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A Jornada Acadêmica Científica do CBPF, evento organizado pela Associação dos Pós-Graduandos (APG) em parceria com a Coordenação de Formação Científica (COEDU), tem como objetivo promover a integração dos alunos de pós-graduação à comunidade científica do CBPF. Nesta edição, os estudantes do 3º ao 7º período de doutorado apresentaram palestras sobre os trabalhos desenvolvidos em seus processos de pesquisa. O evento constitui um excelente momento para discutir novas ideias e promover a troca de experiências entre todos os participantes.

Gostaríamos de agradecer à Coordenação de Formação Científica (COEDU) e ao Comitê da Pós-Graduação pelo esforço e dedicação; à Direção do CBPF e ao Núcleo de Comunicação Social (NCS); aos funcionários, técnicos, pesquisadores e membros do CBPF. Por fim agradecemos às agências de fomento CAPES, FAPERJ e CNPq pelo apoio à ciência.

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ALLAN R. C. GONZAGA
EDUARDO M. BITTAR - ORIENTADOR

Exploring Charge Density Wave (CDW) and Superconductivity through Uniaxial Pressure

Several efforts have been made by the condensed matter physics community to study charge density waves (CDWs) through correlations between physical and electronic properties in materials. CDWs are modulations in the density of conduction electrons due to a periodic lattice distortion, resulting in energy gaps in the electron spectrum. A deeper understanding of these phenomena is essential for unraveling the interplay between charge order, superconductivity, and magnetism, as well as for exploring potential applications in nanoscale devices and quantum technologies. An effective way to investigate the correlation between CDWs and the crystalline structure of materials is to study the response of the electronic structure to uniaxial pressure. While hydrostatic pressure induces general (electronic and structural) changes across all three spatial dimensions, uniaxial pressure generates anisotropic differences, enabling direct comparisons. Although the strain technique is well-established in the literature, its use is still concentrated among a few research groups outside of synchrotron light sources. By the end of 2024 we finished the CBPF setup for uniaxial pressure studies in bulk materials through DC resistivity and AC susceptibility measurements. The strain cell and probe were acquired from Razorbill, while the electronics and programming for the measurement routine were developed by our group using CBPF equipment. With this setup, we hope to contribute to the advancement of this field in the literature and promote a better understanding of the correlations between crystal structure and electronic properties, encouraging new collaborations and research in the field of condensed matter. The materials currently being studied are presented along with potential directions for future investigations.

ALVARO ANDRES MARTINEZ BURBANO
GABRIEL AGUILAR - ORIENTADOR

Rio Quantum Network

The arrival of second-generation quantum technologies will undoubtedly revolutionize the areas of communication, sensing, and computing in the near future. With the emergence of Shor's algorithm and the race among various players to develop a scalable quantum computer, a threat arises to the security of current cryptographic systems based on integer factorization, since this algorithm allows for the factorization of prime numbers exponentially faster than a classical computer, thus compromising the RSA (Rivest–Shamir–Adleman) cryptosystem, which is based on integer factorization. In this context, the field of Quantum Key distribution (QKD) emerges as a solution capable of guaranteeing security based on the fundamental laws of physics. Although several protocols have been implemented, their large-scale deployment presents significant technological challenges, especially over long distances. In recent years, the Twin-Field QKD (TF-QKD) protocol has emerged as a promising alternative because it overcomes the fundamental attenuation limit in optical fiber (PLO limit), achieving a key rate that scales as $R \propto \sqrt{\eta}$ in contrast to the conventional linear dependence $R \propto \eta$, where R is the key generation rate and η is the efficiency of the optical channel. This positions TF-QKD as a leading candidate for implementation in long-distance and metropolitan areas networks. In this work, we present the implementation of the TF-QKD scheme in the Rio de Janeiro metropolitan area, with the aim of evaluating its experimental feasibility and performance under real-world conditions in an urban optical channel.

AMANDA FARIAS DOS SANTOS
BRUNO MORAES - ORIENTADOR

Investigating cosmological biases due to errors in the shape of observed tomographic redshift distributions

The Rubin Observatory Legacy Survey of Space and Time (Rubin LSST) is a 10-year optical survey that will map most of the southern sky, with a central goal of improving our understanding of dark matter and dark energy. To achieve this, it focuses on “3×2pt” analyses, which combine galaxy clustering and weak lensing measurements to constrain cosmological parameters. One of the key challenges in this type of analysis is ensuring that galaxy redshift distributions are accurately characterized. Errors in the shapes of these distributions can propagate into cosmological parameter estimates, introducing potential biases that can falsely mimic new fundamental physics or create tensions with other types of cosmological experiments. This project aims to perform a controlled investigation of how realistic distortions in the shapes of redshift distributions affect cosmological parameter values. We use state-of-the-art simulated galaxy catalogs specifically tailored to represent the quality of LSST data. We build paired sets of true redshift distributions (directly from the simulations) and observed distributions obtained by running the photometric redshift estimator FlexZBoost on a representative training sample. We use these pairs to generate $C(l)$ data vectors and covariance matrices and run full cosmological pipelines, quantifying the resulting parameter shifts with the Fisher-bias formalism. Starting from an idealized benchmark with a fully representative training set, we progressively introduce realistic degradations to isolate each effect on the redshift distribution and, consequently, on the inferred cosmological parameters.

AMANDA GUERRIERI MELCHIOR
RAISSA F. P. MENDES - ORIENTADOR

Radial Oscillations of Viscous Neutron Stars

Neutron stars are compact objects endowed with extreme densities and gravitational fields. During dynamical events, such as mergers or oscillations, the stellar fluid can be driven away from local thermodynamic equilibrium, making the inclusion of dissipative processes such as viscosity and heat conduction necessary. Therefore, we may need a description that goes beyond the perfect-fluid model and considers dissipative relativistic hydrodynamics. In this work, we considered a background solution described by a perfect fluid, complemented with a cold equation of state (EOS). Then, we introduced linear radial perturbations in the background solution, where the dissipative effects were described by first-order fluid quantities. Among the existing theories for relativistic dissipative fluids, we employed the Navier–Stokes and the Israel–Stewart prescriptions to complement Einstein’s system of equations. As a result, we obtained a system of equations that fully describes the evolution of linear radial perturbations, encompassing first-order corrections associated with bulk and shear viscosity, including energy dissipation through the first-order heat flux. To isolate the specific role of viscosity and obtain a tractable master equation for the fluid perturbation, we subsequently limited the analysis to the case of negligible heat flux. Our numerical results reveal a rich mode spectrum where non-hydrodynamic modes emerge in addition to the perfect fluid’s hydrodynamic modes. Consequently, instabilities in certain cases may be dictated by these non-hydrodynamic modes. We are currently incorporating heat flux, which requires solving a different coupled system. We are also extending this analysis to the recently proposed Bemfica–Disconzi–Noronha–Kovtun (BDNK) framework.

BRUNO HONORATO MOREIRA SCORZELLI
ALEXANDRE MELLO DE PAULA SILVA - ORIENTADOR

From plasma to coating: The mechanism leading to Hydroxyapatite crystallization at room-temperature produced by Nd:YAG (532 nm) pulsed laser deposition

The mechanism leading to hydroxyapatite (HAP) coatings with room-temperature crystallinity using Nd:YAG (532 nm) pulsed laser deposition (PLD) is investigated. It is demonstrated that kinetic energy transfer from the ablated material to the coating surface is not the mechanism responsible for the phenomenon, as previously suggested in the literature. Time-of-flight measurements and Grazing Incidence X-ray Diffraction revealed that it is possible to control crystal formation without altering the kinetic energy of the ablated materials. Concurrently, it is also shown that altering the kinetic energy doesn't necessarily impact HAP crystal formation. Furthermore, the impacts of parameter tuning on the physics of the PLD process are determined and correlated with the resulting properties of the coatings. This is achieved using X-ray Photoelectron Spectroscopy to measure stoichiometry and chemical properties, FTIR to determine the vibrational molecular spectra, and by combining these results with SEM images to evaluate surface morphology. Thus, this work discusses how parameter tuning (laser pulse energy, chamber pressure, and laser repetition rate) influences the dynamics of plasma plume propagation and how this change generates different physicochemical properties. The impact of various properties on the biomedical applications of HAP coatings is also presented, allowing control of the desired properties to generate high-performance materials in the context of biomedicine. The mechanism investigated and the framework developed can also be applied to other structurally complex materials.

EDINE SILVA DOS SANTOS
MUCIO AMADO CONTINENTINO - ORIENTADOR

Quasiparticles in the context of topological phase transitions

Topological materials have been extensively explored, motivated by their wide range of potential technological applications. These systems provide a privileged setting for the discovery of quasiparticles. Among the most relevant advances are the study of superconductivity with the emergence of Majorana fermions, as well as Dirac and Weyl semimetals and Fermi points. During the Ph.D., we investigate one- and two-dimensional superconductors with antisymmetric hybridization that exhibit topological phases. We analyze their edge states and topological properties, identifying the parameters that govern the phase transitions. We calculate the topological invariant that characterizes the different phases of the system and construct its phase diagram. We also study the presence of Weyl fermions in topological insulators with antisymmetric hybridization. Since at finite temperatures this system may undergo a dehybridization phenomenon characterized by the appearance of points in the Brillouin zone where the Hamiltonian becomes non-diagonalizable, we are currently investigating this behavior in the context of non-Hermitian Hamiltonians.

FELIPE SOBRERO SORAGE MARQUES
NAMI FUX SVAITER - ORIENTADOR

An entanglement between quantum systems in inertial and non-inertial frames of reference

We discuss the radiative processes associated with two two-level systems (qubits), both initially prepared in their ground states and coupled to a massless scalar field in the Minkowski vacuum. The coupling between the qubits and the field is assumed to be weak, allowing us to treat the problem perturbatively. Since one of the qubits remains inertial while the other co-moves with a non-inertial rotating frame, their final joint state can differ from the initial one, leading to the generation of entanglement. Our main goal is to quantify the amount of entanglement produced as a function of the distance between the qubits.

GUILHERME FERREIRA FRANCO
ULISSES BARRES DE ALMEIDA - ORIENTADOR

The SWGO collaboration: Brazil's leading role in opening the last EM window to the universe.

The Southern Wide-field Gamma-ray Observatory (SWGO) is a collaboration that will build a high-energy gamma-ray observatory in the Atacama Desert, Chile. It will employ an array of Water Cherenkov Detectors (WCDs), covering a ground area of 1 km² (initially) at 4,770 m altitude, which will allow for the detection and reconstruction of air showers—cascades of particles initiated by both cosmic rays (high-energy charged particles) and gamma rays (high-energy photons) in the upper atmosphere. Its design focuses on enabling a precise identification and reconstruction of gamma-ray-initiated air showers, allowing the determination of the energy and direction of arrival of gamma rays over a large area of the upper atmosphere. This enables a statistically significant observation of the very rare Ultra-High-Energy (UHE) gamma rays, which would otherwise be unfeasible through space telescopes due to the required collection area. The location in the southern hemisphere provides an unobstructed view of the center of our galaxy, revealing details of the most energetic physical processes within our cosmic vicinity and deepening our understanding of astrophysical objects and processes, such as how and where cosmic rays are accelerated. Brazil and CBPF have a leading role in this collaboration, with members participating in the working groups and the steering committee. This presentation will give an overview of the collaboration and showcase our role and latest work in its development.

ISAQUE PORTO DE FREITAS
NAMI FUX SVAITER - ORIENTADOR

Hydrodynamic fields in fluctuating environment: a model for heat capacity of simple liquids

Using functional methods, we investigate a simple liquid at low-temperature, the sound quanta defined by the quantized hydrodynamic fields, under the effects of high-energy processes on the intermolecular scale. To obtain excitation spectra of liquids in this situation, we assume that the quantum fields are coupled to an additive delta-correlated in space and time quantum noise field. The hydrodynamic fields are defined in a fluctuating environment. After defining the generating functional of connected correlation functions in the presence of the noise field, we perform a functional integral over all noise field configurations. This is done using a formal object inspired by the distributional zeta-function method, named configurational zeta-function. We obtain a new generating functional written in terms of an analytically tractable functional series. Each term of the series describes in the liquid the emergent non-interacting elementary excitations with the usual gapless phonon-like dispersion relation and additional excitations with dispersion relations with gaps in pseudo-momenta space. Furthermore, the Fourier representation of the two-point correlation functions of the model with the contribution coming from all phononic and new emergent fields is presented. Finally, the behavior of the specific heat as a function of temperature is obtained, providing a theoretical foundation for experiments in simple liquids.

LUIZA MAYARA SANTOS MIRANDA
FRANCESCO TOPPAN - ORIENTADOR

Lévy-Leblond Spinors and Clifford Algebras Structures in Nonrelativistic Quantum Theories

The first-order Lévy-Leblond differential equations (LLEs) are the nonrelativistic analogs of the Dirac equation: they act as square roots of the Schrodinger equation in dimensions $(1 + d)$. While the Schrodinger equation is first-order in time and second-order in spatial derivatives, its square-root formulation allows spinor solutions encoded in Clifford algebra structures. The goal of this work is to present a clear and systematic classification of nonrelativistic spinors in different spatial dimensions. To achieve this, we use a matrix construction called the “alphabetic” method, where all required matrices are generated from tensor products of four fundamental real 2×2 matrices. This approach helps us to understand how the number of spinor components increases with spatial dimension and how different internal symmetries naturally emerge. We also compare two distinct ways of obtaining first-order nonrelativistic field equations: the LLEs, derived as the nonrelativistic limit of the Dirac equation, and a construction known as “contraction.” Although both produce equivalent free-particle physics in simple cases, their mathematical structures differ significantly. This shows that some nonrelativistic systems may not originate from any relativistic theory, revealing the existence of genuinely nonrelativistic models. Furthermore, we analyze explicit examples in low dimensions such as $(1 + 1)$, $(1 + 2)$, and $(1 + 3)$, including cases with external potentials that introduce additional dynamical symmetries. To assist in verifying symmetries and conserved quantities, we use the CDE package in REDUCE, designed for computations with total derivatives and differential operators. This work organizes and unifies the study of nonrelativistic spinors, providing a foundation for future applications in quantum systems with emergent nonrelativistic symmetries, particularly in condensed matter physics.

MARIA LUIZA DE ARAUJO DORNELES
FERNANDO LOUREIRO STAVALE JUNIOR - ORIENTADOR

**Physical and Chemical properties of V2O5 model surfaces investigated by
NAPXPS and IRRAS**

Vanadium oxide is an inorganic compound with the chemical formula V₂O₅, commonly known as vanadium pentoxide. It is a material of great interest due to its electronic and catalytic properties, and it has been extensively studied in the field of surface science. Because of its high oxidation state, V₂O₅ behaves both as an amphoteric oxide and as an oxidizing agent. From an industrial perspective, it is the most important vanadium compound, serving as the main precursor for vanadium alloys and as a widely used industrial catalyst. The formation and termination of its surface layers directly influence its reactivity, making the use of advanced characterization techniques essential. However, some questions remain unanswered regarding the nature of its activity in oxidation reactions and its interaction with various molecules. In this study, we employed Low-Energy Electron Diffraction (LEED) to investigate the surface structure, X-ray Photoelectron Spectroscopy (XPS) to analyze the chemical composition, and Fourier Transform Infrared Spectroscopy (FTIR) to identify the functional groups present. Through these techniques, we aim to understand how V₂O₅ can be used in the adsorption of different chemical species and as a catalyst in reactions such as the conversion of CO and O₂ into CO₂. These studies are fundamental for applications in heterogeneous catalysis and the development of new functional materials.

MATHEUS CURADO FERREIRA
FELIPE TOVAR FALCIANO - ORIENTADOR

Primordial Ghost Collider & Bootstrap

The Cosmological Bootstrap, can establish a solid relation between a quantum field theory and curved spacetimes. For a deSitter (dS) spacetime this framework has already proven promising for calculating correlation functions and quantum corrections associated to particle scattering in the early universe. The entire program has the conformal group as its starting point, for the primordial universe it fits perfectly, if we conceive the primordial universe as being a approximately deSitter universe. This is possible since the isometries of the de Sitter space-time are given by the conformal group $SO_{d+1,1}$. One important result of this method is that it shows how particle production during inflation can affect the signals we observe today. Particles created by the expanding spacetime leave signatures in the distribution of matter, such as specific momentum-dependent features and angular patterns. These signatures carry information about the physical processes that happened during inflation and can be used to study very high-energy physics. Future observations could make it possible to detect these signals more precisely. This would allow us to test ideas about particles that existed during inflation and learn more about how the early universe worked. In our proposal, we study a situation where the usual symmetry is broken. We look at a version of the cosmological collider with a massive ghost particle that breaks Lorentz symmetry. This particle is produced by gravity in a spacetime that is close to de Sitter, but not exactly. If such a particle exists, it could leave a signal that helps us understand the geometry of the early universe and test physics beyond the Standard Model.

MATHEUS DE MIRANDA BALBINO
NAMI FUX SVAITER - ORIENTADOR

Dimensional reduction and the diagonalization method

In the continuous random field Ising model (RFIM), a well-known result in the literature is the dimensional reduction, which is an equivalence between the RFIM in “ D ” dimensions and the Ising model in “ $D-2$ ” dimensions. However, this result remains controversial due to the method used to prove it, which relies on a tree level approximation and to a supersymmetric model. Although the proof is for any dimension “ D ”, the only dimension that this property actually works for is “ $D=5$ ” for the RFIM, “ $D=3$ ” for the IM. Therefore, in light of some recent developments made by the group, we are going to revisit this problem using the distributional zeta function method. This was made possible by the discovery of a diagonalization process that improves the effective action of the RFIM, yielding an action with a Z_2 cross $O(k-1)$ symmetry, a generalization of the usual cubic anisotropic theory. With this effective action, we are able to calculate the critical exponents and compare our results with the existing results in the literature.

MATHEUS MONTEIRO RAMALHO POLTRONIERI MARTINS
RODRIGO COELHO - ORIENTADOR

Force-Induced Ordering Transitions in Vortex Lattices of Active Nematics

Active nematics consist of self-propelled elongated particles that tend to align with their neighbors. Examples include swarming bacteria at high densities and microtubule–kinesin mixtures. When confined, such systems often develop persistent vortices, as observed for instance in bacterial colonies within soil pores, where neighboring vortices can interact and communicate. This work investigates the transition between ferromagnetic and antiferromagnetic ordering in vortex lattices of active nematics. Using Lattice Boltzmann simulations, we explored how an external body force affects the interaction between the vortices. In the absence of a force, the system transitions from ferromagnetic to antiferromagnetic ordering as the gap width between cavities increases. The application of a force induces anisotropy, causing spins to exhibit ferromagnetic alignment perpendicular to the force and antiferromagnetic alignment parallel to it. Furthermore, a sufficiently strong force can suppress antiferromagnetic correlations, resulting in a preference for a purely ferromagnetic state. We derive an Ising-like model to better understand the emergence of these force-induced phases at the mesoscopic scale.

**MUNIQUE EVA PAIVA DE ARAUJO MONTEIRO DE BARROS
ELVIS OSWALDO LOPEZ AND ALEXANDRE MELLO - ORIENTADOR**

**Crystallinity and Stoichiometry Control of Nanostructured SrTi_{0.8}Nb_{0.2}O₃
Oxide Produced at Room Temperature for Application in Efficient Energy
Generation**

Niobium-doped strontium titanate is an n-type semiconductor that presents high thermal stability, high oxidation resistance, non-toxicity and low cost. This oxide material has shown excellent results of thermoelectric efficiency (zT) in bulk structure at temperatures close to room temperature. In addition to these perovskites (ABO₃), they have applications in photocatalysis and photovoltaic cells. However, the production of room-temperature crystalline films of this thermoelectric oxide is rarely found in the international literature. In this work, we synthesized Nb-doped SrTiO₃ thin films by right-angle magnetron sputtering (RAMS) at 180°C. The RAMS system has been widely studied for room-temperature production of thin films of complex crystalline structures, such as hydroxyapatite, ion-substituted hydroxyapatites and cubic tungsten carbide (β -WC). Our goal is to reduce as much as possible the temperature at which the films are produced. The results show a production of crystalline cubic SrTiNbO₃ prepared at 180°C. These results are confirmed by grazing incidence X-ray diffraction (GIXRD), X-ray photoelectron spectroscopy (XPS) and scanning electron microscopy (SEM).

PHÉLIPE ANTONIE D'ARC DE MATOS
CLÉCIO ROQUE DE BOM - ORIENTADOR

Long-Term Optical Follow Up of S231206cc: Multi-Model Constraints on BBH Merger Emission in AGN Disks

The majority of gravitational wave events detected by the LIGO, Virgo, and KAGRA Collaboration originate from binary black hole (BBH) mergers, for which no confirmed electromagnetic counterparts have been identified to date. However, if such mergers occur within the disk of an active galactic nucleus (AGN), they may generate observable optical flares induced by relativistic jet activity and shock-heated gas. We present results from a long-term optical follow-up of the gravitational wave event S231206cc, conducted with the T80-South telescope as part of the S-PLUS Transient Extension Program (STEP). Our search prioritized AGN-hosted environments by crossmatching the gravitational wave localization with known AGN catalogs. No candidate met the criteria for a viable optical counterpart. We explored three BBH merger scenarios predicting optical emission in AGN disks: (i) ram pressure stripping, (ii) long-term emission from an emerging jet cocoon, and (iii) jet breakout followed by shock cooling. Using our observational cadence and depth, we constrained the BBH parameter space, including the remnant's location within the AGN disk, kick velocity, and supermassive black hole (SMBH) mass. Detectable flares are most likely when mergers occur at 0.01-0.1 parsecs from SMBHs with masses between 10^7 and 10^8 solar masses, where short delay times and long durations best align with our follow-up strategy. These results provide a framework for identifying AGN-hosted BBH counterparts and guiding future multimessenger efforts.

RODRIGO FERREIRA PINHEIRO
NELSON PINTO-NETO - ORIENTADOR

Single-field matter bounce with dark energy era: constraints and best-fit parameters from Planck 2018 CMB data

Despite the Λ CDM model fitting the Cosmic Microwave Background (CMB) data very well, it is incapable of resolving the problem of the universe's initial singularity. This is because general relativity breaks down in the regime of extremely high energies, such as those encountered at the origin of the universe. In this context, both quantum mechanics and gravitation play important roles, and unifying these theories becomes fundamental. An important step in this direction is the canonical quantization of gravitation, which leads to the Wheeler-DeWitt equation. Solutions to this equation, combined with the de Broglie-Bohm interpretation of quantum mechanics, give rise to bouncing models of the universe. An important solution, which yields an approximately scale-invariant primordial power spectrum, includes a scalar field with an exponential potential. In this model, the scalar field behaves as a fluid with a variable equation of state, passing through several phases: initially as dust during the contraction phase, then as stiff matter during the bounce, later as dark energy during the expansion phase, and eventually returning to behaving as dust in the far future. Using statistical tools such as Markov Chain Monte Carlo (MCMC), the Akaike Information Criterion (AIC), and the Bayesian Information Criterion (BIC), we estimated the best-fit cosmological parameters and their confidence regions, and compared the goodness of fit of the Λ CDM model against the single-field matter bounce model using the Planck 2018 data.

ULISSES RIBEIRO DA SILVA
CLÉCIO ROQUE DE BOM - ORIENTADOR

An Agentic System for BAO Extraction

The Baryon Acoustic Oscillations (BAO) signal provides a robust standard ruler for observational cosmology, enabling precise constraints on the expansion history of the Universe. To enhance the detectability of the signal, the process typically requires a series of data selections to define the tracer and reduce possible systematic errors. Then, one can use statistical estimators such as the 2-point correlation function to extract it, but this approach is very sensitive to the coverage area of the sample, number density of points, and other statistical properties that need to be adjusted to each survey's specifications. Since the method is based on counting pairs of points at discretized distances, the number of bins used to define these separations is also a parameter that must be optimized. In general, one can create a pipeline that covers the steps involved in the extraction of BAO, but the decisions made to define the set of selections adapted to the survey specifications and the number of bins required to calculate the 2-point correlation function are difficult to implement in a script. These steps require deep analysis and contextual knowledge to be implemented, something that is usually done by humans. However, with the recent advances in Large Language Models and their capabilities for reasoning and contextual understanding, this task can now be addressed to a machine, especially using AI agents. This project aims to develop a multi-agent architecture that will adapt to the survey specifications, define the set of selections, and extract the BAO signal from the data sample. It will also be able to run statistical analyses such as MCMC to evaluate the signal and, based on these analyses, decide on a new set of selections or proceed to fitting cosmological constraints.

WIDERVAN DE DEUS MORAIS
JOSÉ ABDALLA HELAYÉL NETO - ORIENTADOR

Exploiting the edges between Condensed Matter systems and emergent Quantum Field Theories

The amount of diverse applications of field theory techniques to describe condensed matter systems in the literature has been notably increasing over the recent years. As representative examples, we mention the study of Dirac materials, the correspondence between relativistic field theories and topological materials, Majorana fermions appearing as edge states and Lorentz-symmetry breaking scenarios in effective models which enhance the need for investigation of new physics. A particularly interesting case is the study of a specific class of materials collectively known as metamaterials (MTMs), which can constitute media that behave as relativistic materials and are a potential source for electromagnetic applications. The present work investigates the physics of a planar electromagnetic system that includes nonlinear effects and de Broglie-Proca and Chern-Simons masses in vacuum which can be tuned to describe new planar MTMs that might be suitable for technological applications. As a result, we observe interesting effects generated by a spatially-dispersive profile, by virtue of the de Broglie-Proca term. This characterizes the three-dimensional QED vacuum as a non-local metamaterial. The constitutive relations are worked out and the vacuum electric permittivity display spatial dispersion by virtue of the Chern-Simons mass. The dispersion relations are analysed in terms of applied external magnetic fields and the mass parameters. A general expression for the vacuum refractive index is developed that depends on the nonlinearity parameters, the applied external magnetic field and both the de Broglie-Proca and Chern-Simons mass parameters.

