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Book of Abstracts

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Probing Unification Scenarios with Big Bang Nucleosynthesis

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Big Bang Nucleosynthesis (BBN) is an observational cornerstone of the Hot Big Bang model and a sensitive probe of physics beyond it. Although some analytic approximations can be made, a fully consistent analysis must be done numerically, starting with the classic code by Kawano and leading to the recently developed PRyMordial, a publicly available Python code. An example of physics beyond the standard model to which BBN is sensitive are Grand Unified Theory (GUT) models. A self-consistent perturbative analysis of the effects of variations in nature's fundamental constants, which are unavoidable in a broad class of GUT models, has recently been developed. The specific goal of this PIC project is to implement this perturbative approach in the PRyMordial code. This will enable a subsequent use of the extended code to obtain constraints on GUT models using current observations, and also detailed forecasts of improvements expected with next generation astrophysical facilities, such as the ANDES spectrograph for the ELT.

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Descriptive and Predictive Modeling of Chaos in Cold Atom Physics using Explainable Deep Learning

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Ultracold atom clouds have garnered significant attention for their intricate dynamics, which may exhibit chaotic behavior and remain without a comprehensive explanatory framework. This work explores these dynamics in a ^{85}Rb cold atom cloud through the integration of explainable deep learning techniques, given the recent meteoric rise of artificial intelligence (AI). This is employed through the analysis of image series data obtained in a laser cooling experiment in a magneto-optical trap. This study aims to uncover low-dimensional structures and chaotic behaviors within the system by employing convolutional autoencoders and dimensionality reduction methods, along with explainability strategies. Preliminary results reveal evidence of a potential phase transition between stable and turbulent regimes, with further analysis providing critical insights into system parameters. This interdisciplinary approach highlights the transformative potential of explainable AI in elucidating complex phenomena in cold atom physics.

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Transport Through A Critical Magnetic Quantum Dot Away From Equilibrium

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The last decades saw substantial progress in understanding the equilibrium phases and phase transitions of low-temperature quantum matter. These so-called quantum phase transitions host genuine

quantum coherent phenomena that may display exotic properties and phase transitions whose universality classes differ from those of classical systems. However, certain systems —namely electronic transport setups —are inherently out of equilibrium, as they are coupled to different environments (leads) with distinct thermodynamic potentials. Such setups may host energy, charge and spin currents, and must be modeled as non-equilibrium open quantum systems. These bring novel paradigms for studying quantum matter and its phases transitions, with properties not possible under equilibrium conditions. Although these represent new opportunities for fundamental and technological advancements many challenges need yet to be addressed to understand these phases. Recent studies indicate that non-equilibrium conditions can significantly alter the properties of equilibrium stable phases, induce exotic phase transitions, cause heating, and generate novel phases of matter. A comprehensive body of work has addressed the so-called Markovian regime where the memory of the environment is much shorter than the typical system's time scales. Here it was possible to develop field-theoretical models that capture qualitative aspects of non-equilibrium quantum criticality. In a transport setting this regime corresponds to a large bias or high temperature. The non-Markovian regime, which connects known equilibrium results to these extreme conditions, and is especially relevant for low temperature electronic systems at small bias, remains widely unexplored. Recent analyses of simplified models have shown that critical fluctuations influence current noise, suggesting this quantity could serve as a probe for non-equilibrium quantum criticality. However, the explored models are often limited in experimental relevance, and a field-theoretical understanding of the transition beyond Gaussian fluctuations is still lacking.

The current project aims to fill in some of these gaps by investigating non-equilibrium phase transitions in a voltage-biased magnetic quantum dot. This model is directly relevant to understanding the transport and magnetic properties of quantum spintronic devices in systems near criticality. Specifically, we aim to develop a theoretical framework in terms of the quantum dots' collective degrees of freedom as they undergo a quantum phase transition under an applied bias voltage.

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Real-Time Beam Monitoring Based on Cherenkov Effect for FLASH Radiotherapy

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In 2021, cancer was the second leading cause of death in the European Union, representing more than 20% of the total number of fatalities, according to Eurostat. Even though there are several treatment options, such as chemotherapy, surgery, and radiotherapy, there is no single, fully effective treatment.
Radiotherapy (RT) is one of the most used therapies worldwide, accounting for more than 50% of prescribed therapies. However, it induces several undesirable side effects, such as nausea and skin irritation, which affect the patient's quality of life. But what if we could minimize them?
In 2014, researchers used high dose rates to deliver the radiation in less than a second to mice and concluded that they could achieve the same results on tumour control while sparing the healthy tissue –the so-called FLASH Effect. This resulted in a new and promising field of research, FLASH Radiotherapy, called by some the Holy Graal of cancer treatment. However, the full implementation of FLASH in the clinic poses several challenges for physicists, since it requires unprecedented beam currents to achieve FLASH dose rates and fast beam monitoring. This thesis has the bold purpose of addressing this last limitation using a Cherenkov-based detector, thus bringing FLASH one step closer to transforming cancer treatment and tackling one of modern medicine's most formidable challenges.