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Instituto Superior Técnico

Book of Abstracts

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Noise Analysis in Vortex Tunnel Magnetoresistance Sensors

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The Tunnel MagnetoResistance (TMR) effect has been seeing extended use from magnetic read heads of hard disk drives to memories, logic/spintronic devices or magnetic field imaging. One of the major applications is in magnetic sensing, specially in industry where magnetic sensors have been used in compass, biomedical, automotive and aerospace applications. The most popular design of these magnetic sensors is the spin valve, composed of 3 layers: the pinned layer which is a ferromagnetic layer with a fixed magnetization; the free layer which is another ferromagnetic layer but it's magnetization is influenced by external magnetic fields; separating both of these layers we have an oxide, the insulator, which will act as the barrier to the tunneling effect. The TMR effect states that the electrical resistance of the spin-valve will vary accordingly to the angle
between the magnetization of both of the ferromagnetic layers.
A good magnetic sensor has high dynamic range, accuracy and sensibility, i.e., a high Signal to Noise Ratio (SNR) in all operating frequencies. In 2015, a new sensor design with a disk shaped free layer was pattented; this new shape, material properties and the right dimensions allow for the formation of a flux-closed vortex magnetization state when small or no external fields are applied. These sensors show negligible hysteresis and saturate at high magnetic fields increasing, in general, the SNR and the dynamical range of the device.
In my Master's thesis I yearn to build, with the help of INESC-MN facilities, these sensors and study their various parameters in order to achieve a high SNR design.

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Universal Properties of Non-Markovian Dissipative Quantum Systems

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The development of quantum computers and quantum electronics is hampered by our understanding of their quantum coherence properties. As these are open quantum systems, their evolution depends on how they interact with the environment. Unfortunately, this is notoriously hard to model. One commonly used approximation is to consider memory-less environments. In this so-called Markovian approximation, the evolution of the system can be given in closed form which greatly simplifies the analysis. However, this approach fails in many relevant situations, such as transport setups and for noisy intermediate-scale quantum computers. Moreover, it is impossible to completely specify the environment due to its complexity and large number of degrees of freedom. Nevertheless, for the Markovian case, universal properties were recently shown to emerge. In this work, we aim to determine universal signatures of non-Markovian dissipative systems by applying random matrix methods to study their spectral and steady-state properties. We will focus on quadratic systems where an exact solution can be found using non-equilibrium Green's function methods. We aim at identifying how the departure from Markovianity modifies the universal properties of the ergodic regimes identified in the Markovian case. In particular, we shall establish how the system-bath coupling and the thermodynamic features of the environment affect spectral and steady-state properties.

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Startup channel of a FISSIONIST

Author: Luís Cabral[1]

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FISSIONIST will be a simulator of a small nuclear reactor, using a control system of the Portuguese Research Reactor (RPI) with signal generators replacing the neutron detectors. My task is to make operational the start-up channel of FISSIONIST, programming the output of an Arbitrary Function Generator to reproduce the signal of a fission chamber as a function of the position of the control rods of the reactor

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The role of competition in the diffusion of misinformation

Author: Miguel Félix[1]

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Information spreads across social networks much like a colony of organisms that grows exponentially. And just like organisms compete for resources, information competes for human attention. In this project we compare the diffusion of real news and of misinformation, using a simple model that takes inspiration from biological and physical processes. We call cascade the set of copies of information derived from a single source. In our case, we are analyzing Tweets and therefore a Twitter cascade is a set of re-tweets of an original message.
In the simplest version of our mode, the growth of the information cascade follows an adapted geometric random walk, given by:
dN(t)/dt = a * exp(-gt+ε),
where N(t) is the size of the cascade at time t and a and g are fitted parameters that capture the competitive ability or fitness of the piece of information. Randomness is captured by the parameter, which has a Gaussian distribution. The two fitted parameters represent different aspects of the process: a measures the appeal of the information when it is first introduced in the social network, while g captures the rate of loss of importance as time passes.
This simple model was shown previously by our group to effectively capture the growth of twitter cascades. We will now apply it to misinformation and expand the model to explicitly account for competition between tweets.
In parallel, we will also apply this competition model to diffusion on a social network. We will ask how relevant the properties of the network are to the spread of misinformation. Since there is no precise analytical solution to growth on a network, we will make use of Monte Carlo simulations, combined with Bayesian methods to estimate the best fit for the model parameters. In the case of the network, the probability that a node (a person) shares a given piece of information is given by:
p(share) = a' * exp(-g't+ε),
where a' and g' are fitted for each cascade and are this model's equivalent to the parameters described above.
With this analysis, we expect to better characterize the differences in the spread of fake and real news, across different topics. We can then devise better strategies to stop the spread of misinformation.

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Axions in plasmas: from active production to dark matter candidates

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Axions are hypothetical particles proposed as an elegant solution to the strong CP problem in the Standard Model. However, they were soon discovered to be very well-motivated dark matter candidates due to their low interaction with photons and ordinary matter. More recently, there has been a hype around axions in the context of Plasma physics. It was shown that their interaction with the quanta of plasma oscillations (plasmons) forms a new quasiparticle, the axion-plasmon-polariton, and together with the use of dynamical instabilities to excite electron waves in plasma, we can exploit this new mode to bring about new axion detection schemes that are highly competitive in comparison with current experiments. In this work, we will attempt to discover which dynamical instability yields the best axion-photon conversion rate while re-writing this semi-classical theory in a brand new formalism within the framework of Quantum plasma dynamics.

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Magnetic sensor (TMR) design and fabrication optimization using artificial intelligence

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The demand for advanced sensing technologies in industries like automotive, robotics, medical imaging, and data storage has elevated the importance of magnetic sensors. Among these sensors, tunnel magnetoresistance (TMR) sensors have emerged as crucial components due to their exceptional precision in detecting and measuring magnetic fields.
TMR sensors possess attractive features such as increased sensitivity, a larger signal-to-noise ratio, lower power consumption, and better compatibility with miniaturization. These qualities make them highly desirable for high-performance sensing applications.
However, designing and fabricating TMR sensors involve complex tasks that require careful consideration of numerous parameters, materials, and manufacturing processes. Traditional approaches relying on empirical methods and extensive experimentation tend to be time-consuming and often yield suboptimal results. To overcome these challenges, the integration of artificial intelligence (AI) techniques, specifically machine learning and optimization algorithms, is proposed to accelerate the design and fabrication optimization of TMR sensors.
This master's thesis aims to experimentally converge TMR sensor fabrication with AI predictive models, with a focus on leveraging AI techniques to advance the design and fabrication processes. The research is centered around two key objectives: characterizing each fabrication step to assess their impact on sensor yield and alignment with design specifications, and utilizing AI algorithms to identify optimal parameter configurations for enhancing specific fabrication steps. By integrating AI methodologies, this study aims to enhance the overall performance and reliability of TMR sensor fabrication processes, providing more efficient and effective approaches to meet the evolving requirements of modern industries.

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How to build a quantum computer with superconducting qubits

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Quantum computing has emerged as a promising paradigm for solving computationally challenging problems. Superconducting qubits have garnered significant attention due to their scalability and potential for achieving fault-tolerant quantum computation. In this project, I discuss the basic theoretical and experimental requirements for creating a quantum computer using superconducting qubits. From the physics of a single qubit and the fabrication of a single Josephson junction to the material and architectural challenges involved in fabricating a full quantum processor. To progress

from the current noisy intermediate-scale quantum (NISQ) era to a stage where quantum computing is utilized for solving real-world problems, quantum processors must scale to millions of qubits. This can be achieved through hybrid systems that incorporate technologies beyond superconducting circuits or through the implementation of modular architectures.

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All-glass metasurfaces for ultra-high power lasers

Author: Beatriz Oliveira[1]

[1] *INESC MN*

The field of photonics focuses on our ability to generate, manipulate and detect light. The technologies that allow us to shape light properties have been improving, but there are still many physical and engineering obstacles preventing a more rigorous and precise control. Recently, the rise of nanophotonics has introduced the possibility of tailoring light-matter interactions at the nanoscale. In fact, the fabrication of optical materials with nanostructures has made it possible to shape the light's wavefront in amplitude, phase and polarization. Meanwhile, although the field of high-power lasers is already serving several applications, the existing optics for manipulating these lasers are still significantly limited, relying mostly on bulk optics, such as lenses and dielectric mirrors, which only provide a basic control of light. Metasurfaces are planar materials patterned with engineered arrays of nanostructures, consisting of subwavelength unit cells. When tailored specifically for high-power lasers, they could help us overcome these limitations, enabling a complete manipulation of structured light in the realm of intense electromagnetic fields. This thesis proposal aims to demonstrate such nanophotonic
technology and demonstrate high-power structured light lasers. To achieve this goal, we will develop a class of dielectric metasurfaces, primarily consisting of fused silica glass, that are specifically designed to have a high laser damage threshold. Solving this challenge will open the door to new possibilities in high-power laser microscopy, ultrafast laser machining, compact laser-plasma particle accelerators, and several other scientific
and technological domains.

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Schwinger Pair Production in AdS2 geometries.

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A well-known effect in Quantum Electrodynamics (QED) is the Schwinger pair production effect, describing the rate of production Γ of e+ e− particles out of the vacuum in a constant background electric field. This effect also occurs in curved space-times in the presence of an electric field, an example of which is the Schwinger effect in a two-dimensional Anti-de Sitter space-time (AdS2) with a constant electric field. The importance of the AdS2 space-time lies in the fact that the near-horizon geometry of asymptotically flat extremal black holes in four space-time dimensions takes the form of a product geometry AdS2×Sˆ2 and is entirely determined in terms of the electric-magnetic charges carried by the black hole. We study the pair production of charged particles in these AdS_2×Sˆ2 geometries with a view to gaining new insights into extremal black hole entropy and its subleading corrections.

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Quantum Hacking

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Quantum Key Distribution (QKD) is a quantum communication method that provides a provably secure way to share secret keys between users. Although QKD protocols are theoretically secure, their practical implementation is never perfect and since most security proofs for QKD protocols stand on assumptions made about the setup's devices, this compromises security. Side channel attacks are a type of attack on a cryptographic system which explores the weakness of its physical implementation, rather than problems in the devised algorithm. Studying new vulnerabilities of QKD systems is a crucial step towards devising future implementations which are more secure against these types of attacks.
This project will be developed within the framework of the European Project QSNP - Quantum Secure Networks Partnership, and it aims to use electronic side-channel analysis to find and study new vulnerabilities of QKD systems, and to develop approaches to quantify these vulnerabilities, distinguishing between the classical and the quantum parts. It will also help to build a quantum communication system at Instituto Superior Técnico.

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Optimization of the Passivation Layer

Author: Mafalda Moniz[1]

[1] *INESC MN*

Nowadays, Biomedical Research and Medicine Clinics are relying substantially more on Lab-on-Chips to overcome daily tasks, such as clinical tests, mixing and separating substances, drug delivery, and so on. Magnetic Flow Cytometry is gaining relevance in these fields and the investigation of this type of cytometry is increasing exponentially in the last few years, including in INESC MN. In this work, we look forward to exploring the dimension's limitations of the Spin-valve sensors that constitute the Lab-on-Chip for Magnetic Flow Cytometry applications with the goal to increase the output signal of the sensor. More concretely, we aim to reduce the Passivation Layer of the nanodevice and test its durability in different environmental conditions. Further in this paper, we present a simulation showing that by reducing the Passivation Layer from 3000 Å to 500 Å the output signal increases almost 10%.

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Numerical simulation of wave dynamics over a multifunctional artificial reef (MFAR)

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A multifunctional artificial reef (MFAR) is an artificial reef structure, typically submerged during most tides, which is designed to tackle a variety of objectives such as coastal protection, ecological habitat enhancement, and improved surfing amenity. For instance, detached submerged breakwaters are a major example of a MFAR. Even though they are primarily used to secure the coastal profile against erosion, a careful optimization of the breakwater design can unlock a broader spectrum of applications, such as important enhancement of wave surfing conditions. This dissertation project aims to conduct numerical simulations of wave dynamics using the COULWAVE and OpenFOAM numerical models, focusing on a feasibility case study of a detached breakwater located in front

of Vagueira's Beach in Aveiro, Portugal. Initially, simple cases, similar to the examples provided with COULWAVE, will be examined, and comparable results are anticipated to be reproduced using OpenFOAM. Subsequently, the focus will shift towards improving wave breaking and overall surf amenity at Vagueira's Beach. This will involve calibrating the models using physical model data obtained by Mendonc¸a et al. (2022), who conducted tests to evaluate wave breaking conditions at Vagueira's Beach in various scenarios. The objective is not only to replicate these results but also to consider new design configurations for the breakwater, such as different profiles, angles, or a V-shaped reef, to assess their potential for enhancing surf conditions at Vagueira's Beach.

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Towards hyperboloidal numerical relativity with the Einstein Toolkit

Author: Diogo Miguez[1]

[1] *CENTRA*

The Einstein Field Equations are a set of non-linear partial differential equations that lie at the core of the theory of general relativity. Numerical relativity focuses on solving these equations using numerical methods and simulations. A major research topic in this area is the computation of gravitational waveforms generated by compact binaries at a spacetime region called future null infinity. This is a region in asymptotically flat spacetimes (spacetimes with zero cosmological constant) where outgoing null rays converge to and, ideally, we can place earth there in our simulations, since the practical use of these simulated waveforms is to compare them to the ones we get on earth coming from very distant astrophysical sources. In this project we will include future null infinity in our computational spacetime domain using a technique called hyperboloidal compactification and we will solve some toy models including (i) the hyperboloidal wave equation in Minkowski and Kerr spacetimes, (ii) non-linear wave models in Minkowski spacetime and (iii) linearized GR on hyperboloidal 3d slices.

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Search for CP violation in H->bbγ decays at ATLAS

Author: Carolina Costa[1]

[1] *LIP*

The Standard Model of Particle Physics is a theory that describes the fundamental particles and how they interact. Although being a well-accepted theory, there are phenomena that the Standard Model of Particle Physics cannot explain, e.g. the baryonic asymmetry, indicating that it must be part of a broader theory. By probing the Higgs sector experimentally and looking for discrepancies compared to the Standard Model predictions, physics Beyond the Standard Model may be found. It is important to notice that all the properties of the Higgs boson, i.e., all its possible interactions have to be probed experimentally. This work is focused on the study of the H-b-b-γ vertex. In order to proceed with this study, it is necessary to choose the best channel of production to the Higgs decay, from the ones available at the LHC. Due to contradictory results previously obtained, this work intends on determining if the gluon-gluon fusion production channel has enough sensibility for this analysis.