Project MEFT Workshop (2nd Edition)

Wednesday 5 February 2020 - Thursday 6 February 2020

Instituto Superior Técnico

Book of Abstracts

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Plasmonics in two-dimensional materials: a wave-kinetic description

Author: Jose Figueiredo[1]

[1] *Ist*

Corresponding Author: zefigueiredo01@hotmail.com

The aim of this project is the construction of a ab-initio theoretical framework for plasmonics in two-dimensional materials. The approach is based on the Wigner-Moyal formalism, able to capture the phase-space dynamic of the electrons in low-dimensional quantum plasmas. Once established the mathematical structure of the various families of wave-kinetic equations (to be derived starting from the low-energy limit of the field-theoretical problem), the quantum hydrodynamics of two-dimensional materials such as graphene and Weyl semimetals are expected to be obtained, thus consistently addressing the issue of which hydrodynamical model is best suited for a particular system. The constructed framework will certainly contribute towards a more accurate description of graphene field-effect transistors (FETs), which have been investigated extensively in terahertz (THz) applications

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Application of Machine Learning Techniques to Heavy-Ion Jets

Author: João Silva[1]

[1] *IST*

Corresponding Author: joao.m.da.silva@tecnico.ulisboa.pt

The Quark-Gluon plasma (QGP) is a state of hot and dense matter where quarks and gluons are deconfined and is produced in ultra-relativistic heavy-ion collisions. This medium can be indirectly studied by infering its properties from the modifications suffered by jets - collimated bunches of particles resulting from the branching of energetic partons - which are created and developed within it. Additionally, Machine Learning's (ML) pervasiveness in today's world and the extreme large amount of data produced in particle collisions make the use of such techniques both a necessity and a potentially very fruitful path to follow. This project explores ML as a powerful physics discovery tool allowing to identify, from 'detector-level'information, important properties of jets modified by QGP that had escaped the imagination of theorists.

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The distribution of Dark Matter particles in the Milky Way and its influence on stars

Author: João Rato[1]

[1] *IST*

Corresponding Author: jpedrorato@tecnico.ulisboa.pt

Dark Matter (DM) stands for around a quarter of the Universe's energy density and 85% of its mass. However, not much is known about it, from the fact that it weakly interacts through electromagnetic

processes, becoming effectively invisible. Nevertheless, many clues point towards its existance. This work builds on this assumption and extends the recent discovery of visible matter being able to trace DM. This is specifically true for old (metal-poor) stars. Then, this work aims to study these stars, relying on the Gaia Satellite Data Release 2, to build connections to DM. This will mainly come in the form of velocity distributions, where the principal focus will be to extract these distributions empirically and draw constraints on the possible DM particle candidates. Different statistics will be used, straying away from the Standard Halo Model, in an attempt to explore different characteristics of this type of matter.

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Data-driven discovery of the mechanism of the Belousov-Zhabotinski reaction

Author: Mariana Mota[None]

Corresponding Author: marianavmota97@gmail.com

An important inverse problem in physics is the discovery of laws that determine the behavior of a given system, described by temporal and spatial data. Recently, Rudy and co-authors introduced deep learning techniques to fit observed data, with and without noise, with models based on space-time partial differential equations. Several benchmark tests were performed with the Navier-Stokes equations, reaction-diffusion equations, Korteweg-de Vries equations, among others.
In this project, the main goal is to infer the kinetic mechanism associated with reaction- diffusion waves and Turing patterns observed in the Belousov-Zhabotinski reaction. The data is obtained by analyzing images of reaction-diffusion traveling waves during successive instants of time and observed in the laboratory. After the calibration of the reaction diffusion model, we compare the properties of the fitted model with the properties of the real system.

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Spacebased Quantum Communications

Author: Pedro Mendes[1]

[1] *IST*

Corresponding Author: pedro.neto.mendes29@gmail.com

Quantum Key Distribution (QKD) protocols have attracted a lot of attention since their first proposal in 1984. In the last decade, many implementations of different protocols have been performed worldwide. However, a large-scale network has not yet been achieved. In this work, a miniaturized and scalable system is design and tested in order to be used for practical applications. For example, the development of a quantum payload for a CubeSat to establish a ground-to-satellite quantum communication device.

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Plasma in-situ production of fuels and oxygen on Mars

Author: Gonçalo Raposo[1]

[1] *IST*

Corresponding Author: goncalo.raposo@tecnico.ulisboa.pt

Sending a manned mission to Mars is one of the next major goals in space exploration. Since travelling to the Red Planet is a challenging endeavour, a justified interest has emerged in *in-situ* resource utilisation (ISRU) on Mars, with the possibility of harnessing local abundant atmospheric CO2 and converting it into breathable oxygen (O2) for a future outpost and carbon monoxide (CO), to be used in rocket propellant production. Martian atmosphere favours the vibrational excitation and subsequent up-pumping of the asymmetric stretching mode, which constitutes a key factor for an energy-efficient plasma dissociation, making plasma technology a strong candidate to perform the CO2 conversion. The aim of this project is to characterize the plasma discharge experimentally and develop a self-consistent kinetic model for the ternary CO2/N2/Ar Martian mixture.

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Gold Nanoparticles as Radiosensitizers for Radiation Therapy

Author: Ana Marques[1]

[1] *IST*

Corresponding Author: ana.s.marques@tecnico.ulisboa.pt

Radiotherapy is one of the most reliable and widely used treatments for tumours. However, it is not possible to irradiate only the tumour cells, surrounding healthy tissue will also receive a considerable dose. It is therefore necessary to reduce the radiation dose delivered to the healthy tissues of the patient, while maximizing the dose delivered to the tumour. One attractive option is the use of gold nanoparticles as radiosensitizers, as they are biocompatible, easy to fabricate and effective in dose enhancement. The aim of the work is to determine the potential benefit of combining radiation treatment with gold nanoparticles, by studying the effects induced by gamma- and X-rays in prostate cell lines loaded with these radiosensitizers.

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Sensor Qualification In An Industrial Environment

Author: Daniel Sousa[1]

[1] *IST*

Corresponding Author: daniel.h.c.sousa@tecnico.ulisboa.pt

Nowadays sensoric electronics importance is irrefutable, there is a constant demand to push forward limits in matters of detection limits, spatial resolution, among others. In applications that need sensing magnetic fields magnetoresistive (MR) sensors have attracted much interest in particular because of their high sensitivity, low power consumption, low cost and small size. Due to the typical sizes of the elements involved, tens of microns down to a few nanometers, strict micro/nanometric control is essential in all of the fabrication processes. As deviations in the process can compromise critically the behavior of the final device, either electrically (e.g. Resistance Area product, $R \times A$) or magnetically (e.g. saturation magnetization, M_{Sat}). Metrology is then critical for process validation and control for process evolving

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Development of a trigger system for the ESTHER Shock Tube Spectroscopy/Streak-Camera Diagnostic

Author: Francisco Figueira[1]

[1] *IST*

Corresponding Author: francisco.figueira@tecnico.ulisboa.pt

A new kinetic shock tube (ESTHER) is being commissioned at Instituto Superior Técnico under funding from the European Space Agency (ESA). Its main goal is to support planetary exploration missions, by studying high speed radiative and chemical processes kinetics relevant to planetary entries. ESTHER is capable to produce shock speeds up to 14 km/s in air and 18 km/s in H_2/He. The main diagnostic is time-dependent spectroscopic measurements radiation emitted and absorbed in the wake of the shock-wave with a streak camera/spectrometer setup located a test section of the shock tube. Since there is an uncertainty on the arrival of the shock-wave at the test section an accurate trigger system is essential for the appropriate operation of this diagnostic. The ESTHER streak camera trigger system proposes the use of four piezo-sensors to measure the rise in pressure at different locations, a signal conditioning system, a FMC fast ADC converter and a FPGA based development board that will include an embedded microprocessor.

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Dosimetric comparison between proton and carbon ion beams for oncological treatments using Monte Carlo methods

Author: Carlos Correia[None]

Corresponding Author: carlos.e.correia@tecnico.ulisboa.pt

Radiotherapy has been estimated as being beneficial to about 50% of cancer patients. Conventional radiotherapy has inherent limitations due to how photons interact with matter. Particle therapy has a more advantageous dose distribution but its harder to plan. Both protons and carbon ions are currently used to treat patients. Each of this therapy methods has its advantages and disadvantages. The goal of this project is to make a dosimetric comparison between proton and carbon ion beams for oncological treatments.

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Vector fields around black hole spacetimes

Author: Tiago V. Fernandes[1]

[1] *IST*

Corresponding Author: tvfernandes1@hotmail.com

For centuries, a description of the Universe has been searched for. Currently, the most acceptable theory that describes the geometry of the Universe is General Relativity (GR). Tests of GR in weak gravitational fields have been done and corroborate this theory. Now it is the era to test GR in regions of strong gravity: close to black holes, using the data from the observations of Event Horizon Telescope or LIGO (in the future, LISA). Black holes cannot be observed directly. To understand them, it is needed to see how matter behaves around black holes. Focusing on vector fields around rotating black holes (in GR), there is a recent work that decouples and separates the equations of motion for these fields. My work is to apply this formalism to vector fields with more curvature couplings and see which couplings allow for separation and decoupling. Possible numerical calculations might be done for the quasinormal modes of these fields.

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Radioactive hot-spot detection using machine learning algorithms

Author: Miguel Barros[1]

[1] *IST*

Corresponding Author: migueltrbarros@tecnico.ulisboa.pt

Radioactive sources provide many benefits throughout the world, in industry, medicine and science. Accidents involving radioactive sources as well as illicit trafficking in radioactive materials have raised awareness of the nuclear security risks. The main objective of this work is to detect hot-spots with radioactive sources using data acquired by multiple Geiger-Müller counters and geo-referenced by GPS receivers, which involves the estimation of the radioactive sources coordinates and quantification of the energy of each source. The algorithms are based on machine learning algorithms, such as Neural Networks and Deep Learning. Experimental results are expected in old deposits of radioactive ore for uranium production.

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Multi-Higgs Models

Author: Rafael Boto[1]

[1] *Instituto Superior Técnico*

Corresponding Author: rafael.boto@tecnico.ulisboa.pt

The Higgs particle was predicted in 1964 and discovered at CERN on July 2012, earning Higgs and Englert the 2013 Physics Nobel Prize. This is a spin zero particle (scalar), necessary to give masses to the all other massive particles in the Standard Model of Electroweak interactions. But, there is no fundamental reason why there should be only one such scalar. Thus, as one achieves a more precise determination of the properties of the new particle, one should look for which signals there would be of extra particles; the so-called multi-Higgs theories. The project is divided into three phases, with the first two being theoretical analyses of two Higgs models and the third more related to experimental data.

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Charge and time signal modelization in large liquid scintillator detectors; the SNO+ Neutrino Physics Experiment

Author: Joao Antunes[1]

[1] *IST*

Corresponding Author: j.c.l.a.3114@gmail.com

In large volume liquid scintillator detectors scintillation is registered by the large number of the photomultiplier tubes (PMTs) more or less uniformly distributed around the active volume of the detector. For each event the charge and time of the signal arriving is measured at each PMT of the detector. On the base of this information the energy and position of each event is reconstructed and used in further analysis.
In this project, a numerical method will be developed to provide numerical estimations of the charge and temporal signals arriving to detector photomultipliers. The method shall include all the physics

processes associated to light propagation in the detector volume, as emission, absorption/re-emission and scattering without Monte Carlo simulations. Its application to particle reconstruction and identification will be studied. The method is to be applied to the SNO+ detector.

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A biophysical model for the evolution of Portuguese agriculture using artificial learning

Author: Bruno Costa[1]

[1] *Instituto Superior Técnico*

Corresponding Author: bruno.pereira.costa@tecnico.ulisboa.pt

The Portuguese agricultural sector has undergone substantial changes in the last half century as a consequence of increased industrialization and the entry into the European single market. In the near future, new challenges will emerge such as the need to compete with new and emerging markets and to adapt to environmental issues such as climate change and resource shortages, achieving sustainable production. The goal of the thesis will be to help develop a biophysical model for the evolution of Portuguese agriculture that explains how materials, land and energy have been used to produce value for the Portuguese economy, and apply the model to produce forecasts of plausible sustainable pathways for the future of the sector. The work will be carried out at the macro level, taking the entire Portuguese agricultural sector as a whole.
This goal will require the compilation of available time series of land use, resource use and output of the sector, including cropland, forest and animal products. Time series should go back until the 1960's. In case data is missing, the work will involve the application of data filling and extrapolation methods for completing the time series. Using the time series data, the work will involve the application of machine learning/artificial intelligence tools for analyzing hidden patterns in the data and establishing connections between variables. As mechanistic relationships between variables are unknown and conventional statistics is limited by high covariance and indeterminate causality, the application of an advanced toolkit drawn from Physics and Computer Science will attempt to produce clarity regarding the interdependencies between drivers of change and outcomes.
The work will be embedded in the project "Intergenerational Impact of Biophysical Resource use in Portugal Within Planetary Environmental Boundaries". The project will estimate the impact of biophysical resource use by different generations in Portugal and relate that resource use to global environmental boundaries, providing explanatory hypotheses to rationalize observed trends. The project will also estimate what each generation received from the previous generation and left to the next.

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Semiclassical Approximation and Dynamics for Non-Hermitian Operators

Author: Carlos Couto[1]

[1] *Instituto Superior Técnico - University of Lisbon*

Corresponding Author: carloscouto4@gmail.com

The main goal of the thesis will be to obtain a semiclassical description for the evolution of physical systems under non-hermitian Hamiltonian dynamics. Non-hermitian Hamiltonians (NHH) often arise in the effective description of decay processes in open quantum systems. Most notably, in optics, they appear naturally in the study of absorbing or optical active materials that can be modeled by a complex refraction index. In the emerging field of the topological photonics, NHH are now being used to design and control the behavior of light. Recently, a semiclassical treatment of

non-hermitian models and of the evolution of Gaussian coherent states has led to a system of equations describing the approximate semiclassical evolution through the evolution of the center and of the associated metric. They satisfy a system of coupled equations which can be efficiently investigated with methods suggested by geometric quantization. The goal is then to further generalize this formalism for bosons and spin systems under the semiclassical approximation.

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Phenomenology of low-scale neutrino mass mechanisms

Author: Henrique Brito Câmara[1]

[1] *Instituto Superior Técnico*

Corresponding Author: henrique.b.camara@tecnico.ulisboa.pt

The discovery of neutrino oscillations, awarded a Physics Nobel prize in 2015, imply massive neutrinos and lepton mixing, which are not accounted for within the framework of the Standard Model (SM). Therefore, from the theory viewpoint addressing this question requires going beyond the scope of the SM. In the last decades, numerous models have been put forward to explain the origin and smallness of neutrino masses. The most popular ones are those based on the seesaw mechanisms, in which new particles are introduced. In this work, we are interested in studying the phenomenology of the inverse seesaw (ISS) mechanism. Its main advantage lies in its testability, since it can be regarded as a low-energy neutrino mass mechanism. This opens the possibility of the detection of direct new physics signals at experiments like the Large Hadron Collider, and those searching for lepton number violating processes. Different ISS realisations are possible depending on the number of extra singlet fermions added to the SM. Our analysis of this mechanism will start with the identification of the scenarios that reproduce current experimental neutrino oscillation data and lepton mixing. The next step is to study their associated phenomenology comprised of rare processes, experimental signals and further low-energy effects.

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Pentaquarks in QCD

Author: Madalena Lourenço[None]

Corresponding Author: madalena.lourenco2343@gmail.com

For many decades after the invention of the quark model by Murray Gell-Mann and, independently, George Zweig in 1964, there was no evidence that hadrons are formed from anything other than the simplest combinations of quarks and antiquarks: mesons are formed of a quark-antiquark pair and baryons of three quarks. In the last decade, however, in an explosion of data from hadron colliders, there are many recently observed states that do not fit into this picture: exotic hadrons.
They can be explained if the new mesons contain two quarks and two antiquarks (tetraquarks), while the baryons contain four quarks plus an antiquark (pentaquarks). The theoretical explanations for these states take two divergent tracks: tightly bound objects, just as in the case of normal hadrons, but with more constituents, or loosely bound "molecules" similar to the deuteron, but formed of a meson and a baryon.

The goal of this thesis project is to calculate pentaquark states in QCD within the Dyson-Schwinger/Bethe-Salpeter formalism and make predictions for this observed LHCb states made of light and charm quarks. The main objective is to numerically solve a two-body equation for a meson-baryon system which couples the relevant channels in the equation. In contrast to other approaches, the interaction between meson and baryon is not an effective particle exchange but a genuine quark exchange, which follows from the five-body equation for the pentaquark system.

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Automatic characterization and calibration of a superconducting quantum processor capable of error correction

Author: Victor Negîrneac[None]

Corresponding Author: victor.negirneac@tecnico.ulisboa.pt

Quantum processors are carefully designed under models that involve certains approximations and are later translated into solid state fabrication steps with their own limitations. Therefore the parameters of a (superconducting) transmon qubits will deviate from the ideal design and require individual characterization (e.g. qubit excitation frequency, associated resonator frequency, coherence time, dephasing time, etc.). Beside that, the complex circuit quantum electrodynamics between the components of the superconducting chip make necessary to calibrate the operations (quantum gates) and measurements that are applied to the qubits through engineered microwave pulses, including individual pulse tune-up for each qubit.
The characterization and calibration of the current state of the art transmon based quantum processors are executed mostly "manually" or "semi-automatically" by the experimentalists. With the scaling up of the number of qubits the manual approach would slow down the research and development of the quantum processors. Furthermore, in the long run such procedures will not be viable at all for a large scale quantum computer. Therefore, it is of high value to be automated. It will tackle as well the need of recurrent calibrations, that can arise due to slight variations of the experiment conditions, or even device aging.
Next, with a fully characterised and calibrated processor, follows a natural step on the roadmap of a fault tolerant quantum computer: to demonstrate an error correction capability of the current processor.

The specific goals of this project are to automate the characterisation of a 7-qubit quantum processor and the calibration of high-fidelity operations (two-qubit gates in particular) and measurements on it; and, time permitting, demonstrate a quantum error correcting code on the processor.

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First Experimental Campaigns at FAIR: Heavy Ion Tracker Systems Based on Scintillating Fibres

Author: Beatriz Pereira[None]

Corresponding Author: beatrizcpereira@tecnico.ulisboa.pt

Nuclear reactions have been a powerful tool to study and understand the fundamental properties of nuclei, as well as the governing nuclear force. This is possible due to nuclear and particle detectors that have been developed and adapted to correctly and as completely as possible characterize the nuclear reactions under study. They can provide useful information such as particle position and energy, among others, depending on their intrinsic characteristics. One of these detectors, commonly used in the characterisation of nuclear reactions at very high energies (relativistic energies) are scintillation fibres, which are the main topic of this dissertation.
The aim of this work is to investigate the response, performance and properties of scintillating fibres used as tracker detection systems for heavy ions at relativistic energies, taking as reference the R3B experiment. The properties of the fibres will be studied, such as the geometry and the impact of coating fibres with aluminium to avoid crosstalk between fibres. Thus, study the impact of the final detection efficiency and position resolution in the detector.

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Development of a Magnetic Camera for Bio-imaging

Author: Francisco Matos[None]

Corresponding Author: francisco.de.matos@tecnico.ulisboa.pt

With limited scaling and high costs of current magnetic-marker based medical diagnostics, strides have been made to adapt magnetoresistive devices to areas where traditionally used devices such as superconducting quantum interference device (SQUID) magnetometers, impose conditions with either limited usage range or increased complexity and expense of such systems. By developing a tunnel magnetoresistive (TMR) sensor and adapting a magnetic scanner equipped with an older generation giant magnetoresistive (GMR) sensor, a mapping of magnetic nanoparticles can be accomplished, allowing detection of marked cells.

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Orbit transfers between three-dimensional Keplerian orbits

Author: Mariana Sá[None]

Corresponding Author: asanairam_95@hotmail.com

In the latter half of the 20th century, rockets were developed and overcame the gravity force. Thus, the space exploration era had begun: in 1957, the first human-made object to orbit the Earth, the satellite Sputnik 1, was launched and in 1961 the first human space flight occurred. After that, many other missions took place and others are still currently in progress, such as the famous Hubble Space Telescope, launched in 1990.
However, there is still much work to do regarding space exploration and a fundamental part of that is the application of orbital maneuvers, i.e., the transfer of a spacecraft or satellite between orbits. This is a problem of high complexity and many new strategies of transfers have been developed, involving optimization criteria to minimize the costs and the transfer time.
The goal of this project is to design new strategies of orbit transfers of satellites between three-dimensional two-body Keplerian orbits, starting at any instant or point in the orbit, based on different optimization criteria. Firstly, it will be studied the transfer in the plane of the orbit and then we will proceed to a three-dimensional problem. This will be done controlling the constants of motion of the Kepler problem.

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Design and analysis of a new calorimeter for inline characterization of solar concentrating collectors working fluids

Author: Plamen Avramov[None]

Corresponding Author: plamen.avramov@hotmail.com

There is a need for a fast change of the global energy resource model as we've known for some time that fossil fuels are no longer a viable solution either for the future or for the environment well fare. Among other renewable energy sources Concentrating Solar Energy (CSE) is a very promising one due to its particular features namely its dispatchability. A brief introduction to different concentrating solar technologies is made. The great majority of solar concentrating systems use some kind of heat transfer fluids (HTF). Its choice depends on their favourable thermodynamic behaviour and operation range.
Knowledge and control of their thermophysical properties are mandatory during operation as they tend to degrade over time and data from manufacturer becomes unreliable. The level of certification is very important to have a thorough knowledge of the HTF properties for a rigorous calculation of the collectors'performance. This report presents a revision of the literature of HTF and calorimetry and a proposal and methodology for the development of a new improved inline calorimeter.

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Blockchain-based automatic energy efficiency model for performance contract implementation

Author: Pedro M. F. Sismeiro[None]

Co-authors: Carlos Augusto Santos Silva ; Ilídio P. Lopes

Corresponding Authors: pedro.air14@hotmail.com, ilidio.lopes@tecnico.ulisboa.pt, carlos.santos.silva@tecnico.ulisboa.pt

Energy Service Companies frequently resort to Energy Performance Contracts to finance improvements and projects on energy efficiency, assuming performance and/or credit risk. Nowadays, there's lack of trust between parties when calculating cost savings and the expected deliverance of these projects, since the auditing methods are developed and implemented by the ESCOs to a generally unskilled market. The goal of this thesis is to develop an automatic central authority that can handle these energy transactions in a fast, independent and efficient energy market, using Blockchain technology, thereby guaranteeing security, transparency and standardization. As an extra feature, an energy consumption forecasting model is used both as an auditing method and as a mean to improve energy efficiency on all IST buildings.

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Integrated UV Sensors in Microfluidics for Biosensing

Author: Cristina Rosa[None]

Corresponding Author: cristinamartarosa@tecnico.ulisboa.pt

Microfluidic devices integrated with a sensor for biological to electrical signal transducing provides a miniaturized, cost effective, quicker and portable solution for point-of-care biological analysis systems with applications on biomedical, environmental and food safety fields. The fact that the transducing mechanism that will be developed during thesis does not require biomolecules labelling,as fluorophores, provides the benefit of not altering the native characteristics of the biomolecules.
In this thesis an hydrogenated amorphous silicon p-i-n photodiode will be optimized and integrate it in a microfluidic structure for biodetection based on UV absorbance. In order to perform biodetection at low light absorption levels,the focus will be on the optimization of photodiode design, signal processing and circuit configuration.

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Experimental characterization of pedestal density fluctuations and correlation with pedestal evolution on JET

Author: Daniel Costa[None]

Co-author: Carlos Silva

Corresponding Author: daniel.l.costa@tecnico.ulisboa.pt

Electromagnetic and electrostatic fluctuations with a broad range of frequencies are commonly observed between Edge Localized Modes (ELMs), disruptive events that affect performance in all fusion devices. This work aims to explore the correlations between the pedestal density fluctuations and the pedestal evolution, during the inter-ELM phases of many discharges at JET.
Discharges with variation in parameters such as density and plasma current will be analyzed, allowing the investigation of the correlation between the onset of the fluctuations with the pedestal parameters (electron temperature, density and their gradients).
The evolution of the instabilities and pedestal parameters for the many discharges will be compared

to the EPED model (leading model for pedestal structure prediction) to check for consistency. These studies may contribute to a better understanding of the pedestal evolution.

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Entanglement Signatures of Random Quantum Circuits

Author: Beatriz Dias[None]

Corresponding Author: beatrizcd97@gmail.com

Systems in equilibrium, whose observables are time independent, are generally well understood. For quantum systems out of equilibrium, the time evolution is highly complex and so there is no general method nor as many tools available. Due to the lack of theoretical approaches, it is of fundamental importance to find universal properties and systematic ways to describe non-equilibrium dynamics. The dynamics of systems with many degrees of freedom is of particular interest, having technological applications such as quantum computers.
Quantum dynamics generates complex highly entangled states hard to treat analytically without introducing additional structure, such as conservation laws. Random quantum circuits provide a minimally structured model for generic quantum dynamics, allowing to probe universal behaviours and scaling forms. A random quantum circuit consists of a discrete set of local operations, involving only a few degrees of freedom, that are applied randomly both in space and time.
The general goal of this thesis on "Entanglement Signatures of Random Quantum Circuits"is to understand generic features of universal and non-universal quantum dynamics. This is going to be done by considering quantum circuits as toy models for quantum dynamics, with random and Clifford gates respectively for the universal and non-universal cases.

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Asteroseismology: Tracking the cooling curve of white dwarfs

Author: Fernando Lima[None]

Corresponding Author: fernandov.lima@hotmail.com

Recently the Corot and Kepler satellite missions have discovered sun-like oscillations in more than a few tens of thousands of stars. This large amount of data has the potential of revolutionizing our understanding of the internal physics of stars in the main-sequence, sub-giant and red-giant phases. Equally the forthcoming stellar planetary mission Plato will extend the potential for discoveries in stellar astrophysics even further.
This study will focus on the computation of the evolution models and the spectra of oscillations of pulasational white dwarf stars at critical stages of their evolution along their characteristic cooling curves. These models will be done using high precision numerical codes of stellar evolution and stellar oscillations. Equally when possible, an analytical model is to be used in order to interpret the theoretical data sets and check the theoretical predictions against real astronomical data. Additionally, predictions for the forthcoming Plato mission are to be performed.

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Growth of Noble metal Au-Nano Particles into selected Dielectric Matrices

Author: Ana Ribeiro[None]

The main focus of the proposed project is on the research of the optimal conditions for the growth of noble metal, Gold (Au), Plasmonic nanoparticles (NPs), into selected dielectric matrices, as transition metal oxides. The ultimate goal will be the development of an optical biodetection system, able to detect low concentrations of Biomolecules.
The used undoped matrixes will be deposited by conventional methods as magnetron sputtering. The semiconducting/dielectric films will then be ion implanted at Laboratório de Aceleradores e Tecnologias de Radiação do IST. The beam power density will be optimized to minimize the heating effects during the implantation. All the Au-doped matrixes will be then annealed at different temperatures to promote the coalescence of the implanted ions into nanoparticles inside the matrix. Different annealing procedures (temperature vs. time) and fluences will be studied to find the ideal process to grow the nanoparticles with different distributions and dimensions.

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Real-time radionuclides detection using artificial intelligence

Author: Filipe Mendes[None]

The objective of this work is to detect and identify in real-time the radionuclides contained in gamma ray spectrometric data acquired during expeditions in outdoor scenarios. The algorithms are based on artificial intelligence techniques, such as Neural Networks and Deep Learning. The gamma ray spectrometric data can be simulated or acquired by a Micro-sized Gamma Spectrometer, based on a CdZnTe (CZT), with sources in the laboratory or in a real scenario. In outdoor scenarios, the CZT is synchronized with a GPS receiver. The radionuclides must be identified and georeferenced.

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Evolution Of Cooperation through Opportunism and Trust

Author: Carlos Miguel Garrido[1]

[1] *Instituto Superior Técnico*

Corresponding Author: carlos.garrido@tecnico.ulisboa.pt

Empirical evidence highlights the importance of different forms of institutions for Human cooperation and collective action to thrive. It remains, however, disputed which types of incentives are more likely to prevail and evolve in nature and societies. In this thesis the stochastic evolution of different classes of institutions based on distinct types of incentives will be investigated. This problem involves Markov processes of significant complexity, which will lead to the development and application of a hierarchy of analytical approximations. The methods developed will be general enough to be applicable to a wide range of discrete Markov processes with time-invariant transition probabilities and a large number of states.