lasers to create plasma, which, in turn, emits THz radiation through a variety of mechanisms [1-5] . This study is significant for the generation of intense radiation fields having frequencies lying in the THz to near IR range. The novelty of the present mechanism is that the frequency of the generated radiation can be controlled by continuously varying the frequency difference between the two laser pulses. In order to portray the significance of the present mechanism laser frequency differences equal to twice and thrice the plasma frequency have been considered. However, arbitrary frequency differences can lead to a continuous range of tunable radiation. The present analytical mechanism of tunable radiation generation has been validated via simulation studies which show that the transverse orthogonal electric and magnetic fields generated in plasma are essentially radiation fields that can propagate in vacuum. The discrepancy in analytical and simulation results may be attributed to the approximation scheme used for the analytical case.

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[Tu.Po.10] Exploring the Possibility of Evaporating Macroparticles of Vacuum Arcs by an Electron Beam

Iryna Litovko (Institute for Nuclear Research NAS of Ukraine, Leibniz Institute of Surface Engineering (IOM),Germany), Martin Rudolph (Leibniz Institute of Surface Engineering (IOM)) and André Anders (Leibniz Institute of Surface Engineering (IOM)).

Abstract

Erosive plasmas sources creating dense, low-temperature plasma, in particular of the vacuum-arc type, are reliable and well-tested generators of metal plasma. They are widely used in academia and industry for the deposition of hard, protective and functional coatings. Moreover, they are used to modify surface properties of structural and decorative materials. However, the presence of microdroplets of the cathode material in the plasma prevents the use of erosive sources in applications requiring high-quality coatings, especially those demanding high uniformity and low roughness at the nanometer level. The use of modern filtering techniques to remove droplets, especially those of small sizes (< 1 µm), leads to a significant decrease in the deposition rate, which compromises one of the unique features of these sources, namely their high deposition rate. That is why alternative filtering concepts are of interest.

Here, we discuss an approach using energetic electrons injected into the arc plasma [1].They introduce additional energy into the plasma which can promote evaporation from the droplets which may eventually lead to complete destruction of droplets. By solving a self-consistent system of equations for the balance of energy, current to and from a droplet, and the droplet mass, it is shown that favorable conditions for the evaporation of microdroplets may exist. It is shown that the main parameters influencing the droplet evaporation rate are the plasma density as well as the density and energy of the electron beam. It has been shown that droplets with a radius of 1 µm or less may completely evaporate during the time the droplet is in the system if the energy of the electron beam is 3 to 5 keV and the beam-to-plasma density ratio is greater than 0.01.

Acknowledgments This work is supported partly by the grant DFG - Deutsche Forschungsgemeinschaft(DFG) under project number 525228371.

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[Tu.Po.11] Factors Influencing Inactivation Efficacy of Plasma-Activated Water Against Klebsiella Pneumoniae

Dragana Vuković (Faculty of Medicine, University of Belgrade), Boško Toljić (School of Dental Medicine, University of Belgrade), Maja Miletić (School of Dental Medicine, University of Belgrade), Nikola Milojević (School of Dental Medicine, University of Belgrade), Olivera Jovanović (Institute of Physics, University of Belgrade), Nikola Škoro (Institute of Physics, University of Belgrade), Gordana Malović (Institute of Physics, University of Belgrade), Milica Đaković (Faculty of Medicine, University of Belgrade) and Nevena Puač (Institute of Physics, University of Belgrade).

Abstract

Plasma-activated water (PAW) has demonstrated potent antimicrobial efficacy, which is mainly attributed to the reactive oxygen and nitrogen species (RONS) [1]. Our study assessed bactericidal activity of PAW against multidrug-resistant Klebsiella pneumoniae in relation to plasma treatment time, volume of treated water and PAW application time on bacteria samples. The model organism we selected is an important no socomial pathogen, capable of persistence on various surfaces and difficult to eradicate due to resistance to harsh conditions and antimicrobials [2].

The in-house developed plasma source was 3-pin jet with needle electrodes inserted inside three separate glass tubes and positioned vertically above the water sample. Working gas was argon (2.5 slm), frequency of high-voltage power supply 340 kHz and applied power14 W. We have treated 150 ml of deionized water for 20 min (PAW1, pH=6.2) and 15 ml for10 min (PAW2, pH=6.5). Characterization of the PAW chemistry was performed by using colorimetric methods: PAW1 (H2O2=10 ppm, NO3-=34 ppm, NO2-=0 ppm) and PAW2 (H2O2=80 ppm, NO3-=97 ppm, NO2-=41 ppm).

An aliquot of 100 µL of the suspension (108 cells/ml, K. pneumoniae ATCC BAA-1705) was added to 900 µL of PAW in microtubes, homogenized, and maintained for 15 min and 60 min. Bactericidal effects of PAW were assessed by the standard plate count method and expressed in log CFU/mL. Inactivation activity of PAW against K. pneumoniae increased by reducing the water volume for PAW preparation and by extending the incubation time of the bacteria in PAW. PAW1 reduced K. pneumoniae by ≈1.1 log CFU after 60 min of application time, while no reduction was noted after 15 min exposure. PAW2 applied for 15min resulted in ≈1.6 log CFU reduction, while 60 min application achieved complete eradication of K. pneumoniae.

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[Tu.Po.12] Investigating Ultra-High Dose Rate Pulsed X-ray Effects on Cancer Cells Using a Kilojoule Plasma Focus Device

Jalaj Jain (Comisión Chilena de Energía Nuclear), José Moreno (Comisión Chilena de Energía Nuclear), Héctor Araya (Universidad de Chile), Rodrigo Andaur (Universidad de Chile), Sergio Davis (Chilean Nuclear Energy Commission), Leonardo Herrera (Universidad Andres Bello), Biswajit Bora (Chilean Nuclear Energy Commission), Ethel Velásquez (Chilean Nuclear Energy Commission), Cristian Pavez (Chilean Nuclear Energy Commission), Katherine Marcelain (Universidad de Chile) and Leopoldo Soto (Chilean Nuclear Energy Commission).

Abstract

Radiation therapy has been used for the treatment of cancer disease for many decades. Normally, the dose rates in radiation therapy are of the order of tens to hundreds Gy/h. The effects of ultra-high dose rate irradiations (10^3~ 10^7Gy/sec) on cancer cells are less explored. In the present study, several cell cultures, two colorectal cancer cells (DLD-1, HCT-116), one breast cancer cell (MCF-7), one ovarian cell, and one non-cancerous colorectal cell (CCD-841-con) have been exposed to pulsed X-ray (~ ns duration time) with a high-dose-rate (~ 10^7Gy/sec) keeping the total doses low (≤ 1 Gy) using a kilojoule plasma focus device, PF-2kJ.The obtained results are compared with the conventional X-ray irradiation source results. The DLD-1 cell line shows the low-dose hyper-radio-sensitivity (LDHRS) effect at lower doses for pulsed X-ray than the conventional X-ray irradiation. The HCT-116 cell line shows the HRS effect in the case of pulsed X-ray irradiation, which is reported to be absent in the case of conventional X-ray irradiation. The radio-resistive cell MCF-7 shows a larger number of cell death in the case of pulsed X-ray irradiation. The ovarian cancer cell shows a reduced proliferation capacity in the case of 2D cell culture irradiation and reduced vasculogenic-mimic structures in the case of 3D model irradiation using pulsed X-ray. The X-ray energy used for cell culture irradiation was in the range of 8-10 keV. To study further the irradiation effects of different energies of X-ray on cells, a simulation using the Geant4 tool kit was performed. It was found that low-energy X-ray irradiation induces larger toxic effects.

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[Tu.Po.13] Methicillin-Resistant Staphylococcus Aureus Inactivation by Plasma Activated Water

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Abstract

Plasma-activated water (PAW) presents an effective strategy for microbial inactivation, which is linked to synergistic effects of reactive oxygen and nitrogen species (RONS) [1]. We evaluated the antimicrobial effect of PAW against a methicillin-resistant Staphylococcus aureus (MRSA) isolated from an odontogenic abscess. S. aureus strains, and in particular MRSA strains due to their resistance, have an important role in etiology of dental abscesses[2]. For the purpose of comparison, the reference MRSA strain routinely applied in disinfectant testing (ATCC 33591) was included in the study.

The plasma source for PAW preparation was 3-pin jet using argon as the working gas(2.5 slm), with frequency of high-voltage power supply 340 kHz and applied power 14 W. Needle electrodes were inserted inside three separate glass tubes and positioned vertically above the water sample. We have treated 15 ml of deionized water for 10 min (pH=6.5). The PAW chemistry was characterized by colorimetric methods (H_2O_2=80 ppm, NO_3^-=97 ppm,NO_2^-=41 ppm).

Bacterial suspensions containing 108 cells/ml were prepared in sterile saline, and an aliquot of 100 µL per strain was added to 900 µL of PAW in microtubes. Following exposure to PAW for 15 min and 60 min, bactericidal effects were assessed by the plate count method and expressed in log CFU/mL. PAW treatment was ineffective against reference MRSA strain regardless of the exposure time. Only longer PAW treatment showed effectiveness in the clinical MRSA strain, resulting in log CFU reduction equivalent to a 81.67% reduction in the bacterial population. While these results show bactericidal capacity of PAW against MRSA, further optimization of the PAW generating parameters is required for achieving efficient eradication.

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[Tu.Po.14] Hydrolysis of degradable plasma-polymerized poly(ethylene glycol)/ZnO nanocomposites in food simulants: identification of components and potential toxicity

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Abstract

Plasma polymers produced via atmospheric pressure plasma polymerization are an innovative alternative to polymers synthesized through wet chemistry. This solvent-free, eco-friendly technique creates advanced antibacterial polymer coatings suitable for food packaging. Despite advancements in plasma polymer manufacturing, less focus has been on the degradation of these coatings in contact with food. Proper identification of degradation products is crucial for assessing potential toxicity. This study uses an aerosol-assisted atmospheric pressure plasma system to deposit polyethylene glycol (PEG)-like coatings with 1 wt% zinc oxide (ZnO) nanoparticles on a polymer substrate. Fourteen degradation products released into various food simulants were identified, with the highest releases linked to $C_6H_{14}O_4$and $C_{10}H_{22}O_5$, which differ mainly in the number of ethylene oxide groups. This highlights the efficiency of the plasma polymerization approach. Increasing the plasma input power from 200 to 350 W produced nanocomposites with higher degrees of crosslinking and a greater presence of Z_nO nanoparticles (from 1.6 ± 0.3 to 5.9 ± 0.8 at. %), resulting in fewer degradation products being released. Toxicity evaluations, including Daphnia magna LC50 (48 hr) and oral rat LD50 tests, indicate that these substances are non-toxic, supporting the safe use of these plasma-polymerized coatings in antibacterial food packaging.

[Tu.Po.15] Comparative Study of Plasma Parameters by Cathode Size in Low Pressure DC Glow Discharge for Improving Tribological Properties

Ramnaresh Kumar (University of Delhi), Bornali Sarma (University of delhi) and D.N. Gupta (University of Delhi).

Abstract

The glow discharge is a widely-used technique for improving the tribological properties of materials, including the production of thin films using ionic beams and the treatment of surfaces through the sputtering process [1]. In this study, we concentrate on numerical analysis of the glow discharge in a cylindrical quartz chamber filled with argon gas. The chamber has a length and radius of 42 cm and 5 cm, respectively, and it is bounded by two copper electrodes with fixed potentials of 0 V (Anode) and -350 V (Cathode). The simulation has been done with two different conditions for different size of electrodes. The behaviour of plasma parameters presented at low pressure of 0.05 torr. To investigate this time-independent discharge and explore phenomena like the self-sustaining generation of secondary electrons and the formation of fixed regions, we use the Plasma Module of COMSOL Multiphysics software for numerical modelling [2]. The results presented in this paper provide valuable insights for the design and development of new technologies in the field of surface treatment.

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[Tu.Po.16] Elastic Overtaking Collisions of Large Amplitude Solitons

Carel Olivier (North-West University).

Abstract

In this poster presentation, a fluid simulation study of overtaking soliton collisions is undertaken for a plasma consisting of cold ions and Boltzmann electrons. An asymptotic analysis approach is applied to construct single soliton initial conditions directly from the Sagdeev pseudopotential solution. This approach allows for the construction of large amplitude solitons with Mach numbers of up to 1.5, that is, solitons that propagate 50% faster than the acoustic speed. These solutions are used to simulate overtaking collisions of solitons. In the small-amplitude regime, collisions are shown to closely resemble two-soliton solutions obtained from reductive perturbation analysis. At larger amplitudes, results show elastic collisions despite the higher order nonlinear effects. The only effect of the higher order nonlinearities is the reduction (in magnitude) of the phase shift compared to that predicted from reductive perturbation analysis.

[Tu.Po.17] Analytical Model of a Magnetopause Current Sheet with Various Energy Distributions of Particles and Features of Its Small-Scale Instability

Vladimir Kocharovsky (A.V. Gaponov-Grekhov Institute of Applied Physics, Russian Academy of Sciences), Mikhail Garasev (A.V. Gaponov-Grekhov Institute of Applied Physics, Russian Academy of Sciences) and Anton Nechaev (A.V. Gaponov-Grekhov Institute of Applied Physics, Russian Academy of Sciences).

Abstract

We develop analytical kinetic models of quasi-stationary multicomponent current sheets that remind magnetopause configurations and allow for an arbitrary particle energy distributions [1, 2]. Particle-in-cell numerical simulations of their evolution demonstrate that, despite the overall stability of these sheets, the Weibel-type magnetic turbulence can develop within them or be inhibited depending on the model parameters. Both cases are studied and compared for two variants of the particle energy distribution — Maxwellian and Kappa. The purpose of this work is to elucidate the structure and parameters of current sheets, in which the Weibel-type instability is possible despite the presence of a self-consistent magnetic field and inhomogeneity of the plasma. Another aim is to study the main features of a weak magnetic turbulence that exists inside such current sheets of a magnetopause type.

In agreement with analytical estimates, simulations show that our simplest models without countercurrents of particles are stable with respect to the aperiodic Weibel-type instability. On the contrary, sheets with countercurrents and a wide region of weak enough magnetic field between them can be unstable. Nevertheless, in our simulations even they are not destroyed by the Weibel-type instability, which saturates at a relatively low level and leads only to a weak deformation of the large-scale current structure.

The obtained results make it possible to identify the features of growth and nonlinear evolution of Weibel-type turbulence in the presence of a non-uniform self-consistent magnetic field and an inhomogeneous plasma with a non-trivial particle velocity anisotropy. The gradients of the magnetoactive plasma's local properties significantly influence the spectrum of growing magnetic perturbations and the character of its gradual evolution from short to long wavelengths in comparison with the case of a homogeneous plasma.

We show that for both Maxwellian and Kappa particle energy distributions, the global structure of the current sheet and the character of the Weibel-type instability in its inner part are similar. Hence, the possibility of long-term existence of small-scale quasi-magnetostatic turbulence in distributed multicomponent current sheets seems to be quite universal. We discuss the applicability of the constructed current sheet models and the features of their internal small-scale magnetic turbulence to the analysis of the phenomena in the vicinity of the magnetopauses of planets and late-type stars.

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[Tu.Po.18] Analytical Relation Between the Main Parameters of Magnetic Turbulence at the Nonlinear Stage of the Weibel Instability in Collisionless Plasma

Vladimir Kocharovsky (A.V. Gaponov-Grekhov Institute of Applied Physics, Russian Academy of Sciences), Alexey Kuznetsov (A.V. Gaponov-Grekhov Institute of Applied Physics, Russian Academy of Sciences) and Anton Nechaev (A.V. Gaponov-Grekhov Institute of Applied Physics, Russian Academy of Sciences).

Abstract

Based on the energy invariants for the Weibel instability in a collisionless nonrelativistic plasma, an analytical relation is obtained between the instantaneous values of the space-averaged energy density of the magnetic field, its dominant wavenumber, and the average plasma anisotropy parameter [1]. The relation is valid for arbitrary particle velocity distribution functions, including ones that vary with time at the nonlinear stage of instability. It is obtained under the assumption that the plasma is homogeneous along a certain axis, determined, for example, by an external magnetic field, and taking into account only the modes with wave vectors orthogonal to this axis. This limits the justification of the relation's correctness, but does not rule out its approximate validity for a wider class of real systems with a sufficiently narrow spectrum of the Weibel magnetic turbulence.

Universality of the analytical relation is verified for several typical examples with different particle energy distributions using two-dimensional particle-in-cell modelling. The simulations also reveals important features and a self-similar nature of the evolution of the spatial spectrum of the Weibel magnetic turbulence. In particular, the power-law profiles of the small- and large-wavelength slopes of this spectrum and the temporal power-law behavior of its maximum are demonstrated.

Using the obtained relation, we give an analytical estimate of the maximum magnetic field energy achievable during the Weibel instability. Namely, we show that its ratio to the initial longitudinal energy of particles, even for a large initial plasma anisotropy parameter, cannot exceed the value approximately equal to 0.2. This estimate could be used to limit the potential mechanisms of the generation of magnetic fields observed in space and laboratory, especially since the performed simulations give reason to expect that the relation or its close analogues will be approximately valid for a class of quite diverse problems of quasi-two-dimensional Weibel turbulence under the conditions of a relatively narrow spatial spectrum and a weak inhomogeneity of the plasma number density.

We discuss possible applications of the newly found analytical relation to the analysis of explosive kinetic processes in laboratory and space plasmas leading to the small-scale magnetic turbulence due to self-consistent filamentation of the electric current.

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14:00-16:00. [Th.Po] Poster Session Thursday

[Th.Po.1] Determining and Optimizing for Plasma Current, Centroid Position, and Shape in the DEMOnstration Power Plant Using Bayesian Integrated Data Analysis and Experimental Design

Jeffrey De Rycke (Ghent University), Alfredo Pironti (University of Naples Federico II), Marco Ariola (University of Naples Federico II), Antonio Quercia (University of Naples Federico II) and Geert Verdoolaege (Ghent University).

Abstract

For the benefit of accurate and precise plasma parameter inference in the upcoming DEMO demonstration fusion reactor, we aim to leverage the probabilistic framework of Bayesian inference. This framework provides a modular way of combining complementary diagnostics and delivers distributions for the plasma parameters of interest. Using prior physical knowledge of the expected plasma current density distribution, together with forward models to find the theoretical diagnostic measurements, we can infer the most probable plasma current density distribution and its covariance function derived from the diagnostic measurements and their uncertainties. From this, we calculate the plasma current, centroid position, and shape.

The inference is based on multiple diagnostics: pick-up coils, flux loops, and saddle coils. They are external diagnostics and therefore do not provide internal information of the plasma. Nonetheless, it has been shown that using a Gaussian process and a well-informed prior distribution, one can reconstruct the current density distribution and poloidal flux distribution with relatively good agreement [1]. The disagreement between the current density distribution and the ground-truth distribution increases rapidly towards the plasma centre, yet there remains a qualitative agreement. The reconstructed plasma boundary remains reliable, though the error on the poloidal flux distribution becomes quite large towards the centre [2].

In addition, we employed Bayesian experimental design (BED) to study the optimal amount and distribution of tangential and normal pick-up coils, complying with the DEMO design restrictions. BED aims to maximize a utility function, specifically the Shannon entropy, which in our case meant achieving D-optimality or maximizing the determinant of the Fisher information matrix of the plasma parameters.

Acknowledgments J. De Rycke acknowledges the Research Foundation - Flanders (FWO) via PhD grant1SH6424N.

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[Th.Po.2] Predictive Maintenance in Fusion Devices with an Application to Condition Monitoring of Plasma-Facing Components

Leonardo Caputo (Ghent university), D. Dorow-Gerspach (Forschungszentrum Jülich, Institut für Energie- und Klimatforschung), M. Wirtz (Forschungszentrum Jülich, Institut für Energie- und Klimatforschung) and G. Verdoolaege (Ghent University).

Abstract

In the context of Reliability, Availability, Maintainability, and Inspectability (RAMI) analysis for DEMO, achieving an availability of 30-60% and minimizing unscheduled shutdowns annually are essential prerequisites. Predictive maintenance (PdM) can play a crucial role in ensuring regular, rapid, and reliable maintenance of the plant. PdM proactively optimize maintenance schedules estimating the remaining useful life (RUL) of component or subsystems of a machine, from historical sensor measurements. Critical components, such as the divertor and the first wall, face extreme thermal loads, intense thermal shocks, and bombardment by plasma ions, neutral particles, and energetic neutrons. The options for real-time monitoring of Plasma-Facing Components (PFCs) in such conditions are limited. Moreover, computational models for reactor-scale surfaces can require significant computational resources. To overcome these challenges, we employ data-driven PdM to analyse infrared data and expert domain annotations, identifying patterns and anomalies that may indicate damage to the PFC. In particular, this study focuses on the application of modern statistical methods, including machine learning and deep learning on infrared data from steady state heat load experiments.

[Th.Po.3] Collisional Dynamics in Tokamak Plasmas

Y.S. Seitkozhanov (al-Farabi Kazakh National University, Satbayev University), E.O. Shalenov (Satbayev University) and K.N. Dzhumagulova (al-Farabi Kazakh National University, Satbayev University)

Abstract

Collisions between charged and neutral particles in plasma can lead to energy and momentum transfer, which can affect plasma temperature and density profiles. Understanding and controlling these transport properties is necessary to achieve and maintain the conditions required for nuclear fusion reactions to occur in a tokamak.

In this study, we investigate collision frequency and energy transfer between electrons and Helium atoms. The interaction between an incoming electron and He atom was studied by the optical potential method, which consists of three interaction potentials accounting for various effects. Momentum-transfer cross section and phase shifts are found using the partial wave expansion and the variable phase approach, respectively.

The resulting effective frequency has a maximum depending on the energy. The experimental data found in the literature are consistent with the detected maximum. At energies lower than the maximum energy, our results coincide with other works. Energy transfer calculations for the energy values above the detected maximum showed that temperature equalization between helium and electron occurs more slowly than has been known.

Large tokamaks, including JET and JT-60U, also produce electron-positron pairs in plasma, where collisions between several MeV runaway electrons and thermal particles can produce up to 1014 positrons. How many positrons are generated depending on the energy of the runaway electrons, the differential production rate can be calculated using the runaway electron distribution and the Coulomb logarithm.

Acknowledgments This research has been funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. AP AP19679536).

[Th.Po.4] Biased H Mode During Edge Plasma Biasing in the TJ-II Stellarator

Cesar Gutierrez-Tapia (National Institute for Nuclear Research), Daniel Lopez-Bruna (Laboratorio Nacional de Fusion, CIEMAT), Julio Martinell (Instituto de Ciencias Nucleares, UNAM) and Alexander Melnikov (National Research Center "Kurchatov Institute").

Abstract

The transition from the L-mode to H-mode confinement in stellarators is triggered by a sudden local increase of the radial electric field, $\boldsymbol{E}_r$, which in turn reduces the fluctuation amplitudes and consequently suppresses the turbulence. The H mode is achieved only when certain thresholds in the control parameters are exceeded. In the case of biased H modes, the transition is obtained only when the bias voltage applied to the probe exceeds a critical value. In this work we study the biased H mode using a transport model that includes neoclassical and turbulent contributions [1]. The biasing electrode is assumed to produce a localized radial current which in turn affects the ambipolar radial electric field $\boldsymbol{E}_r$. The sharp local change in Er triggers the confinement improvement around the edge region, by suppressing turbulent fluctuations due to the shear of the poloidal ion velocity. For the anomalous transport we use the balooning approximation including the stabilizing effect of the $\boldsymbol{E} \times \boldsymbol{B}$ shear. Starting from experimental profiles, the simulations are carried out using the ASTRA transport code [2] exploring different scenarios, in time and in space, with positive and negative bias. The results of the simulated radial electric field, electric potential and poloidal ion velocity are confronted with experimental data.

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[Th.Po.5] Turbulence Driven by Density Gradients and Biasing in Texas Helimak

Dennis L. Toufen (Federal Institute of Education, Science and Technology of São Paulo), Zwinglio O. Guimarães-Filho (Institute of Physics, University of São Paulo), Felipe A. Pereira (Institute of Physics, University of São Paulo), Giuseppe M. E. Silva (Institute of Physics, University of São Paulo), Iberê L. Caldas (Institute of Physics, University of São Paulo) and Kenneth W. Gentle (Department of Physics and Institute for Fusion Studies, The University of Texas at Austin).

Abstract

The plasma turbulence dependence with the equilibrium density profile and externally imposed electric fields was investigated in Texas Helimak [1], a toroidal plasma device suitable for turbulence studies with flexible configurations regarding the equilibrium magnetic field and electrostatic biasing. In Texas Helimak stable plasma discharges are obtained using ECRH resonant heating whose maximum absorption position depends on the magnetic field intensity. The turbulence is measured simultaneously by 96 Langmuir probes selected among the more than 700 available ones. Also, it is possible to impose the electrostatic potential in some radial regions, by connecting a DC power device in one of the four bias plate sets. Initially, with all the bias plates grounded, the magnetic field intensity was changed by selecting the coils current into 36 different values (one per discharge), which makes the density peak position vary by almost half of the machine radial extension. The turbulence level profile follows the density profile changes. Moreover, by comparing the turbulence radial profiles with the density peak positions, it is possible to see that the turbulence level is enhanced in the negative density gradient side of the peak, as predicted for ideal interchange modes [2]. Furthermore, when considering discharges with just one of the bias plates polarized (the others grounded), we observed strong changes in the density radial profiles for both positive and negative bias values due to biasing, with the peak displacement in different directions depending on the bias signal: the peak is moved out of the bias plate incase of negative bias and in the opposite direction with positive biasing. The turbulence level and the density radial profiles follow similar trends in general, but the link between them is not so clear as in discharges without biasing.

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[Th.Po.6] Novel Energy Absorption Mechanism in Plasma Microdroplets

Animesh Sharma (Indian Institute of Technology Delhi) and Amita Das (Indian Institute of Technology Delhi).

Abstract

Two dimensional (X-Y plane) Particle-In-Cell (PIC) simulation were performed using EPOCH [1] to study the evolution of plasma microdroplet irradiated by a laser pulse. The laser wavelength of 800nm, FWHM pulse duration of 25 fs and spot size of 19 micron were chosen. The target plasma droplet of diameters 15, 30, and 60 microns were chosen. The laser intensity was non-relativistic with a_0= 0.5. The plasma density in the microdroplet had a gradient from zero to 10 n_c (nc being the critical density) over a region of two microns. In the simulation the laser propagates along the X axis and its transverse profile is centered about Y = 0 and is incident normal to the target. At Y = 0 the electric field of the laser is transverse to the surface of the target. At all other Y locations, due to the curvature of the target, an electric component normal to the surface exists. This component of the electric field extracts the electrons out of the target (Fig1a) following the well-known vacuum heating process. The electrons acquire certain amount of energy irreversibly from the laser during this phase. The gain in kinetic energy of the electrons is apparent from the initial rise seen in average particle energy (APE) in Fig.1 a. Thereafter, two additional phases of energy increment are observed. It should be noted that the two subsequent phases occur after the laser pulse has left the simulation box. The energy acquired during these phases is a result of collision between the two surface waves (excited by the laser as it grazes through the target surface Fig.1a) which traverse the top and bottom hemispheres to collide at the diametrically opposite point (Fig 1b). In addition, electrons from the bulk also arrive here. The collision of the two surface and the bulk disturbances lead to irreversible gain of the electron energy. Thus the second phase of growth in energy corresponds to this collision, the third happens at the time when the three colliding disturbances reverse their direction and again hit each other at the other side of the target (Fig 1c). A detail understanding of this process will be provided.

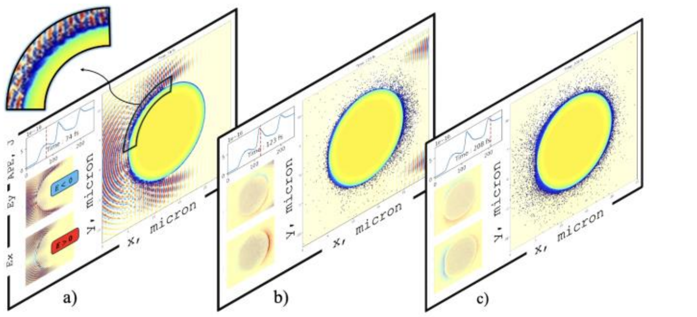

Figure 1. Temporal evolution of electric field, average paricle energy and electrons for laser interacting with plasma microdroplets.

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[Th.Po.7] Full-Wave Simulations of Helicon Waves for Plasma Wakefield Accelerators

Luis Carlos Herrera Quesada (University of Stuttgart), Alf Köhn-Seemann (University of Stuttgart), Nihls Fahrenkamp (University of Greifswald), Stefan Knauer (University of Greifswald), Peter Manz (University of Greifswald) and Günter Tovar (University of Stuttgart).

Abstract

In fundamental particle physics experiments, energy requirements have become difficult to achieve in circular accelerators. Linear wakefield devices appear as a modern solution to produce particles of very high energies: plasma wakefield accelerators provide significantly higher E-fields to accelerate particles than conventional linear particle accelerators. However, to achieve these high electric fields, the plasma medium must have a large electron plasma density to create strong gradients. It is known that helicon plasma discharges achieve very high electron plasma densities, allowing the system to acquire the necessary density magnitudes for accelerator purposes [1].

This study aims to understand helicon wave propagation and dissipation in plasma wakefield systems, as well as the influence of different antenna geometries on the efficiency of helicon wave excitation. Furthermore, the evolution of the radial plasma density gradient on the efficiency of coupling to the helicon wave will be studied.

The research plan consists of performing a theoretical analysis with a full-wave simulation using the finite-difference time-domain (FDTD) 3D code FOCAL, which solves Maxwell's equations coupled to the fluid equation of motion for electrons in a cold magnetized plasma [2]. In parallel, computational simulations are made using the COMSOL Multiphysics code package. The simulations will be applied to the linear plasma device VINETA.75, located at the University of Greifswald. The device's geometry will be implemented in the numerical models as a first step. It is then planned to compare the results with measurements of the wavefield sin VINETA.75. Also, external cooperation is made with the teams in the MAP device at the University of Wisconsin-Madison, and the PROMETHEUS-A and AWAKE experiments at CERN[3].

Acknowledgments This work is funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) - project number 517709182.

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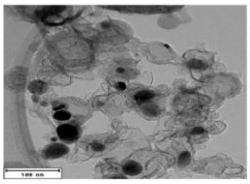
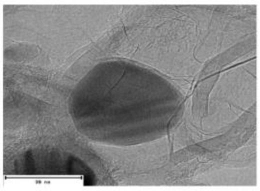
[Th.Po.8] Nickel-Carbon Composite Nanomaterial Synthesis via Plasma Catalytic Pyrolysis

Jafar Fathi (Institute of Plasma Physics, Prague), Ondřej Jankovský (University of Chemistry and Technology Prague), Michael Pohořelý (University of Chemistry and Technology Prague), Vineet Sikarwar (Institute of Plasma Physics, Prague), Michal Hlína (Institute of Plasma Physics, Prague) and Alan Mašláni (Institute of Plasma Physics, Prague).

Abstract





The experiment was conducted using the PLASGAS plasma reactor, which has an internal volume of 200 liters and utilizes the Hybrid Water Stabilized Plasma torch. The characteristics of the Hybrid Water/Gas DC Arc Plasma Torch and the PLASGAS reactor are detailed by Hrabovský et al. [1] and Fathi et al. [2], respectively. Previously, this system has been employed for the pyrolysis of methane [3] and natural gas [4]. In this study, however, we investigate methane pyrolysis by adding Nickel Oxide powder as a catalyst. This experiment introduced a 100 SLM methane feed into the reactor, with plasma power set at110 kW. The resulting gas composition was 86.5 vol% hydrogen and 12.1 vol% carbon monoxide, with only 1.2 vol% methane remaining unconverted and 0.1 vol% acetylene produced. In addition to hydrogen production, a solid carbon-nickel (core-shell) structure nanocomposite material was synthesized. XRD and EDX analysis confirmed that the nickel oxide was reduced to zero-valent nickel nanoparticles with particle sizes less than 50 nm. The TEM images of the produced composite material are shown below.

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[Th.Po.9] Community Structure of Earth's Magnetic Field Measurements

Victor Muñoz (Departamento de Fisica, Facultad de Ciencias, Universidad de Chile) and Sebastian de la Maza (Facultad de Ciencias Fisicas y Matematicas, Universidad de Chile).

Abstract

The Earth's magnetic field has variations both in the time and spatial domains, which are due to the internal dynamics of the Earth's core, the forcing by external sources like the solar wind, or fluctuations induced by coupling between neighbouring regions. This leads to various levels of correlations between magnetic field readings on the Earth's surface, which map the interplay of these factors across multiple time and space scales. In this work, we propose to describe and study this complex dynamics of spatiotemporal correlations by means of tools derived from graph theory and complex networks, which have shown to be useful to describe the behavior of various systems of geophysical interest [1, 2, 3]. In particular, we study the evolution of magnetic field measurements on the Earth's surface along the 23rd solar cycle.

Based on records by 59 magnetometers during the 23rd solar cycle [4], we define a complex network where nodes are points on the Earth's surface (magnetometers), and their connections represent the degree of similarity between the time series observed at those points. Our results show that there is a correlation between the evolution of network community structure and geomagnetic activity. In addition, we study the dependence of the results of the methods used to define the similarity between time series (and, therefore, to define the connection between nodes), in order to establish the best possible sensitivity for the community structure with respect to the geomagnetic activity, as measured by the Dst index and the sunspots number. We show that the choice of similarity method is not as relevant as the choice of the correlation threshold which determines whether two nodes are actually connected or not. Our work suggests that analysis of the Earth's magnetic field variations using complex network and community structure analyses, can be useful to understand the geomagnetic activity along the solar cycle.

Acknowledgments This project has been financially funded by FONDECyT, grant number 1242013 (VM).

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[Th.Po.10] Characterizing the Solar Activity Using the Horizontal Visibility Graph

Tomás Zurita (University of Chile), Víctor Muñoz (University of Chile) and Denisse Pastén (University of Chile).

Abstract

The Sun and its behavior are studied by means of complex networks. The complex network was built using the Horizontal Visibility Graph (HVG) algorithm. This method maps time series into graphs in which every element of the time series is considered as a node and a visibility criterion is defined in order to connect them [1]. The HVG method has been widely used to analyze various systems such as pulsating variable stars [2], solar activity [3, 4] and blazars [5]. Using this method, we construct complex networks for magnetic field and sunspots time series encompassing four solar cycles, and various measures such as degree, clustering co-efficient, betweenness centrality and eigenvector centrality were calculated. In order to study the system in several time scales, we perform both a global, where the network contains information on the four solar cycles, and a local analysis, involving moving windows. Our results suggest that complex networks can provide a useful way to follow solar activity, and reveal new features on solar cycles.

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[Th.Po.11] Radiation Pressure- Driven Rayleigh-Taylor Instability in Compressible Strongly Magnetized Ultra-Relativistic Degenerate Plasmas in White Dwarfs

Ravinder Bhambhu (School of Physical Sciences, Jawaharlal Nehru University) and Dr. Ram Prasad Prajapati (School of Physical Sciences, Jawaharlal Nehru University).

Abstract

The radiation pressure and strong magnetic fields are prominent in the structures of Rayleigh-Taylor (R-T) instability in the interior of white dwarfs. We have investigated the radiation pressure-driven R-T instability in a compressible and magnetized ultra-relativistic degenerate strongly coupled plasma. The equation of state has been derived for such systems incorporating ultra-relativistic degenerate electrons with their radiation pressure and ion gas compressibility. The dispersion relation of the density gradients driven R-T instability is analyzed using the generalized hydrodynamic (GH) fluid model in the strongly coupled and weakly coupled limits [1]. We assumed the electron fluid is inertial-less, ultra-relativistic degenerate and weakly coupled while the ion fluid is non-degenerate and strongly coupled [2].

It is observed that the R-T instability criterion has been modified significantly due to radiation pressure, ion gas compressibility and degeneracy parameter. In the kinetic limit, the instability region is shorter than the hydrodynamic limit due to the dominance of plasma frequency over the viscoelastic relaxation frequency. The outcomes are explored in analyzing the development of R-T instability in the strongly magnetized carbon-oxygen white dwarfs. The radiation pressure, electron temperature and ion density strongly suppress the growth rate of the R-T instability in the interior of white dwarfs. The strong magnetic fields introduce asymmetry to the system by destabilizing the R-T unstable modes. The present results are also useful for understanding the R-T instability in the star formation and dense plasmas in inertial confinement fusion in some limiting cases.

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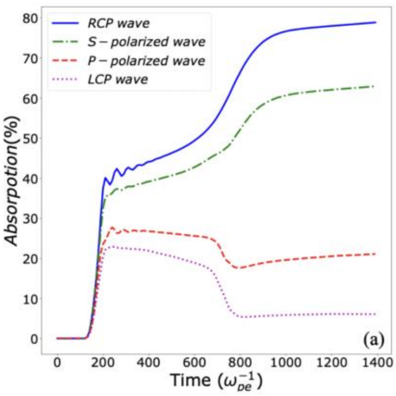
[Th.Po.12] Two-Dimensional PIC Simulations for Electromagnetic Wave Propagation Oblique to Inhomogeneous Applied Magnetic Field in Plasma

Trishul Dhalia (Indian Institute of technology Delhi) and Amita Das (Indian Institute of technology Delhi).

Abstract

There has been significant interest lately in the study of Electromagnetic (EM) waves interacting with magnetized plasmas. The variety of resonances and the existence of several pass and stop bands in the dispersion curve for different orientations of the magnetic field offer new mechanisms of EM wave energy absorption [1,2,3]. However, earlier studies have beeninvestigated only special cases of magnetized plasma geometry (e.g. RL mode ($\boldsymbol{k} /\!/ \boldsymbol{B}_{ext}$ (θ = 0) or X-mode $\boldsymbol{k} \perp \boldsymbol{B}_{ext}$ ($\theta = \pi/2$) configuration). In these cases, EM wave get absorbedat their respective resonances (e.g. for $\theta = 0$ electron cyclotron resonance ($\omega_{EM} = \omega_{erc}$), and for $\theta = \pi/2$, upper hybrid resonance ($\omega_{EM} = \omega_{uh}$)). We consider here the case of EM wave propagation at an oblique angle with respect to $\boldsymbol{B}_{ext}$. We tailor the magnetic field inhomogeneity such that the EM wave pulse encounters resonance layer ($n^2 \rightarrow \infty$) within the plasma. A 2-D Particle - In - Cell (PIC) simulation using the OSIRIS 4.0 platform has been carried out for this particular case. A significant enhancement in absorption leading to almost complete absorption of laser energy by the plasma have been observed (Fig.1). A detailed study characterizing the role of external magnetic field profile, EM wave intensity, etc., has also been carried out.



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[Th.Po.13] On the Gardner Equation for Nonlinear Waves in Multispecies Plasmas

Frank Verheest (Universiteit Gent) and Willy Hereman (Colorado School of Mines).

Abstract

The Gardner equation is a combination of the KdV equation (with quadratic non-linearity having constant coefficient B) and the modified KdV equation (with cubic non-linearity and constant coefficient C). For consistency, whereas C is of order one B should be very small, given the expansions used in the derivation of all KdV-like evolution equations. If B were of order one, the quadratic term would prevail over the cubic term, which could then be neglected. The sign of B is irrelevant because if B<0 the Gardner equation can be rescaled to the case B>0. The sign of C, however, is quite important. Even though the Gardner equation is fully integrable for both positive and negative C, the usual soliton solutions can only be generated for C>0, which is of crucial importance should one want to study the collisions of solitons. A multispecies plasma model should therefore be detailed enough that the compositional parameters allow for a tiny B and a positive C. This aspect has been over-looked or neglected by several authors using the Gardner equation in their analysis, mostly due to the complexity of the plasma compositional parameters. In essence, a simple ion-electron plasma does not have enough compositional flexibility to go beyond the KdV equation.

It will be shown on a relevant dusty plasma model [1], comprising cold negative dust grains, Maxwellian electrons and nonthermal protons, that it is indeed possible to have B close to zero, while C>0. When B gets larger, C can become negative, but in that case the absolute value of B is larger than that of C, leading to a regime where the relevant equation is the KdV, not the Gardner equation. In between, there is a region where the compositional parameter scan be adjusted such that, e.g., B=0.01 and C=0.35. In the theoretical studies of nonlinear electrostatic plasma waves there is another method, namely Sagdeev’s pseudopotential analysis, where the Poisson equation is integrated leading to an “energy integral,” with full nonlinearities but requiring a numerical integration of the Poisson equation to produce the profiles. The case of B=0.01 and C=0.35 will be discussed via the two approaches (Gardner and Sagdeev), and the results compared. Discrepancies might indicate the limits of the Gardner approach at higher amplitudes, given that in reductive perturbation theory the expansions limit the nonlinearities to the quadratic or cubic terms.

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[Th.Po.14] Landau Damping of Dust Ion-Acoustic Solitary Waves in Non-Maxwellian Dusty Plasmas

Hadia Mushtaq (Khalifa University), Kuldeep Singh (Khalifa University) and Ioannis Kourakis (Khalifa University).

Abstract

Landau damping is a captivating phenomenon, manifested as wave dissipation (damping) occurring – despite the absence of inter-particle collisions – due to resonant interactions between waves and particles [1]. Focusing on the ubiquitous presence of charged dust in space and in laboratory plasma environments [2], one may wonder how Landau damping may affect the propagation of electrostatic solitary waves (ESWs) and associated instabilities in space and astrophysical environments [3]. This investigation explores the effect of Landau damping on nonlinear dust-ion-acoustic waves (DIAWs) in a dusty plasma composed of inertial ions, energetic (suprathermal) electrons, and immobile dust. A cold-ion fluid model, coupled to a Vlasov-type kinetic equation for the electron dynamics, has been adopted. A kappa-distribution [4, 5] is assumed as equilibrium state for the electrons, in account of the non-Maxwellian particle behavior observed in Space [5].

A multiscale perturbation technique has been adopted and shown to lead to an evolution equation in the form of a modified Korteweg–de Vries (KdV) equation that incorporates a dissipative term, representing kinetic (Landau) damping [6]. Exact analytical solutions have been obtained, representing solitary waves undergoing amplitude decay over time. The combined parametric effect of Landau damping, non-Maxwellian electron statistics (via the kappa parameter) and dust density on the characteristics of DIAWs has been examined. The results of this investigation aim at generalizing earlier work [6, 7] by shedding some light on the dynamics of nonlinear waves in various space and astrophysical dusty environments [2,3].

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[Th.Po.15] Fluid Simulations of Electrostatic Solitary Waves

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Abstract

Electrostatic solitary waves (ESWs) are an ubiquitous occurrence in plasmas in the laboratory [1] and in Space [2], where they are observed widely in relation with bipolar electric field structures recorded by missions in planetary magnetospheres [3]. Their theoretical modeling represents a long standing challenge for theoreticians and experimental researchers alike. Even though an analytical framework has been established for the modeling of ESWs since the pioneering work of Sagdeev and coworkers [4] since decades ago, that framework provides "static" predictions of the solitary wave profile and provides no information on their propagation characteristics under realistic conditions. In particular, although the Sagdeev (pseudopotential) method -- and its small-amplitude Korteweg – de Vries (KdV) counterpart [5]-- successfully reproduce(s) the expected waveforms (i.e. a pulse for the ES potential and a bipolar form, in general, for the E-field), the (expected, but still not verified) soliton properties of the resulting -numerical- solutions from the Sagdeev formalism have not been analyzed.

We have undertaken a study of the dynamics of electrostatic pulses, from first principles. Based on a basic fluid model as a starting point, we have performed a series of numerical (fluid) simulations, in order to investigate the stability of electrostatic pulses and their interaction properties. Various propagation scenaria have been considered, and the pulses' stability and (anticipated) soliton characteristics have been benchmarked. Solutions near the acoustic speed appear to be "KdV-like" (as expected), while strongly superacoustic (supersonic) pulses are characterized by a different amplitude-velocity relation but still possess the expected stability properties, throughout propagation and mutual interaction.

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[Th.Po.16] Modulated Electrostatic Wavepackets in the Presence of Damping and Forcing

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Abstract

Electrostatic wavepacket modulation in plasmas is a widely studied nonlinear phenomenon: it is manifested as the variation ("modulation") of a wavepacket's harmonic amplitude in space and time, and may be attributed to various processes, such as self-modulation (self-interaction), cross-modulation, wave-wave interaction or due top ponderomotive processes [1, 2]. Modulated envelope (amplitude) dynamics is known to be described efficiently by a nonlinear Schrodinger (NLS) type equation [3], a nonlinear PDE that models the envelope's evolution in space and time, in a slowly-varying amplitude approximation. In a fluid-plasma theoretical context, the NLS equation can be derived from a fluid model by means of a multiple scales technique [1,2,4]. Stability analysis may be performed, leading to predictions for modulational instability occurrence, a mechanism often postulated as a precursor state to freak wave (rogue wave) formation [2,4].

We have earlier undertaken a study of the modulational dynamics of an electrostatic wavepacket, from first principles [5]. Based on a cold-ion fluid model as a starting point, incorporating a phenomenological damping term in account of collisions, we have derived an NLS equation characterized by a complex-valued nonlinearity coefficient Q and a real dispersion coefficient P. The imaginary part of Q is thus associated with nonlinear dissipation of the envelope, as it results in a "damping" force that breaks the integrability of the NLS eq. and results in amplitude decay. Based on (and inspired by) [6], where numerical simulations revealed extreme wave events for the damped and forced NLS equation, we have performed a series of computer simulations in order to investigate the (in)stability and the evolution of an initial condition in the form of an envelope soliton (i.e. an exact solution of the unperturbed NLS eq.). Different possibilities have been explored, namely including the option of stabilizing the envelope pulse by imposing an ad hoc external forcing term to counteract dissipation.

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