ANNUAL REPORT 2012-2013

TÉCNICO LISBOA

ipfn
INSTITUTO DE PLASMAS E FUSÃO NUCLEAR

CONTENTS

DIRECTOR´S FOREWORDS

I am very pleased to bring you the Highlights of 2012-2013 of the Instituto de Plasmas e Fusão Nuclear and of the Association Euratom-IST. This report covers the activities carried out in the scope of Association Euratom/IST, the Contract of Associated Laboratory, the European Fusion Development Agreement (EFDA), the Contracts with the ITER International Organization (ITER IO) and the European Joint Undertaking for ITER and Fusion Energy (F4E), Projects of the general 7th Framework Programme of the European Union, Projects of the European Space Agency (ESA) and Projects funded by Fundação para a Ciência e a Tecnologia.

IPFN accomplished a remarkable number of milestones and achievements:

- Conclusion of contracts with Fusion for Energy on remote handling and of the contract with ITER International Organization for the development of the ITER prototype Fast Plant system Controller;
- Start of the contract for provision of engineering support on instrumentation control and the signature of the Framework Partnership Agreement for the development of ITER Plasma Position Reflectometry and Collective Thomson Scattering;
- Strong participation in the European Fusion Programme: among other activities, it is worth noting the contribution to JET scientific exploitation (at a level of 6% of the participating researchers during campaigns), on JET operation (several IST researchers work full time at JET providing support to operation and diagnostics) and on JET management, and the contribution to medium-size tokamaks, in particular Asdex-Upgrade, which have been an integral part of the activities;
- Access to external large scale research infrastructures, namely, the approval of two experiments at the Stanford Linear Accelerator Center in the scope of LCLS and FACET, more than 45 million cpu hours of supercomputing time on SUperMUC (Munich, Germany), and an experiment on double stage plasma electron acceleration at the Astra Gemini laser facility (Rutherford Appleton Laboratory, UK);
- Strong progresses on the synthesis of graphene and other carbon nanostructures, the pretreatment of biomass, the production of hydrogen by the decomposition of alcohols, and the production of active species of interest for biomedical applications, using microwave generated plasmas;
- Conclusion of the construction works of the building for the new laboratory infrastructure, the European Shock Tube for High Enthalpy Re-

search (ESTHER) – this world-class research infrastructure, funded by ESA, will enable the participation in high-level research on plasma re-entry effects as well as further synergies between IPFN research groups, namely on control and data acquisition, diagnostics development, and material characterization, benefitting from the recently created Group of Materials.

These projects fostered innovation, created qualified employment and potentiated the creation of teams able to attract additional funding and innovation through R&D activities. The excellence of the research performed at IPFN has been recognized through several awards won by our researchers and through a high number of publications in prestigious journals.

High Level Education and Outreach activities are essential in this strategy. IPFN continues actively striving towards attracting the best MSc and PhD students. The Advanced Programme on Plasma Science and Engineering (APPLAuSE) awarded to IPFN in 2013 will be crucial to achieve this goal. Furthermore, we know that new blood is fundamental to the research unit's success and we continue motivating new generations to science through courses on Lasers and Nuclear Fusion for secondary school teachers, seminars at high schools and regular visits to IPFN laboratories.

2013 has also been the end of a cycle with the end of the contract of Association-Euratom-IST (to be replaced by the consortium EUROfusion from 2014 onwards). The integration into the activities of the Fusion Roadmap and of the Framework Programme Horizon2020 will require strategic thinking and adaptation. The challenges ahead are enormous! I am nevertheless certain that it is an endeavour that IPFN researchers will endure and succeed.

Participation on large-scale projects is made through long-term commitment and funding support. On behalf of IPFN, I would like to acknowledge the support of EURATOM, EFDA, FCT (through project Pest-OE/SADG/LA0010/2013), and IST, for having made such commitments possible.

Science is also made through collaborations. I would like to thank all our partners who have contributed to our projects, or those who lead projects to which IPFN contributes with results.

A few words of acknowledgement to Prof. Carlos Varandas are mandatory. He was the president of IPFN until May 2012 and remained as the Head of the Research Unit for the Contract of Association Euratom-IST. His vision, support and advice were and continue to be a key for the success of IPFN.

Last but not least, on behalf of the IPFN Administrative Board I would like to thank our staff for the work performed and the excellent results achieved throughout the years of 2012 and 2013. I am absolutely confident that, together, we will successfully face the challenges that Horizon2020 brings and continue in the path of excellence!

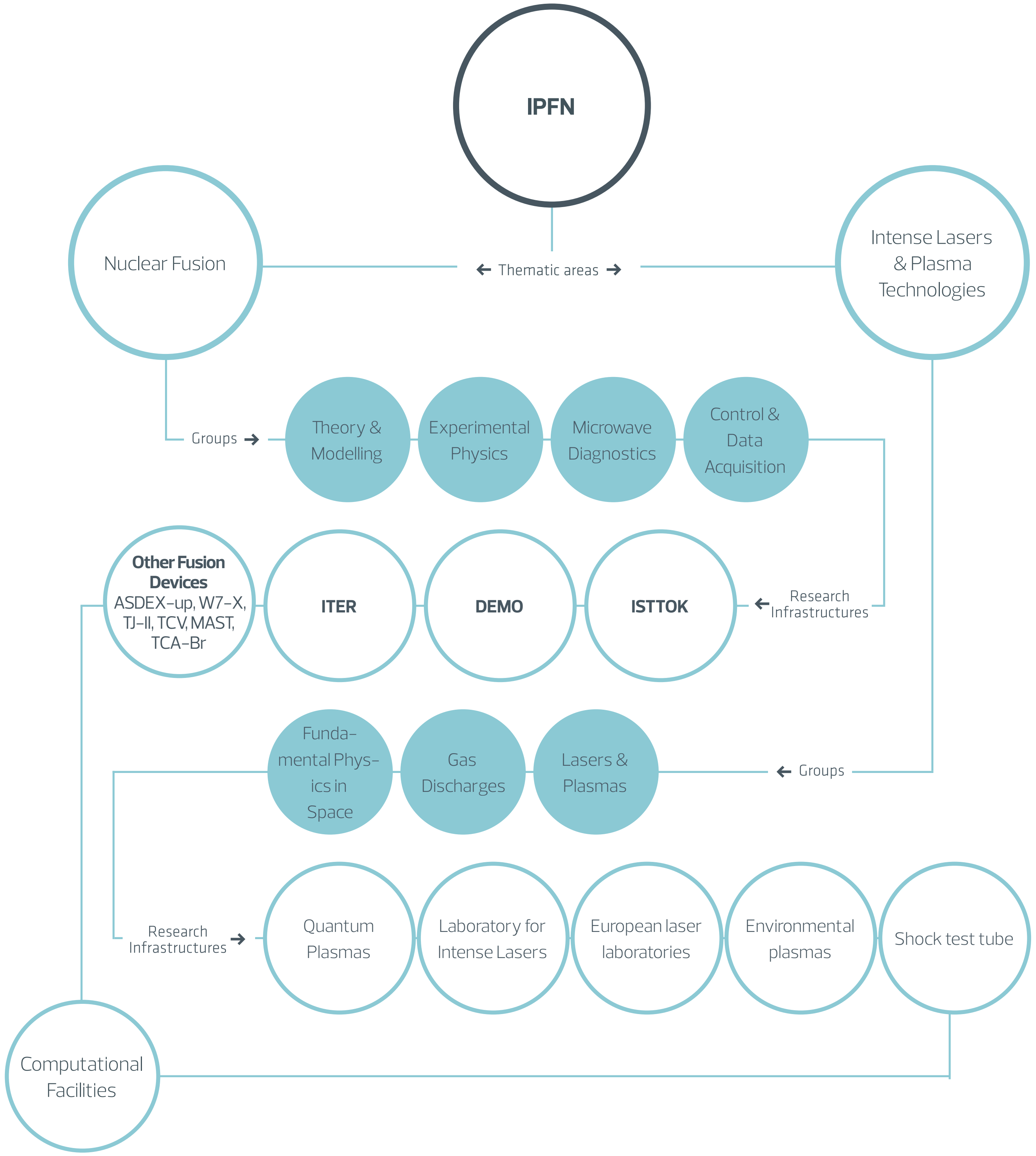
Bruno Soares Gonçalves
President of IPFN

ABOUT IPFN

Instituto de Plasmas e Fusão Nuclear (IPFN, Institute for Plasmas and Nuclear Fusion) is a research unit of Instituto Superior Técnico (IST) with the status of Associated Laboratory granted by Fundação para a Ciência e a Tecnologia. IPFN is also the research unit of the Contract of Association Euratom/IST, which frames the Portuguese participation in the Euratom Fusion Programme.

The main aim of this Programmes the development of a commercial reactor based on nuclear fusion reactions. The roadmap towards a fusion reactor is focused on three devices: JET, its successor ITER and a demonstration reactor called DEMO. While JET represents a pure scientific experiment, the reactor scale experiment ITER is designed to deliver ten times the power it consumes. The next foreseen device, DEMO, is expected to be the first fusion plant to reliably provide electricity to the grid.

The Research Line on Intense Lasers and Plasma Technologies takes advantage of the critical mass of the groups within it to address frontier questions in gas electronics, sources of particles and radiating species, ultra-short, ultra-intense lasers and their applications, plasma accelerators and advanced radiation sources, ultra cold plasmas, and fundamental science in space.



KEY INDICATORS

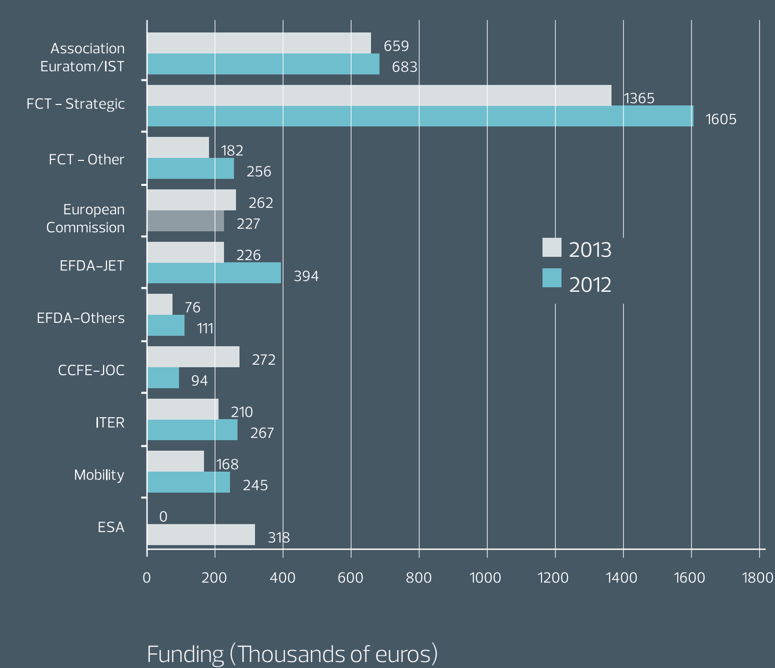
IPFN HAD A TOTAL OF **159** PEOPLE AT THE END OF 2013.

STAFF / GROUPS

- (17) Theory and Modeling
- (39) Experimental Physics
- (39) Engineering and Systems Integration
- (19) Materials Processing and Characterization
- (31) Lasers and Plasmas
- (25) Gas Discharges and Gaseous Electronics
- (5) Space Physics

STAFF WITH A **PHD DEGREE** INCREASED FROM **81 IN 2012** TO **93 IN 2013.**

FUNDING PER SOURCE



NUMBER OF PUBLISHED PAPERS: **119** (1.47/PHD) **IN 2012, 154** (1.66/PHD) **IN 2013**

NUCLEAR FUSION

Fusion is the process at the core of stars, such as our sun, that produces amazing quantities of energy.

It occurs when light atoms such as hydrogen become so hot that they fuse into new elements, releasing large amounts of energy.

The most efficient fusion reaction reproducible in the laboratory is that between two hydrogen (H) isotopes, deuterium (D) and tritium (T), which produces the highest energy gain at the 'lowest' temperatures.

Fusion ingredients are abundant on earth, and no greenhouse gases or long-lived nuclear waste are created by fusion.

One way to achieve a controlled fusion reaction is inside a device called a tokamak, where magnetic fields are used to contain and control the hot plasma.

Once harnessed, fusion power will be a nearly unlimited, safe and climate friendly energy source.

The fusion programme of the european atomic energy community (euratom) aims at the development of models, design, operation and scientific exploitation of experimental facilities which may allow the construction of fusion power plants capable of producing electric energy.

PLASMA TECHNOLOGIES AND LASERS

The plasma state is commonly called "the fourth state of matter". It is generated when energy is provided to a solid, liquid or gas such that a fraction of its atoms are ionised.

The plasma state is the most abundant state of visible matter in the universe, comprising the stars and the interstellar space. On Earth, we are used to natural plasmas, in the form of lightning and flames; and artificial plasmas such as plasma TV displays and fluorescent lamps.

Plasmas come in an amazing variety of parameters, making plasma science a fascinating subject, both at the fundamental and application levels.

Plasma-based technologies are used today in a variety of fields spanning from microelectronics and materials processing to waste treatment and environmental control, biotechnology and health care.

Laser-produced plasmas are test beds for extreme regimes of nature, where electrons can oscillate at relativistic velocities – and, for instance, become accelerated to GeV energies in a few millimeters, thanks to the overwhelming electric fields associated to electron plasma waves.

Research at IPFN in plasma technologies and intense lasers is dedicated to investigating a multitude of topics in these areas, encompassing theory, simulation and experimental research, in a strongly international environment, and in the frame of several important collaborations with world-leading institutions.

> "THE MOST EFFICIENT FUSION REACTION REPRODUCIBLE IN THE LABORATORY IS THAT BETWEEN TWO HYDROGEN ISOTOPES: DEUTERIUM AND TRITIUM"

ENGINEERING & SYSTEMS INTEGRATION

Head: Bruno Gonçalves

The Group of Engineering and Systems Integration results of merging two previous groups (Microwave Diagnostics and Control & Data Acquisition) and from integrating the Remote Handling (RH) activities previously carried out by the Group of Experimental Physics. The integration of all engineering activities enables answering in a focused, timely, effective and qualified manner to F4E and ITER calls and other contract opportunities for RD&I activities developed by the EU fusion program. The main activities of the GESI include the development of diagnostics for study of nuclear fusion plasmas, bespoke and state-of-art Control and Data Acquisition systems for nuclear fusion and large-scale physics experiments, studies+ of Remote Handling in nuclear fusion environments, microwave high-frequency components to be used in nuclear fusion experiments, and computer codes to simulate diagnostic performance.

www.ipfn.ist.utl.pt/engineering

Participation in ITER construction

ITER Fast Plant system Controller

IPFN lead the consortium with CIEMAT and UPM (Spain) to develop innovative solutions for ITER prototype Fast Plant System Controller. The 2-year, 1.5 M€ contract contributed to the ITER Plant Control Design Handbook effort of standardization on fast controllers and resulted in about 20 publications in peer-reviewed journals. IPFN also provided F4E with consulting regarding CODAC through a 0.5 M€ contract with F4E (lead by INDRA) for Provision of System & Instrumentation Engineering support.

ITER Plasma Position Reflectometer

The consortium lead by IPFN, with CIEMAT (Spain) and IFP-CNR (Italy), was awarded an 8.5 M€ grant for development of the Plasma Position Reflectometer for ITER. The contract covers R&D, including prototypes of transmissions lines and MW electronics, engineering, quality support and managerial activities, testing from functional specifications up to supply of an approved final design and support for production of manufacturing drawings for all components of the system, as well as the final design for electronics components and for data acquisition and real-time software. The contract acknowledges a long tradition of development in this domain by IPFN and the successful demonstration on AUG of plasma position feedback control via reflectometry. In fact, the related paper reached the Top 10 papers of 2012 on Nuclear Fusion, a collection that celebrates the most influential research published in the journal during the previous 12 months.

F4E design and performance assessment of Integral and Proportional Data Acquisition Electronics for Real-Time Applications

The Control and Data Acquisition group won an ITER-related contract for the design and performance assessment of Integral and Proportional Data Acquisition Electronics for Real-Time Applications. This small contract with Fusion for Energy opens the possibility to work on the data acquisition systems for ITER magnetics diagnostics, representing more than 900 sensors in the whole device.

ITER remote handling activities

IPFN lead two F4E grants in consortium, together with CIEMAT/ASTRIUM and ASTRIUM, for feasibility and logistic studies for the nominal operations of the Cask Transfer System (CTS) in the ITER buildings (Tokamak and Hot Cell). Results were crucial to proceed with the construction of ITER Tokamak building. Application software was developed and tested for optimization and path following of the CTS trajectories inside the buildings. These remote handling tasks were an opportunity for more than 15 of publications and collaborations with several European groups. IP protection for the engine implementing the steering and motion capabilities of a single wheel is currently under evaluation.

Participation in the European Fusion Programme

Development programme in microwave diagnostics in view of ITER and DEMO

- Ultrafast swept generators for JET profile reflectometers and correlation reflectometer
- High speed frequency synthesizer for hopping systems and hybrid reflectometers for TJ-II and COMPASS
- Novel front-end for FM-CW reflectometry diagnostic at AUG compatible with ECRH radiation allowing plasma position measurements
- Automatic procedure to validate position for the feedback controller in ELMy regimes
- Assessment studies on the use of MW diagnostics for DEMO and W7X
- Enhancement of JET correlation reflectomter

W7X integrators tests at Greifswald

Development of control and data acquisition systems

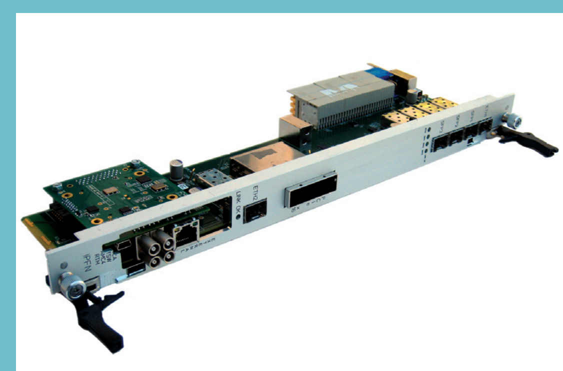
IPFN is participating in JET diagnostics enhancement projects on the development of control and data acquisition systems for the JET gamma-ray camera, gamma-ray spectrometer and lost-alpha Gamma Ray Monitor. Additionally, two fusion devices, W7X (Germany) and RFX (Italy), are producing under royalties instrumentation fully developed by IPFN.

Modelling activites

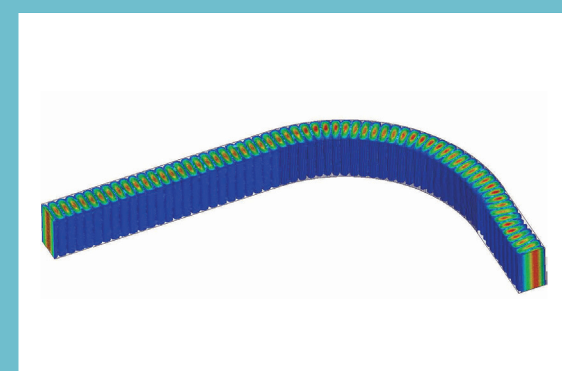
- Modeling of reflectometry experiments at ASDEX Upgrade, JET and ITER: together with Institut Jean Larmour, Nancy, and Laboratoire J. J. Lions, Paris, research on numerical kernels for FDTD codes result on a modified Xu & Yuan kernel and on the proposal of a new kernel (Deprés & Pinto), which exhibits improved long run stability.
- Tore Supra and ITER: a new study started on beam widening induced by edge turbulence during the electron cyclotron heating, a very hot topic for ITER.
- ITER: ERCC European code under the ITM_ERDG team held work on code comparison work and discussions on the 3D reflectometry code under development.
- ASDEX Upgrade and RZG: Important advances on modeling of reflectometry with the integration of REFMUL(X) code with GEMR.

Awards

- IEEE-NPSS RT2010 (first place) and RT2012 (third place) Outstanding Student Paper Award
- ANACOM - URSI Portugal 2012: Jorge Santos was awarded the ANACOM – URSI Portugal 2012 Prize for his work "Microwaves used for the first time in the position control of a fusion machine". He was also interviewed for the weekly science news program "Com Ciência", broadcast by the national RTP television channel 2.
- A. Vale, F. Valente, I. Ribeiro, J. Ferreira and R. Ventura, Robótica'2012 Best presentation award and 2nd best paper
- Daniel Fonte, best master thesis award by Portuguese Robotics Society.



FPGA based programmable timing module for ITER Fast Plant System Controler



Simulation of microwave propagation in ITER waveguide for the Plasma Position reflectometry system

THEORY AND MODELLING

Head: Nuno F. Loureiro

The Group of Theory and Modelling focuses on theoretical and numerical studies of magnetic confinement fusion plasmas, in support of the European fusion programme. The main areas of expertise are turbulent transport of particles and energy, fast particle physics, MHD activity, tokamak equilibrium, interpretation of diagnostic data, particularly reflectometry, and edge physics. The group's healthy mix of analytical theory, numerical modelling and direct interpretation of experimental data provides a symbiotic, diverse and productive research environment. In addition to fusion-specific research, GTM carries out research activities in fundamental plasma theory, with applications not only to fusion but also to space and astrophysical plasmas.

www.ipfn.ist.utl.pt/gtm

Momentum transport studies

Detailed analysis of intrinsic rotation data obtained from JET experiments (with the Carbon wall) suggests that the intrinsic rotation on ITER will be much lower than what was previously predicted by the multi-machine rotation scaling (i.e., Rice's scaling).

The role of plasma collisionality in regulating so-called intrinsic rotation in tokamak plasmas has been identified, including the confirmation of a reversal in the rotation direction, in agreement with existing experimental observations.

Physics of Energetic Particles

The transport of energetic ions generated by nuclear reactions or by auxiliary heating away from the plasma core through its interaction with Alfvénic modes is a key issue for future tokamaks. A model explaining the transport of energetic ions all the way from the plasma core to the plasma edge through the precessional drift resonances of different types of Alfvénic modes (TAE and tornado modes) has been proposed.

Equilibrium studies

A new method was devised to investigate the stability of tokamak equilibria with non-nested axisymmetric island systems, which occur in the context of AC tokamak operation.

It was found that, in general, it is not possible to decrease the toroidal current density that flows in the magnetic axis of an axisymmetric equilibrium towards zero and, simultaneously, keep all its magnetic surfaces nested. This result is important when modeling some extreme reversed-shear tokamak scenarios (current holes).

Magnetic Reconnection

A novel hybrid fluid-kinetic massively parallel computer code (Viriato) allowed the first demonstration of the dominant role of Landau-damping as an energy-conversion mechanism in magnetic reconnection. Further work on the topic of magnetic reconnection proved analytically that reconnection sites (i.e., current sheets) are unstable to both the plasmoid and the Kelvin-Helmholtz instability.

Participation in the Integrated Tokamak Modelling Task

A strong effort was made on the maintenance, development, verification and validation of the European Transport Solver (ETS), focusing on the integrated equilibrium and transport modules. Modelling validation for dedicated JET hybrid scenario pulses with the ETS, using H-mode Bohm-gyroBohm and NCLASS modules, showed good agreement with the experimental data.

An upgraded set of tokamak devices and of experimental data integrated in the ITM platform was deployed, e.g., DEMO1 conceptual design, passive structure inserts in the design of ITER, and TRANSP run data import.

Runaway electron studies at JET

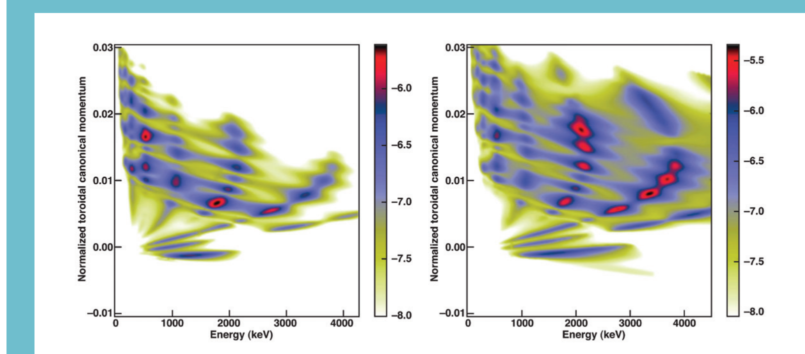
Analysis of disruptions and runaway electrons (RE) data from JET provided important contributions to the physical model of runaway electrons generated at disruptions, in support of the development of disruption-mitigation techniques for ITER. Enhanced capabilities of JET diagnostics provided new in-flight data on runaway electron beams. 2D tomography of hard and soft x-ray emissions enabled detailed study of the spatial structure and time evolution of RE beams on plateau stage. The maximum energy of RE populations was found to reach ~15 MeV in some disruptions.

Novel numerical methods

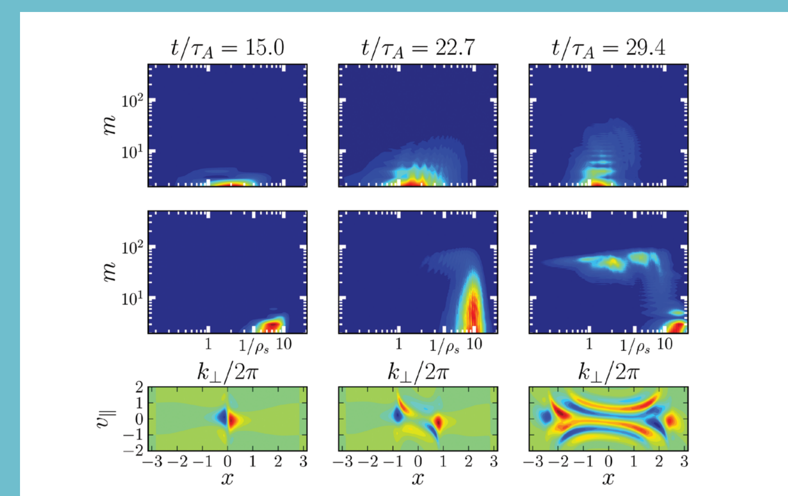
A stochastic approach to the solution of the MHD equations has been derived for the first time. Such stochastic methods yield considerable computational savings in massively parallel computations by reducing the requirements on processor communication.

Studies of a lower-hybrid-current-drive launcher for ITER

The maintenance of long pulse steady-state conditions in tokamaks requires driving the plasma current non-inductively. This may be achieved using external current drive power, as provided by lower-hybrid waves. Various PAM configurations were modeled; studies were carried to optimize these PAMs under broad plasma loading while aiming for a shorter unit, and were mostly focused on an alternative to the "2010 design", which has not been addressed before for ITER.



Regions in phase-space of enhanced energy exchange between toroidal Alfvén eigenmodes (TAEs) and energetic ions in a JET discharge, as modelled by the CASTOR-K code.



Phase-mixing caused by magnetic reconnection: Plots show a time sequence of the path through position and velocity space of energy (top row) and dissipation (middle row). The bottom row depicts the electron distribution function undergoing phase-mixing.

EXPERIMENTAL PHYSICS

Head: Horácio Fernandes, Carlos Silva (deputy)

The Group of Experimental Physics (GExP) is focused on the scientific exploitation and operation of magnetic confinement fusion devices across Europe. The activity of the Group is aligned with the European fusion programme being launched for H2020. Current activities include also the commissioning, operation and scientific exploitation of the Portuguese magnetic confinement fusion device – the ISTTOK tokamak. Our ultimate goal is to contribute to the development of a physics-based understanding of plasma confinement and transport in magnetic fusion devices. The GExP leads IPFN's participation in several educational European initiatives such as the Erasmus Mundus Fusion-DC programme and Fusenet, the European Nuclear Fusion education network.

JET

Disruption mitigation techniques were developed for the JET ITER-like-wall, with modest plasma current quenches and small runaway electron generation rates found. Scrape-off layer properties of ITER-like limiter start-up plasmas in JET were characterized with profiles found to be substantially broader for inner wall limited plasmas, supporting the existence of a poloidally localized region of enhanced radial transport near the outboard midplane.

Geodesic Acoustic Modes, critical agents in the turbulence self-regulation, have been identified for the first time on JET. Their properties and structure have been investigated and experimental evidence was presented suggesting an interaction between GAMs and the ambient turbulence.

We have contributed to the effort of understanding and improving the energy confinement, control of W accumulation in the core and robustness of the scenarios against disruptions to assess the compatibility of high performance operation with ILW.

ISTTOK

Routine multi-cycle alternating discharges was achieved for the first time in a tokamak. The recent control through MARTe and the improvements on power supplies allowed the achievement of 1 second discharges, enabling ISTTOK to be a material test facility. The AC operation brings ISTTOK to a forefront plasma facility were retention and heavy elements plasma compatibility can be tested and evaluated.

We have demonstrated the capability to use heavy ion beam diagnostics (HIB) to measure and study plasma fluctuations. Usually fluctuations measurements are limited to scrape-off layers with more conventional diagnostics, but the HIB allow a deep view inside the full plasma volume. We also demonstrated that the amplitude of the floating potential fluctuations measured by Langmuir probes is larger than that measured by ball-pen probes, confirming the importance of temperature fluctuations.

The amplitude of the large-scale fluctuations was observed to be significantly larger in deuterium plasmas in agreement with previous observations on TEXTOR. However, contrary to TEXTOR results, no change has been observed in the local structure of the fluctuations.

We have demonstrated that liquid metals as droplets are not suitable for limiter operation as they were subject to the same displacement effect previously demonstrated for jets.

TJ-II

We have demonstrated the importance of self-regulation mechanisms between plasma transport and gradients in fusion devices. The dynamical coupling between density gradients and particle transport has been investigated in different tokamak (JET, ISTTOK and TJ-II), showing that the size of turbulent events is minimum in the proximity of the most probable density gradient.

Remote handling

We have concluded the trajectory optimization and feasibility studies of Hot Cell building for cask transfer operations. Research and development of localization system to supervise and monitor in real time the cask during transfer operations and path following to rhombic kinematics applied to the cask transfer system.

Materials

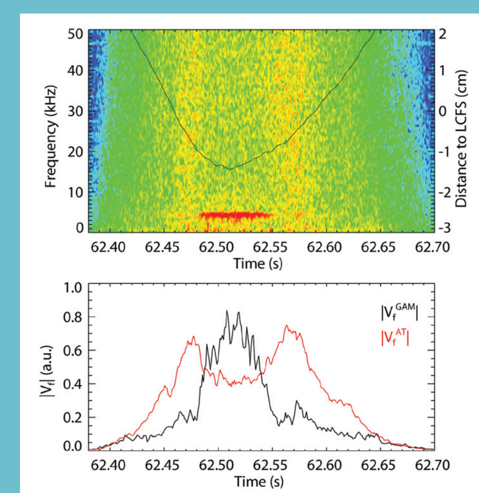
Helium irradiation of tungsten samples was observed to enhance Deuterium retention with different trapping mechanisms between the alloys and the composites. Deuterium retention was also found to be lower in W plates than in W-Ta composites. We have shown that cracks in full-densified W-Ta could be diverted by the tantalum microfibers. Studies of plasma facing components have been pursued where several functional tungsten materials were developed, produced and tested.

Asdex Upgrade

First measurements of the poloidal rotation of edge Quasi-Coherent modes were performed on AUG using poloidal correlation reflectometry and found to be in agreement with the poloidal flow velocity.

A novel technique for detection of plasma filaments with reflectometry systems operating in fixed frequency was validated. It was observed that along the ELM cycle the maximum filamentary activity occurs ~400 μs before the peak of the ELM, in agreement with the expected time scale of the ELM lifetime. Furthermore, filaments were found to propagate with a dominant poloidal velocity.

Eroded tungsten sample during an ISTTOK AC discharge.



Identification of coherent electrostatic fluctuations consistent with the GAM on JET

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MATERIALS PROCESSING AND CHARACTERIZATION

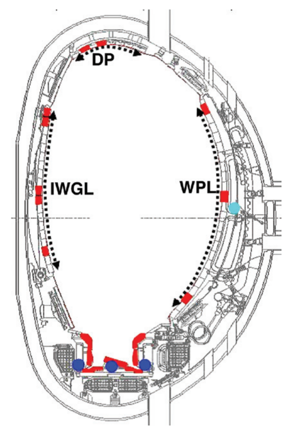
Head: Eduardo Alves

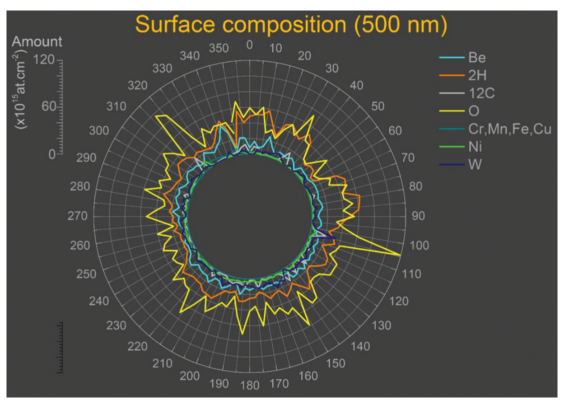
The Group of Materials Processing and Characterization operates the Ion Beam Laboratory of the Accelerator and Radiation Technologies Unit of IST. The laboratory hosts two electrostatic accelerators, an ion implanter, an ion microprobe and micro-AMS system. A large number of experimental ion based techniques are installed and intensively used for characterization and processing of materials. The major interest of the Group is to use ion beam analysis to unveil the fundamental processes behind plasma material interactions and process and develop new materials with engineered properties. Other work includes the application of irradiation techniques to tailor the properties of materials to develop new electronic devices able to stand harsh environments, e.g. space or nuclear fields, and the understanding of defect production and interaction for the development of materials for fusion applications.

Study of plasma interaction with the main wall and divertor in JET

JET remains as the principal machine to study transport in the plasma and interaction of the plasma with the main wall and divertor in conditions close to ITER. Tiles and components from the new JET ITER-like wall were now available and the first post-mortem analyses started. Erosion/deposition studies were performed to assess the extent of deposition and the associated D retention over surfaces interacting with the plasma and to give an overall pattern of the deposition. Several of the tiles from the 2011-2012 experimental campaign were analysed under this task activity using ion beam techniques and are indicated in the figure below (red).

The results show that the mid-plane inner limiter is found to be a net erosion zone as a result of interaction with limiter plasmas. The erosion rate of Be from this region, 2.3×1019 atoms.s-1, is higher than for JET-Carbon, 1.4×1019 atoms.s-1. To fully understand these results further investigation into the factors that influence erosion rates, such as variation in incident flux, temperature, power, and contact point of the plasma, is required. Overall deposition in the divertor during the divertor plasma is



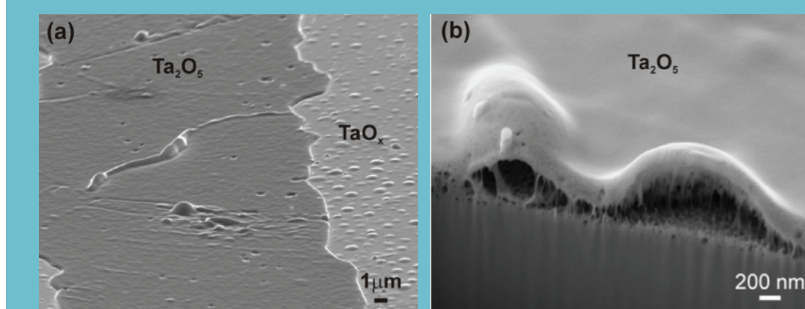


Scheme of JET chamber showing the tiles studied (top) and the results obtained for a rotating collector (below).

reduced. The main area for deposition is at the top of the inner divertor where deposits of the order of 10 – 20 μm are observed. The deposition in the base divertor is two orders of the magnitude lower than for JET-Carbon and the migration of material to remote areas is also lower.

Development and fuel retention on high-Z materials for first wall applications

We studied the influence of allowing W with ductile Ta fibers on the mechanical and retention properties of this metal. Tungsten-tantalum composites (W-Ta) were consolidated by pulse plasma sintering (PPS) at 1500 °C. Several samples were prepared and implanted with He+ (pre implantation step) and D+ ion beams at room temperature with fluences in the 1020-1021 at/m2 range. The microstructure observations revealed that after consolidation the W/Ta interface reflects internal oxidation of Ta surface. Extensive (W,Ta) interdiffusion has not been observed and Ta2O5 and TaOx interlayers have been identified at the W/Ta interface by Electron Backscatter Diffraction(EBSD). Results have also shown that W matrix remains unaltered after the implantations. However, blistering occurred in the Ta2O5 and in TaOx regions, with the blister cavities evidencing the formation of a nanometer-sized fiber structure. These findings point out for the importance of the atmosphere during the allowing step. A reducing environment is necessary to avoid the Ta oxidation.

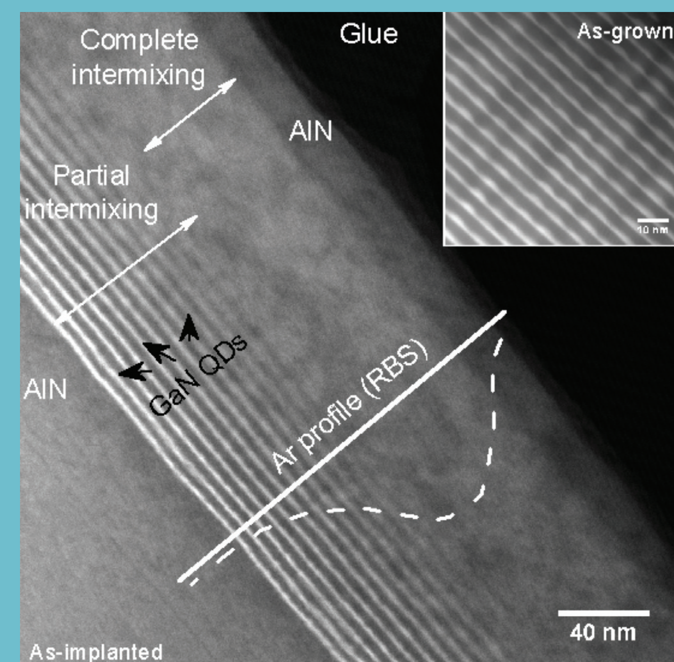


SE images showing microstructures observed in W-Ta implanted sequentially with He+ and D+ ions evidencing blistering in Ta2O5 and TaOx regions (left) and blister profile in Ta2O5 region (right).

Ion Beam Processing of Wide Band Gap materials

Two new projects funded by FCT started in 2013 with the objective of studying the effects of ion implantation in wide-band-gap semiconductor nanostructures. The project "Nanowires" aims at establishing the ion implantation technique for doping and defect engineering of GaN and oxide nanowires (NWs). GaN, Ga2O3 and Bi2O3 NWs have been successfully doped with rare earth ions exhibiting light emission in the visible and ultra violet spectral region.

In the project "Greenlight", ion beam enhanced quantum well (QW) intermixing is studied as a means to improve the internal quantum efficiency of group-III nitride LED structures. A detailed ion beam mixing study of GaN/AlN superlattices containing GaN QW or quantum dots (QD) revealed on the one hand the strong radiation resistance of GaN nanostructures and on the other hand an enhanced selective intermixing in 3D QD compared to QW.



TEM image of a GaN QD/AlN superlattice implanted with 100 keV Ar at 15 K to a fluence of 1×1016 at/cm2. Regions of complete and partial intermixing as well as the Ar-profile measured by Rutherford Backscattering Spectrometry (RBS) are indicated.

LASERS AND PLASMAS

Head: Luís O. Silva

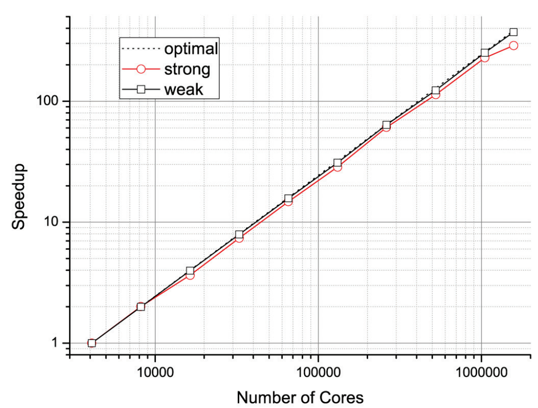
TThe Group for Lasers and Plasmas was established in 1994 and is focused on research in Plasma Physics, Advanced Photonics and Advanced Computing towards generating, understanding and taming the behaviour of plasmas under extreme conditons. GoLP's research program weaves together their two strongest suits — theory/simulation and experiments/technology — with the goal of further increasing the impact of our activities and reaching higher levels of excellence by exploring this uniqueness. The Group is currently leveraging on its experimental expertise to tackle new science on world leading laser facilities demanding outstanding simulation resources, while developing simulation models grounded on novel theoretical approaches to design future experiments led by its PI's, from LCLS in Stanford to CERN in Geneva.

golp.ist.utl.pt

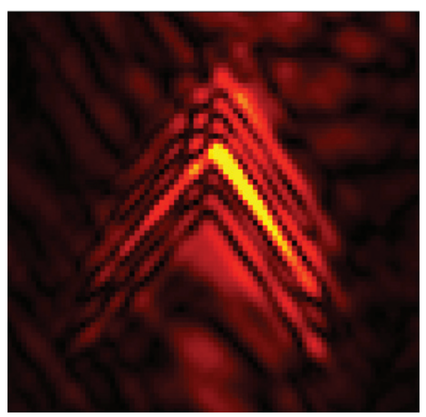
Plasma theory and simulation

The role of the ion dynamics in particle acceleration and wake excitation in self-modulated plasma wakefield accelerators was demonstrated. Optimal regimes for monoenergetic ion acceleration in electrostatic shocks driven by lasers were identified, and experimentally confirmed.

Laboratory regimes where laser-driven Weibel mediated shocks can be launched were determined. A multidimensional theory of the collisionless instabilities in sheared flows was developed, and the role of kinetic effects and multi-species in the properties of relativistic unmagnetized and magnetized collisionless shocks was identified.
A novel mechanism to generate at the electron scale B-fields in flows with a velocity sheared and developed the theoretical models and the numerical simulations to demonstrate this magnetic field generation mechanism was predicted.



Parallel scalability of Osiris on the Sequoia system at Lawrence Livermore, from 4096 to 1572864 cores (full system).



Multiwavelength reconstructed image of a 2×2 μm2 target. The wavelengths are separated giving a spectrally and spatially resolved sub micron resolved image.

The properties of collisionless shocks have also been explored in a series of papers, building on the 2012 results published in Nat. Physics and Phys. Rev. Letters, presenting an in-depth analysis on the properties of electrostatic shocks driven by intense lasers.

A collaboration with researchers at LLNL and at the UCLA has allowed the demonstration of strong and weak scalability of Osiris in Sequoia on more than 1.5 M CPU cores (full system) achieving a new milestone for particle-in-cell simulations.

PhD student Paulo Alves was awarded the prestigious Gulbenkian Prize for Young Researchers for a project on the ab initio study of the nonlinear properties of plasma metamaterials, and alumni Frederico Fiuza was awarded with the 2013 PhD Research Award from the Plasma Physics Division of the European Physical Society, recognising his thesis work performed at GoLP.

On the 7th PRACE call for supercomputing time at SuperMUC, Jorge Vieira was awarded 45 M CPU core hours, the largest on that call, to explore the nonlinear behaviour associated with intense beam-plasma instabilities, and also beam time at SLAC for the E209 experiment to identify the signature for the self-modulation instability of long beams in plasmas.

Novel radiation sources and plasma acceleration

A new high harmonics source at the LCLS facility (SLAC) was implemented and characterized. A future experiment was approved, for demonstrating the self-modulation of ultra-relativistic lepton bunches.

Ultra-short, intense laser beams were successfully guided in plasma channels generated by field ionization using the same pulse, with transmission of 30% over an 8 mm hydrogen plasma length.
A new high-density plasma diagnostic was demonstrated, capable of high harmonic wavefront sensing in the XUV. Also a conceptual design of a new X-ray laser was proposed, extending chirped pulse amplification to the x-rays.

It was shown for the first time that, through the correct selection of reference and object distances that dictate the spatial interference frequencies in lens-less holography schemes, image reconstruction is possible through a single Fourier transform. Using a frequency comb of several discrete wavelengths (such as those created through HHG), an individual image can be reconstructed corresponding to each discrete wavelength, yielding a spectrally and temporally resolved image with spatial resolutions below 200 nm.

High power lasers and optical physics

The collaboration with GSI led to an improved ASE contrast of more than 1012 at the PHELIX petawatt laser system, thanks to the integration and demonstration of a temporal contrast-boosting module for the pre-amplifier.

The first experiments on ultrabroadband OPCPA in YCOB were made, following the successful completion of a 100 mJ, 1 Hz diode-pumped laser amplifier. The YCOB crystals are cut at specific phase matching angles in order to maximize nonlinear efficiency, and both single and double stage amplification were demonstrated.

A pseudophakic eye model was developed, based on ray-tracing optical evaluation, which allows a personalized assessment of Intra Ocular Lens power even for unnatural aberrated eyes. The model was validated through comparison with current established population-based clinical formulas for 104 eyes.

The INSCAN LITE spectrometer prototype was completed with the integration of electronics hardware and data acquisition firmware and software developed at INESC that allow function with two different, exchangeable detectors. The response bandwidth, spectral resolution and sensitivity were characterized using calibrated reference lamps, for each sensor.

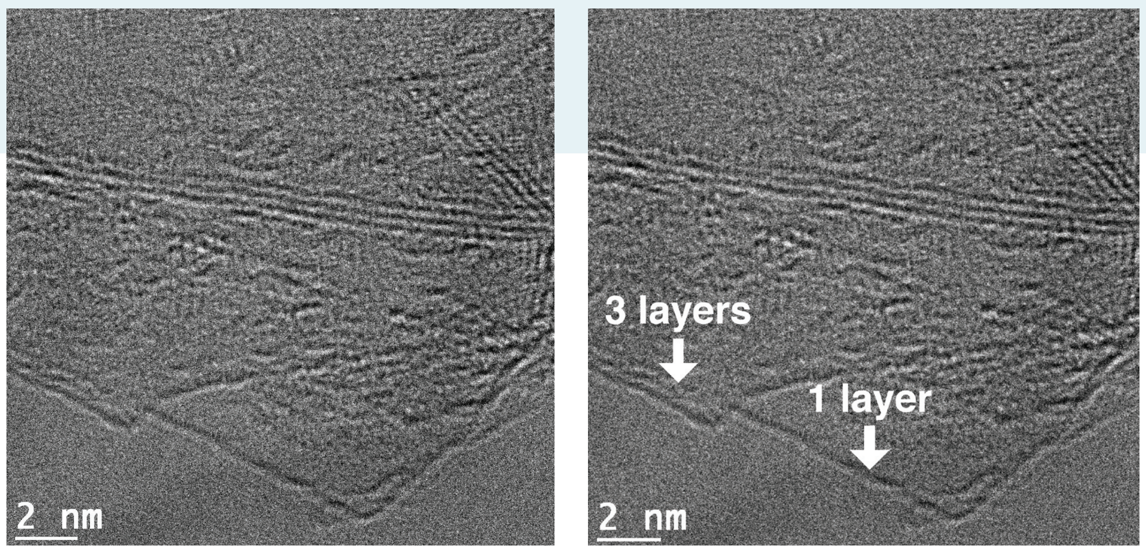
GAS DISCHARGES AND GASEOUS ELECTRONICS

Head: Luís Lemos Alves

The mission of the Gas Discharges and Gaseous Electronics Group is to develop experimental, theoretical and model-based predictive capabilities, crucial to integrate the intellectual diversity and the speeding advances in low-temperature plasma science and engineering that answer fundamental science issues and provide societal benefits. GEDG explores its potential under two main activities: the Plasma Engineering Laboratory (PEL) and Plasma Modelling and Simulation (PMS). The new ESA experiment European Shock-Tube for High Enthalpy Research (ESTHER), to study highly-excited plasmas (as produced in re-entry phenomena), will provide an excellent basis for further developing GEDG scientific heritage in the field of non-equilibrium molecular plasma kinetics and radiation.

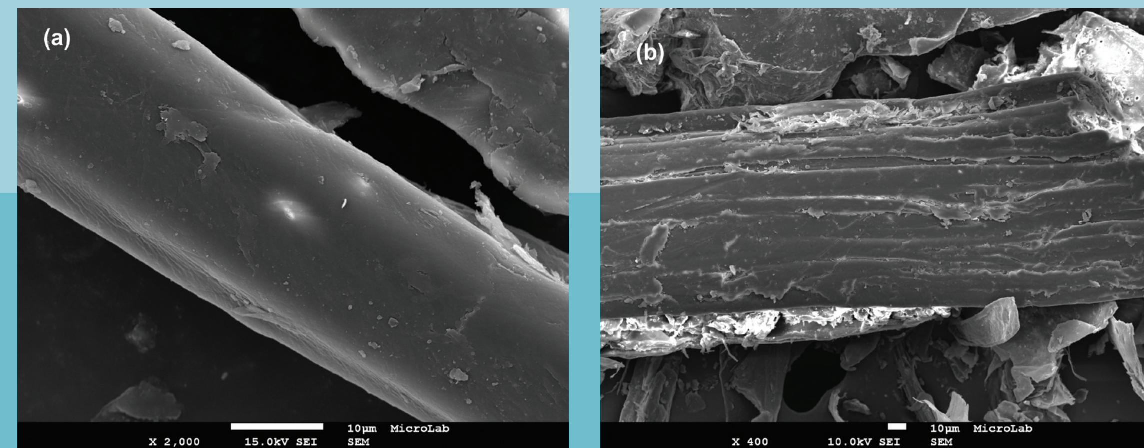
Successful development of new plasma technologies

An innovative microwave plasma-based single-step method was developed to synthesize graphene sheets from vaporized ethanol molecules at atmospheric pressure. The structural quality of graphene is controlled via externally forced heating in the nucleation zone of the plasma reactor.



A microwave "tornado"-type plasma at atmospheric pressure was used to decompose alcohol molecules, viz., methanol, ethanol and propanol, into hydrogen-rich gas stream. The hydrogen yield has an average value of about 98% and it increases using vortex gas flow instead of laminar flow.

An air-water microwave plasma source, operating at atmospheric pressure, was applied to the pre-treatment of sugarcane biomass. Samples of dry and wet biomass have been exposed to the late afterglow plasma stream. The highly-reactive plasma environment provides a number of long-life active species that destroy the cellulose fibres wrapping, facilitating biomass reconversion.



Breakthroughs on plasma kinetics

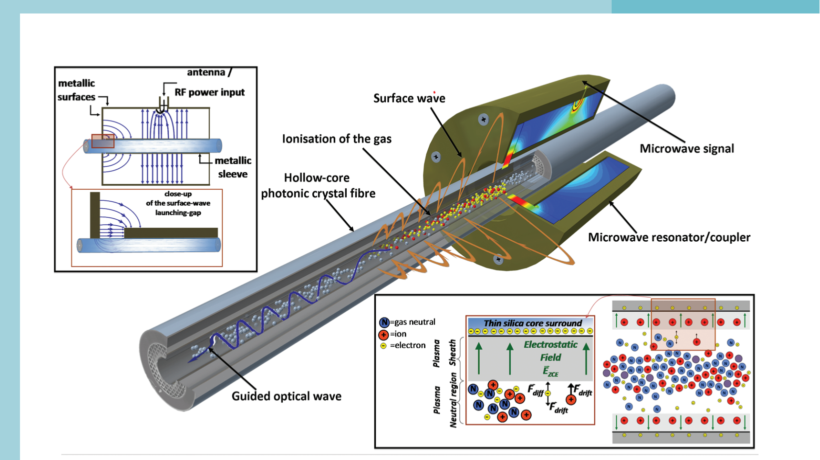
For the first time, the rate coefficient of the very important NO formation reaction $N_2(X,v \geq 13)+O \rightarrow NO+N$ was estimated experimentally, using and comparing innovative variants of optical emission spectroscopy line-ratio methods.

The role of vibrationally excited ozone in the overall ozone kinetics was evidenced and quantified, by combining experimental and modelling investigations. O_3 is mainly formed in vibrationally excited states that are efficiently destroyed by atomic oxygen and $O_2(a)$ metastables.

Vibration-Electronic processes have been modelled using analytical Landau-Zener/Rosen-Zener expressions, accounting for accurate vibrational manifolds both for ground and excited vibrational states, providing reliable reproduction of experimental rates.

Breakthroughs on plasma photonics

Ignition and study of microwave-driven plasmas in hollow-core photonic crystal fibres with 100 µm core diameter, causing no damage to the host structure, was successfully achieved. The impressive confinement and interaction of plasma and UV-light at micrometre scale opens a new route for highly-integrated photonic applications.

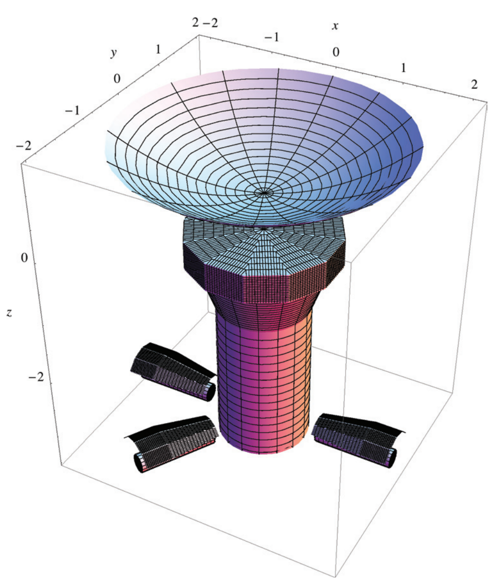


Extreme VUV emission was obtained using low-pressure Ar-H_2 microwave plasmas. The spectra feature intense lines in the 100 nm region, which are strongly affected by changes in the hydrogen content of the mixture.

SPACE PHYSICS

Head: Orfeu Bertolami

The Group of Fundamental Physics in Space is devoted to the study of new ideas to understand and interpret the Universe. These include the study of new extensions of quantum mechanics and their impact on laboratory experiments and extreme situations such as black holes. Other topics include extensions to General Relativity, the modelling of the anomalous acceleration of the Cassini spacecraft and flyby anomalies, and the design of new space missions to better understand the law of gravity.



Simplified geometric model of the Cassini deep-space probe. This model will be used for the thermal analysis of this spacecraft which aims to determine the acceleration generated by anisotropic thermal emissions. The analysis uses the same point-like source method already successfully applied to the study of the Pioneer Anomaly.

Method to compute on-board thermal effects of spacecraft

Further development of our pioneering finite point source method, which previously showed that the reported values of the so-called Pioneer anomaly are closely accounted for once the reflections are properly accounted through the use of a Phong shading algorithm. This included its application to other spacecraft and outstanding problems, such as modeling of the Cassini probe and the Flyby anomaly, a reported anomalous change of momentum imparted upon several spacecraft when performing gravitational passages close to the Earth.

Use of Global Navigation Satellite Systems to test extensions and modifications of General Relativity

We showed that GNSS-based tracking can be used to experimentally validate the Flyby anomaly. This was followed by an applied case, showing that the general strategy outlined for this measurement can be implemented in the STE-QUEST mission proposal for ESA.

Non-commutative quantum mechanics

We obtained new and interesting results, namely the study of non-commutative grapheme to the violation of the Robertson-Schrodinger uncertainty principle.

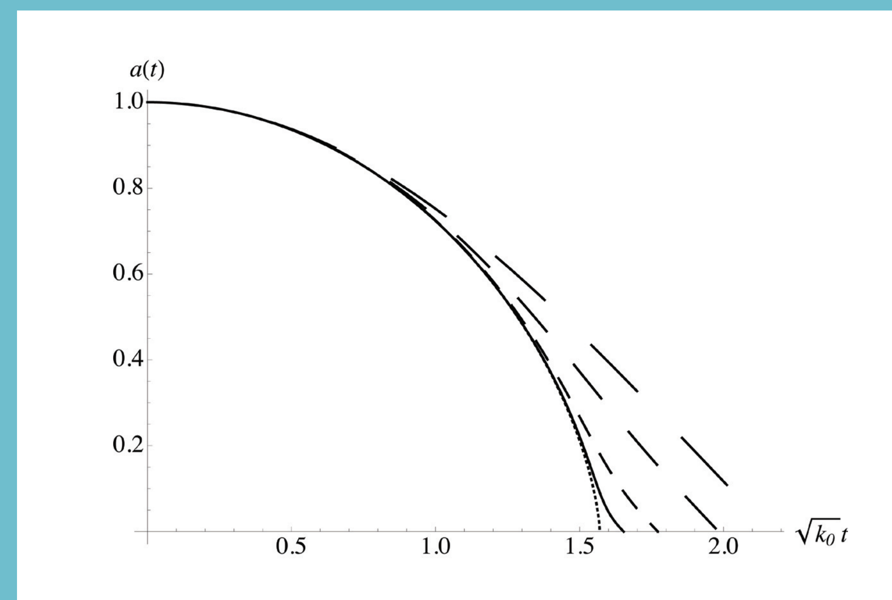
Model with a non-minimal coupling between matter and curvature

This well-established line of research was continued with studies concerning the viability of transversable wormholes, Solar System tests of the model, spherically symmetric objects in hydrostatic equilibrium, and the impact of the non-minimal coupling on structure formation and gravitational collapse.

Interaction between dark matter and dark energy

This concept, which has guided the work of our group throughout the years, was explored with studies of the impact of a two-scalar field model on the accelerated expansion of the Universe and Hamiltonean formalism of model with a scalar-field non-minimally coupled to gravity.

Impact of quantum mechanics in cosmology - This relevant issue was further developed with two works assessing the relevance of nonlinearities in the quantum Multiverse and the relation between interacting Universes and the cosmological constant.



Evolution of gravitational collapse of a homogeneous star, with the dashed lines indicating the impact of a non-minimal coupling with varying strength

QUANTUM PLASMAS

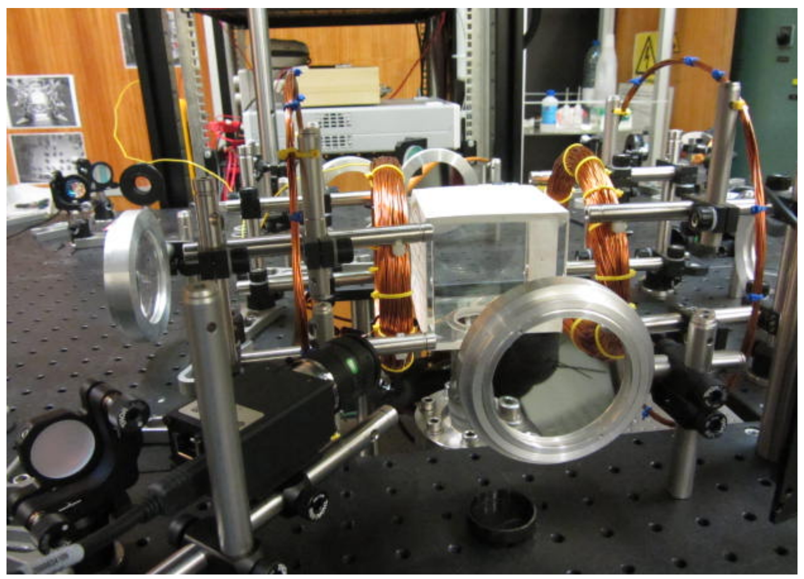
Head: J. Tito Mendonça

The purpose of the Laboratory for Quantum Plasmas of IPFN is to explore the area of ultra-cold plasma physics, including collective effects of the laser-cooled gas, as well as the study of Rydberg atomic states and quantum plasmas. Our main aim is to understand the main physical processes associated with plasma creation, the quasi-equilibrium density and temperature profiles, and the elementary and global oscillation modes of the plasma cloud. Additionally, we propose to explore the analogies between the three different phases of ultra-cold matter: neutral gas, Rydberg plasmas, and Bose Einstein condensates.

The magneto-optical trap (MOT) experiment was completed and became operational very recently. This laser cooling apparatus creates a gas of 1011 Rubidium atoms, at a temperature of 100 micro-Kelvin.

Equilibrium profiles and modes of oscillation of the ultra-cold gas were studied, which are very similar to those of stellar objects. The astrophysical analogy was explored further, by showing that Saturn-like rings can be excited in the ultra-cold cloud. Our MOT experiment could be used for studies of laboratory astrophysics.

A new model of joint neutrino flavor and plasma oscillations was introduced, in terms of the dynamics of the neutrino flavor polarization vector in a plasma background. This could contribute to the understanding of neutrino beam instabilities and collective neutrino plasma interactions.



Detail of the completed vacuum cell and magnetic confining coils.

Overall view of the experiment.

We have shown that the second sound can exist in the ultra-cold gas, by using a two-fluids model, similar to that used to explain superfluidity. Both fluids, the atomic gas and the phonon gas, were described by similar kinetic equations. The second sound modes are elementary excitations of these two coupled fluids.

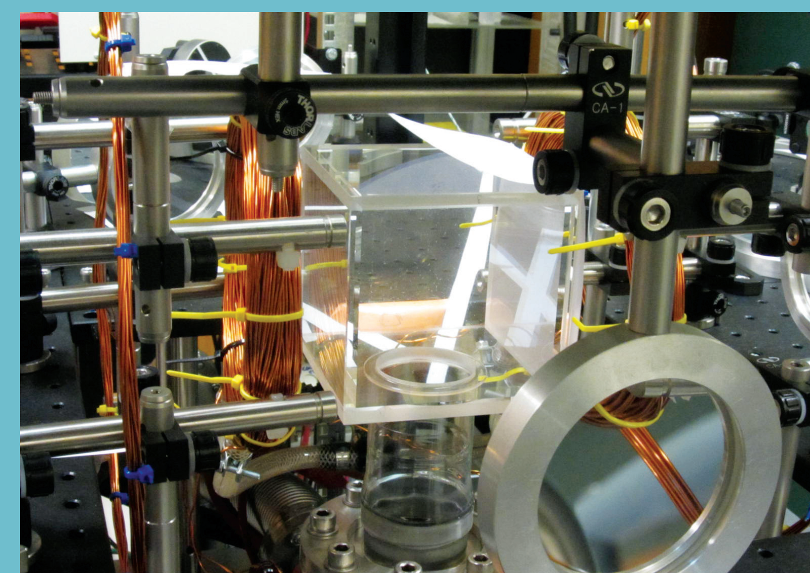
A new theoretical approach to microwave reflectometry in a turbulent plasma was proposed, which goes beyond the usual Born approximation. This could be relevant to magnetic fusion diagnostics.

A new theoretical approach to inverse bremsstrahlung in a relativistic quantum plasma was also proposed, which is the dominant mechanism for absorption of radiation in laser fusion experiments, and could be useful for plasmas created by X-ray beams.

The magneto-optical trap (MOT) experiment was completed in 2013. This laser cooling apparatus creates a gas of 1011 Rubidium atoms, at a temperature of 100 micro-Kelvin. We had to tackle some quite sensitive technical problems, such as a vacuum leaking and stability of the lasers, both preventing the stable operation of the experiment.

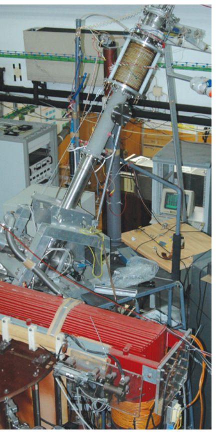
This experiment, which may also be operated at a so-called mode astrophysics at the lab, may show the equilibrium profiles and modes of oscillation of the ultra-cold gas that forms Saturn-like rings in the ultra-cold cloud and has been anticipated in our previous simulations.

The novel theoretical approach to inverse bremsstrahlung in a relativistic quantum plasma was further developed. This is a dominant mechanism for absorption of radiation in laser fusion experiments and can be useful for plasmas created by X-ray beams.



Detail of the vacuum cuvette where confinement of ultracold rubidium atoms takes place.

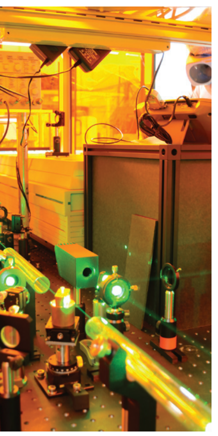
RESEARCH FACILITIES



ISTTOK Tokamak

The ISTTOK tokamak is the only Portuguese fusion device in operation since 1990. Most of the tokamak's components as well as its diagnostics and control and data acquisition system, were designed and built locally. At ISTTOK several physics studies are being conducted from material science with liquid metals to edge turbulence. Its main goals besides the education and training in nuclear fusion are focused on the cutting edge of engineering and technology enforced by the development of new diagnostic techniques, control and data acquisition concepts and modeling physics.

Alameda campus http://www.ipfn.ist.utl.pt/isttok/



L2I - Laboratory for Intense Lasers

L2I is a leading laser research facility, dedicated to the study of laser-matter interaction at very high optical powers. It is located at the main IST campus and operated by IPFN researchers. It hosts several high power lasers, including a 15 TW CPA-type laser system based on Ti:sapphire / Nd:glass, the most powerful in Portugal. The target area is equipped with optical, IR, VUV, X-ray, and particle diagnostics. The main research areas are plasma sources, plasma channels, high harmonic generation, diode-pumped lasers and optical parametric amplification. L2I is a fundamental stepping-stone in the preparation of high-intensity experiments at large-scale facilities, while also playing an important role in the advanced training of young researchers and technological development.

Alameda campus http://xgolp.ist.utl.pt

PEL - Plasma Engineering Laboratory

PEL hosts several microwave plasma sources and diagnostic equipment for visible emission and absorption spectroscopy (atomic and molecular), UV and XUV spectroscopy, Fourier-Transform infrared spectroscopy, laser diagnostics (TALIF, photo-detachment), mass spectrometry, and electrical diagnostics. Current research at PEL focuses on plasma-based production of nanoscale materials (graphene, carbon nanotubes), plasma technologies for renewable energy sources (production of hydrogen from alcohols) and environmental improvements (NOx, CFCs, VOCs and fly ash decomposition, bacteria inactivation), and plasma sources for biomedical applications (wound healing, blood coagulation, treatment of living tissues, destruction of cancer cells, sterilisation).

The experimental work is paralleled by modelling studies of plasma kinetics and wave-plasma coupling, for preparation and interpretation of measurements.

Alameda campus

ANNUAL REPORT 2012-2013 | **IPFN**

ESTHER - European Shock Tube for High-Enthalpy Research

ESTHER is a facility specifically designed for supporting European planetary exploration and Earth return missions. It was developed by an international consortium, under funding from the European Space Agency.

The facility is capable of reproducing the conditions of a spacecraft entry in a planetary atmosphere, allowing validation of the vehicle design, and namely of its thermal protections.

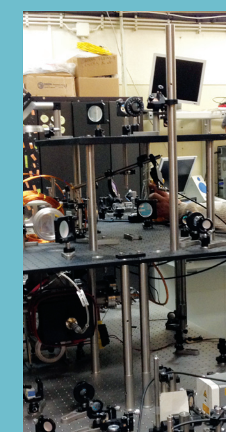
As world-class high-performance facility, capable of reaching shock speeds in excess of 10 km/s, ESTHER employs a large array of state-of-the-art optical diagnostics, such as optical emission and absorption spectroscopy, laser spectroscopy, and microwave interferometry. These encompass a large spectral range, from the vacuum-ultraviolet to the infrared regions, and will allow achieving a better understanding of the elementary energy exchange processes taking place in such high-temperature, nonequilibrium plasmas.

Loures campus http://esther.ist.utl.pt

MotLab - Ultra-cold Atoms Laboratory for Ultra-Cold Atoms and Quantum Plasmas

MotLab hosts a large magneto-optical trap, capable of confining rubidium atoms at room temperature in a cubic quartz cell, and cooling them down to a temperature of 100 micro-Kelvin through a system of three counter-propagating pairs of laser beams operating in CW mode at 780 nm. The system is equipped with confining magnetic coils and optical diagnostics. The main research areas are ultra-cold atoms, collective atom-atom interactions, and Rydberg ultra-cold plasmas. MotLab intends to play an important role in the advanced training of young researchers and technological development at IST.

Alameda campus



LATR - Laboratory of Accelerators and Radiation Technologies

LATR researchers explore, develop and offer the scientific community the multidisciplinary capabilities of ion beam techniques for studying and processing of materials. The unit hosts a unique set of equipment in Portugal, such as two electrostatic accelerators (a 2.5 MV Van de Graaff and a 3.0 MV Tandem), an ion implanter (210 kV, Danfysic), an Oxford ion microprobe, two high resolution X-ray diffractometers a micro-AMS system (Accelerator Mass Spectrometry) and a semi-industrial Co-60 unit. These are complemented by a wide range of techniques for the characterization and processing of materials, whose characteristics make them an asset in multidisciplinary research and industrial use. These techniques are unique for quantitative elemental analysis, offering detection limits in the range of ppb without affecting the samples or requiring standards. In-house research activities are focused on the development and processing of advanced materials using ion beams and the study plasma interactions with wall materials in fusion devices.

Loures campus http://www.ctn.ist.utl.pt/facilities/pt_lab_ion_beam.htm

OUTREACH, COMMUNICATION & COMMUNITY

IPFN is strongly committed to taking an active role in the communication of science and the dissemination of its scientific and technological achievements to the society. Our outreach activities are targeted at a broad range of audiences: from undergraduate students to secondary school students and teachers, from industry representatives to the media.

Both through the Image and Public Communication team and through individual efforts from IPFN researchers, the scope of initiatives is very lively and diversified. In developing these activities, IPFN collaborates with its international Association partners through the EFDA Public Information Group, and at a national level with the Council of Associated Laboratories and the "Ciência Viva" agency.

Bruno Gonçalves and Gonçalo Figueira are interviewed for a local newspaper after presenting talks on lasers and nuclear fusion.

Bruno Gonçalves presenting a talk on nuclear fusion to secondary school students at Batalha, central Portugal.

HIGHLIGHTS

IPFN's 5-days summer worskshops for secondary school teachers have become highly successful, now featuring two themes: Lasers (in July) and Nuclear Fusion (in September), including visits to the Rutherford Appleton Laboratory and JET, respectively.

There was a large number of visits from high school students to IPFN facilities, namely the IST-TOK laboratory (400 students in 2012-13) and the Laboratory for Intense Lasers.

A large number of invited talks by several IPFN researchers at secondary schools and public events, namely during the National Science Week.

Talks to visiting schools during the Physics Week at IST on nuclear fusion, lasers, and plasma technologies.

Starting of a new quarterly newsletter – IPFNews – featuring highlights from activities during the previous period, and announcements of events to come.

Six press-releases about IPFN research results and events, including the signature of an 8.5 million contract with F4E (2013).

VIP visits included: Secretary of State for Science, President of the Portuguese Science Foundation (FCT), President of F4E.

The online presence has been extended beyond the web page, Facebook and Flicker pages to include new pages on YouTube and LinkedIn.

In July 2013 IPFN organized the first edition of PlasmaSurf, an international summer school on plasma physics aimed at graduate students who have just finished their degree. PlasmaSurf took place in Oeiras, close to Lisbon, and attracted 23 students from many different nationalities.

Summer Workshop on Lasers: Secondary school teachers visiting the Laboratory for Intense Lasers.

Summer Workshop on Nuclear Fusion: a group of teachers during the visit to JET.

EDUCATION & TRAINING

APPLAuSE

2013 witnessed the start of IPFN's new doctoral program: APPLAuSE, the Advanced Program in Plasma Science and Engineering.

APPLAuSE is a student-centered and highly modular doctoral program designed to enhance each student's capabilities and maximize his/her potential. The hosting institution is IPFN, and the degree is awarded by the University of Lisbon, Portugal. The Portuguese Foundation for Science and Technology is the funding institution, supporting up to ten scholarships per year. The program director is Prof. Carlos Matos Ferreira.

Each PhD program has a duration of four years. Successful applicants are awarded a fellowship for this period and have the opportunity to enroll in an exciting and international research environment.

The first call for applications took place between August and September 2013. A total of 41 candidates applied, from 18 different continents, from which the top ten were selected. The classes started in March 2014.

PlasmaSurf

This was also the year when our first Summer School in Plasma Physics – PlasmaSurf – took place. Its name draws inspiration from the venue: Oeiras, a tranquil seaside village ten kilometres away from Lisbon, famous for its surfing spots.

The program covered the basic aspects of plasma physics, high power lasers and nuclear fusion. The recruitment of students was very successful with the help of the Fusenet web site, with more than 65% of participants coming from abroad.

But Plasmasurf was more than plasma science. Students were offered a vast social program, including sightseeing, practicing canoeing, climbing and mountainboarding. Finally, invited speaker Prof. Pedro Bicudo gave a talk on how the oceans generate waves for surfing.

Welcome to Lisbon! The first group of APPLAuSE students together with the members of the doctoral program board.

Participants in PlasmaSurf – 2013 Summer School in Plasma Physics relaxing after the lectures.

IPFN Annual Report – Highlights 2012/13

Cordination and Chapter Editors
Gonçalo Figueira e Bruno Gonçalves

Section Editors
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