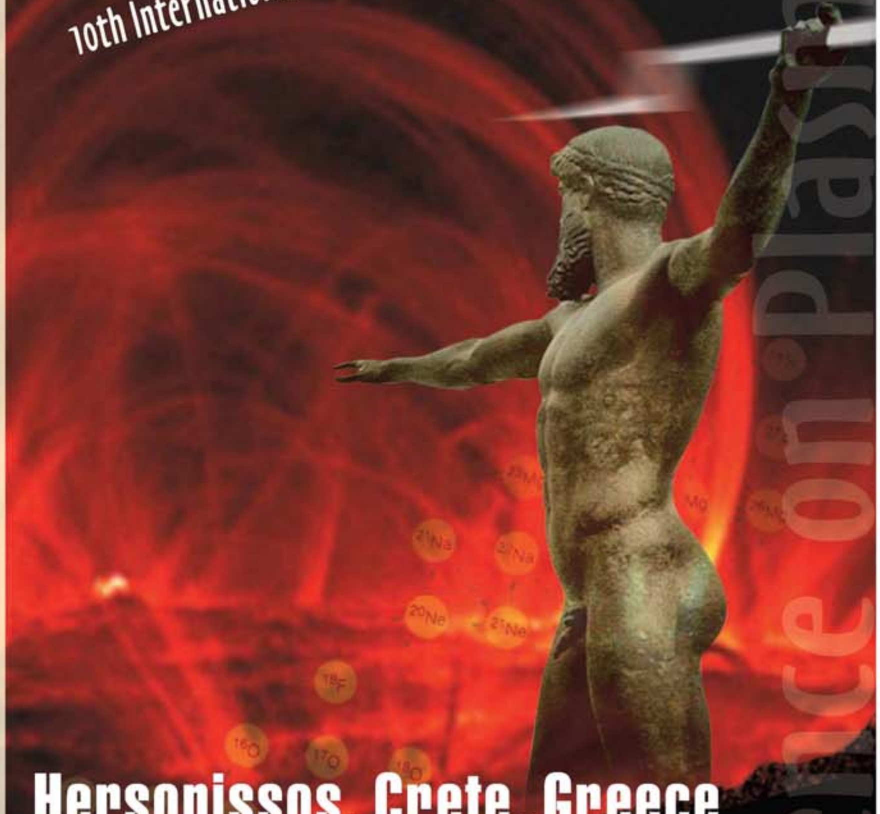
35th
PLASMA
HELLAS
2008

35th EUROPEAN PHYSICAL SOCIETY

Conference on Plasma Physics

10th International Workshop on Fast Ignition of Fusion Targets



MAIN TOPICS:

- Magnetic Confinement Fusion
- Beam Plasmas & Inertial Fusion
- Dusty & Low Temperature Plasmas
- Basic Plasmas & Space & Astrophysical Plasmas

Hersonissos, Crete, Greece

9 - 13 June 2008

PROGRAMME

Conference on Plasma Physics

35th EUROPEAN PHYSICAL SOCIETY

Conference on Plasma Physics

10th International Workshop on Fast Ignition of Fusion Targets

Hersonissos, Crete, Greece
June 9-13, 2008

PROGRAMME

Organized by:

- **Association EURATOM – Hellenic Republic**
- **Institute of Electronic Structure and Laser (I.E.S.L.) – FO.R.T.H.**

CONTENTS

Objectives of the Conference

One of the main objectives of the Conference is to facilitate the presentation and discussion of most recent developments in all areas of plasma physics and controlled fusion physics. The exchange of cross-disciplinary information among various plasma physics related fields is strongly encouraged. Plenary sessions covering the latest developments in plasma science are being held each day. Every day parallel invited talks related to the main topics of the Conference are held covering advanced technical aspects. Among the contributions submitted to the Conference, a number of papers are presented in parallel oral sessions, and the other contributed papers are presented as posters. A fraction of the Conference time during each day, after lunch, is exclusively devoted to poster sessions During the Conference and afterwards the 10^{th} International Workshop on Fast Ignition of Fusion Targets will take place.

Scope

This conference continues the series of **European Physical Society (EPS)** conferences on **Plasma Physics**, encompassing the fields of fusion research, magnetic confinement fusion, beam plasmas, laser-plasma interaction and inertial confinement fusion, dusty and low temperature plasmas, as well as space and astrophysical plasmas and basic plasmas.

TOPICS

- **Magnetic Confinement Fusion (MCF)**
  - Edge and plasma-wall interactions
  - Turbulence and transport
  - Equilibrium and MHD
  - Operational limits and plasma control
  - Diagnostics
  - Heating and fuelling
  - Concept development and engineering
- **Beam Plasmas & Inertial Fusion**
  - Inertial confinement and high gain
  - Hydrodynamics and instabilities
  - Ultra-intense laser interaction and fast ignition
  - Frontiers in hot dense matter research, pulsed power
  - Radiation hydrodynamics, laboratory astrophysics
  - Inertial fusion energy drivers and reactors
  - Laser and ion beam coupling with plasmas
  - Radiation sources - harmonics, X-ray lasers, etc.
  - Laser and plasma based accelerators
- **Dusty & Low Temperature Plasmas**
  - Theory and numerical simulations
  - Liquid and crystalline complex(dusty) plasmas

- Nucleation and growth
- Waves
- Diagnostics
- Plasma Processing and applications
- Dust in fusion

- **Basic Plasmas & Space & Astrophysical Plasmas**
    - Solar, space and astrophysical plasmas
    - Fundamental plasma physics.
    - Laboratory-based space and astrophysical plasmas

EPS PROGRAMME COMMITTEE MEMBERS

Carlos	Hidalgo	Spain	(Chair PC)
Jo	Lister	Switzerland	(Chair EPS PPD)
Paraskevas	Lalousis	Greece	(Chair LOC)
Vincent	Chan	USA	(APS)
Kazuo A.	Tanaka	Japan	(JSPF)

Magnetic Confinement Fusion

Xavier	Garbet	France
Howard	Wilson	United Kingdom
Paolo	Buratti	Italy
Ralph	Dux	Germany
Alberto	Loarte	EFDA/EU
Fernando	Meo	Denmark
Maria	Puiatti	Italy

Beam Plasmas and Inertial Fusion

Sylvie	Jacquemot	France
Martha	Fajardo	Portugal
Kate	Lancaster	United Kingdom
Manuel	Perlado	Spain
Francesco	Pegoraro	Italy

Dusty and Low Temperature Plasmas

Mark	Bowden	United Kingdom
Hubertus	Thomas	Germany
Francoise	Massines	France

Basic Plasmas and Space and Astrophysical Plasmas

Fabrice	Doveil	France
Michel	Tagger	France
Nigel	Woolsey	United Kingdom
Luis	Silva	Portugal

THE LOCAL ORGANISING COMMITTEE

Paraskevas	Lalousis (chair)
Stavros	Moustaizis (Scientific Secretary)
Basil	Duval (Switzerland)
Alkis	Grecos
Kyriakos	Hizanidis
Lucas	Vlahos
Giannis	Vomvoridis

Conference date and location

The Conference is being held on June 9-13 at the Creta Maris Conference Center, Hersonissos, Crete, Greece. The plenary invited talks are scheduled for early mornings from Monday to Friday, and also on Friday afternoon, in the Zeus theatre, in level 1 of the Conference Center. Parallel invited talks and contributed orals are held in four thearte rooms, Zeus, Minos, Danae, and Athina. The 10th International Workshop on Fast Ignition of Fussion Targets, will be held on June 12-13 at the Creta Maris Conference Centre, and will be continued on June 16-18 at the Apollo Room of Creta Maris Hotel.

Organisation

The organisation of the Conference is carried out by the Association EURATOM-Hellenic Republic and the Institute of Electronic Structure and Laser FORTH, Heraklion, Crete, Greece . The Secretary of EPS 2008 is :

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World Wide Web Site

Detailed and updated information on the 35th European Physical Society Conference on Plasma Physics is provided on the website:http://eps2008.iesl.forth.gr.

Presentation ID

The presentation ID (e.g. P1.001) reads as follows:

- First character indicates type of presendation
  I – Invited talk *O – Oral contribution*
  P – Poster contribution *D – post deadline paper*
- Second number indicates the day of presentation:
  1 - Monday June 9, 2008 2 – Tuesday June 10, 208
  3 – Wednesday June 11, 2008 4 – Thursday June 12, 2008
  5 – Friday June 13, 2008
- Third number (three digits) indicates the sequence number

Oral presentations

The allotted time for oral presentations is:

- Plenary invited oral: 40 minutes (including 5 minutes for discussion)
- Parallel invited oral: 30 minutes (including 5 minutes for discussion)
- Contributed oral: 20 minutes (including 5 minutes for discussion)

Speakers must keep strictly to the allotted time due to the large number of presentations. To avoid unnecessary delays between talks, all speakers are kindly requested to contact the Chairman five minutes before beginning of the session. Speakers are also requested to copy the file of their presentation at the conference slide Table on registration or at least one day before the oral presentation. Authors' laptop will not be allowed for presentation papers. Speakers with an oral presentation on Monday are requested to copy their presentation on Sunday afternoon. Speakers can also e-mail their file presentation to epstalks@iesl.forth.gr any time before the begging of the Conference.

Poster presentations

All posters are to be presented on level 0 of the Creta Maris Conference Center. Authors of posters are reminded that they should put up their posters before the morning session commences and remove them at the end of the day, 18:00pm. The available poster area is 1.80 (height) x 0.95(width)m.

Paper abstracts

All abstracts are available on the Conference website: http://eps2008.iesl.forth.gr
Abstracts of the invited papers are included in this Programme.

Proceedings

All papers will be available on the website after the Conference. Invited papers will be published in a special issue of the Plasma Physics and Controlled Fusion Journal. Contributed orals and posters will be published on CD-ROM, and will be distributed after the Conference.

Awards

Hannes Alfven prize of the European Physical Society for outstanding contributions to plasma physics

Each year, the European Physical Society awards this Prize to one or more persons who have made outstanding contributions to plasma physics in experimental, theoretical or technological areas. This year's Prize winner is Prof. Liu Chen from the University of California, Irvine, USA.

PhD Research Award

The Plasma Physics Division of the European Physical Society created the "European Physical Society Plasma Physics Division PhD Research Award" in 2005. This year (EPS2008) Prize winners are: Louise Willingale (UK), Ivo Classen (NL), and Bredan Dromey (IRL). The Prize winners will be presented on Monday morning.

EPS-PPD Innovation Prize

Research in Plasma Physics has multiple and rich outcomes with direct and/or indirect applications. These applications, which are sometimes inconspicuous and even unknown to the layman, can have significant impacts on daily human life as well as on economic activity. Surprisingly, some of the impacts seem far from the basic Plasma Physics research which gave birth to these key original ideas, but nonetheless represent exemplary innovative strategies. Today, applications of Plasma Physics flourish in vastly different domains, such as radioactive waste transmutation, medicine, isotope separation processes (with fundamental applications to cancer therapy), infection treatment, material processing, torch cutting and welding, flat TV screens, lighting systems, thrusters, as well as countless other medical, industrial and engineering applications. Within the general framework of the relationship between "Science and Society", there is a strong effort on communication between research and public domains in many countries.

The European Physical Society is keenly aware of these important applications. As a dual gesture of stimulation and recognition, a new annual prize has been created by the Plasma Physics Division of the European Physical Society. This prize targets research which has demonstrably led to robust innovative applications or important effects on society. Nominations in any fields are encouraged.

PPCF Poster Prize

The International Journal Plasma Physics and Controlled Fusion (PPCF) is proud to sponsor the PPCF Student Poster Prize at this Conference. Four € 150 prizes (one for each of the Topics of the Conference) will be announced on Friday afternoon, during the Closing Session.

Itoh Project Prize in plasma Turbulence

This is the fourth time that Prof. Sanae-I Itoh, in agreement with the Conference organizers, has offered the Itoh Project Prize in Plasma Turbulence to students presenting a poster at the conference. The prize includes the chance to visit Kyushu University, Japan, for one week, including flights and living expenses.

Education in Plasmas

Theme: **European educational networks - what can it bring to plasma physics.** This session will be chaired by N. Lopes Cardozo, and held on Monday 9th from 18.15-19.00. Prof. Lopes Cardozo will give an introduction on the importance of education in attracting and training the next generation of plasma physics researchers, and on the opportunities for European cooperation to create an attractive education environment.

Speakers include Peter DeRegge (SCKSEN Mol, Belgium) on the European Nuclear Educational Network ENEN, Mark Westra (FOM Rijnhuizen, the Netherlands) on the European Fusion Education Network FUSENET, and Michael Geissler (QUB, Ireland) on the web-based Master course in Plasma Physics.

ITER Session

This session will be held on Tuesday 10 June, at 19:20-20:15, chaired by Jo Lister. Dr. Paul Thomas will present his views on “After the ITER Design Review”.

Women in Physics

On Thursday, June 12, 2008, the session “Women in Physics” will be held at 18:10-19:45 and chaired by S. Jacquemot.

Satellite meetings:

The following Workshops will take place after the Conference

10th International Workshop on Fast Ignition of Fusion Targets, 12-18 June 2008.
For the dates 12-13 June, 2008, it will be held in the Conference Center, and for 16-18 June in the Apollo Room of the Creta Maris Hotel .

EFTSOMP2008 - 11th Workshop on Electric Fields, Turbulence and Self-Organisation in Magnetized Plasmas
This Workshop will take place on 16-17 June, 2008, at the Hotel Albatros, Hersonissos.

Fuelling of Magnetic Confinement Machines, 16-17 June, 2008.
This Workshop will be held at the hotel Knossos Royal Village.

Registration

The registration desk opens at the Conference Centre on Sunday 8 June 2008 at 16:00 and closes at 20:00. On Monday morning, opening time is 08:15. Late registration fees are:

EPS Member	€ 530,00
Member of National Physical Society	€ 560,00
Non-EPS Member	€ 590,00
Student (on request by a supervisor)	€ 200,00
Accompanying person	€ 60,00

Access to the Conference centre will be restricted to participants wearing their badge. Registration fee for participants includes the welcome drink, the morning and afternoon refreshments, the Conference reception, the Conference services (Internet connection, etc.), a special Conference issue of Plasma Physics and Controlled Fusion containing the invited papers (if explicitly requested on the registration form), a Conference CD-ROM containing all contributed papers (distributed after the Conference).
Registration fee for accompanying persons includes the welcome drink, and the conference reception.

Registrations and hotel reservations are handled by:
Mrs. Maria Leventi
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Fax: + 30 2810 301689
E-mail: info@eps2008.gr

Social programme

Sunday June 8, 2008	19:30	Welcome drink	Romantic Bar, Creta Maris Hotel
Monday June 9, 2008	20:30	Conference Reception	Cochlias Restaurant, Creta Maris Hotel
Tuesday June 10, 2008	21:00	Choral Drama	Open-air theatre, Creta Maris Hotel
Wednesday June 11, 2008	14:00	Official excursion	Knossos Palace
Thursday June 12, 2008	20:15	Conference Dinner	Arolithos Village

Accompanying persons excursions

On Monday, before the excursions start, there will be greek coffee and sweets at 09:00 am for all accompanying persons. Meeting point is the Reception of Terra Maris Hotel.

Tour	Date
East Crete	09/06/2008
Spinalonga bbq	10/06/2008
Samaria Gorge	13/06/2008
Lassithi-Elounda & Spinalonga	12/06/2008
Festos-Gortys & Matala	12/06/2008
1-day Cruise to Santorini	11/06/2008
Rethymno-Arkadi & Chania	10/06/2008

Lunches

Creta Maris Restaurant, coupons which are available from the Secretariat desk.
Sandwich bar in the Terrace of the Conference Center.
List of Restaurants in the near by area is available in the Secretariat desk.

Buses

In the mornings there will be buses from the official Hotels to the Conference Center, and at the end of the day (18:00) there will be buses from the Conference Center to the Hotels. Also during the Conference days there will be a bus from the Conference Center to the Hotels and back to the Conference Center on the following times:

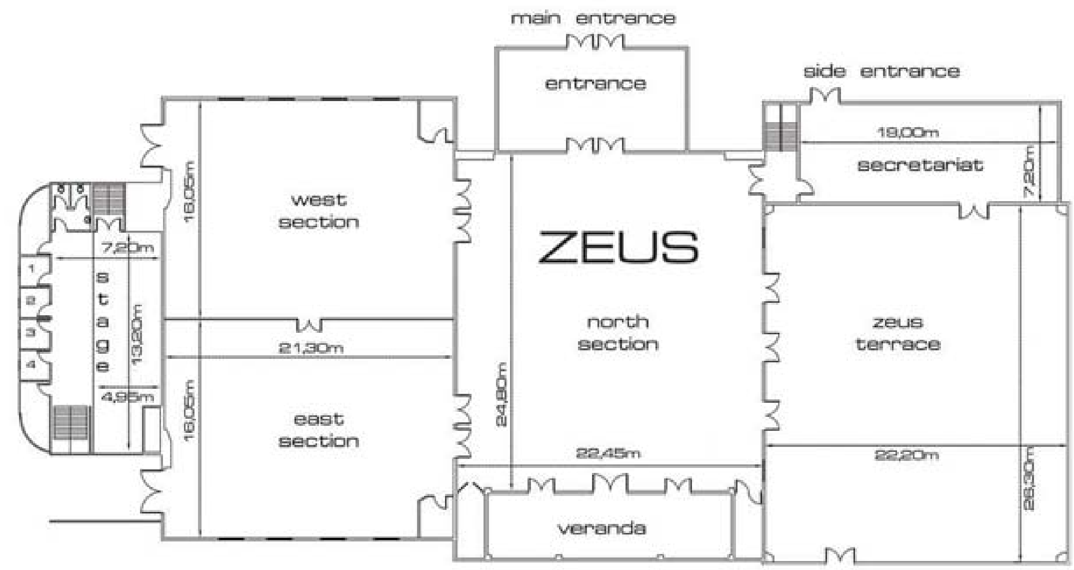
Monday –Tuesday-Thursday-Friday	10:30, 12:30, 14:30
Wednesday	10:30, 12:30

Map of the Creta/Terra Maris Hotels

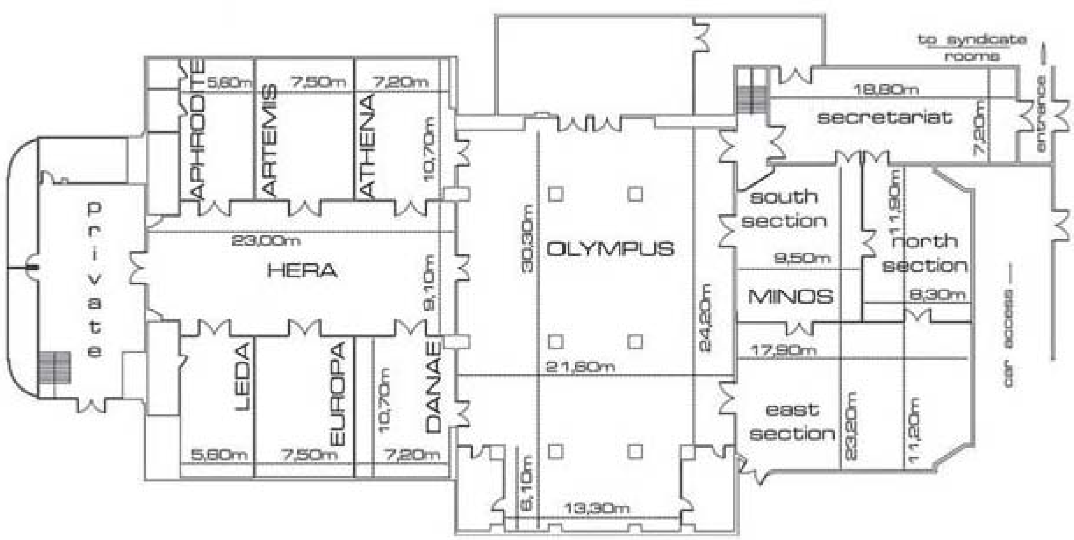
The Conference will be held at the Creta Maris Conference Center Hersonissos, Crete, Greece.

Plan of Conference Centre

Conference Centre Level 1 - Zeus Hall



Conference Centre Level 0
Olympus, Minos, Hera, Danae, Europa, Leda, Athena, Artemis & Aphrodite



PROGRAMME

Monday 9 June 2008				
	Room Zeus **Chair: J. Lister**			
8:30-9:20	*Opening*			
9:20-10:00	Alfvén Prize: I1.001: L. Chen			
10:00-10:20	EPS PhD and Innovation in Plasma Science Prizes			
10:20-11:00	*Coffee Break*			
	Chair: A. Boozer			
11:00-11:40	I1.002: G. Tsakiris			
11:40-12:20	I1.003: A. Piel			
12:20-13:30	*Lunch Break*			
13:30-15:30	Poster Session			
15:30-16:00	Coffee break in Poster Session			
	Room Zeus **Chair: M. Puiatti**	**Room Minos** **Chair : M. Fajardo**	**Room Athina** **Chair : F. Massines**	**Room Danae** **Chair: B. Lembege**
16:00-16:30	I1.004 S. Günter	I1.008 T. Ceccotti	I1.012 C. Oehr	I1.016 D. Gericke
16:30-17:00	I1.005 S. Brezinsek	I1.009 D. Jaroszynski	I1.013 M. Kushner	I1.017 F. Paganucci
17:00-17:30	I1.006 A. Boozer	I1.010 F. Quéré	I1.014 L. Boufendi	Innovation in plasma science: Thesis I Thesis II
17:30-18:00	I1.007 S. Ide	I1.011 F. Albert	I1.015 D. Karabourniotis	
18:00	*Close*			
18:15	**Education in plasmas (Chair: N. Lopes Cardozo)**			
20:30	**Reception**			

Invited Plenary	40 min
Invited	30 min
Oral	20 min

Tuesday 10 June 2008

	Room Zeus **Chair: P. Buratti**			
8:30-09:10	I2.018: S. Pinches			
9:10-9:50	I2.019: T.C. Killian			
9:50-10:20	*Coffee Break*			
	Room Zeus **Chair: R. Dux**	**Room Minos** **Chair: D. Batani**	**Room Athina** **Chair: H. Thomas**	**Room Danae** **Chair: R. Bingham**
10:20-10:50	I2.020 B. Dudson	I2.024 P. Renaudin	I2.032 W. Goedheer	I2.034 D.F. Escande
10:50-11:20	I2.021 D. McDonald	I2.025 B. Rus	O2.007 A. Lipaev O2.008 S. Khrapak	I2.035 A. Schekochihin
11:20-11:50	I2.022 S. Sakakibara	I2.026 R. Singleton	O2.009 V. Tsytovich	I2.036 R. Bamford
11:50:-12:20	I2.023 G. Falchetto	I2.027 L. Videau	I2.033 O. Petrov	I2.037 M. Marklund
12:20-13:30	*Lunch Break*			
13:30-15:30	Poster Session			
15:30-16:00	Coffee break in Poster Session			
	Room Zeus **Chair: F. Meo**	**Room Minos** **Chair: X. Garbet**	**Room Athina** **Chair: S. Atzeni**	**Room Danae** **Chair: H.Kersten**
16:00-16:20	O2.001 L.Bertalot	I2.028 P. Diamond	O2.010 G. Huser	I2.038 T. Gans
16:20-16:40	O2.002 Wolfrum		O2.011 R. Florido	I2.039 G. Kroesen
16:40-17:00	O2.003 A.C.C.Sips	I2.029 F. Alladio	O2.012 B. Yu Sharkov	
17:00-17:20	O2.004 S.H.Kim		O2.013 C. Labaune	02.016 B. James
17:20-17:40	O2.005 P.Gohil	I2.030 F. Casse	O2.014 I.B. Földes	O2.017 J. Donoso
17:40-18:00	O2.006 V.Pericoli-Ridolfini	I2.031 D. Hughes	O2.015 R. Ramis	O2.018 A.B. Ustimenko
18:00	*Close*			
18:20-20:15	**(chair J. Lister) ITER session**			

Wednesday 11 June 2008

	Room Zeus Chair: H. Wilson			
8:30-9:10	I3.040: G. Conway			
9:10-9:50	I3.041: K.H. Spatschek			
9:50-10:20	*Coffee Break*			
	Room Zeus Chair: P. Monier-Garbet	**Room Minos Chair: M. Perlado**	**Room Athena Chair: M. Bowden**	**Room Danae Chair: N. Woolsey**
10:20-10:50	I3.042 O. Gruber	I3.047 T. Liseikina	I3.050 J.P. Borra	I3.053 K. Ronald
10:50-11:20	I3.043 O. Schmitz	I3.048 R. Fonseca	I3.051 U. Kortshagen/ R. Anthony	I3.054 Ch. Gregory
11:20-11:50	I3.044 M. Gryaznevich	I3.049 A. di Piazza	I3.052 P. Rocca	I3.055 F. Hansen
11:50-12:10	I3.045 M. Valisa	O3.019 M. Geissler	O3.022 A.E. Sorokin	O3.025 F. Delahaye
12:10-12:30		O3.020 H. Kuroda	O3.023 B. Layden	O3.026 A. Frank
12:30-12:50	I3.046 J. Garcia	O3.021 S. Kneip	O3.024 B.J. Lee	O3.027 L.P. Babich
12:50-14:00	*Lunch Break*			
14:00	Excursion			

Invited Plenary	40 min
Invited	30 min
Oral	20 min

Thursday 12 June 2008

	Room Zeus Chair: K. Tanaka			
8:30-9:10	I4.056 : M. Borghesi			
9:10-9:50	I4.057 : J-P. Boeuf			
9:50-10:20	*Coffee Break*			
	Room Zeus **Chair:W. Suttrop**	**Room Minos** **Workshop** **Chair: K.Lancaster**	**Room Athena** **Chair: J. Winter**	**Room Danae** **Chair: L. DaSilva**
10:20-10:50	I4.058 J. Rice	I4.060 C. Stoeckl	I4.062 K. Bergmann	I4.064 G. Vatistas
10:50-11:20	I4.059 A. Murari	I4.061 N. Blanchot	I4.063 S. Ratynskaia	I4.065 S. Mueller
11:20-11:40	O4.028 M.Muraglia	D4.001 E. Storm (post-deadline)	O4.046 A.D. Gurchenko	O4.055 B. Rubinstein
11:40-12:00	O4.029 P.Piovesan	O4.038 H. Azechi	O4.047 A.G.Peeters	O4.056 M. Psimopoulos
12:00-12:20	O4.030 Ph.Lauber	O4.039 A. Henig	O4.048 M. Pedrosa	O4.057 S. Perri
12:20-13:30	*Lunch Break*			
13:30-15:30	Poster Session			
15:30-15:50	Coffee break in Poster Session			
	Room Zeus **Chair: J. Ongena**	**Room Minos** **Worshop** **Chair: M. Key**	**Room Athena** **Chair: R. Wolf**	**Room Danae** **Chair: F. Doveil**
16:00-16:20	O4.031 S.Zoletnik	O4.040 L. Willingale	O4.049 N.Vianello	I4.066 R. Trines
16:20-16:40	O4.032 S. de Graca	O4.041 I. Tsohantjis	O4.050 R.Guirlet	
16:40-17:00	O4.033 A.Huber	O4.042 L. Lancia	O4.051 Y.Kominis	I4.067 F. Peano
17:00-17:20	O4.034 G.P.Maddison	O4.043 J. Badziak	O4.052 Y.Xu	O4.058 M.V. Goldman
17:20-17:40	O4.035 M.Becoulet	O4.044 O.V. Polomarov	O4.053 R.E. Waltz	O4.059 A. Ram
17:40-18:00	O4.036 T.Kurki-Suonio	O4.045 T. Johzaki	O4.054 L. Garzotti	post deadline
18:00	*Close*			
18:10-19:45	**Women in Physics (Chair: S. Jacquemot)**			
20:15	Conference dinner			

Friday 13 June 2008

	Room Zeus **Chair: P. Norreys**			
8:30-9:10	I5.068 : M. Tabak			
9:10-9:50	I5.069: P. Pasko			
9:50-10:20	*Coffee Break*			
10:20	**Room Zeus** **Chair: E.Rachlew**	**Room Minos** **Chair: K. Tanaka**	**Room Athena** **Chair: N. Cramer**	**Room Danae** **Chair: N. Vlahos**
10:20-10:50	I5.070 J. Menard	O5.060 L. Hallo O5.061 P. Koester	I5.079 A. Ivlev	I5.081 V. T. Tikhonchuk
10:50-11:20	I5.071 F. Tabarés	O5.062 P. Velarde	I5.080 V. Nosenko	I5.082 H. Takabe
11:20-11:50	I5.072 V. Udintsev	I5.077 A. Robinson	O5.063 H. Totsuji	O5.066 A.Y. Pankin
11:50-12:20	I5.073 Y. Andrew	I5.078 J. Honrubia	O5.064 C. M. Ticos O5.065 A. Fruchtman	O5.067 M.E.Dieckmann O5.068 N. Leprovost
12:20-13:30	*Lunch Break*			
13:30-15:30	Poster Session			
15:30-16:00	Coffee break in Poster Session			
	Room Zeus **Chair: S. Jacquemot**			
16:00-16:40	I5.074: F. Moreno-Insertis			
16:40-17:20	I5.075 : S. Krasheninnikov			
17:20-18:00	I5.076: A. Becoulet			
18:00-18:30	*Close*			

I. Pl.	40 min
I. par.	30 min
Or.	20 min
Workshop / BPIF	

LIST OF INVITED TALKS

I1.001	L. Chen	Alfven Waves: A Journey between Space and Fusion Plasmas
I1.002	G. Tsakiris	From relativistic laser-plasma interactions to intense attosecond pulses
I1.003	A. Piel	Complex plasmas: forces and dynamical behaviour
I1.004	S. Guenter	Three dimensional effects in tokamaks
I1.005	S. Brezinsek	Material erosion and migration studies in JET and implications for ITER
I1.006	A. Boozer	Stellarators and the path from ITER to DEMO
I1.007	S. Ide	JT-60U advanced tokamak research towards JT-60SA
I1.008	T. Ceccotti	First results on ions acceleration in an ultra-short, ultra high contrast 50 TW Laser Regime
I1.009	D. Jaroszynski	Radiation sources based on laser-plasma accelerators: current status and challenges
I1.010	F. Quere	Novel radiation sources using plasma mirrors
I1.011	F. Albert	Full characterization of a laser-produced keV X-ray betatron source and applications
I1.012	C. Oehr	Plasma deposition of ultrathin films for biomedical use
I1.013	M. Kushner	Modelling plasma modification on surfaces at low and high pressure. Achieving high control of reactants.
I1.014	L. Boufendi	Particle growth and detection in low temperature plasmas
I1.015	D. Karabourniotis	Diagnostics of dense dispersive plasmas from line reversal.
I1.016	D. Gericke	Temperature Equilibration in Dense Strongly Coupled Plasmas
I1.017	F. Paganucci	MHD instabilities in Magneto-Plasma-Dynamic Thrusters
I2.018	S. Pinches	The Physics of Fast Ion Driven Instabilities in Fusion Plasmas
I2.019	T. Killian	Watching Ions Dance Near Absolute Zero
I2.020	B. Dudson	Experiments and simulation of edge turbulence and filaments in MAST
I2.021	D. McDonald	JET confinement studies and their scaling to high βN scenarios
I2.022	S. Sakakibara	Study of Reactor-Relevant High-Beta Regime in the Large Helical Device
I2.023	G. Falchetto	The European Turbulence Code Benchmarking Effort: Turbulence driven by Thermal Gradients in Magnetically Confined Plasmas
I2.024	P. Renaudin	Investigating atomic properties of warm dense matter produced by laser
I2.025	B. Rus	Warm Dense Matter Generation by soft X-ray laser heating of thin foils
I2.026	R. Singleton	An exact treatment of charged particle stopping in a plasma or The Coulomb logarithm revisited
I2.027	L. Videau	Overview of on-going LIL experiments
I2.028	P. Diamond	Anti-friction, Homogenization and Angular Momentum Transport in Tokamaks, Planets and the Solar Tachocline
I2.029	F. Alladio	Rotating twisted flux tubes buoyancy: comparison between the convective region of the Sun and the edge of a tokamak plasma
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ABSTRACTS OF INVITED TALKS

Alfvén Waves: A Journey between Space and Fusion Plasmas†

Liu Chen [1,2]

Alfvén waves discovered by Hannes Alfvén are fundamental electromagnetic oscillations in magnetized plasmas existing in the nature and laboratories. Alfvén waves play important roles in the heating, stability, and transport of plasmas. The anisotropic nearly-incompressible shear Alfvén wave is particularly interesting; since, in realistic non-uniform plasmas, its wave spectra consist of both the regular discrete and the singular continuous components. In this Alfvén Lecture, I will discuss these spectral properties and examine their significant linear and nonlinear physics implications. These discussions will be based on perspectives from my own research in both space and laboratory fusion plasmas; and will demonstrate the positive feedbacks and cross-fertilization between these two important sub-disciplines of plasma physics research. Some open issues of nonlinear Alfvén wave physics in burning fusion as well as magnetospheric space plasmas will also be explored.

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From relativistic laser-plasma interactions to intense attosecond pulses

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The dawn of lasers capable of delivering Terawatt to Petawatt power output set off the exploration of a host of processes in the realm of relativistic laser-plasma interaction. At intensities beyond 10^{18} W/cm^2 where the electrons mean quiver energy becomes comparable to their rest mass energy, a plethora of new phenomena emerge: X- and γ-rays are copiously generated, the laser light undergoes relativistic self-focusing, electrons and protons are accelerated to breakthrough energies, neutron and positrons are produced, and the laser frequency is up-shifted to harmonic radiation reaching the keV photon energy. The last process of harmonic generation accompanying the interaction of high intensity laser pulses with solid targets gives rise to an intriguing prospect: the production of intense single attosecond pulses. The advent of such pulses will open up the way to real-time observation of a wide range of fast evolving phenomena in atomic, molecular and plasma physics.

Complex plasmas: Forces and dynamical behaviour

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The field of complex (dusty) plasmas, which experienced a tremendous growth after the discovery of “plasma crystals” [1], in 1994, has now become an integral part of plasma physics. This talk addresses some basic physical mechanisms that illuminate typical features of complex plasmas and discusses recent developments.

The first part of the talk is devoted to the confinement and structure of two-dimensional and 2.5-dimensional plasma crystals in the sheath of radio-frequency discharges. It is shown how the super-sonic ion flow affects the interparticle forces and the structure of the plasma crystal. Recently, three-dimensional plasma crystals could be formed [2], which possess an unusual crystal structure of nested shells. The principle of the shell structure and the differences from “Coulomb crystals” in systems of laser-cooled ions are outlined. The imaging methods have evolved from video-microscopy to stereoscopic imaging and holography.

In a second part, the ion wind force on dust particles is discussed, which leads to the formation of particle-free regions (“voids”) of the dust cloud, that are found in many experiments under micro-gravity. Experiments with tracer particles reveal the position where the ion-drag force balances the Coulomb force from the ambipolar electric field. The same technique was used to visualize the sheath around a Langmuir probe. In magnetized plasmas, ion drag leads to torus-shaped dust clouds that are set into poloidal rotation by the ion wind.

The third part addresses 2D dust-lattice waves and 3D dust-density waves. Waves are indispensable tools for the diagnostics of dusty plasmas. On the other hand, complex plasmas can serve as model systems to study phonons in solid and liquid phases of strongly coupled matter.

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THREE DIMENSIONAL EFFECTS IN TOKAMAKS

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We give an overview of 3-d effects in tokamaks, stressing synergies with stellarator research, in particular in the development and use of computational tools. We restrict to situations, where perturbations grow slowly ($\gamma << R/V_{alf}$), so that the plasma passes through a sequence of 3-d ideal-MHD equilibrium states, with the time-dependence determined by the resistive decay of plasma or wall currents (excluding thereby Alfvén-type modes). The actuality of the topics is given by the recent ITER and DEMO discussions, emphasising the active control of neoclassical tearing (NTM) and resistive wall modes (RWM) as well as edge profiles (through resonant perturbations). The slow rate of change of all these states raises the possibility of external feedback.

Localized current deficits at resonant surfaces in standard-q profile discharges can be induced by conductivity (pellet injection or radiation enhancement) or bootstrap current reduction (NTMs), and can result in ideal-MHD stable helical equilibrium states (sometimes termed snakes) with closed flux surfaces and evidently good energy and particle confinement. These perturbations lead to losses of fast particles, generally not associated with resonances in velocity space, but similar to those in non-optimized stellarators. They can now be well diagnosed with fast particle analyzers having high-resolution in time and velocity space.

Even ideal-MHD unstable low-n modes can be reduced to slowly developing equilibrium states by the presence of sufficiently close resistive walls. Realistic wall structures thereby lead to a coupling of different toroidal modes, effectively suggesting the use of stellarator codes for their analysis. Plasma rotation has a strong effect on the predicted growth rate, but the magnitude of the rotation and the critical field amplitude for mode locking depend strongly on rotation damping by 3-d magnetic field perturbations. Even for a given rotation speed the dispersion relation of the mode depends on kinetic effects, and we describe also recent efforts to apply truly kinetic stability codes (developed originally for fast particle driven instabilities) to the analysis of resistive wall modes.

Material erosion and migration studies in JET and its implications for ITER

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Material erosion, long and short range migration, re-deposition, and tritium retention are among the most outstanding problems for future fusion devices aiming to operate in a steady state mode. This is one of the main research topics presently in JET which operates with full carbon walls and Be evaporation, with the particular aim to prepare for future comparison after the installation of the new ITER like wall at JET. A number of important and new insights have been obtained with the help of improved diagnostics and dedicated pulse sequences. Spatial distribution and layer characteristics have been identified with dedicated slow plasma sweeps and spatially resolved hydrocarbon spectroscopy and Quartz microbalance deposition detectors which have been placed around the JET divertor. The main results can be summarised as following:

(i) carbon is mainly released from first wall and deposited in the inner divertor. The magnetic configuration is the main factor which determines the deposition pattern at first, e.g. the private flux region turns from net deposition to erosion when the configuration changes from vertical to horizontal target operation.

(i) the deposited carbon undergoes further transport inside the divertor by a stepwise process induced by new magnetic configurations which lead to enhanced re- erosion of freshly deposited layers. This erosion is much stronger than for bulk graphite substrate.

(iii) this effect is partly attributed to the disintegration of deposited layers by plasma impact far below normal carbon sublimation sets in. Spectroscopy shows that this is accompanied by an enhanced release of carbon clusters.

(iv) a strongly nonlinear increase of the local carbon release and migration inside the divertor with ELM size has been found such that a few large type I ELMs lead to a stronger migration than many small ELMs.

These observations can explain the large carbon deposition and tritium retention on remote areas (louvers) in the JET DTE1 experiment. They show also that the dynamics of carbon transport is a specific carbon property since it is coupled with the deposition and fast disintegration of carbon layers. Such effects are not expected for metallic layers such as Be. This view is also supported by the fact that the Be content in layers on plasma facing areas in the inner divertor reach values typically of 20% while the Be is strongly de-enriched in C-layers in remote areas by factors between 10-100.

* See the Appendix of M.L. Watkins et al., Fusion Energy 2006 (Proc. 21st Int. Conf. Chengdu, 2006) IAEA (2006)

Stellarators and the path from ITER to DEMO

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A low risk extrapolation from ITER to a demonstration of fusion power, DEMO requires information from a broader fusion program on materials and physics issues. Five of the physics issues have been addressed by non-axisymmetric shaping: (1) robustness of the plasma equilibrium, (2) insensitivity to details of profiles, (3) limits on the plasma density, (4) mitigation of magnetic field errors, and (5) the control of large pulses of energy to divertors through ELM's. Operational limits in tokamaks are often set by disruptions, which cannot be tolerated in DEMO and are an extreme example of non-robustness. Profile sensitivity comes in part through the bootstrap current, which is far more important in DEMO than in ITER. The profile sensitivity in tokamak experiments is also implicated in the sustainable pressure being significantly lower that the maximum achievable pressure. The Greenwald density limit of tokamaks would force DEMO to operate where the pressure of alphas makes energetic particle instabilities problematic and the divertors difficult. The only known experimental solution to these three issues is the non-axisymmetric shaping of stellarators. In addition, magnetic field errors due to displacements of coil currents cannot be eliminated, but the deleterious effects can be greatly reduced by controlled non-axisymmetric shaping. Using related techniques, an asymmetric perturbation can be chosen to modify the H-mode pedestal for ELM control while having minimal effects on the central plasma. Non-axisymmetric shaping can be expected on DEMO. The question is the type and the level: (1) a low level for error field and ELM control; (2) a moderate level for robustness against disruptions, reduced profile sensitivity, and elimination of current drive, or (3) a high level to make DEMO as insensitive to plasma profiles as possible. The NCSX stellarator will study quasi-axisymmetric shaping, which means non-axisymmetric shaping consistent with the P_φ invariance of axisymmetry. This shaping can be applied to a tokamak at any level from low to moderately strong. The non-axisymmetric shaping used on the W7-X stellarator allows even more complete plasma control through minimization of $j_{\|}/B$. The broader fusion program will determine the degree to which non-axisymmetric shaping can be used to minimize the risks of DEMO—both the physics benefits and the feasibility of the engineering. Supported by the U.S. Department of Energy grant ER54333.

JT-60U advanced tokamak research towards JT-60SA

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Towards realization of a steady-state tokamak reactor, establishing operational scenario with a plasma of high normalized beta (β_N) and high bootstrap current fraction (f_{BS}) is a key issue. Such a plasma is known as an advanced tokamak (AT) plasma. Development of AT plasmas has been intensively pursued in JT-60U [1]. In the AT development, increasing the key parameters (β_N, f_{BS}, etc.) and extending the sustaining duration are both important equally. In recent JT-60U experiments, β_N ~4.2 and f_{BS} ~100% have been achieved separately in short time scale (~energy confinement time) and sustainment of β_N = 2.3 for 23 s and f_{BS} = 70% for 8 s in long time scale (several to several tens of current diffusion time) have been demonstrated. These achievements have been supported and stimulated progress in understanding of physics issues: effect of plasma rotation on resistive wall mode and energy confinement, effect of localized current drive on neo-classical tearing mode, off-axis current drive by NBI and so forth. Based on the physics understanding, integrated active control on local/global current profile, rotation profile, plasma pressure, either separately or combined, has been developed. These research and development are, as mentioned before, towards DEMO and ultimately a reactor. Moreover, in nearer term, they will contribute to ITER, especially development of the advanced scenarios in ITER. Now a project on modification of JT-60U into a super-conducting machine (JT-60SA [2,3]) is in progress. These JT-60U results will contribute not only to development towards ITER and DEMO, but also to establishing physics operation in JT-60SA. In this presentation, recent progress in AT development in JT-60U will be discussed with emphasis on their impact for JT-60SA.

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FIRST RESULTS ON IONS ACCELERATION IN AN ULTRA-SHORT, ULTRA HIGH CONTRAST 50 TW LASER REGIME

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Recent progresses on laser beam contrast ratio improvement devices [1] have allowed obtaining contrast values as high as 10^{10}. First experiments using ultra high contrast (UHC) pulses for proton acceleration [2] have demonstrated the expected important increase in maximum proton energies reducing the target thickness and, as a consequence, the benefits of UHC pulses in enhancing proton energy scaling laws. Even more, it has been possible to highlight the symmetrical behaviour of ions bunches production from both sides of the target and the role of beam polarization [3]. The recent upgrade of the laser chain at Saclay from 10 TW to 100 TW gives us access to an interaction domain for ion acceleration never explored so far, characterized by ultra short pulse duration (< 25 fs), very high intensity (>10^{19} W/cm^2) and UHC (close to 10^{12}). Measurements of ions bunches properties in this laser intensity range will allow building scaling laws and predicting parameters for future applications. Finally, due to the outstanding high contrast shot-to-shot repeatability, all collected data are of main importance for numerical codes validation.

The first results on ions and protons acceleration obtained using the 100 TW Saclay laser will be presented and the perspectives they open will be discussed.

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RADIATION SOURCES BASED ON LASER-PLASMA ACCELERATORS: CURRENT STATUS AND CHALLENGES

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Radiation sources are ubiquitous tools for studying the structure and dynamics of matter. Current light sources can produce both brilliant and picosecond duration x-ray pulses which are useful for time resolved studies. There is a drive to reduce their pulse durations to a few femtoseconds or less, and increase their brilliance to enable single-shot measurements for unravelling structural or chemical changes on unprecedented time scales. Synchrotron source provide high average power and tuneable x-ray radiation, whereas the next generation x-ray free-electron lasers (FELs), which are currently being developed, will provide intense coherent radiation with several tens of femtosecond pulse durations. However, these sources are some of the largest instruments that exist. Their huge size and cost is a result of the microwave accelerator technology on which they are based. The acceleration gradients are restricted to gradients of 10–100 MV/m. The recent development of table-top multi-terawatt femtosecond lasers has provided the opportunity to significantly miniaturise accelerator technology by harnessing plasma waves as a medium for generating electrostatic fields with gradients approaching 1 TV/m. Recent pioneering developments in laser-driven plasma wakefield accelerators has resulted in controllable high quality electron bunches [1,2] that are providing a realistic prospect of realising a table-top synchrotron source and possibly an X-ray FEL. This could transform the way science is done by making available compact femtosecond infrared, UV and X-ray sources to University sized establishments. We will present the significant challenges facing the realisation of a compact plasma based source and review the first major advance where synchrotron radiation from an undulator driven by wakefield accelerator was demonstrated [3]. Recent progress towards an FEL based on a plasma wakefield accelerator and results from the ALPHA-X project [4] will be presented.

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Novel radiation sources using plasma mirrors

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When an intense ultrashort laser pulse hits an optically-polished solid target, it generates a dense plasma that acts as a mirror, known as a plasma mirror (PM). PMs can be used as ultrafast optical switches to improve the temporal contrast of ultrashort laser pulses [1]. At high enough intensities, high-order harmonics of the incident frequency, associated in the time-domain to attosecond pulses, can also be generated upon reflection on this mirror. Because there is in principle no limit on the laser intensity that can be applied to such a medium, this is a promising path to generate coherent beams of attosecond pulses with higher photon and pulse energies than those obtained by High-order Harmonic Generation (HHG) in gases. HHG from plasma mirrors is also likely to become a unique tool to investigate many key features of high-intensity laser-plasma interactions.

Using Particle-in-Cell simulations, we identify two very distinct harmonic generation mechanisms on PMs: Coherent Wake Emission (CWE) [2] and the Relativistic Oscillating Mirror [1]. Exploiting ultrashort pulses with a high temporal contrast, we demonstrate that harmonics generated by these two mechanisms can be clearly discriminated experimentally [1], through different features, such as their spectral width, spectral range, and intensity dependence. Due to the coherent character of the generation, the properties of the harmonics - *e.g.* their divergence- can be controlled through the phase of the driving laser field [3]. Finally, we demonstrate the mutual coherence of several harmonic beams generated by three spatially-separated focal spots of different intensities, and use the resulting interference pattern to measure the dependence of the CWE harmonic phase on laser intensity [4].

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Full characterisation of a laser-produced keV X-ray Betatron source and applications

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The advance of ultrafast laser technology, with chirped pulse amplification (CPA) laser systems, has allowed the production of X-ray sources in the femtosecond regime.

In previous work [1] a novel laser based hard (a few keV) X-ray source, the Betatron source, that combines the key features of synchrotron radiation, collimation and polychromaticity, with, in addition, a femtosecond pulse duration, has been observed. Relativistic (>100 MeV) electrons are accelerated and oscillate in the electrostatic fields generated in the wake of an ultraintense (30 fs, 50 TW) laser pulse to produce a synchrotron-like X-ray beam.

Following this result, which has provided a novel approach for laser based X-ray generation, the main parameters of the Betatron source have been investigated using three independent methods relying on spectral and spatial properties of the source.

First we will show new studies on the spectral correlation between electrons and X-rays that is analysed by use of a numerical code to calculate expected photon spectra from the experimentally measured electron spectra. High resolution X-ray spectrometers have been used to characterize the X-ray spectra within 0.8-3 keV and to show that the Betatron oscillations lie within 1 µm [2].

Then, we observed Fresnel edge diffraction of the X-ray beam. The observed diffraction at center energy 4 keV agrees with Gaussian incoherent source profile of full width half maximum (FWHM) <5 µm, meaning that the amplitude of the Betatron oscillations is less than 2.5 µm [3].

Finally, by measuring the far field spatial profile of the radiation, we have been able to characterize the electron's trajectories inside the plasma accelerator structure with a resolution better than 0.5 µm [4] .

We will as well demonstrate the potential of the Betatron X-ray source for applications. It has been used as a probe to perform a time-resolved X-ray diffraction experiment [5]. The ultrafast nature of the source has been shown by measuring an ultrafast phase transition (non thermal melting in InSb).

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Plasmadeposition of ultrathin films for biomedical use

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Abstract

Plasma Polymerization is used since more than 40 years to develop thin films for different kinds of applications. At least since the sixties of the last century these films are used in the fields of medicine and pharmacy.

Due to the fact that polymers are applied to design low-weight devices and to realize different geometries very easily, the films are mainly deposited onto polymeric substrates. It is a characteristic property of plasma polymerized films that they show strong adhesion to polymer substrates due to creation of radical sites at the interface when deposition starts. Thus thin layers with good adhesion, a defined amount of chemical functionalities and stability to sterilization processes are generated. This fits to the needs for medical application.

In principle plasma processing offers different approaches for the deposition of thin films with a variable amount of functionalities available for reaction with bio-molecules. Advantages and disadvantages of the different deposition strategies will be discussed.

The interaction of biological systems with materials can be divided in three subsystems. First, the interaction with bio-molecules. Here the binding of molecules with specific activities on one hand and the minimizing of unspecific protein adsorption on the other hand can be influenced by thin plasma polymers deposited on medical devices. Second, the interaction between bacteria and surfaces can be modulated via deposition of thin films with bacteriostatic or bacteriocidic properties on devices. Third, the interaction of surfaces with mammalian cells can also be influenced to enhance the cell growth and cell proliferation for the development of test kits or implants. In this contribution examples for these three categories will be shortly reviewed.

Beside the preparation of the mentioned films also the analytical tools necessary for film development and control of its properties are stressed in the final chapter of this contribution. A correlation between physico-chemical properties of the applied plasma polymerized films and the biological requirements will be tried.

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MODELING PLASMA MODIFICATION OF SURFACES AT LOW AND HIGH PRESSURE: ACHIEVING HIGH CONTROL OF REACTANTS*

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The plasma modification of surface layers has made significant progress, particularly at low pressure where the control of uniformity over large areas and real-time-control strategies are more easily achieved. Ultimately, the quality of the materials produced depends on the ability to deliver the desired reactants and activation energy to those surfaces with a high degree of control. As feature sizes diminish and requirements for selectivity increase, the ability to control the energy and identity of reactants to the surface becomes more important. As plasma modification of surfaces at atmospheric pressure are applied to higher value materials, similar strategies must be developed to achieve uniformity over larger areas. Real-time-control strategies may also be required. In this talk, we will discuss the use of plasma models to develop strategies, both intrinsic to the plasma and externally through real-time-control, to specify reactant fluxes to the substrate to achieve mono-layer resolution of surface modification. The modelling platforms used in these investigations will first be described followed by examples, from low and high pressure plasma modification of surfaces, of how control of reactants to the surface can be achieved.

One such example is the etching of extremely high aspect ratio contacts (HARC) in low pressure plasmas. HARCs having aspect ratios of tens to as much as a hundred, with contact openings of only 50-60 nm, are particularly challenging to uniformly etch with high selectivity. The opening to the feature is so small that the incident charged and neutral fluxes are stochastic in nature. This leads to occasional non-uniform charging inside the feature, producing lateral electric fields and eventually “twisting” (that is, turning of straight features). Advanced equipment concepts that tailor high energy electron fluxes with a narrow angular spread enables those fluxes to penetrate into the feature and neutralize the errant positive charge. HARCs also are challenged by micro-trenching which requires extremely high selectivity to address. Achieving this high selectivity may ultimately require atomic-layer, self-limiting processes. Results will be discussed from plasma modelling of these processes which has provided strategies for optimizing the shape of features.

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Particle growth and detection in low temperature plasmas

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Dust particle nucleation and growth has been widely studied these last fifteen years in different chemistries and experimental conditions. This phenomenon is correlated with various electrical changes at electrodes, including self-bias voltage and amplitudes of the various harmonics of current and voltage[1]. Some of these changes, such as the appearance of more resistive plasma impedance, are correctly attributed to loss of electrons in the bulk plasma to form negative molecular ions (e.g. SiH_3^-) and more precisely charged nanoparticles. These changes were studied and correlated to the different phases on the dust particle formation. It is well known now that, in silane argon gas mixture discharges, in the first step of this particle formation we have formation of nanometer sized crystallites. These small entities accumulate and when their number density reaches a critical value, about 10^{11} to 10^{12} cm^{-1}, they start to aggregate to form bigger particles. The different phases are well defined and determined thanks to the time evolution of the different electrical parameter changes.

The purpose of this contribution is to compare different chemistries to highlight similarities and/or differences in order to establish possible universal dust particle growth mechanisms. The chemistries we studied concern SiH_4-Ar, CH_4, CH_4-N_2 and $Sn(CH_3)_4$ [2]. We also refer to works performed in other laboratories in different discharge configurations[3].

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Diagnostics of dense dispersive plasmas by line reversal

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Plasma spectroscopy by optically thick lines is yet an open problem due to a lack in the knowledge of fundamental mechanisms of the line formation. For instance, the intensity in the central part of self-reversed lines emitted from the high-pressure plasmas of high-intensity discharge (HID) lamps is much higher than that calculated by solving the conventional radiative transfer equation [1]. On the other hand, absorption measurements have proved that the optical depth at the central part of the line is one to two orders of magnitude less than that calculated according to the conventional theory of radiation transport [1, 2]. These striking differences between experimental and theoretical results in dense, strongly absorbing plasmas might be explained by the possibility of non-radiative transfer of excitation in the neighborhood of the transition frequency by resonant collisions leading to a rapid increase of the intensity in the vicinity of the line center followed by a rapid increase of the corresponding optical depth [3]. This phenomenon depends on the dispersion of the radiation in the dense plasma-medium and it arises when the mean free path of the photons with respect to absorption is comparable to the wavelength of the radiation. A diagnostic method was proposed [1, 4] for temperature determination from line reversal based on an approximation for the source function [5]. This method relates the radiance at the reversal maxima of the spectral line to the maximum temperature along the line of sight through the so-called inhomogeneity parameter which strongly depends on the central line minimum. In this work we show that the presence of dispersion effects does not affect the determination of the inhomogeneity parameter and therefore the applicability of the diagnostic method. The temperatures in a high-intensity discharge (HID) lamp are therefore determined from self-reversed lines and the changes in the minimum intensity and the optical depth caused by the dispersion-related effects are determined by comparing the experimental results with those obtained by numerical simulation of the studied dense discharges**.**

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Temperature Equilibration in Dense, Strongly Coupled Plasmas

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The equilibration of multi-temperature plasmas is a fundamental problem in plasma physics since such systems are often created after laser or particle beam interactions with matter. In dilute, weakly coupled plasmas, where binary collisions dominate the energy transfer, this process is well understood whereas in dense and strongly coupled plasmas, more complicated processes have to be considered: first of all the surrounding medium modifies the electron-ion collisions [1]; moreover, the collisions seemed to be suppressed by collective modes in the system [2]. Energy transfer through such modes is therefore an important relaxation process and the fact if low energy ion modes occur or not strongly influences the relation times [3]. Furthermore, the potential energy due to correlations must be included in the description of the equilibration process [5, 4].

This contribution will focus on the influence of coupled collective modes: firstly, their influence on the electron-ion energy transfer is discussed for weakly coupled plasmas where the modes can be described by the well-known Lenard-Balescu equation. Explicite expressions when coupled mode effects are expected can be derived. Strong coupling effects included by static local field corrections shift these modes and, accordingly, reduce the energy transfer rates. The description of the full relaxation process must include potential energy contributions on the same level [5]. These correlation energies have the overall effect of an energy sink that slows down the ion heating during temperature equilibration in laser heated plasmas.

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MHD Instabilities in Magneto-Plasma-Dynamic Thrusters

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Magneto-plasma-dynamic (MPD) thrusters represent a high power electric propulsion option for primary space missions. They act as electromagnetic plasma accelerators, with a possible range of operations spanning from orbit-raising to interplanetary missions of large spacecrafts. One of the major problems facing MPD thruster operation is the onset of a critical regime, which is found when the power is increased beyond a threshold value, mainly depending on thruster geometry, type and mass flow rate of propellant, applied magnetic field intensity. In this regime, large fluctuations in the electrode voltage signals and damage to the anode are observed along with efficiency degradation. Since 2000, Centrospazio-Alta and Consorzio RFX have been carried out several experimental campaigns aimed at investigating the electrostatic and magnetic properties of plasma fluctuations, by means of electromagnetic and optic probes and ultraviolet tomography. The experimental results have evidenced a strong relation between the onset phenomena and the growth of a large-scale magnetohydrodynamic (MHD) instability, with the features of a helical kink mode. Its growth is well described by the Kruskal-Shafranov stability criterion, which gives results in very good agreement with a semi-empirical stability criterion for MPD thrusters, proposed by other authors. On the basis of the experimental observations, some active as well as passive instability suppression methods have been proposed and partially tested, with encouraging results. The paper gives a synthesis of the main results of the activity carried out so far and indications for the next investigations.

The Physics of Fast Ion Driven Instabilities in Fusion Plasmas

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As the fusion community moves towards the realisation of devices containing burning plasmas, i.e. devices in which the intrinsic heating from energetic particles (by-products of fusion reactions) is dominant, it is timely to examine the recent progress made to understand the range of energetic particle driven modes observed and their consequences in terms of fast ion redistribution and loss.

JET's large size and high current capabilities furnish it with excellent fast ion confinement properties which together with its extensive range of dedicated fast ion diagnostics (scintillator probe, Faraday cup array, gamma-ray spectrometer, gamma-ray tomography, neutral particle analyser) and extensive range of sensitive fluctuation measurements (magnetics, far infra-red interferometry, O and X-mode microwave reflectometry, soft X-rays, electron cyclotron emissions) make it an ideal testing ground for investigating the instabilities driven by fast ions with energies in the MeV range.

Dedicated experiments examining fast ion losses and redistribution have been conducted, drawing together the extensive range of diagnostic information to reveal the modes responsible, together with quantitative measurements of their consequences in terms of fast ion redistribution and loss. Experiments in which minority ions are accelerated to MeV energies have been used to study the redistribution of fast ions due to various instabilities including large core modes (n = 1 fishbones and sawtooth) which have been observed to redistribute fast ions across the $q = 1$ surface. In other experiments, fishbones have been observed to trigger neoclassical tearing modes, indicating that sawtooth control alone may be insufficient to avoid these confinement degrading modes.

Core-localised modes are often difficult to detect using magnetic pick-up coils and so the use of X-mode reflectometry techniques to detect and localise these modes has been pioneered. Experiments examining fast ion losses due to tornado modes (core-localised toroidal Alfvén eigenmodes) have been conducted using far infra-red interferometry measurements to detect these Alfvénic perturbations. In general, the radial gradient of the fast ions provides the drive for modes, however recently Alfvénic modes that propagate both co and counter to the plasma current have been observed following sawteeth, indicating the possibility that such modes can be driven by fast ion anisotropy. The application of these core fluctuation diagnostics have made MHD spectroscopy an even more powerful tool in assisting scenario development.

Even modes which are expected to be unstable in burning plasmas but which are stable in JET are not beyond scrutiny. The new active excitation system installed on JET is capable of driving the modes predicted to be most unstable in ITER and measuring their properties. This provides a measurement of the proximity to instability and valuable data against which theoretical understanding can be validated.

As a result of these advances, both our linear and nonlinear understanding of the phenomena expected to arise in burning plasmas have been enhanced and we can move towards the realisation of fusion devices with an increased level of confidence.

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* See Appendix of M.L. Watkins *et al.*, Fusion Energy 2006 (Proc. 21st Int. Conf. Chengdu, 2006) IAEA, (2006)

Watching Ions Dance Near Absolute Zero

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Ultracold neutral plasmas, formed by photoionizing laser-cooled atoms near the ionization threshold, stretch the boundaries of traditional neutral plasma physics. The electron temperature in these plasmas is from 1-1000K and the ion temperature is around 1 K. The density can be as high as 10^{10} cm^{-3}. They provide a playground for studying strongly coupled plasmas, in which the Coulomb interaction energy exceeds the thermal energy. Strong coupling is of interest in many areas of physics, and in ultracold plasmas it leads to spatial correlations and surprising equilibration dynamics. The expansion of ultracold plasmas into the surrounding vacuum can also probe the physics of plasmas produced with short-pulse laser irradiation of solid, liquid, foil, and cluster targets.

This work is supported by the U.S. National Science Foundation and David and Lucille Packard Foundation.

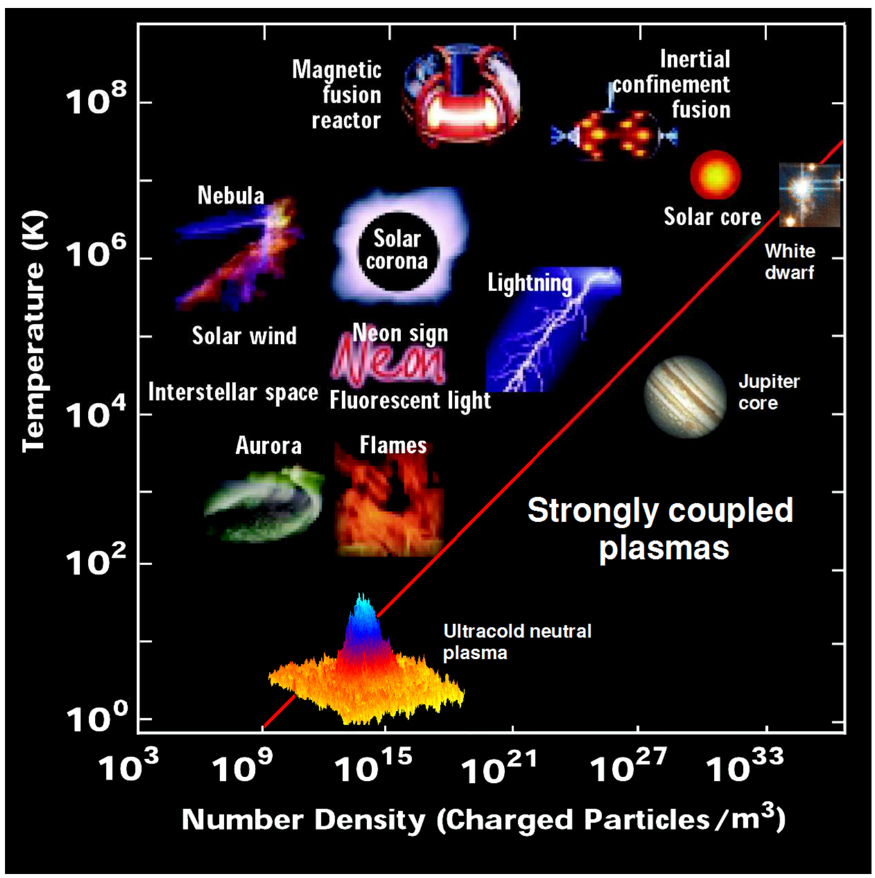

Figure 1. Ultracold neutral plasmas occupy a previously unexplored region of phase space and can be strongly coupled. The graphic shown for ultracold neutral plasmas is an absorption image of ions in the plasma. Adapted with permission from the Contemporary Physics Education Project. Copyright 1996.

Experiments and simulation of edge turbulence and filaments in MAST

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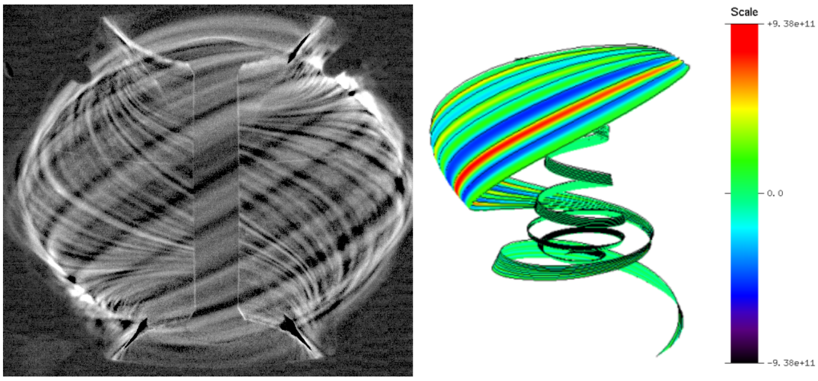
Experimental and simulation results on filament structures observed in MAST from L-mode and H-mode plasmas will be presented. Understanding these structures is important both due to their influence on transport in the pedestal, and also due to their effect on cross-field transport in the SOL and hence power loading on plasma-facing components.

Fast camera and reciprocating Langmuir probe data have been used to determine the mode-number, toroidal and radial velocities of the filaments observed. A comparison of the data from L-mode, inter-ELM and during ELMs shows that while ELM filaments move coherently, those observed in L-mode and inter-ELM regimes move toroidally and radially independent of each other. In both L-mode and inter-ELM regimes, the number of filaments is found to increase with plasma density. L-mode simulations using the 3D, 2-fluid BOUT code produce similar widths and radial velocities to the observations. Detailed examination of simulation results indicate the presence of a mixing layer within 2cm of the separatrix, across which the character of the turbulence changes.



Fast imaging (left) and BOUT simulations (right) of MAST L-mode plasmas

Statistical analysis of L-mode edge fluctuations associated with edge filamentary structures is presented, examining correlation functions, scaling of moments and PDFs. These results confirm a dual temporal scaling with a time t ~ 40-60μs separating the two regimes. Combining these results with the image analysis indicates that the dual temporal scaling is due to the properties of the individual filaments.

Progress in understanding ELM events using linear and non-linear codes is reviewed, including results concerning the effect of x-point geometry, edge rotation and poloidal beta on ELM stability. First results from a new modular code (developed from BOUT in collaboration with LLNL) for non-linear ELM simulations will be presented. This code is capable of simulating a wide variety of plasma fluid models and magnetic geometries. One objective is to study and compare plasma eruptions in a range of different situations, such as ELMs and solar flares.

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JET confinement studies and their scaling to high β_N, ITER scenarios

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Operating at high β_N (plasma pressure normalised to the Troyon limit), the ITER Hybrid and Steady State scenarios aim to use increased bootstrap current to enable burn times _ 1000*s*. To achieve this, and optimise fusion performance, these scenarios must have good energy confinement. ELMy H-mode plasma studies, with β_N primarily in the range $1 < \beta_N < 2$, have been described by scalings, such as IPB98(y,2), which are used for extrapolation to ITER. However, dedicated ELMy H-mode β_N studies in JET and DIII-D did not find the negative dependence of confinement on β_N in IPB98(y,2). Focusing on recent JET results, this paper describes the extension of confinement scaling to higher β_N _ 2−4 and to different scenarios. In the Hybrid scenario, JET has attained $\beta_N^{MHD} = 3.6$. Despite a different initial phase, plasma parameters evolve rapidly towards those of equivalent ELMy H-modes with confinement normalised to IPB98(y,2), $H_{98(y,2)}$ _ 1. Dedicated scans in this scenario have found decreasing confinement with increasing β_N. This is strongest in the pedestal - consistent with gyro-fluid transport modeling which predicts β_N independent core confinement. Study of a wider database suggests that the different scaling is related to operating at higher triangularity. In contrast, DIII-D and ASDEX Upgrade Hybrid scenarios have confinement that is not well described by IPB98(y,2). This implies that either the machines are in different confinement modes or that the Hybrid scenario has a different size scaling to IPB98(y,2). Both cases will be discussed. Candidate Steady State scenario plasmas with and without ITBs on JET have attained $\beta_N^{MHD} = 3$. Pedestal confinement losses associated with gas fuelled small ELMs are compensated by core confinement improvements from ITBs giving $H_{98(y,2)}$ _ 1. Without ITBs, $H_{98(y,2)}$ _ 1 plasmas are observed with increased confinement associated with low values of minimum safety factor. Confinement in all of the scenarios will be compared and conclusions for high β_N, ITER operation discussed.

* *see appendix of M Watkins et al, Fusion Energy 2006 (Proc 21st Int Conf Chengdu, 2006) IAEA*

Study of Reactor-Relevant High-Beta Regime in the Large Helical Device

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The volume averaged beta value of 5 %, which is relevant to that required in a fusion energy reactor, has been achieved in the Large Helical Device (LHD). The obtained high beta plasmas are free from disruptive phenomena. The extended high beta regime serves to expand the understanding of physics concerning the beta-limit as well as to demonstrate the potential capability of a helical fusion reactor. The magnetic configuration was optimized in terms of MHD equilibrium, stability and transport properties [1]. Net-current free heliotron plasmas are free from current-driven instabilities unlike in tokamaks, therefore the characterization of pressure-driven instabilities and their control in the high beta regime are critical issues for stable steady state operation. The dominant low-*m* MHD modes move from the core region to the periphery when the beta increases, and the modes excited at the outermost resonance near the plasma edge are enhanced in the beta range over 4 %. A clear dependence of the amplitude of the mode on the magnetic Reynolds number has been found, which is close to that of the linear growth rate of the resistive interchange mode [1]. The increase in equilibrium currents with the increment of the beta value leads to the disorder of the peripheral magnetic field structure, which possibly limits the confinement region. This effect on the confinement property should be clarified experimentally. The comparison between the measured temperature profile and the magnetic field structure calculated by the 3D MHD code HINT has been done in order to investigate the effect of the change of the magnetic topology on the confinement. The temperature gradient in the periphery with a disordered magnetic field structure seems to be lower than that in the core region with nested magnetic surfaces. Although the clear beta limits due to stability and equilibrium have not been observed in the present beta range of experiments, it has been found out that the global confinement gradually deteriorates with the increment of the beta value. This is mainly due to the increment of the heat transport in the periphery, and the causal relation with enhanced resistive-g mode turbulence is discussed [2].

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The European turbulence code benchmarking effort: Turbulence driven by thermal gradients in magnetically confined plasmas

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Computation of turbulence and transport in magnetised plasmas continues to make rapid advances. Global electromagnetic gyrofluid simulations are now possible, and global electromagnetic gyrokinetic simulations are beginning. Local "fluxtube" cases have been available for several years. Nevertheless, since the last major effort ten years ago there has been only sporadic work to benchmark the various approaches generally and individual implementations ("codes") particularly. We report the establishment of such an effort within the EFDA Task Force on Integrated Tokamak Modelling. Standard cases for both core and edge turbulence are included. Not only time trace information of anomalous fluxes are included, but the mode structure (spectra, radial envelopes, zonal flow amplitude, etc) are also compared. Results so far include good agreement between gyrofluid and gyrokinetic codes for core ion temperature gradient (ITG) driven turbulence but for trapped electron cases (driven mostly by the density gradient) the gyrokinetic models are needed as fluid ones predict stability. However, there is still an important disagreement on the core ITG zonal flow saturation level, even between gyrokinetic codes. More diagnostics on the global core cases will be reported and the main physical reasons for disagreement outlined. Edge results agree very well on collisionality scaling and acceptably well on beta scaling below the MHD boundary for cold-ion cases. They also agree well on the elements of mode structure. A sufficient number of warm ion edge turbulence codes for benchmarking is still lacking.

The support infrastructure for the benchmarking effort is also to be briefly described. This is a novel element allowing the continuously renewed effort required to assure quality control of ITER simulation in the longer term.

Investigating atomic properties of warm dense matter produced by laser

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Warm dense matter (WDM) is at the center of the density-temperature plane and, for some material, it is a barrier between different regions. Therefore a large number of technologic and scientific applications cross the WDM or need WDM properties. Recently, generation of WDM with minimized gradients has been obtained by irradiating solids with intense laser or ion beams. Short-pulse X-ray sources of a few ps duration emitting in the sub-5-keV range have been generated by irradiating high-Z materials with a sub-ps laser pulse. This offers the possibility to use point-projection time-resolved absorption spectroscopy for the study of spectral opacities of dense plasmas.

I will present results of recent X-UV pump-probe experiments performed in France with the 100 TW LULI facility. The experimental setup uses two ultra-fast laser beams to produce the plasma and the X-ray probe. The first ultra-short laser pulse was used to create a thin, high-density plasma slab fairly uniform in temperature or a short MeV ions bunch that allows an energy deposition in the bulk of a second target. Each shot allows to measure transmission spectra in the WDM regime.

The laser produced plasma is weakly ionised and density effects are not negligible. The continuum lowering modifies the ionization balance and pressure ionization tends to delocalize atomic orbitals. The temperature of the ions beam produced plasma is lower than the Fermi temperature. As the density remains high, the increasing temperature induces a change of the free electron degeneracy and a thermal smoothing of K-edge.

Warm dense matter generation by soft x-ray laser heating of thin foils

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We present results of experimental and numerical studies of generation of cold, near solid density, plasmas by volumetric heating of thin foils by focused soft x-ray laser (21.2. nm, i.e., 58.5 eV) pulses. Time-integrated and time-dependent transmission of the soft x-ray radiation through aluminium and polyimide was experimentally investigated for intensities of up to 10^{12} Wcm^{-2}. A simple diagnostics based on VIS camera was employed to assess temperature (<20 eV) of the heated matter. As the critical electron density for the 21.2-nm radiation is 2.4×10^{24} cm^{-3}, the incident x-ray laser always encounters undercritical matter or plasma and heats the entire volume of the irradiated foil; the heating is near-isochoric in the beginning of the x-ray laser pulse. The initial absorption of the soft x-ray radiation is dominated by bound-free transitions (photoionization). The experimental data show significant difference in transmission of the 21.2-nm radiation through heated aluminium and polyimide. In Al, the transmission of heated matter essentially corresponds to that of the solid-state, however in polyimide the absorption increases significantly for intensities $>5\times10^{11}$ Wcm^{-2}. This increase is seen to occur transiently during the rising edge of the heating pulse, and was indentified as due to bound-bound transitions in Li-like C resonant with the soft x-ray laser. The experimental data were simulated by radiation hydrodynamic code Lasnex, using a hybrid equation of state model interfaced with a model solving non-LTE rate equations in a hydrogenic approximation. Results of the simulations were found to be in good agreement with the experimental data, providing benchmarked insight into the absorption mechanisms of intense soft x-ray radiation in matter heated from cold solid through the warm dense matter regime to plasma states.

An exact treatment of charged particle stopping in a plasma or The Coulomb logarithm revisited

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The charged particle stopping power in a highly ionized and weakly coupled plasma has recently been calculated exactly to logarithmic accuracy by Brown, Preston, and Singleton (BPS) [1]. A very powerful regularization method from quantum _eld theory, called dimensional continuation, was employed in a novel way by BPS to calculate the Coulomb logarithm exactly, without appealing to *ad hoc* long- and short-distance cutoffs. The exact transition between the classical and quantum regimes was also included in the calculation. Since the technique of dimensional continuation might be unfamiliar to many plasma physicists, and since the same methodology can also be used for other energy transport phenomena, such as electron-ion temperature equilibration in a plasma [1, 3], I will spend the _rst part of the lecture reviewing the main ideas behind the calculation. I will then talk about the implications for ignition in Inertial Con_nement Fusion (ICF). The BPS stopping power gives longer ranges and deliverers less energy to the plasma ions than typical models in the literature, thereby making ignition harder to achieve. This could have implications for the Laser Mégajoule (LMJ) facility in France and the National Ignition Facility (NIF) in the United States.

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OVERVIEW OF ON-GOING LIL EXPERIMENTS

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The Ligne d'Intégration Laser (LIL) has been completed in 2002 and was first dedicated to laser physics experiments as a prototype for the future Laser MegaJoule. It delivers up to 15kJ at 3ω on target. We will present the experimental setup at the LIL facility and some plasma experiments carried out during 2005-2008. We have installed X-ray and visible-UV diagnostics allowing full characterization of the laser-plasma interaction (LPI) including the transmitted, scattered and backscattered 3ω beams. During the first LPI campaign of 2007 with gas-filled Au-hohlraums, we have obtained high quality signals for both Raman and Brillouin measurements. Another LPI campaign in collaboration with the Institute of Laser Plasma was devoted to the study of plasma smoothing in foam targets. Measurement of the transmitted beam after propagation through the foam demonstrated the effectiveness of laser plasma smoothing. Supersonic propagation of the ionization wave has been evidenced using time-resolved side-on X-ray imaging. Two CELIA campaigns devoted to the study of the nonlocal electron-energy transport, used x-ray diagnostics : hard x-ray time-resolved Bragg spectrometer allowed a discrimination between different modellings of the heat flow. Finally, we will present the last installed standard diagnostic devoted to EOS experiments, which is composed of a pyrometer, a VISAR and a shock breakout measurement.

Anti-friction, Homogenization and Angular Momentum Transport in Tokamaks, Planets and the Solar Tachocline

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This lecture will address the ubiquitous phenomenon of 'up-gradient' momentum transport (i.e. anti-friction) which is known to occur in tokamak plasmas - i.e. inward convective momentum 'pinch' and stress, planetary atmospheres - i.e. sharpening of high latitude zonal flows by Rossby wave breaking, and the solar tachocline - i.e. a thin, stably stratified layer at the base of the convection zone formed by spin-down driven meridional cells and turbulent momentum transport. These seemingly unrelated phenomena each have the common elements of low 'effective Rossby number', quasi-geostrophic dynamics, and a governing homogenization or relaxation principle. Like the Taylor Relaxation Hypothesis in low-β MHD, homogenization principles provide conceptually simple guiding frameworks which facilitate understanding the complex dynamics of turbulent relaxation, evolution and transport. This lecture emphasizes the physics of homogenization principles and their application to tokamak and tachocline phenomena.

In the case of tokamak plasmas, the homogenization of toroidal angular momentum by a compressible turbulent flow (n.b. inhomogeneous $B_0(\underline{r})$ implies $\underline{V}_{\underline{E}\times B}$ compressible!) enables the formulation of a turbulent equipartition (TEP) theory for angular momentum (L_ϕ) transport. This is equivalent to a homogenization theory for L_ϕ/B^α, $(\alpha \sim 2)$, which naturally leads to a toroidicity-induced inward pinch of toroidal angular momentum. Zonal flow formation, which is a common element of tokamak, planetary atmosphere and tachocline dynamics, is encapsulated by the principle of PV (potential vorticity) homogenization. Of particular relevance to tokamak phenomenology is the fact that PV homogenization encompasses the relative branching of total PV flux between guiding center flux (i.e. particle or thermal transport) and polarization charge flux (i.e. vorticity transport or, equivalently, Reynolds stresses), such as occurs in transport barrier formation. PV homogenization theory can be used to predict a critical fluctuation intensity gradient for the dominance of the polarization charge flux channel (i.e. transition threshold for transport barrier formation).

The tachocline is a more challenging application, on account of its dynamically active toroidal field. We note, though, that the details of PV and momentum transport are central to *both* tachocline formation scenarios (Spiegel-Zahn; Gough-McIntyre) and may also ultimately hold the key to deciding between these two competing approaches. Here, PV homogenization theory can be used to understand relevant but subtle questions, such as how strong an ambient magnetic field must be in order to convert 2D fluid turbulent dynamics (i.e. inverse energy cascade) to 2D MHD dynamics (i.e. forward energy cascade). Similarly, we show how stronger magnetic fields inhibit PV mixing and thus the formation of a zonal jet 'staircase' in the tachocline. This simple insight into PV transport processes in the unusual tachocline environment has profound complications for tachocline formation, and suggests that the fossil field scenario of Gough and McIntyre is the more viable one, since it limits tachocline penetration by fossil field magnetic stresses, rather than by turbulent viscosity.

Rotating twisted flux tubes buoyancy: comparison between the convective region of the Sun and the edge of a tokamak plasma

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The filament state of magnetic field is the usual way for plasmas to avoid magnetic inhibition of convective overturning. However it requires Dynamo conversion of kinetic into magnetic energy and is therefore often associated with a plasma velocity shear layer.

In the Sun, isolated current carrying magnetic filaments (twisted flux tubes) are produced by the Solar Dynamo from a continuous strong toroidal field, sitting just below the radiative-convective transition, on the Sun rotation shear layer (Tachocline, R_{Tach}~2•$R_{©}$/3 in terms of the solar radius, $R_{©}$). The twisted flux tubes, because of their internally suppressed convective transport, experience a net heating due to non-zero divergence of radiative heat flux at the radiative-convective transition; the mechanical equilibrium (magnetic curvature force vs. rotation) is altered and the filaments become buoyant: the emergence of the rotating magnetic filaments through the solar convection zone is influenced by viscosity, which adds external kink to the their internal twist. Some rotating filaments, after winding dragged by viscosity, in the more rapidly rotating convective zone, fall back into the Tachocline adding up to the continuous toroidal field; some emerge from the photosphere kinked and twisted, reconnect and produce flares.

In the mode of high magnetic confinement (H-mode), when a magnetic separatrix bounds the axisymmetric tokamak discharge and a sheared plasma rotation is present, magnetic filaments with concentrated internal currents (nonergodic twisted flux tubes, ELMs) are produced at integer values of the MHD safety factor (q=4,5,6) near the velocity shear layer (pressure Pedestal, at $\rho_{Ped} \geq 0.94 \bullet a_{Sep}$ in terms of the minor radius of the plasma boundary, a_{Sep}): again a Dynamo conversion of kinetic into magnetic energy is required in order to filament the current density at the Pedestal. The current carrying filaments break the unperturbed axisymmetric tokamak equilibrium, producing ergodicity in the edge plasma that surrounds them. The faster loss of energy from the ergodic plasma makes the nonergodic rotating magnetic filaments outboards buoyant: therefore they convect outboards from the Pedestal, without any further reconnections with the ergodic background plasma.

The buoyancy and motion model for the tokamak case will be compared with the buoyancy and motion model for the Sun.

Vertical angular momentum transport in astrophysical turbulent MHD accretion disks and the formation of large-scale collimated jets

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Accretion is a quite common phenomenon that occurs in many types of systems across the Universe. Under the action of a central object (star, black hole, etc..), the plasma surrounding this object is prone to a rotating motion counteracting the gravity. The resulting disk (called "Keplerian" disk) exhibits an angular momentum distribution such that the plasma angular velocity is $\Omega \propto R^{-3/2}$, where R is the distance to the central object. Simultaneously to the presence of such disk, large-scale twin jets are often observed in these systems. These jets, flowing perpendicularly to the disk, are made of plasma and contain magnetic fields acting to maintain their excellent collimation. Accretion thus requires an anomalous transport of angular momentum coming from plasma turbulence. This turbulence is likely provoked by MHD instabilities occurring in the disk, and the ubiquitous connection observed between accretion and ejection indicates that this turbulence is also at the origin of the jets.

In this talk I will first present observational data that shed light on the mechanisms at work within a magnetized accretion disk launching large-scale magnetized jets. In particular I will show how important is the presence of the magnetic field in the jet in order to explain the marvelous collimation of these cylindrical flows occurring over distances larger than thousands of light-years. MHD models also show that these jets are an important contribution to the removal of the disk angular momentum. However, as I will discuss in this talk, usual MHD simulations showing the role of the magneto-rotational instability (MRI) as the source of the disk turbulence are not yet able to provide near-stationary solutions of fully accreting disks associated with the formation of jets. I will present a family of models where the turbulence is parameterized by the use of turbulent transport coefficients for viscosity and magnetic diffusivity such that these coefficients can be written as $\nu = \alpha C_S H$ where Cs is the local disk sound speed, H is the disk scale height and a a dimensionless parameter. In these models, it is possible to obtain near-stationary solutions where accretion is allowed thanks to a vertical angular momentum transfer from the disk into the jet. The angular momentum carried away by the jet is then used locally to speed-up mass and the twisting of the jet magnetic field due to the disk differential rotation provides a self-collimating mechanism for the jet just as in tokamaks. I will finish my talk by discussing the missing parts of accretion-ejection theory and the remaining issues regarding the description of disk turbulence.

Turbulent Transport and Coherence in MHD

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A topic of fundamental importance in magnetohydrodynamic turbulence is mean induction. In plasma devices such as the RFP this may arise from interactions between small-scale fluid velocity and small-scale magnetic field in the presence of a strong imposed magnetic field. In an astrophysical context the interest is in the means of generating a magnetic field that has a significant component on scales large compared with those of the velocity field. For example, the Sun has a coherent global scale field that is generated, at least in part, by much smaller scale motions.

The concept of mean induction has traditionally been studied within the framework of mean field electrodynamics, a one-point closure model for MHD turbulence. A formal averaging of the magnetic induction equation leads to the new term (in comparison with the unaveraged equation) $\mathscr{E} = \langle \mathbf{u} \times \mathbf{b} \rangle$ — the mean electromotive force arising from correlations between small-scale fluid velocity and small-scale magnetic field. The system is then closed by linking $\mathscr{E}$ to the mean (large-scale) magnetic field $\mathbf{B}_0$ in a formal expansion

$$\mathscr{E}_i = \alpha_{ij} B_{0j} + \beta_{ijk} \frac{\partial B_{0j}}{\partial x_k} + \cdots$$

I shall discuss some of the problems involved in determining and interpreting the leading term in this expression — the so-called α-effect of mean field electrodynamics. Parity considerations show that the symmetric part of the α_{ij} tensor (the part responsible for field regeneration) can be non-zero only in turbulence lacking reflectional symmetry — a feature typically characterised by non-zero helicity. At small values of the magnetic Reynolds number Rm the relation between the α-effect and the helicity of the flow can be made explicit. The more interesting question though concerns the nature of α_{ij} at *high* values of Rm, the astrophysically relevant case.

I shall discuss two recent series of numerical experiments that explore the nature of the α-effect in turbulent flows. The first explores rotating turbulent convection, and highlights the difficulties in obtaining a significant α-effect even in flows possessing considerable helicity. The problem turns out to be not one of *local* induction, but of very weak *average* induction. The second series, motivated by the results from the investigations into convection, considers more idealised, but more controllable flows, in which the influence of spatial correlation on the α-effect can be carefully examined. The issues explored are I believe extremely general ones pertaining to the nature of averaging in highly turbulent flows.

Simulation of dust voids in complex plasmas

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A well-known phenomenon in dusty radio-frequency (RF) discharges under micro-gravity conditions is the generation of a void, a dust free region in the discharge centre. This void is generated by the drag of the positive ions that are pulled out of the discharge by the ambipolar electric field. In the last decade, the theoretical insight into the interaction of the ions with a negatively charged dust particle has reached a level that enables realistic simulations of these complex plasmas. We have used a hydrodynamic model for dusty radio-frequency discharges in argon to study the interaction between the dust and the plasma background. This model is based on expressions for the ion drag force and the dust charge that contain the effects of large-angle scattering, the ion flow speed and ion-neutral collisions [1]. With this model, we studied the plasma inside the void and obtained insight into the way it is sustained by heat generated in the surrounding dust cloud [2].

When this mechanism is suppressed by lowering the RF power, the plasma density inside the void decreases, even below the level where the void collapses, as was recently shown in experiments [3]. Results of simulations of this collapse will be presented. At reduced power levels the collapsed central cloud behaves as an electronegative plasma with corresponding low time-averaged electric fields. In this case the potential well that contains the dust becomes very shallow and the internal pressure of the leads to large and relatively homogeneous Yukawa balls, containing more than 100.000 particles. The generation of a Yukawa ball and the evolution of a void at higher power levels can also be studied from the other side, that is, along a scheme where we start at a low power, inject dust, and increase the power. No hysteresis was observed in this transition.

The creation of large homogeneous Yukawa balls along this scheme possibly opens a route to studies of, for instance, wave propagation and phase transitions in a three dimensional dust structure.

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Dusty Plasmas under Effect of External Forces: Basic Phenomena and Applications

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The dusty plasma is a partly ionized gas with negatively or positively charged (~10^3-10^5e) dust particles of micron size (~ 1-10 μm) that may form quasi-stationary plasma-dust structures similar to a liquid or a solid. In view of this, dusty plasma may be experimentally investigated on a kinetic level with high temporal and spatial resolution. As a result, dusty plasmas are good experimental models for studying the properties of non-ideal systems and for proofing existing empirical models and numerical results.

Investigations were directed on the study of dusty plasma structures and dynamics on kinetic level under action of different external forces (visible and uv radiation, magnetic and thermal fields, electron beam) in glow rf and dc discharges.

Results of experimental study of the dusty plasma kinematic viscosity and the diffusion are presented. A uniform flow of dusty plasma liquid was experimentally realized under laser beam action, and the results of analysis of the obtained data made it possible to estimate the viscosity coefficient of dusty plasma liquid.

The results are given of an experimental investigation of heat transport processes in fluid dusty structures in rf discharge plasmas under different conditions: for discharge in argon, and for discharge in air under an action of electron beam. The analysis of steady-state and unsteady-state heat transfer is used to obtain the coefficients of thermal conductivity and thermal diffusivity.

Experimental investigations of structures of monodisperse dust particles in dc low-pressure glow discharge at temperatures of liquid nitrogen (~ 77 K) and liquid helium (~ 4.2 K) are presented. Structural and dynamic characteristics of the cryogenic dust structures were measured.

The influence of high magnetic field on dusty plasma structures is now of great interest in the field of dusty plasma physics. In the present work the rotation of the dusty clouds and anomalous dust acceleration near the discharge tube wall in strong magnetic field was observed. This work was supported by the Russian Foundation for Basic Research (Grants No.06-02-17532, No. 06-08-01584 and No. 07-02-13600).

When can the Fokker-Planck equation describe anomalous or chaotic particle transport ?

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The Fokker-Planck Equation (FPE) is a basic model for the description of transport processes in several scientific fields. It has been used a lot in plasma physics to model chaotic and/or collisional kinetic effects. Furthermore, FPE backs up the diffusion-convection picture of anomalous transport in magnetized thermonuclear fusion plasmas. Though very popular, the drift-diffusive picture underlying FPE breaks down in some cases. This was shown for electron dynamics due to Langmuir waves [1], for the transport of tracer particles suddenly released in pressure-gradient-driven turbulence [2], and for pollutant transport in fluid dynamics. These facts triggered a series of studies where the Brownian paradigm was abandoned, and transport was described in terms of Lévy jumps, and of fractional diffusion models [3]. This sets the issue: when is FPE relevant for anomalous or chaotic transport, when is it not? This work [4] shows that, for particle transport ruled by chaotic Hamiltonian dynamics, FPE can be justified for generic particle transport provided that there is enough randomness in the Hamiltonian describing the dynamics. Then, except for 1 degree-of-freedom, the two transport coefficients of FPE (diffusion coefficient and dynamic friction) are largely independent. Depending on the kind and amount of averaging performed on it, the same dynamical system may be found diffusive or dominated by its Lévy flights. FPE may work even whenever the dynamics of individual particles exhibit strong trapping motion. Diffusion is justified by locality of trapping in phase-space, or by locality in velocity of particle resonance with fluctuating fields, then leading to a quasilinear estimate. If the system involves a particle source that is narrower than the mean random step of the true dynamics, FPE fails, while the density displays spatial features that are not related to the transport coefficients. If the width of the density distribution is of the order of the system size, there are indications that, even whenever Lévy flights rule the dynamics, FPE becomes a good description. Indeed Lévy flights bring efficiently into the system the information that the matter is lost outside of it.

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Kinetic phase-space turbulence in space and laboratory plasmas

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I will first discuss how the gyrokinetic theory, originally developed for fusion applications, is applicable to astrophysical and space plasma turbulence problems. I will then explain how the familiar "fluid" turbulence ideas such as the energy cascade are generalized for a kinetic turbulence in a weakly collisional plasma. I will introduce the concept of a cascade of generalised energy in a 5D phase space and explain how small-scale structure develops both in the real and velocity space ("the entropy cascade") and how this process is fundamental in the conversion of electromagnetic fluctuation energy into heat. Astrophysical applications are the dissipation range of the solar wind and the heating of minority ion species. I will discuss how theory and measurements of turbulence in space can help us understand the fundamental features of plasma turbulence, also applicable to the microturbulence in fusion devices.

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Star Trek plasma shields: Measurements and modelling of a diamagnetic cavity

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Solar energetic ions are a known hazard to both spacecraft electronics and to astronauts health. Of primary concern is the exposure to keV--MeV protons on manned space flights to the Moon and Mars that extend over long periods of time. Attempts to protect the spacecraft include active shields that are reminiscent of Star Trek “deflector” shields. Here we describe a new experiment to test the shielding concept of a dipole-like magnetic field and plasma, surrounding the spacecraft forming a “mini magnetosphere”. Initial laboratory experiments have been conducted to determine the effectiveness of a magnetized plasma barrier to be able to expel an impacting, low beta, supersonic flowing energetic plasma representing the Solar Wind. Optical and Langmuir probe data of the plasma density, the plasma flow velocity, and the intensity of the dipole field clearly show the creation of a narrow transport barrier region and diamagnetic cavity virtually devoid of energetic plasma particles. This demonstrates the potential viability of being able to create a small “hole” in a Solar Wind plasma, of the order of the ion Larmor orbit width, in which an inhabited spacecraft could reside in relative safety. The experimental results have been quantitatively compared to a 3D particle-in-cell ‘hybrid’ code simulation that uses kinetic ions and fluid electrons, showing good qualitative agreement and excellent quantitative agreement. Together the results demonstrate the pivotal role of particle kinetics in determining generic plasma transport barriers.

Vaccum and plasma QED nonlinearities

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Classically, the vacuum constitutes a trivial nothingness. However, this notion dramatically changed with the marriage of quantum mechanics and special relativity. The natural theory for photon interactions with matter, quantum electrodynamics (QED), indeed shows that the vacuum has certain nontrivial properties [1]. Currently, laser intensities are developing rapidly [2], and systems such as ELI [3] and HiPER [4] is expected to take this development to a new level. Moreover, techniques such as harmonic focusing [5] and plasma induced ultra-short pulse generation [6, 7] could be able, using front-ends such as ELI or HiPER, to produce pulse intensities above the Schwinger limit $\sim 10^{29}\,\mathrm{W/cm^2}$ [8]. In fact, even current technology allows for laser induced pair creation, albeit in combination with accelerator generated electron beams [9]. Previous experiments on the quantum vacuum has used atomic nuclei or accelerator based *high-energy* techniques as a means for testing quantum field theory, and in particular QED. The future development of laser sources will in this sense give completely new tools for testing QED in the *high-intensity* regime. In light of this, new laser-based tests of quantum vacuum phenomena is described. Moreover, many environments in which such high fields are present also contain plasmas. Thus, the alteration of mode propagation and nonlinear dynamics due to quantum vacuum/plasma interactions, such as nonlinear photon splitting (i.e., frequency down-conversion) will be reviewed.

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Phase resolved optical emission spectroscopy: Multi-frequency discharges and atmospheric pressure plasmas

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Despite its technological significance, important aspects of power coupling and ionisation mechanisms in radio-frequency (rf) discharges are not yet fully understood. Of particular interest are multi-frequency discharges and recently developed homogenous non-equilibrium rf discharges at ambient pressure. Insight into the complex plasma dynamics requires close combination of advanced diagnostics and specifically adapted simulations. Phase resolved optical emission spectroscopy (PROES) in combination with numerical computer simulations reveal details of the dynamics on a nanosecond time scale within the rf cycle.

Multi-frequency discharges provide additional process control for technological applications. The electron dynamics exhibits a complex spatio-temporal structure. Excitation and ionisation, and, therefore, plasma sustainment is dominated through directed energetic electrons created through the dynamics of the plasma boundary sheath. Non-linear frequency coupling is observed in plasma boundary sheaths governed by two frequencies simultaneously. The nature of these coupling effects strongly depends on the ratio of the applied voltages. Under technologically relevant conditions (low frequency voltage >> high frequency voltage) interesting phenomena depending on the phase relation of the voltages are observed.

Recently developed rf discharges at ambient pressure bear enormous potential for future technological applications providing high reaction rates without the need of expensive vacuum systems. Fundamental discharge mechanisms are, however, only rudimentarily understood. The atmospheric pressure plasma jet (APPJ) is a homogeneous non-equilibrium discharge. A specially designed rf μ-APPJ provides excellent optical diagnostic access to the discharge volume and the interface to the effluent region. This allows investigations of the discharge dynamics and energy transport mechanisms from the discharge to the effluent. PROES measurements in the discharge volume show a complex combination of different excitation and ionisation mechanisms controlled by the dynamics of the plasma boundary sheaths. Interesting interaction phenomena between the two plasma boundary sheaths are observed.

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Electrical Breakdown: Experiments and Modeling

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Plasma breakdown is a highly transient process that involves particles drifting in electric fields, charge multiplication in electron avalanches and moving ionization fronts. The driving force for these processes is the electric field in the discharge volume. The temporal evolution of the electrical field strength and other parameters have been studied by in-situ diagnostics as well as numerical modeling.

A pulsed discharge between parabolic, metal electrodes in a low pressure argon environment has been studied by light emission imaging with an ICCD camera. This diagnostic provided time- and space-resolved information on the characteristic features of the breakdown process. Different phases in the breakdown process were identified. Firstly, the build-up of a light emission region in the discharge gap in front of the anode, followed by a light front crossing the electrode gap from anode to cathode and finally, a stable discharge, which gradually covers the cathode surface. The experimental results also showed that before the main breakdown process started, a weak flash of light could be observed around the anode. This stratified pre-breakdown light emission occurred during the rise of the applied voltage, but before the breakdown voltage was reached. The origin of this feature was found to be electron avalanches seeded by volume charges left over from previous discharges in combination with the specific discharge geometry used in our experiments.

Additionally, a new diagnostic was developed to measure electric field distributions during the breakdown phase of a discharge. With this diagnostic, electric field strengths were determined by measuring Stark effects in xenon atoms using laser-induced fluorescence-dip spectroscopy. Stark shifts of up to 4.8 cm^{-1} (160 pm) were observed for *ns* and *nd* Rydberg states, with principal quantum numbers ranging from 12 to 18. This corresponds to electric fields between 250 and 4000 V/cm, which were measured with an accuracy of about 50 to 150 V/cm.

For the first time, quantitative, direct measurements of the evolution of electric field during breakdown were obtained. Electric fields between 0 and 1600 V/cm were measured with a resolution of 200–400 V/cm, depending on the magnitude of the electric field. These experiments showed that the ionization front, already observed in the ICCD imaging experiments, is sustained by a spatially narrow, rapidly moving region of strong electric field. Additionally, this ionization front did not completely modify the potential distribution in the discharge gap; the discharge continued developing towards a steady-state after the ionization front crossed the gap.

The discharge was also modeled numerically using a fluid code and a hybrid fluid-particle code. The prebreakdown flash is modeled with the hybrid model. It is caused by the charges that remained in the volume from previous pulses. The model results correctly reproduce the striations in the electron energy and density, which are found to occur due to the specific electric field configuration of the electrodes in the discharge chamber. The crossing of the light front is described with the fluid model. Ionization avalanches that start at the cathode due to secondary electrons cause a space charge that is largest near the anode and starts to affect the electric field there first. This extends the anode potential toward the cathode and is observed as a moving front. The results of both models agree qualitatively with the experimental observations.

Turbulence measurements in fusion plasmas

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Turbulence measurements in magnetically confined toroidal plasmas have a long history, and indeed relevance due to the role of turbulence induced anomalous transport on particle, energy, impurity and momentum confinement. Turbulence - the microscopic random fluctuations in particle density, temperature, potential and magnetic field - is generally driven by gradients or sheared flows. The correlation between the turbulence properties and global confinement, via enhanced diffusion, convection and direct conduction, is now well documented. Theory, together with recent measurements, also indicate that non-linear interactions within the turbulence generate large scale "zonal" flows and geodesic oscillations, which can feed back onto the turbulence and equilibrium profiles creating a complex interdependence. An introduction to turbulence basics will be given, together with an overview of the current status of plasma turbulence measurements in tokamak/stellarator fusion devices highlighting recent developments and outstanding problems. Emphasis will be given to measurement techniques, such as new microwave based diagnostics for density and electric field fluctuations in the closed flux surface confinement region.

Aspects of stochastic transport in laboratory and astrophysical plasmas

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Anomalous transport belongs to the key problems in plasma research and nuclear fusion applications. During the last decades, considerable progress was reported in understanding basic features. Since in general analytical evaluations based on turbulence models are very difficult, numerical simulations become more and more important. Fusion-orientated plasma physics leads to a rich data base with many hints for fundamental transport scaling. Anomalous charged particle transport is also a long-standing problem in astrophysical issues. A variety of observational evidences, such as low-energy cosmic ray penetration into the heliosphere, the transport of galactic cosmic rays in and out of the interstellar magnetic field, the Fermi acceleration mechanism, exist which await full theoretical understanding.

A possible approach to the problem of anomalous plasma transport is to consider the (passive) motion of (test) particles under the influence of given perturbations. Such a treatment is quite common in fluid turbulence where passive motion of scalars, vectors, particles, etc has been investigated extensively. In fusion-orientated plasma physics, there exists an additional, qualitatively important reason to investigate particle motion in given stochastic fields. Perturbations in the magnetic field structure are more or less unavoidable because of errors in the coil arrangements of the devices. In addition, and recently that aspect became very important, additional coils are being installed in tokamaks to control the particle and heat loads on the walls via magnetic stochastization of the edge. The strength of the magnetic field fluctuations may be quite small, e.g. less than one-tenth of a percent of the zeroth-order confining field, for a strong influence on transport. It turns out that perpendicular fluctuations in the magnetic field are effective channels of parallel diffusivity in perpendicular direction.

The proposed talk reviews the present state of art of stochastic transport theory in fluctuating electric and magnetic fields. It dwells on recent developments such as, e.g., non-diffusive motion along tangles, Lagrangian closures, trapping and percolation limit, relativistic particle drifts, generation of radial electric fields, non-Gaussian magnetic field statistics, pitch angle scattering, and control of stochasticity.

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Compatibility of ITER Scenarios with an all-W Wall

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The wall material mix of the present ITER design tries to optimize the use of the armour materials beryllium, carbon and tungsten at appropriate positions. This concept will be tested in the ITER like wall project at JET. But a future reactor cannot rely on low-Z plasma facing components due to the high erosion and - in case of carbon - tritium co-deposition and neutron damage. The tungsten programme at ASDEX Upgrade emphasizes the plasma wall interaction, its implications for the plasma operation and the compatibility of ITER relevant scenarios in an all-metal divertor tokamak, including the characterization of the transition from a carbon to a W machine and the behaviour of different heating methods. Main elements are the extension of the working space of radiatively cooled integrated scenarios (using impurity seeding) and advanced operation modes as the improved H-mode (hybrid scenario) and H-modes with internal transport barriers. Starting with the 2007 campaign all PFCs including the bottom divertor targets are equipped with W coated graphite tiles.

Restarts were successfully performed without boronizations strengthening the credibility of possible operation with a W wall. The ITER baseline H-mode scenario was established over a wide density range with plasma currents up to 1 MA, H_{98P}~1, a radiation fraction of about 60% and ITER compatible moderate W concentrations below $3 \cdot 10^{-5}$ using NBI and central wave heating. The divertor is now the largest W source, but this source plays only a minor role for the tungsten in the core plasma. The removal of all macroscopic carbon sources facing the plasma led to a reduction of the C content to about 4 per mille. Applying ICRH, results in large W influxes due to sputtering from light impurities accelerated by electrical fields at the ICRH antennas. ICRH operation could be optimized using large plasma-structure distances and gas puffing close to the antennas.

High performance improved H-modes over the full ITER relevant parameter regime in ν^*, β_N and n_e/n_{GW} as well as ion-ITBs were extensively investigated in previous campaigns with nearly complete W coverage using boronization to transiently suppress W sources. Applying central ECRF of 2 MW in the all-W machine allowed us to keep the central peaking of the W concentration low, to produce electron-ITBs and to achieve high confinement phases of improved H-modes with $H_{98P} \approx 1.2$-1.3 even without boronization. In improved H-modes the plasma energy was limited to $\beta_N \approx 2$ at the presently reduced heating power.

To elucidate the influence of a high-Z wall on all ITER relevant scenarios, especially the advanced operation modes, and to extend the working space in plasma shaping, density and beta the presently available power supplies for PF coils and heating systems was enhanced by 30 MVA and a new installed 1 MW gyrotron will allow more than 3 MW ECRF. Additionally, after the repeated restart without boronization this tool will be used again to improve the discharge conditions at low collisionality, in particular improved H-mode studies.

Three Dimensional Transport Analysis for ELM Control Experiments in ITER Similar Shape Plasmas at Low Collisionality in DIII-D*

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The mitigation of large type-I edge localized modes (ELMs) is important to maintain long term integrity of the ITER first wall. At the DIII-D tokamak, application of resonant magnetic perturbation (RMP) was pioneered as a tool to control edge transport and thereby the ELM characteristics [T.E. Evans, *et al.*, Nucl. Fusion **48**, 024002 (2008)]. In this contribution we present recent results from experiments in ITER similar shape plasmas with high average triangularity ($\bar{\delta}$ = 0.56) at low ITER similar collisionality ($\nu_e^* \leq 0.2$). Here complete ELM suppression was achieved robustly at an edge safety factor of $q_{95} \sim 3.5$. The resonant window width $\Delta q_{95} \sim 0.1$-0.3 was increased by a factor 2-4 by optimizing the RMP spectrum and increasing the RMP amplitude. In general suppression of ELMs is achieved via a reduction of the pedestal pressure gradient below the stability limit of the peeling ballooning modes, mainly by a decrease in pedestal density while pedestal temperatures slightly increase.

The transport characteristics in the perturbed, three dimensional magnetic field structure are analyzed in a collaborative approach by comparison of experimental and numerical results from TEXTOR-DED and DIII-D. For both devices, modelling of the magnetic topology and transport modelling with the E3D thermal transport code and with the plasma and neutral transport code EMC3-EIRENE were carried out. From this comparative analysis the magnetic topology suggests for DIII-D three radial transport domains for normalized flux Ψ_N: *resonant magnetic island chains* in $0.7 < \Psi_N < 0.85$ and a *highly stochastic volume* closer to the separatrix ($0.85 < \Psi_N < 0.99$) lead to enhanced radial transport. The last step towards the divertor target is governed by parallel transport along *open magnetic field lines* which end in a striated, non-axisymmetric pattern of the perturbed separatrix. They have a connection length $L_c \leq 500$ m of the same order as the thermal correlation length $L_t \simeq 400$ m and small compared to the electron mean free path $\lambda_e \sim 10^3$-10^4 m. From field line tracing it is shown that they penetrate as deep as $0.8 \leq \Psi_N \leq 1.0$ in the perturbed boundary. Therefore large parallel heat conduction and a clear imprint of the striated separatrix in the target heat flux were expected.

At TEXTOR-DED a striation of heat and particle fluxes caused by the helical ergodic divertor separatrix was observed for high $\nu_e^* > 0.9$ [M. Jakubowski, *et al.*, J. Nucl. Mater. **363-365**, 371 (2007)]. In DIII-D these fluxes also show striation during complete ELM suppression at high ν_e^*. However, at low ν_e^* a weak heat transport to the outer lobes of the separatrix and strong parallel particle flux along all lobes of the separatrix are measured. Here, the stochastic domain is not well-connected thermally to the separatrix structure at the target while parallel particle fluxes yield a strong particle loss from the pedestal region. In contrast, large heat and particle flux along the open field lines was detected for low ν_e^* also in strike point splitting of particle and heat flux for (a) interaction of the RMP with ELM filaments and (b) during pellet injection. Such an enhanced radial heat transport – which was originally anticipated to be dominant for transport in a stochastic magnetic boundary – is not apparent during ELM suppression. To explain these counter-intuitive experimental observations two mechanisms are discussed here: a limitation of the parallel heat conduction [M. Tokar, et al., Phys. Rev. Lett. **98**, 095001 (2007)] and a screening of the external RMP field by plasma rotation [A. Cole, et al., Phys. Plasmas **13**, 32503 (2006)].

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Beta Limit in JET

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Advanced tokamak regimes are associated with increased normalised beta, $\beta_N = \beta_t B_t a/I_p$ ($\beta_t = 2\mu_0\langle p\rangle/B_t^2$) and are often limited by MHD instabilities. Although the presence of a conducting wall increases this beta limit, it is important to know the no-wall ideal β-limit to be able to prevent/avoid the most dangerous pressure-driven disruptions in JET and ITER.

Systematic studies of the no-wall beta limit have been carried out on JET, for the first time in tokamaks, by measuring the plasma response to an externally applied helical magnetic perturbation. This Resonant Field Amplification (RFA) is strongly enhanced when a plasma exceeds the ideal no-wall stability limit or an ideal beta-limited determined by other modes, so it can be used as an indication of the beta limit. This method of the beta limit identification has been routinely used in scenario development of high-beta discharges on JET in several advanced regimes: the hybrid low-shear regime with $q(0)$ close to 1, the high-beta low shear regime with less then or $\sim 1 < q(0) < 2.0$ and in a reversed shear ITB regime.

It was shown that increase in q(0) results in significant reduction in the measured beta limit going down to $\beta_{lim}^{RFA} \sim 1.5$ at q(0), or q_{min} in a case of a slightly reversed shear, going down close to 2. Numerical stability simulations based on JET pulses have been performed and confirm this observed trend. It was observed that the measured β-limit has been routinely exceeded on JET by ~ 10%.

Comparison of beta limits in different advanced regimes has been made and shows similar beta limit in hybrid and high-beta no-ITB scenarios for same q(0). However, for the ITB scenario, the q_{min} has been found to be more relevant to characterise the beta limit.

The method developed for β-limit identification will be used to carry out β-limit dependence studies on q and pressure profile in AT scenarios on JET and to optimise plasma parameters in development of high performance regimes.

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Physics issues in the new high current regimes on RFX-mod.

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Remarkable progress has been reported in the recent past by the Reversed Field Pinch community worldwide, with enhanced plasma performances and new contributions to the wider fusion environment in terms of both physics understanding and plasma control. Results of general interest regard themes like MHD active control, current profile control, density limit, fast particles confinement, spontaneous momentum generation, core transport barriers, electrostatic instabilities, edge turbulence, spontaneous transition from magnetic chaos to order, to name some of them. This paper describes in particular the physics issues emerging in RFX-mod where for the first time good quality RFP plasmas with a 1.5 MA current have been obtained. The progress towards higher currents has been permitted by the improvement of the model-based algorithm that drives as an artificial shell the large set of saddle coils tightly wrapping a conducting shell of 50 ms penetration time. Successful phase decoupling and amplitude reduction of the m=1 tearing modes resonating in the core has lead to improved performance, reduced plasma-wall interaction and discharge duration well beyond the wall penetration time with full suppression of the Resistive Wall Modes. At high plasma current and with the improved magnetic boundary the MHD spectrum spontaneously evolves towards the Quasi Single Helicity regime, that is toward a better ordered magnetic topology, favored by the higher Lundquist number. The boundaries of the magnetic island with the dominant helicity are a transport barrier for the electron energy, with temperatures beyond 1 keV at densities of 2.10^{19} m^{-3}. The island boundaries have been studied with the aid of a field line tracing code and investigated at the light of electrostatic turbulence theories. QSH islands generated in induced enhanced confinement events can become remarkably large and represent an interesting possibility for an advanced RFP scenario. The m=0 modes, resonating at the reversal surface, have been studied in particular for their relation with the Greenwald density limit. Where m=0 modes induce an inward excursion of the Last Closed Flux Surface, at high density, locally increased density, enhanced radiation and converging ExB flows are seen, similarly to the MARFE. The thermal instability that develops, expanding towards the plasma core ultimately quenches the discharge, in a non disruptive way. Control of the m=0 activity is speculated to allow the overcome of the density limit.

Integrated modelling of ITER steady-state scenarios

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Steady-state scenarios in ITER combine a high number of challenges, which are not only technical, but mainly conceptual. The simultaneous constraints of vanishing loop voltage and $Q \geq 5$ can only be satisfied for extremely high bootstrap current fractions (significantly higher than 50 %), which, in turn, are more likely to be obtained in the presence of an Internal Transport Barrier (ITB). In ITER, ITBs would be associated to negative magnetic shear rather than to rotation shear, owing to the lack of a powerful torque source. This implies that the control of the current density profile by non-inductive current drive (CD) is essential to sustain ITBs for a long time, but this is notoriously difficult when the bootstrap fraction is the dominant contribution (current alignment problem). Although various scenarios have been considered for steady-state operation on ITER, no steady sustainment of ITB for times of the order of 3000 s, with the amount of additional power expected on ITER, has been documented in simulations so far.

In this work, state-of-the-art integrated simulations with the CRONOS suite of codes [1] are used to study the physics involved in the ITB sustainment, and to identify the main obstacles to the establishment of a steady-state scenario in ITER. These simulations integrate, for the first time, advanced computational modules such as MonteCarlo calculations of the alpha particle distribution function and a 3D Fokker-Planck code for Lower Hybrid CD (LHCD), which proved essential for the correct simulation of this complex non-linear system. Since low rotation levels are expected in ITER, the empirical transport model used only takes into account the anomalous transport reduction due to negative magnetic shear. It is shown that any current driven inside the ITB leads to the progressive shrinking and disappearance of the barrier (current alignment current [2]). This physics property has strong implications on the choice of the current drive sources: for instance, Neutral Beam Current Drive, which is naturally localised in the central part of the plasma, proves to be of little use in these scenarios.

In contrast, a pure Radio Frequency (RF) scenario is proposed using 20 MW of Ion Cyclotron Resonant Heating (ICRH), 20 MW Electron Cyclotron Resonant Heating (ECRH) and 13 MW of LHCD. Within a framework of reasonable assumptions, it is shown that such a power combination provides a solution of principle to the current alignment problem. The main feature of this scenario is that there is a minimum negative magnetic shear, $s=-0.8$, to steadily sustain the ITB for 3000s, below which, low performance inductive scenarios are recovered. The actual design of the ECRH power system in ITER can provide such a negative magnetic shear at $\rho=0.45$ through Electron Cyclotron Current Drive (ECCD), which leads to a clear dependence of the temperature gradient (with a well defined threshold) on the $P_{ECH}/\langle n_e \rangle$ parameter. The threshold obtained for the ECRH power can be characterized as a second order phase transition as it has been done previously in the ITB formation of other completely different fusion devices as, e.g., the Large Helical Device (LHD) [3].

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Radiation Pressure Acceleration by Ultraintense Laser Pulses

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The future applications of the short-duration, multi-MeV ion beams produced in the interaction of high-intensity laser pulses with solid targets will require improvements in the conversion efficiency, peak ion energy, beam monochromaticity, and collimation. Regimes based on Radiation Pressure Acceleration (RPA) might be the dominant at ultrahigh intensities [1] and be most suitable for specific applications. These regimes may be reached already with present-day intensities using circularly polarized pulses [2, 3] thanks to the suppression of fast electron generation, so that RPA dominates over sheath acceleration at any intensity.

We present the results of a comparison of 1D, 2D and 3D PIC simulations for circularly (CP) and linearly polarized (LP) pulses, which evidentiate the different features of ion acceleration and help in deeper understanding of RPA mechanisms. A detailed 1D study of the interaction of the CP laser pulse with thin, solid density targets is performed in order to find the optimal thickness of the target as well as scaling for ion energy and efficiency vs laser and plasma parameters. The 2D and 3D PIC simulations show that the onset of density rippling at the target surface is affected by the pulse polarization. Rippling of the front surface was observed in early simulations of high intensity laser pulse interaction with overdense plasmas [4]. Recently this topic has been revisited for thin plasma foils accelerated in the radiation-pressure-dominated regime [5]. Explanation of the surface rippling have been mostly based on Rayleigh-Taylor like instabilities due to the strong acceleration of the target driven by the radiation pressure. The case of CP is most adequate to test such theoretical description and its scaling with laser and plasma parameters since radiation pressure dominance holds at any intensity. On the other hand, the differences observed between CP and LP suggest that additional effects are at play for linear polarization. These effects might be due to fast electrons or to stimulated surface instabilities.

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One-to-one direct modelling of experiments and astrophysical scenarios: pushing the envelope on kinetic plasma simulations

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There are many astrophysical and laboratory scenarios where kinetic effects play an important role. These range from astrophysical shocks and plasma shell collisions [1], to high intensity laser-plasma interactions, with applications to fast ignition [2] and particle acceleration [3,4]. Further understanding of these scenarios requires detailed numerical modelling, but fully relativist kinetic codes [5] are computationally intensity, and the goal of one-to-one direct modelling of such scenarios and direct comparison with experimental results is still difficult to achieve.

I will discuss the issues involved in performing such numerical experiments, focusing on what needs to be achieved for one-to-one direct modelling. I will also discuss the computational requirements involved, and present the recent developments in the efficiency and algorithms of the simulation tools, pointing out some future directions (e.g. dynamic load balancing, high-order interpolation and boosted frame simulations). Finally, I will present recent simulation work, illustrating these techniques and key results, in both laser wakefield acceleration, and astrophysical shock acceleration.

In collaboration with, M. Fiore, F. Fiuza, J. Martins, S. F. Martins, F. Peano, J. Vieira, L. O. Silva, J. Tonge, F. S. Tsung and W. B. Mori.

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Quantum vacuum effects in strong laser beams

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In view of the increasingly stronger available laser fields it is becoming feasible to use them to probe the nonlinear dielectric properties of vacuum as predicted by quantum electrodynamics (QED) and to test QED in the presence of intense laser beams. We first study the process of light-by-light diffraction mediated by the virtual electron-positron pairs present in vacuum [1]. The typical laser intensity at which these nonlinear vacuum effects are predicted to become apparent is of order of $I_{cr} \sim 10^{29}$ W/cm^2. We investigate a mechanism to enhance vacuum polarization effects (VPEs) at a given laser intensity by exploiting the dielectric properties of a cold plasma [2]. Our results show a large enhancement of VPEs in a plasma with respect to those predicted in pure vacuum when the frequency of the probe field (that in our case is also the field that polarizes the vacuum) approaches the plasma frequency. Moreover, we analyze the process of photon splitting in a laser field as a consequence of the vacuum-mediated interaction between the photon and the laser field. The possibility of the experimental observation of this process is also discussed [3].

The study of the properties of quantum vacuum is closely related to the possibility of testing QED in the presence of strong background fields. We investigate in detail two processes which soon could be in principle feasible experimentally: laser photon merging in laser-proton collisions [4] and laser-assisted bremsstrahlung [5]. In the first case, we show that laser photons merge due to VPEs when interacting with the electromagnetic field of a high-energy proton, manifesting an observable, non-perturbative dependence on the laser field parameters. In the second one, the dramatic influence of the presence of a strong laser beam on the bremsstrahlung process is pointed out.

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CHARGING of AEROSOLS and NUCLEATION IN ATMOSPHERIC PRESSURE ELECTRICAL DISCHARGES

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The goal of this presentation is to highlight potential applications of plasmas produced in Atmospheric Pressure Electrical Discharges (dc corona, streamer and spark filamentary discharges, as well as for ac filamentary and homogeneous Dielectric Barrier Discharges).

At first, respective properties of electrical regimes that can be induced in such discharges are briefly depicted to introduce applications of these atmospheric pressure plasmas in aerosol processes for Materials and Environment (filtration, diagnostics).

Then, the charging mechanisms of submicron sized particles by collection of ions are presented in corona, post-corona and Dielectric Barrier Discharges. In such defined electric field and ion densities profiles, both field and diffusion charging laws are presented to account for the related potential applications of controlled kinematics of charged aerosol (electro-filtration, homogeneous/focussed deposition and coagulation to produce composites).

The last part addresses key parameters controlling both the formation by nucleation and the growth by coagulation of particles in plasmas. Two sources of vapour leading to nucleated nano-particles are depicted in Atmospheric Pressure Electrical Discharges: (i) when dc streamer and spark filamentary discharges as well as ac filamentary Dielectric Barrier Discharges interact with the surface of electrodes or dielectrics, and (ii) when both filamentary and homogeneous Dielectric Barrier Discharges induce reactions with gaseous precursors in volume. In both cases, condensable gaseous species are produced, leading to nano-sized particles by physical and chemical routes of nucleation. It will be shown how composition, size and structure of primary nano-particles as well as the final size of agglomerates are related to plasma parameters (Energy, number per unit surface and time and thermal gradients around each filament as well as the transit time). Once produced, so-formed nano-sized aerosol can either be deposited in the plasma for thin films coatings or kept in suspension to produce fine powders, depending on both charging and electro-thermal collection.

PLASMA SYNTHESIS OF SILICON QUANTUM DOTS FOR PRINTED ELECTRONICS AND PHOTOVOLTAICS

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Plasmas are a unique source of semiconductor nanocrystals. Exothermic surface reactions combined with slow cooling at low pressures selectively heat nanoparticles immersed in plasmas to temperatures exceeding the gas temperature by hundreds of Kelvin. This enables the synthesis of nanocrystals even of high melting point materials. Moreover, the electrical charging of nanocrystals allows for the generation of non-agglomerated nanoparticles, conserving the size-dependent properties of quantum dots.

We have developed a plasma approach for the synthesis [1], electrical doping, and surface functionalization of silicon nanocrystals [2]. Silicon crystals are generated in a continuous flow-through RF-plasma process, and injected into a second capacitively coupled RF-plasma, in which organic molecules are grafted to the hydrogen-terminated nanocrystal surfaces. The so functionalized nanocrystals are readily soluble in organic solvents and form stable silicon nanocrystal colloids or "inks."

This talk will equally focus on a description of the plasma process and a discussion of the materials properties. We will discuss issues of nanoparticle charging and heating in plasmas as well as aspect of dopant incorporation, activation, and location within the nanocrystals. Finally, we will review materials properties of functional semiconductor films prepared from plasma-synthesized and functionalized nanocrystals.

This work was supported by the National Science Foundation under award CMMI-0556163, IGERT grant DGE-0114372, and NIRT grant CBET-0506672. Partial support was provided by the MRSEC Program of the National Science Foundation under Award Number DMR-0212302 and by the Initiative for Renewable Energy and the Environment under grant LG-C5-2005.

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Low temperature plasma synthesis of silicon nanocrystals: the way for high deposition rate and efficient polymorphous and microcrystalline solar cells

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With the spectacular increase in photovoltaic solar energy (~40% annual growth over the last 10 years) and the anticipated increase in the market share of thin films (20% in 2010), new more stringent demands are being placed on thin film deposition technologies, and low temperature plasma processes need to be revisited. Indeed, the standard a-Si:H deposition process based on the production of SiH_X radicals by the dissociation of silane suffers from a low deposition rate. In previous studies we have addressed the synthesis of silicon clusters and nanocrystals which offer a new route for thin film deposition [1]. Here, we focus on plasma diagnostics which provide a clear signature for the presence of nanocrystal formation in the gas phase, as well as the application of this synthesis route to polymorphous and microcrystalline silicon solar cells. We show that superior electronic transport properties are achieved at higher deposition rates, and the device properties reflect this result.

Hydrogenated polymorphous silicon (pm-Si:H) has developed as an alternative to a-Si:H and its application to PIN solar cells has resulted in devices with improved stability [2]. In this presentation we summarize our progress in the understanding of this material, with particular emphasis on its application to PIN solar cells and mini modules deposited at high rates.

It is quite generally accepted that the growth of microcrystalline silicon films involves four phases: incubation, nucleation, growth, and steady state, and that atomic hydrogen is a key element at each stage. As a result, the film structure develops in a columnar fashion with an amorphous interface with the substrate. Moreover, the increase in deposition rate results in a decrease of the crystalline fraction as the competition between growth rate and crystallization rate is in favour of the growth. However, for practical applications one needs µc-Si films with thicknesses in the range of 1-2 microns and thus a high deposition rate is mandatory. The synthesis of silicon nanocrystals in the plasma allows to circumvent this hurdle. Indeed the growth rate of nanocrystals in the plasma can be extremely large (up to 100 nm/s). Thus, the incubation and nucleation phases, difficult to achieve on the substrate, are easily obtained in the plasma and allow an increased deposition rate. We have applied this concept to the deposition of microcrystalline silicon solar cells and have achieved short circuit currents up to 25 mA/cm^2 for 1.5 µm thick solar cells, resulting in efficiencies of 8-9%. Plasma diagnostics during these depositions show low frequency oscillations in the self-bias voltage, which provide a signature for nanocrystal nucleation and growth in the plasma [3].

In summary the increasing demands being placed on solar cell fabrication technology is driving an intensification in the development of low temperature plasma processes able to produce high quality silicon thin films at high rates. Processes employing plasma-synthesized nanocrystals and clusters address this demand in an elegant way, and demonstrate tremendous potential in both deposition rate as well as device quality.

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LABORATORY INVESTIGIONS OF AURORAL CYCLOTRON EMISSION PROCESSES

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Auroral **K**ilometric **R**adiation, **AKR**, occurs naturally in the polar regions of the Earth's magnetosphere where electrons are accelerated by electric fields into the increasing planetary magnetic dipole where conservation of the magnetic moment converts axial to rotational momentum forming a horseshoe distribution in velocity phase space. This distribution is unstable to cyclotron emissions and radiation is emitted in the X-mode. In the laboratory a 75-85kV electron beam of 5-40A was magnetically compressed by a system of solenoids. Results are presented for an electron beam gyrating at cyclotron frequencies of 4.42GHz and 11.7GHz resonating with near cut-off TE_{01} and TE_{03} modes respectively. Measurements of the electron transport demonstrated that the horseshoe distribution function was formed and were analysed to yield the 1D number density as a function of pitch angle. The total power emitted experimentally was ~19-35kW [1] with a maximum emission efficiency of ~2%. These results were compared to those obtained numerically using a 2D PiC code KARAT with a maximum efficiency of 2% predicted for the same mode and frequency, comparable with astrophysical and theoretical results. The experiment is currently being modified by introducing a background plasma to give a better representation of the natural environment.

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Astrophysical Jet Experiments

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Some of the most inspiring images in science are of astronomical objects, and the study of the phenomena responsible for such images has long been of interest. Traditionally, such understanding has come from theoretical models and computational simulations. The current capabilities of pulsed power devices, such as high-intensity lasers and z-pinch facilities, can deliver energy densities comparable to those found in astrophysical objects. This allows us to perform laboratory experiments that, if correctly designed and interpreted, can provide valuable insight into some of the outstanding problems in astrophysics.

An area of considerable progress in this field is the laboratory simulation of astrophysical jets, and in particular those associated with the accretion phase of young stellar objects. The relative proximity of these objects, and their ubiquity, has lead to a large amount of high quality observational data. There remain a number of uncertainties about these systems, for example: how are these jets launched? Why are they so well collimated over such long length scales? To what extent do magnetic fields, radiative losses and the ambient medium affect their dynamics?

This talk will give a brief introduction to young stellar object jets, and outline some of the questions that may be adressed in the laboratory. The focus will be on laser-plasma experiments, in which jets have been created through the collision of two expanding plasmas. These experiments have succeeded in driving high-velocity outflows that are in a regime which suggests scaling to astrophysical systems is possible, and have begun to investigate the effects of an ambient gas on the jet propagation.

Experiments on interstellar cloud evolution following strong shock passage*

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The evolution of interstellar clouds following the passage of a supernova shock is an important astrophysical phenomenon; the shock passage may trigger star formation and the post-shock flow surrounding the clouds will strip them of material, effectively limiting cloud life times. Experiments conducted at the Omega laser attempt to (a) quantify the mass-stripping of a single cloud, and (b) simulate the effects of nearby clouds interacting with each other. A strong shock is driven (using 5 kJ of the 30 kJ Omega laser) into a cylinder filled with low-density foam with embedded 120 m Al spheres simulating interstellar clouds. The density ratio between Al and foam is ~9. Material is continuously being stripped from a cloud at a rate which is inconsistent with laminar models for mass-stripping; the cloud is fully stripped by 80ns-100ns, ten times faster than the laminar model. A new model for turbulent mass-stripping is developed [1,2,3] that agrees with the observed rate and which should scale to astrophysical conditions. Two interacting spherical clouds are observed to turn their upstream sections to face each other, a result that is completely opposite of earlier work [4] on two interacting cylinders. The difference between these two cases is explained by the relative strength of shocks reflected from the clouds.

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LASER-DRIVEN PROTON ACCELERATION: SOURCE OPTIMIZATION AND PERSPECTIVES FOR APPLICATIONS

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Ion acceleration from solid targets irradiated by high-intensity pulses is a burgeoning area of research, and is currently the focus of intense research activity worldwide. Under presently achievable irradiation conditions, the acceleration is driven by relativistic electrons, which acquire energy directly from the laser pulse and set up extremely large (~TV/m) space charge fields at the target interfaces. The properties of laser-driven ion beams (high brightness and laminarity, high-energy cut-off, ultrashort burst duration) are, under several respects, markedly different from those of "conventional" accelerator beams. In view of these properties, laser-driven ion beams have the potential to be employed in a number of innovative applications in the scientific, technological and medical areas.

We will review here some of the most recent results of research in this area by our group and collaborators, and we will discuss prospects for further developments and applications.

Important results in some applicative areas have been obtained already with currently available beam characteristics (e.g. broadband spectrum and ~ 50 MeV cut-off energy). In particular the use of these beams as a particle probe for the detection of electric fields in plasmas has led in recent years to a wealth of novel information regarding the ultrafast plasma dynamics following high intensity laser-matter interactions. We will discuss some of the most recent results obtained with this technique, applied to the diagnosis of transient self-generated electric and magnetic field during high-power laser-plasma interactions.

Other applications (including the possible use of laser-driven protons for cancer radiotherapy) will require optimized performance compared to characteristics currently available, in terms of particle numbers, energy, spectral content or beam divergence. Some recent experimental studies aimed to characterize and optimize the beam properties and to better gauge perspectives in these areas will be reported. Laser facilities currently becoming available or being planned will open up over the next few years previously inaccessible interaction regimes. This, coupled to ongoing developments in targetry and laser beam control, will lead to the possible implementation of novel ion acceleration schemes, highly promising for the delivery of optimised beams for applications.

HALL EFFECT THRUSTERS FOR SATELLITE PROPULSION

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Hall Effect Thrusters (HETs) are a class of gridless ion sources that can generate thrust from 10's to 100's of mN, with specific impulse in the 2000 s range (i.e. exhaust velocity of the propellant on the order of 20 km/s). They are well suited for tasks such as satellite station keeping and are also considered for interplanetary missions. For these missions, where a relatively small thrust is needed for a very long period of time, their large specific impulse makes them much more efficient than chemical thrusters and allows important cost reduction.

After a general introduction on space propulsion, the lecture will be centred on the principles and the physics of Hall Effects Thrusters. We will focus on basic physics questions related to electron and ion transport in a HET. HETs use an EXB configuration, where an external magnetic field perpendicular to the applied electric field and discharge current increases the residence time of electrons in the thruster and allows ionization of the xenon neutral flow. The gridless ion acceleration is provided by the electric field resulting from the drop of electron conductivity associated with this EXB configuration. Most of the neutral flow is ionized and the neutral gas density in the exhaust region of the thruster is not large enough to allow sufficient electron transport across the magnetic field and to explain experimental measurements.

The physics of electron transport in HETs is still an open question although important progress have been made in the last ten years. We will describe the recent efforts[1] toward the understanding of charged particle transport in HETs, and present a synthesis of the combined results of Particle-In-Cell models, hybrid models, Laser Induced Fluorescence measurements and Collective Scattering experiments. One possible explanation of the observed anomalous electron transport is the generation of an azimuthal drift instability that has been predicted by PIC models. Experimental efforts are aimed at confirming the anomalous turbulent transport predicted by the kinetic models.

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SPONTANEOUS ROTATION IN ALCATOR C-MOD PLASMAS

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Spontaneous toroidal rotation, self-generated in the absence of external momentum input, exhibits a rich phenomenology. In L-mode plasmas, the rotation varies in a complicated fashion with electron density, magnetic configuration and plasma current, and is predominantly in the counter-current direction. The rotation depends very sensitively on the balance between upper and lower null, and plays a crucial role in the H-mode power threshold [1]. Rotation inversion between the counter- and co-current direction has been observed following small changes in the electron density and plasma current, with very distinct thresholds [2,1]. In stark contrast, the intrinsic rotation in H-mode plasmas has a relatively simple parameter dependence, with the rotation velocity proportional to the plasma stored energy [3], and is always directed co-current. A comparison of spontaneous rotation in H-mode plasmas from many devices leads to a relatively simple scaling, with the observed thermal Mach number proportion to the normalized pressure [4]. This scaling obtains over a wide range of operational parameter space, and for H-modes produced by many different techniques (ICRF heating, Ohmic heating, ECH, ECH with LHH), indicating a universality of the phenomenon. Extrapolation to ITER plasmas suggests RWMs may be suppressed without external momentum input. In plasmas with internal transport barriers, formed either with off-axis ICRF heating or LHCD, the rotation velocity inside of the ITB foot is found to be in the counter-current direction.

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Innovative Diagnostics for ITER Physics addressed in JET

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The JET scientific mid-term programme, whose main pillars are the installation of a completely new first wall (made of Beryllium and Tungsten) and a significant increase in the additional heating power, is aimed at controlling plasmas of performance closer to the next step device, ITER. Extending the operational space towards more reactor relevant parameters requires further understanding of various physical phenomena including a) the dynamics of low temperature plasmas close to the containment wall b) the effects of turbulence, at the macroscopic and meso-scale level, on the transport of energy, particles and momentum in the plasma internal region c) the burning plasma aspects linked to the interplay between collective instabilities and energetic particles generated by the fusion reactions. Obtaining the necessary experimental information on these issues poses significant challenges for the measurement systems. Therefore, during the last couple of years, about thirty new or improved diagnostics were installed and a similar number will be finalised during next campaigns, providing JET with state of the art instruments, covering all the main measuring techniques used in physics, from interferometry to scattering, from spectroscopy to tomography, from radar to thermography.

The boundary region of fusion plasmas is particularly difficult to study because of the often non-linear mutual influences between plasma physics effects, atomic processes and material properties. With regard to <u>the interactions of the plasma with the surrounding material surfaces</u>, significant improvements in JET infrared systems and magnetic diagnostics have allowed, for the first time, a careful evaluation of the power losses caused by the most harmful global instabilities, which can even cause the premature termination of the discharge and structural damage to the machine. Innovative detectors and techniques, from Quartz microbalances to visible and infrared spectroscopy, have provided new information on processes typical of low temperature plasmas, like erosion, re-deposition and material migration. They have also contributed to elucidate the main physical and chemical aspects of these phenomena.

Plasma properties at <u>the edge</u> have to be determined with high accuracy and resolution mainly in order to control the performance and the transient thermal loads on the wall. The gradients of the electron fluid have been resolved for the first time with spatial resolution of about 1.5 cm using the new High Resolution Thomson Scattering; the ion temperature can be measured with a spatial resolution of a few centimetres from upgraded active spectroscopy. The effects of the changes in the magnetic topology (toroidal field ripple, ergodization etc) on the plasma transport have been quantified. A high time resolution bolometric tomography has been systematically used to characterise the total radiation pattern during fast instabilities and the radiation peaking factor during disruptions. Advanced modelling, integrating atomic physics and impurity transport, is essential for stabilising low temperature plasmas at the limit of detachment, a particular plasma state close to the target tiles where the pressure is not longer constant along the magnetic field lines. A new fast visible camera has confirmed the presence in JET edge plasmas of various structures like filaments and blobs. This diagnostic is expected not only to shed light on the macroscopic instabilities at the edge but also to provide information about meso-scale phenomena and turbulence.

In the plasma core, the <u>energy, particle and momentum confinement</u> is crucially determined by the non-linear saturation level of the turbulence and its effects on transport. In order to understand the impact of these phenomena on the global machine performance, the main plasma parameters have been measured with higher spatial and time resolution using upgraded active spectroscopy, Thomson scattering and microwave diagnostics. Recently particular attention has been devoted to the transport of momentum, the accumulation of light impurities and their dependence from the current profile and the strength of the transport barriers. Advances in the atomic physics of high Z species, mainly tungsten, have been promoted to determine their behaviour in all the various regions of JET plasmas (from edge to core). Neutron diagnostics, with their spectrometric and imaging capability, are essential for burning plasma studies and to accommodate the future changes to the environment (mainly Be tiles).

A multi year upgrade programme has been devoted to the detection of <u>energetic particles</u>. For the first time energetic ions can be measured at JET during their whole life time. In particular their interplay with collective Magneto-Hydro-Dynamic instabilities, which can significantly increase their losses, has been investigated with a new scintillator probe and a set of Faraday cups. To understand their thermalisation process, several advances in detection techniques and atomic physics, of relevance also for various atmospheric physics studies, have proved to be necessary.

In addition to a discussion of the various measuring techniques prospects for ITER, the relevance of the implemented diagnostic upgrades for other scientific communities, from low temperature plasmas to astrophysics and inertial fusion, will also be addressed.

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Fast-Ignition Target Design and Experimental Concept Validation on OMEGA

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The OMEGA EP Laser Facility [1] will be completed in Spring 2008, adjacent to the 60-beam, 30-kJ, OMEGA Laser Facility [2] at the University of Rochester's Laboratory for Laser Energetics. OMEGA EP consists of four beamlines with a NIF-like architecture [3]. Each of the beams will ultimately produce 6.5 kJ in 10-ns pulses directed into the OMEGA EP target chamber. Two of the beamlines can operate as high-energy petawatt (HEPW) lasers, with up to 2.6 kJ each at a 10-ps pulse duration. The HEPW beams can be injected into either the OMEGA EP chamber or combined collinearly into the existing OMEGA target chamber for integrated fast-ignitor experiments. A comprehensive scientific program is being pursued to explore the physics of fast ignition for both channeling and cone-in-shell approaches. Multidimensional hydrodynamic simulations integrated with a hybrid PIC code are used to optimize ignition designs and to prepare for integrated experiments using OMEGA/OMEGA EP. Fuel-assembly experiments on OMEGA explore the options to achieve high-fuel-areal densities and the effects of a cone on the fuel assembly. Experiments on short-pulse laser systems investigate the conversion efficiency from laser energy to fast electrons, the transport of the electrons, and the energy deposition in plasma.

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Overview of PETAL, the multi-Petawatt project on the LIL facility

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PETAL (PETawatt Aquitaine Laser), this projected up-graded LIL [(1)] (LMJ prototype), will offer a unique combination of one of the highest intensity beams, synchronized nanosecond LIL beams. The primary system requirement is the addition of one short-pulse (500 fs to 10 ps) ultra-high-power, high-energy beam (3.5 kJ compressed energy) to the LIL facility motivated by specific needs, such as:

- as a first step for the HiPER[(2)] project, to carry out fast ignition related experiments, providing fundamental information on fusion plasma physics and demonstration of the required laser and optics technology.
- to widen the field of research in High Energy Density Physics, particle production and acceleration and nuclear physics that can be done on this facility, among other possibilities providing a short pulse, high-energy backlighting capability that also allows the development of backlighting techniques.

We will present the conceptual design of PETAL, the experimental realization of the front-end with OPCPA [(3)], the compression [(4)] stage and the longitudinal chromatism corrector [(5)].

This work is being performed under the auspices of the *Conseil Régional d'Aquitaine* and the technical supports of the *Institut Lasers et Plasmas*.

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Present Status of Pinch Plasmas for EUV and Soft X-ray Radiation

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Discharge plasmas are well known as intense emitter oft soft x-ray and extreme ultraviolet radiation with wavelengths ranging from 1 nm to 50 nm (XUV). The basic mechanism of generating the characteristic short wavelength radiation by heating and compressing a plasma to temperatures of several tens to several hundreds of electron volts and densities of 10^{18} -10^{19} cm^{-3} has been intensively investigated for several decades. However, mainly driven by the activities in extreme ultraviolet lithography aiming at a compact and powerful source at a wavelength of 13.5 nm these sources have experienced a remarkable progress over the last ten years with respect to technological aspects. These are operating at several tens of kilowatts electrical input power with related challenges in cooling of the electrode system, repetition rates up to 10 kilohertz and more, debris and lifetime. These technological problems have in turn triggered basic studies in different areas, since the systems have to be pushed to their respective theoretical limits, which also have to be explored. The current status of source development for EUV lithography at different places will be presented with focus on the Philips's vacuum arc as the most advanced technology. Strategies and state of the art of the system lifetime, radiation and input power levels as well as integration into the optical system will be addressed. Taking into account that small source for power levels much lower than required for EUV lithography are already commercially available this technology envisions a new generation of small and cost effective XUV sources. So they might be the appropriate light source for many applications of analysis and patterning on the nanometer scale required in future disciplines of semiconductor industry, life- and material sciences. Scaling of the EUV source technology to ever smaller wavelengths will be presented using the example of a radiation source in the water window spectral range at 2.88 nm to be used in x-ray microscopy.

IN-SITU DUST DETECTION IN FUSION DEVICES

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It is expected that during the discharge most of the dust particles concentrate in the scrape-off layer (SOL) close to the chamber wall. Currently established diagnostics for monitoring the dust during the discharge are visible imaging and laser light scattering. The first can yield velocity of the dust particles provided particles are bigger than a few μm and their velocities are below 1 km/s. The scattering gives an insight on the amount of submicron dust though the interpretation of the scattered signals might be complicated as it depends on the optical properties of the dust grains and can require modelling of the laser-dust nonlinear interaction.

The dust-impact ionization phenomenon can be used for detection of particles with velocities above few km/s. Impact events can be registered by electrostatic probes, by analysis of the surfaces where the events took place and by light emission associated with the impact ionization. Particularly valuable for such diagnostic could be targets of aerogel – light porous material which allows capturing of fast particles without destroying them, hence providing information on their velocity distribution, size and composition. Preliminary outgasing tests demonstrated that pure silica aerogels are compatible with tokamak plasma conditions in SOL.

Other diagnostics include the microbalance technique which permits measurements of the cumulative weight of the collected dust and electrostatic dust detectors counting impinging dust particles.

Recently the possible use of changes in the collective scattering cross-section due to the presence of dust (provided that the dust number density is sufficiently high) was proposed for diagnostic purposes.

The Dynamic Similarity Between Polygonal Satellite Vortices and Electron Columns in a Malberg-Penning Trap

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When employed judiciously, classical analogy is a sensible method of scientific inquiry. Two systems, that may not necessarily resemble physically each other, are considered to be analogous, if both are described by the same set of evolutionary equations. For instance, the stability of point vortices arranged in a ring has its foundation in the similarity among point vortices and the gravitating *N*-body problem, whereby the vortex strength is replaced by the mass. Furthermore, the Two-Dimensional (2-D) Drift-Poisson equations describing strongly magnetized electron columns and those of 2-D Eulerian fluid motion are dual. In this paper we revisit the dynamics of polygonal vortex core formations, generated under shallow water conditions inside a cylinder by a revolving disk. The observed fluid vortex patterning is isomorphic to pure electron plasma diocotron waves generated in Malmberg-Penning Traps. The present work adds on the description of the event via targeted experiments using the image processing technique. We show the interfacial axial symmetry not to break spontaneously but through spectral development, and the functional relationship amongst the polygon rotation and the disk speed to be surprisingly simple. The route to turbulence first begins by spectral development distinguished by an increase of the number of satellite vortices (up to six) orbiting the parent vortex. Due to resonance inside the bulk flow, the last stage is succeeded by an amplification of dynamical noise that destroys the sharp spectral peaks and eventually gives rise to fully blown turbulence. Power spectrum analysis reveals that harmonic waves modulate the fundamental patterns. At the end of the state, a solitary wave revolving at approximately the frequency of the next equilibrium appears. This system can also be viewed as vortices rotating with a solitary vortex (solitron) encircling the pattern. As the solitron gyrates, about the *N* pattern, makes each consecutive ridge to appear momentarily fatter. As the *N+1* state is reached the wave locks-in at a frequency of 1/3 thus producing the extra apex required to form the next equilibrium pattern. A large distortion of the pattern precedes the birth of the new one.

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Studies of blob formation, propagation and transport mechanisms in basic experimental plasmas (TORPEX and CSDX)

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Plasma blobs are ubiquitous in the tokamak edge and responsible for the majority of transport across the Scrape-Off Layer (SOL). Their generation and propagation mechanisms have been widely studied theoretically, but limited experimental information is available to validate these models. Here, results from basic experiments are presented, in which plasma blobs are studied with much better access and control than possible in tokamaks, using both conditional-averaging and new pattern-recognition analysis techniques.

On the basic toroidal device TORPEX, the blob formation mechanism is found to be related to the breaking of an interchange-driven wave. Blobs form when wave crests extend into regions where they completely dominate the background plasma parameters. The self-generated electric shear is found responsible for the detachment of blobs. Theoretical models of blob propagation are tested by investigating the statistical relation between blob speeds and dimensions. Direct measurements of the blob-induced transport reveal that blobs constitute the dominant cross-field particle and heat transport mechanism across the TORPEX SOL region. Their effect on toroidal momentum transport is investigated using correlated Mach probe measurements.

On the linear device CSDX, radial bursts are observed to emerge from a coherent m=1 mode. The conditions under which these bursts form detached blobs are investigated using combined fast-camera and probe measurements. In the absence of an interchange driving force, blobs lose their initial radial momentum quickly and stagnate in the SOL region. During bursts, the azimuthal rotation of the plasma column is slowed down significantly, indicating the conservation of angular momentum when the plasma's moment of inertia increases.

The magnetopause is really a transport barrier like in tokamaks

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Internal transport barriers (ITB) are indispensable for reaching high-confinement modes in tokamaks. An ITB is set up by introducing a shear in the magnetic field or the $\mathbf{E}\times\mathbf{B}$ rotation velocity. This shear stabilises plasma turbulence and prevents particles and energy from escaping the plasma core, thus improving confinement. The most characteristic feature of an ITB is the appearance of strong gradients near the plasma edge. In this lecture, we will show that the magnetopause, the boundary between the shocked solar wind and the Earth's magnetospheric plasma, is a transport barrier in its own right. Strong density gradients, magnetic field and velocity shear, as well as stabilisation of turbulence, can all be observed at the magnetopause.

Recently, we investigated the interaction between broadband drift mode turbulence and zonal flows near the edge of a region of magnetised plasma [1, 2]. Our simulation results showed the development of a zonal flow through the modulational instability of the drift wave distribution, as well as the existence of solitary zonal flow structures about an ion gyro-radius wide, drifting towards steeper relative density gradients. Both the growth rate of the turbulence and the particle/energy transport across the plasma boundary can be stabilised by adjusting the plasma density gradient. This spontaneous formation of of solitary wave structures has also been found in Cluster satellite observations [3], confirming our earlier theoretical predictions. We will discuss the consequences of our results for our understanding of the Earth's magnetopause, as well as for the study of Edge Localised Modes in tokamaks.

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Expansion of nanoplasmas in ultraintense laser-matter interactions

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The expansion dynamics of nanometer-sized plasmas is a relevant physical problem for applications such as the laser-induced production of nuclear particles in jets of clusters or nanodroplets [1,2], or the imaging of biological samples with ultraintense x-ray pulses [3]. These scenarios involve the prompt formation and expansion of dense nanoplasmas [1], with cold ions and hot electrons. Depending on the physical conditions, the electrons are heated by the laser, driving the hydrodynamic-like expansion of electron-ion plasmas, or swept off the single clusters, causing the Coulomb Explosion (CE) of pure ion plasmas.

The transition from the hydrodynamic-like regime to the CE regime is investigated with a novel ergodic model, which provides a self-consistent, kinetic description of the collisionless expansion of spherical plasmas driven by hot electrons: simple relationships are deduced for the key expansion features, valid for a wide range of initial conditions [4], and a threshold electron energy marking the transition to CE-like ion energy spectra is identified.

A technique to control the expansion regime by acting on the amount of energy delivered to the electrons is described, wherein suitable sequences of intense radiation pulses are used to tailor the phase-space dynamics of the ions [5], inducing the formation of large-scale shock-shell structures [6], capable of driving intracluster nuclear reactions. A new solution to the pure CE problem is also illustrated, which involves the simultaneous overtaking of all the ions initially contained in a given 3D volume (dimensional collapse), and the corresponding formation of a density singularity containing a finite amount of charge [7].

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Fast ignition: original concept and new developments*

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Over the last decade many scientists around the world have studied Fast Ignition, an alternate form of inertial fusion. In this scheme, the fuel is first compressed by a long pulse driver and then ignited by the short pulse laser. Due to technological advances, external energy sources (such as short pulse lasers) can produce focused power density equivalent to that produced by the hydrodynamic stagnation of conventional inertial fusion capsules. This review will discuss the ignition requirements and gain curves starting from simple models and then describing how these are modified as more detailed physics understanding is included. The critical design issues revolve around two questions: How can the compressed fuel be efficiently assembled? And how can power from the driver be delivered to the ignition region? Schemes to shorten the distance between the critical surface and the ignition region will be discussed. The status of the project is compared with our requirements for success. Recent approaches to point designs that integrate all of the relevant physics will also be discussed.

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Lightning-related transient luminous events at high altitude in the Earth's atmosphere

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Transient luminous events (Fig. 1) are large-scale electrical discharges occurring at high altitude in the Earth's atmosphere, which are directly related to the electrical activity in underlying thunderstorms. Several different types of transient luminous events have been documented and classified. These include relatively slow-moving fountains of blue light, known as 'blue jets', that emanate from the top of thunderclouds up to an altitude of 40 km; 'sprites' that develop at the base of the ionosphere and move rapidly downwards at speeds up to 10,000 km/s; 'elves', which are lightning induced flashes that can spread over 300 km laterally, and upward moving 'gigantic jets', which establish a direct path of electrical contact between thundercloud tops and the lower ionosphere. The goal of this talk is to provide an overview of the history of discovery of different types of transient luminous events, and some of the recent modeling efforts directed on interpretation of observed features of these events. We will discuss a physical mechanism proposed for explanation of sprites, which is build on original ideas advanced many decades ago by the Nobel Prize winner C. T. R. Wilson. We will also discuss similarity properties of electrical discharges as a function of gas pressure in the context of a selected set of results from the recent laboratory and modeling studies of streamers, which are directly applicable for understanding of recent high spatial and temporal resolution imagery of sprites revealing many internal filamentary features with transverse spatial scales ranging from tens to a few hundreds of meters.

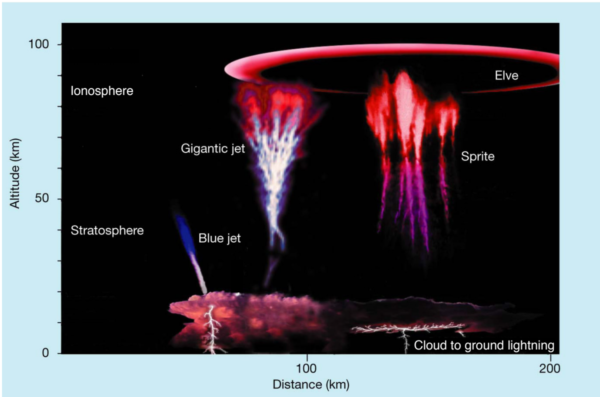

Figure 1: Lightning related transient luminous events. Reprinted from [1] by permission from Nature.

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The response of tokamak plasmas to 3D magnetic field perturbations*

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The loss of axisymmetry in tokamak plasma has wide-ranging implications for plasma performance in both present experiments and ITER burning plasmas. An important new tool for understanding 3D magnetic field effects in tokamaks is the Ideal Perturbed Equilibrium Code (IPEC) [1], which can treat ideal plasma response effects including poloidal mode coupling, plasma amplification, and flux-surface displacement. IPEC has been used for optimizing Resonant Magnetic Perturbation (RMP) coil designs for ELM suppression in ITER, and all the above plasma response effects are found to be important. IPEC RMP optimizations minimize resonant perturbations in the plasma core which could excite locked modes, and also minimize plasma flow-damping in the core and edge. IPEC results indicate that coils above, below, and possibly at, the midplane are required to achieve simultaneous minimization of core island excitation and flow damping. Another key question is how much rotation is required to shield low-n (in particular n=1) error fields (EF) that would otherwise excite magnetic islands potentially leading to disruption. IPEC calculations show that poloidal mode coupling effects are needed to explain EF correction results on DIII-D and NSTX [2], and recent NSTX results indicate that local magnetic shear at the q=2 surface is an important parameter determining the n=1 locked mode threshold scaling. The inclusion of plasma response effects can significantly reduce the predicted locking threshold for ITER, but the predicted threshold is estimated to be a factor of two above ITER's minimum correction capability. RMP coils in ITER might also provide additional EF correction capability. Finally, beyond IPEC results, NSTX has discovered that n > 1 EFs can be just as important as n=1 EFs at high β_N. Correction of n > 1 intrinsic EFs is not commonly considered in existing tokamaks or ITER, and without such correction in NSTX, some discharges are prone to rotation decay and n=1 Resistive Wall Mode (RWM) growth and plasma disruption. For these discharges, surfaces with q > 2 are apparently most important for providing RWM stabilization, a result that is providing new insight into the stabilization physics of the RWM.

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Plasma performance and confinement in the TJ-II stellarator with lithium-coated walls

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As it is well known, proper selection of the plasma facing components is one important tool for the control of plasma parameters and confinement. The effect is typically ascribed to the associated changes in recycling, radiated power and impurity penetration, all of them having direct impact in the plasma parameters critically governing particle and energy confinement. In the last experimental campaign, the TJ-II stellarator, which has been operated under boronized first wall condition until now, has been coated with lithium by vacuum evaporation. This has led to important changes in plasma performance. Particularly conspicuous has been the change in recycling associated to the new wall conditions, but also impurity content, with direct impact on radiative losses and total energy confinement is modified by the type of coating, as expected in a first-wall dominated plasma-wall interaction device. Changes in the shot by shot fuelling characteristics as well as in the total particle inventory compatible with good density control and plasma reproducibility under ECRH scenarios have been recorded after the Li deposition. Thus, a rise by a factor of 4 in the fuelling rate at constant density compared with the B-coated walls was recorded, and even a higher factor was estimated for the allowed H inventory at the walls. These changes were also mirrored in the radiation and edge radial profiles, with increased electron temperatures. The replacement of dominant impurity at the edge also led to the extension of the effective density limit in NBI heating scenarios. This limit, formerly ascribed to the development of a radiation instability at the edge, seems to be due to a global energy balance mismatch under the new wall conditions, opening the way to heating upgrading for high beta operation in TJ-II. Transport analysis with Proctr code to fit the different impurity profiles and the changes in the effective electron heat diffusivity is ongoing. The radiation radial profiles, which are basic for understanding the local power balance, are obtained considering four impurity species (Li, C, B, O) and using the local corona equilibrium. At densities above 3.10^{13} cm^{-3}, higher plasma energy contents were measured under Li-coated wall conditions as compared with boronized conditions under the same heating scheme, and the effect of such scheme (ON-OFF axis ECRH launching, OH induction, etc) on absolute Wdia values has also been addressed.

Of special relevance in the confinement properties of TJ-II plasmas is the spontaneous development of radial electric fields at the edge at a critical density, concomitant to the transition to the enhanced global particle confinement (EPC) mode. The apparent lack of such a transition under Li walls, easing the way to density control by external puffing, has been analyzed trough the associated development of a velocity shear layer at the edge, as measured by Langmuir probes, and changes in plasma potential by the HIBP diagnostic, and results in this line will be also presented.

Global Plasma Oscillations in ITBs

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In the Tokamak à Configuration Variable (TCV; R/a = 0.88 m/ 0.25 m, BT < 1.54 T), global plasma oscillations have been discovered in fully non-inductively driven plasmas featuring Electron Internal Transport Barriers (eITBs) with strong Electron Cyclotron Resonance Heating and Current Drive (ECRH/ECCD). They are linked to the destabilisation and stabilisation of MHD modes near the foot of the internal transport barrier and can lead to large oscillations of the total plasma current and line-averaged density for example. These regimes are similar to the so-called O-regime first observed on Tore Supra [1], but are actually of much more general nature. Indeed they are intrinsically linked to the fact that ITBs have large pressure gradients in a region of low magnetic shear. Therefore the ideal MHD limit is relatively low and infernal modes can be unstable. When these ideal infernal modes are destabilised, minor or major disruptions can be observed. However depending on the proximity to the ideal limit, small crashes or resistive modes can appear which affect the time evolution of the discharge. They reduce the improved confinement, which lowers the pressure and thereby decreases the bootstrap current density. Since bootstrap fraction is large, the total plasma current is also affected. Being near marginal stability, the modes can self-stabilise due to their modification of the pressure gradient and local q profile. The plasma recovers good confinement, reverse shear and the build up of the internal transport barrier, until a new MHD mode is destabilized.

TCV has shown that this cycling behaviour can be controlled by modifying the current or the pressure profiles, either with Ohmic current density perturbation or by modifying the ECH/ECCD power. It has also been shown that either resistive type modes or ideal type crashes can lead to similar oscillations observed on the plasma current time evolution. These are consistent with the fact that near an ideal limit, resistive modes can also be unstable due to the pole in Δ'. Therefore we can see that many observations like q = 2 sawteeth, beta collapse and minor disruption in ITBs, oscillation regimes, periodic relaxation regimes can be assigned to the same physics origin: the proximity to the infernal mode stability limit [2].

This result is important since it is inherent to any steady-state type scenario. Indeed, the latter needs ITB, large bootstrap fraction and no inductive current contribution [2]. These lead to reverse shear q profiles and therefore large pressure gradient near q_{min}. These scenarios are only weakly controlled by external actuators, since most of the current profile is sustained by the bootstrap current. 'It was also shown that a small perturbation to an existing electron internal transport barrier by power modulation triggered an oscillation regime, which continued after the power modulation was stopped. As steady-state burning plasmas might also incur small perturbations, it is very likely that such oscillations will occur; which may be very damaging. This detailed study will show the relation between oscillations and MHD modes and how the scenarios can be controlled and modified with current density tailoring or with a modification of the pressure profile.

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Access to H-mode on JET and implications for ITER

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One of the critical issues for ITER is access to an H-mode regime with good confinement, H_{98} = 1. Studies of the transition from L-mode to H-mode (the L-H transition) have been carried out for many years on a wide range of different sized devices such as, JET, JET-60U, DIII-D, ASDEX, Alcator C-MOD, MAST and NSTX. Experiments across the world have contributed data on H-mode access to an international threshold database (13 tokamaks) managed by the International Tokamak Physics Activity (ITPA) Confinement Database and Modeling (CDM) Topical Group, from which several scalings for the power threshold for the L-H transition, P_{th}, have been derived. The most basic scaling laws for P_{th} take in account the variation with plasma density, magnetic field and plasma size. However, the large variation in P_{th} data from the values estimated with such simple scaling laws indicate other underlying dependencies. Another important consideration is that P_{th} corresponds to the power required to enter the H-mode, but not necessarily the power needed to obtain an H-mode with good confinement. H-modes with higher values of energy confinement are often only achieved with input power values much greater than P_{th}.

This paper will present results from recent studies on JET to assess possible hidden variables for H-mode access over a wide range of plasma conditions. These experiments have also benefited from recent improvements to the spatial and temporal edge plasma diagnostics on JET, providing a unique opportunity to improve our understanding of the physics of H-mode transitions. A key result from this work is the significant variation in the plasma density dependence of P_{th} with divertor X-point and strike-point configuration, ranging from $n_e^{1.26}$ to $n_e^{0.12}$. Sensitivity to the divertor geometry could account for some of the scatter in the international threshold P_{th} database. Hysteresis in the L-H transition P_{th} has also been studied on JET by comparing values of P_{th} at the forward and back H-mode transitions over a range of densities. No evidence of hysteresis in the H-mode power threshold is observed for the two different magnetic configurations considered. The impact of edge plasma rotation on H-mode access has also been studied on JET with a Toroidal Field ripple scan of the L-H transition and ELM phase access. Despite a large change in edge toroidal rotation velocity no significant variation in P_{th} was measured, however the subsequent access to high confinement H-mode is clearly altered. Finally, results from experimental studies of the total input power, P_{in}, requirements relative to measured values of P_{th} will also be shown for a highly shaped magnetic configuration. The data show that $P_{in}=1.5P_{th}$ is necessary on JET for the Type-III to Type-I ELM transition. The implications of all these results for the attainment of H-mode with good confinement on ITER will be discussed in terms of present-day scaling laws and ongoing studies.

**See appendix of ML Watkins et al.,2006 Proc. 21st IAEA Fusion Energy Conference (Chengdu, China 2006).*

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MAGNETIZED PLASMA ERUPTIONS IN THE SOLAR ATMOSPHERE

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Abstract:

Magnetized plasma is emerging continually from the solar interior into its atmosphere. Magnetic flux emergence events and their consequences at different levels in the solar atmosphere are being observed with high space, time and spectral resolution by a large number of space missions in operation at present (e.g. SOHO, Hinode, Stereo, Rhessi), sent by different international space agencies (ESA, NASA, ISAS). The collision of an emerging and a preexisting magnetic flux system in the solar atmosphere leads to the formation of current sheets and to field line reconnection. Reconnection under solar coronal conditions is an energetic event; the reconnecting outflows lead to launching of high-speed (hundreds of 1000 km/s), high-temperature (order 10 million K) plasma jets, which are conspicuous features in the observations with the X-Ray and EUV detectors currently in orbit. Further, the spectacular increase in computational power in recent years thanks to the new supercomputer installations permits to carry out three-dimensional numerical experiments of the time evolution of magnetic flux emerging systems that include magnetofluid and radiative transfer aspects in large computational grids.

In this lecture, the state-of-the-art in this field of research will be reviewed. Observations of X-Ray jets in the solar corona by the satellite missions Hinode and Stereo will be presented. The focus of the lecture will be on the theoretical understanding of these processes. An important computational effort is being done by teams in different countries to model and understand the physics of flux emergence events and its related phenomena. Recent advances obtained through the interplay of theory, numerical simulation and direct observation will be presented.

Recent progress in understanding the behavior of dust in fusion devices

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It is known that micro-particles (dust) exist in fusion devices. Some of them, seen with cameras and for a long time known as "UFOs" (e.g. see Ref. 1), travel through hot fusion plasma on rather large distance and may contribute to the contamination of core plasma with impurities. Amount of such UFOs significantly increases during abnormal events (e.g. large ELM, disruption). Yet, an impact of dust on plasma contamination, material migration, and performance of fusion devices is still under debate (e.g. see Ref. 2-4 and the references therein). Meanwhile, ITER-scale plasma experiments bring another dimension to the dust's story: dust can pose safety problems related to it's chemical activity, toxicity, tritium retention, and radioactive content [5]. In order to address these safety and performance issues we need to understand the physics of dust generation, dynamics, and transport. However, the physics of dust is very complex and multifaceted. Here, the results of recent theoretical and experimental studies of dust in fusion plasmas are reviewed. We consider the latest experimental observations of dust dynamics in fusion plasmas with fast cameras, dust statistics obtained with Thomson scattering systems, the results of analysis of dust collected from the walls of fusion devices, and dust generation mechanisms. We also discuss different aspects of the physics of dust motion in fusion plasmas including dust-plasma, and dust-surface interactions. We consider the physics of dust charging, heating, destruction, spinning, forces acting on dust, dust collision with material walls, etc. The numerical models of these processes have been incorporated into the dust transport code DUSTT, which is capable of tracking of dust particles in 3D geometry (needed plasma parameters can be taken either from edge plasma codes or from experiments). The results of the simulations of dust particle dynamics, transport, and the impact on edge plasma performance will be discussed.

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Technology and science of steady state operation in magnetically confined plasmas

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The steady-state operation of magnetically confined fusion plasmas is considered as one of the “grand challenges” of the future decades, if not the ultimate goal of the research and development activities towards a new source of energy. Reaching such a goal requires the high-level integration of both the science and technology aspects of magnetic fusion into self-consistent plasma regime(s) in the relevant devices.

On the physics side, the first constraint addresses the magnetic confinement itself which must be made persistent. This means either rely on intrinsically steady-state configurations, like stellarator one, or turn the inductively driven tokamak configuration into a fully non inductive one, through a mix of additional current sources. The low efficiency of the external current drive methods and the necessity to minimize the re-circulating power claim for a current mix strongly weighted by the internal “pressure driven” bootstrap current, itself strongly sensitive to the heat and particle transport properties of the plasma. A virtuous circle then forms as the heat and particle transport properties are themselves sensitive to the current profile conditions. Note that several other players, e.g. plasma rotation profile, magneto-hydro-dynamics activity, …, also influence the equilibrium state. In the present tokamak devices, several examples of such “advanced tokamak” physics research demonstrate the feasibility of such steady-state regimes, though with a number of open questions still under investigation. The modelling activity also develops very fast in this domain and supports understanding and extrapolation.

This high-level of physics sophistication of the plasma scenario then needs to be combined with steady-state technological constraints. The technology constraints for steady-state operation are basically twofold: the specific technologies required to achieve the steady-state plasma conditions and the generic technologies linked to the long pulse operation of a fusion device. The first ones include specific additional heating and current drive methods (through externally launched waves or fast particles), fuelling and pumping methods, dedicated plasma diagnostics as well as software and middleware technologies used to create the mandatory real time control loops, involving such actuators and sensors. The second class of technologies, generic to any magnetic fusion device, include the superconducting magnet technologies, in order to provide stationary confinement magnetic field, the actively cooled plasma facing components handling either radiated or convected power fluxes (often in excess of several tens of MW/m^2), dedicated diagnostics monitoring the interfaces (like infrared survey of plasma facing components), … The detailed specifications of such elements must comply with reactor relevant parameters, in terms of operational parameters as well as life time.

The paper presents an overall picture of the present status and understanding of the technology and science of the steady state operation in magnetically confined plasmas, as well as the forthcoming work programme dedicated to the vast R&D programme undertaken in this domain, in particular within the European fusion framework.

Magnetic Collimation of Fast Electrons using Structured Targets

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The propagation of beams of multi-MeV fast electrons with current densities of the order of 10^{16}Am^{-2} through solid targets irradiated by ultra-intense ($> 10^{18}$Wcm^{-2}) lasers is a subject of great interest to many in the ultra-intense laser-plasma community. The collimation or divergence of the fast electron beam, and how this might be controlled, is particularly important for Fast Ignition Inertial Confinement Fusion, x-ray production from solid targets, heating solid targets, and ion acceleration from the rear surface of the target.

Our recent work has focussed on a target engineering approach to controlling collimation (the "structured collimator") [1]. The basic idea is to use a fibre which surrounded by less resistive material. Since one expects that the electric field required to draw a return current is determined by $\mathbf{E} = -h\mathbf{j_{fast}}$, there is a gradient in the electric field at the interface between the two materials. The curl of the electric field is in the correct sense to generate a collimating B-field. Furthermore, simple estimates (using a 'rigid beam' model) indicate that the magnetic field should grow fast enough to be able to bend divergent fast electrons back towards the target axis. When this concept is investigated using 2D hybrid Vlasov-Fokker-Planck codes, it is indeed found that strong collimation occurs.

The theory and simulation studies on this concept will be discussed, and different geometries will be considered and compared to initial experimental studies validating the concept.

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ELECTRON TRANSPORT IN IMPLODED FAST IGNITION TARGETS

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Fast ignition involves transport of GA currents of laser-driven electrons through dense coronal plasma of imploded fusion targets [1, 2]. Recently, we have reported integrated simulations of target ignition by fast electrons by means of a hybrid approach that allowed us to investigate important transport features such as current filamentation and magnetic beam collimation simultaneously with ignition physics [3, 4]. In those simulations, we assumed that the electron kinetic energies are given by the ponderomotive scaling and considered an initial divergence half-angle of 22.5º, consistent with the experiments reported in Ref. [1]. We found minimum ignition energies from 25 to 30 kJ, depending on the distance from the cone tip to the compressed core. Assuming a laser-to-fast electron conversion efficiency of 40%, those energies correspond to laser beam energies from 60 to 75 kJ, of the same order than those envisioned for HiPER [5].

Recent experiments carried out at RAL [6] at laser intensities relevant to fast ignition have evidenced an enhancement of the beam divergence with the laser intensity and electron kinetic energies lower than those predicted by the ponderomotive scaling [7]. We have re-computed the ignition energies of fast electron beams taking into account those experimental results. We have taken divergence angles consistent with the experiments of Ref. [6] and mean energies of fast electrons from 1 to 2 MeV. In addition, we have accounted for the scattering of electrons with the cone tip, typically a gold layer of tens of microns, which may induce a beam divergence comparable with those measured in the experiments. In this talk, we will present a parametric study on fast electron energy deposition and actual ignition of an imploded target configuration for different mean kinetic energies and divergences of the relativistic electrons.

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New Phenomena in Liquid Complex Plasmas

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Rheology of strongly coupled complex (dusty) plasmas is remarkably diversified and often reveal essential features peculiar to regular complex fluids. We will present a few highlights from recent dedicated experiments where rheology of complex plasmas was investigated under different conditions.

In ground-based experiments with the PK 4 dc discharge setup the flow curves (shear stress vs. shear rate) were measured [1]. Shear flow of microparticles was induced either by inhomogeneous flow of neutral gas, or by using the laser forces. Combination of the two methods allowed us to investigate the entire range of shear rates up to the limit where discreteness enters and complex plasmas cannot be formally considered as a continuous medium. Analysis of experiments suggests that liquid complex plasmas exhibit strong non-Newtonian behavior, which can be accompanied by significant shear thinning (more than an order of magnitude).

Another series of experiments was performed with PK 3 Plus rf discharge setup under microgravity conditions onboard ISS, where "electrorheological plasmas" were discovered [2]. In contrast to conventional electrorheological fluids where the dipoles (induced by external electric fields) are due to polarization of microparticles themselves, in complex plasmas the primary role is played by clouds of compensating plasma charges (mostly, excessive ions) surrounding negatively charged grains. This discovery adds a new dimension to the research of strongly coupled particle systems – in terms of time/space scales and for studying new phenomena.

Also, we briefly discuss a novel and quite general type of the shear flow instability [3] that can occur in complex fluids with density-dependent viscosity. We show that this instability can be easily triggered in shear flow experiments with complex plasmas, and also can explain shear-induced cavitation observed in numerous experiments with regular complex fluids.

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Monolayer complex plasma experiments

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A complex (dusty) plasma is a suspension of charged solid particles in a plasma. Typical particle size ranges from tens of nanometers to tens of microns. The particles are either grown *in-situ* or introduced into a plasma of a radio-frequency (rf) or direct current (dc) gas discharge. Usually particles acquire a large negative charge, because they collect more electrons than ions from plasma. Due to the mutual interaction of particles and their confinement by electric fields present in plasma they self-organize in an ordered structure that is called a plasma crystal. In the presence of gravity, a monolayer plasma crystal can be formed. In this two-dimensional (2D) crystal, particles interact through a screened Coulomb (Yukawa) potential and self-organize in a triangular lattice with hexagonal symmetry. A typical interparticle separation is of the order of 0.1-1 mm, characteristic frequencies are of the order of 10-100 s^{-1}, and the speed of sound is of the order of 10 mm/s. In addition, the particle motion is not overdamped. Therefore, the fully resolved dynamics of a 2D plasma crystal can be studied using direct video imaging. This makes 2D plasma crystals an excellent model system to study phase transitions, transport phenomena, and linear and nonlinear waves, all at the kinetic level.

Recently, dislocation nucleation and dynamics were observed in a 2D plasma crystal [1]. Edge dislocations were created in pairs in the lattice locations where the shear stress exceeded a threshold. The shear stress was presumably introduced due to the differential rotation of the lattice with two “rigid” domain walls imbedded in it. After nucleation, dislocations moved apart in the glide plane at a speed of approximately twice the sound speed of shear waves and created shear-wave Mach cones.

Observing dislocation nucleation and dynamics at the level of individual “atoms” and in real time allows us to reveal new details of these complex multi-stage processes. We also discuss laser manipulation as an alternative method of creating dislocations in a plasma crystal in a controllable way.

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LABORATORY MODELING OF SUPERSONIC RADIATIVE JETS PROPAGATION IN PLASMAS AND THEIR SCALING TO ASTROPHYSICAL CONDITIONS

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Laboratory studies can address issues relevant to astrophysics [1] and in some cases improve our understanding of the physical processes that occur in astrophysical objects. The issues related to the jet propagation and collimation over considerable distance and their interactions with surrounding media have begun to be addressed these last years. Laboratory plasmas and astrophysical objects have different length, time and density scales. However, the typical velocities are the same, of a few hundred km/s and the similarity criteria [2] can be applied to scale the laboratory jets to astrophysical conditions. Moreover, by choosing appropriate pairs of colliding plasmas, one can fulfil the scaling conditions for the radiation emission rates.

In this presentation, we use a method of jet formation [3], which allows launching a very fast jet having a velocity ~ 400 km/s and the Mach number ~ 10 by using a relatively small laser energy ~ 100 J. The interaction of these jets with a gas puff has been recently studied in an experiment carried out at the PALS laser facility. Varying gas pressure and composition, we show that the nature of interaction zone changes from a quasi adiabatic outflow to a strongly radiatively cooling jet. The fine scale structures of the interaction zone are studied by means of optical and x-ray diagnostics, and they are interpreted with a semi-analytical model and 2D radiation hydrodynamic simulations.

The conclusions from the laboratory experiment are rescaled to the astrophysical conditions.

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High-Mach Number Collisionless Shock and Photo-ionized Non-LTE Plasmas for Laboratory Astrophysics with Intense Lasers

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Large scale laser facilities mainly constructed for fusion research can be used to produce high-energy-density plasmas like the interior of stars and planets. They can be also used to reproduce the extreme phenomena of explosion and high Mach number flow in mimic scale in laboratory. With advanced diagnostic technique, we can study the physics of plasma phenomena expected to appear in Universe. The subjects studied so far are reviewed, for example, in [1], [2].

The project to promote the laboratory astrophysics with Gekko XII laser facility at Osaka was initiated from April 1, 2007 as a project of ILE institute. It consists of four sub-projects:

1. Physics of collisionless shock and particle acceleration,
2. Physics of Non LTE (local thermodynamic equilibrium) photo-ionized plasma,
3. Physics of planets and meteor impact,
4. Development of superconducting Terahertz device.

Regarding the first sub-project, we have carried out hydrodynamic and PIC simulation to design the experiments with intense laser. We clarified the physical mechanism of generation of the magnetic field in non-magnetized plasma and the collsionless shock formation caused by the ion orbit modifications by the magnetic fields generated as the result of plasma instability, Weibel instability. Detail simulations have been carried out to see the physics of the generation of magnetic fields.

The Weibel instability which is founded in 1959 in plasma physics region is found to be the main reason for the field generation. It has been studied in laser plasma society in 1970-now in relation to ablation instability to fast ignition. It was common in Astrophysics that in order to explain the collisionless shock, for example, of supernova remnants an external week magnetic fields are essential, because of the resemblance with the bow shock on the earth driven by the solar wind. The detail of this physics is reported by Dr. T. Kato in case of electron-positron plasma[3] and such usual plasma[4]. In the first sub-project, we aim at the experimental measurement of the generation of the Weibel instability and related plasma dynamics. The experiment of this subject has been carried out as joint experiment with UK and France.

The second topics is researched as joint experiment with China. By use of the X-ray radiation generated inside the gold cavity in irradiating intense laser, we can generate the photo-ionization dominant plasma. Two experiments have been done at Osaka and Shanghai. The experimental data has been analyzed with non-LTE atomic code newly developed. We found that the nitrogen plasma spectrum heated by 80 eV Planckian radiation is highly ionized, while the free electron temperature reached only to 20 eV[5]. We will report the physical mechanism and give notice that this spectrum can also reproduced with assumption of LTE with 60 eV.

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