

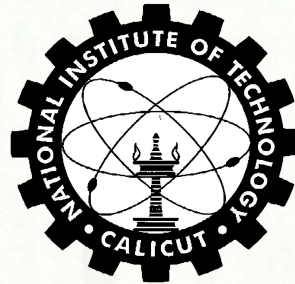


CONFLUENTIA
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Abstract Book

Fourth In-House Symposium



तमसो मा ज्योतिर्गमय

Department of Physics

National Institute of Technology Calicut

TALKS

1. Conjugate Measurements Decoherence and Equilibration

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In this talk, I will discuss how simultaneous decoherence of conjugate observables in an open quantum system can lead to the emergence of a classical statistical mechanical description. In particular, I show that under certain conditions the system evolves toward a state that can be interpreted as a uniform ensemble with constant probability density over phase space. I will focus on a scenario in which the environment effectively measures a pair of basic conjugate observables of the system, and examine how this measurement-induced decoherence drives the system toward classical behavior. The results provide a concrete mechanism for understanding how classical phase-space descriptions can arise dynamically from quantum dynamics.

2. Random Lasing in a Disordered Non-distributed Microfluidic Device

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Non-distributed feedback optofluidic random laser (NDFBORL) developed and realized using disordered microfluidic device. NDFBORLs are different from conventional optofluidic random lasers (ORLs) by means of the spatially separated scattering medium from the gain medium. This architecture for NDFBORLs enables perturbing the scattering medium without affecting the gain. The threshold characteristics and the nature of emission were analysed.

3. Förster Resonance Energy Transfer between green synthesised Carbon dots and Fluorescein

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Förster Resonance energy transfer (FRET) has been a topic of active research for its extensive applications to study molecular conformations¹, nanoscale interactions² and biosensing³. The selection of a proper donor-acceptor system is so crucial for FRET and carbon dots were found to be good candidates as FRET donors owing to their broad UV-Vis absorption, strong and tunable photoluminescence, excellent photostability and biocompatibility⁴. The carbon dots were green synthesised by hydrothermal approach using Tulsi leaves (as shown in Fig. a) at 180 °C for 5 hours. This approach is environmentally benign as it utilises only water as the reaction medium and eliminates the need of toxic precursors and byproducts.

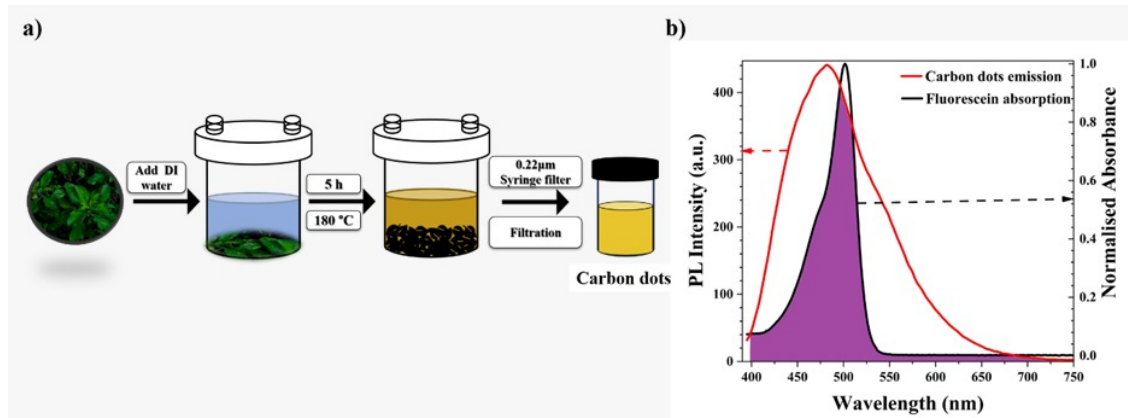


Fig.a) Schematic representation of the hydrothermal synthesis of carbon dots and Fig.b) Spectral overlap between carbon dots emission and absorption spectrum of fluorescein.

The synthesized carbon dots show an emission maximum around 482 nm on exciting it at 380 nm and the resulting photoluminescence spectrum overlaps significantly with the absorption spectrum of fluorescein dissolved in water as in Fig. b), making it a suitable acceptor. The overlap integral is calculated to be $2.07 \times 10^{15} \text{ nm}^4 \text{ M}^{-1} \text{ cm}^{-1}$ which indicates the possibility of an efficient energy transfer between carbon dots and fluorescein. In this work the FRET between carbon dot donors and Fluorescein acceptors are explored.

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2. D. Nettels, N. Galvanetto, M. T. Ivanović, M. Nüesch, T. Yang, and B. Schuler, *Nat. Rev. Phys.*, 6, 189–205 (2024).
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4. J. Liu, R. Li, and B. Yang, *ACS Cent. Sci.*, 6, 2179–2195 (2020).

4. Exploring the Dark Ages Using 21-cm Cosmology

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The cosmic dark ages represent a crucial phase in the evolution of the Universe and provide a powerful probe of fundamental cosmology, similar to the role played by the cosmic microwave background (CMB). Unlike later epochs, this period is largely free from complex astrophysical processes, making it a relatively clean probe of cosmological models. The redshifted 21-cm signal from neutral hydrogen emerges as the most promising and potentially the only direct observational probe of this era. It can be studied through measurements of the global (sky-averaged) signal as well as through the spatial fluctuations encoded in the 21-cm power spectrum. In contrast to the CMB, which offers a snapshot of the Universe at a single cosmic time, the 21-cm line spans a wide range of redshifts, providing a three dimensional view of cosmic evolution. The Dark Ages therefore offer a natural laboratory to explore non-standard physics, including alternative dark matter models, dark matter–baryon interactions, features in the primordial power spectrum, and primordial non-Gaussianity. Observations of the 21-cm signal with future lunar and space-based experiments can significantly advance precision cosmology and provide insights into aspects fundamental physics.

5. Spatially and Chromatically Programmable Soft Actuation in Plasmonic Hybrid Multilayers of Starch

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Biocompatible soft actuators that can respond to multiple stimuli and execute programmable, directional motion are crucial to the development of adaptive soft robotics and intelligent systems [1-3]. We present an eco-friendly, multi-stimuli-responsive soft actuator fabricated from free-standing cassava starch films incorporated with gold and silver nanoparticles. The composite films exhibit significant humidity-driven deformation, as well as repeatable bending upon exposure to green and blue laser irradiation. Notably, optical excitation generates a localised humidity gradient that acts as the dominant driving force for actuation. Directionality is achieved by asymmetrically coating one surface with a thin polydimethylsiloxane (PDMS) layer. A trilayer silver–PDMS–gold configuration further allows wavelength-selective bidirectional actuation, wherein blue light induces bending toward the light source while green light produces bending in the opposite direction, representing the first report of such chromatically controlled bidirectional behaviour in multilayer soft actuators. Importantly, the actuators retain reliable performance under confinement and can be directly integrated into electrical circuits, highlighting plasmonic starch films as a sustainable and versatile platform for programmable, multi-stimuli soft actuation.

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2. V. Kumar, and D. K. Satapathy, *Langmuir* 2024, 40, 11206-11214.
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6. Primordial Magnetic Fields and Early Structure Formation: Implications for the High-Redshift 21 cm Signal

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Primordial magnetic fields (PMFs) can act as an additional source of small-scale density perturbations, thereby enhancing matter clustering at comoving wavenumbers that are well above those sourced by standard inflationary initial conditions. This excess small-scale power accelerates the collapse of low-mass dark matter halos, advances the onset of star formation, and can therefore modify the radiation backgrounds (Ly- α , X-ray, ionizing UV). The redshifted 21-cm signal from neutral hydrogen during Cosmic Dawn (CD) and the Epoch of Reionization (EoR) is a potential probe of this accelerated structure formation. We use N-body simulations to generate the halo abundance, which are the sites of the first luminous sources, to study the impact of PMFs on the 21-cm signal during the EoR. We find that stronger PMF contributions significantly enhance early halo formation, leading to earlier and faster reionization than in the standard Λ CDM scenario. This ongoing work demonstrates that the 21-cm signal offers a promising avenue for constraining PMF models.

7. Epsilon-Near-Zero Metamaterial for Electromagnetic Confinement and Waveshaping Applications in the Terahertz Regime

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In this work, we propose an Epsilon-Near-Zero (ENZ) metamaterial (MTM), in which the relative dielectric permittivity and hence the refractive index of the MTM are near zero at terahertz frequencies. The proposed MTM exhibits near-zero values of $\epsilon_r = 0.0712 - 0.0053j$ and $n = -0.0047 - 1.8377j$ at 0.6984 THz. The near-zero refraction is confirmed through electromagnetic (EM) wave phase

invariance in a forty-layered MTM array for normal incident Transverse Electric (TE) waves. Using the realized MTM, a cavity resonator formed by pentagonal, trigonal and square closed structures were constructed, and the EM field enhancement due to cavity confinement was studied numerically. Also, the potential for using the ENZ MTM for waveshaping applications was demonstrated.

8. Investigation of Simultaneous Bidirectional Excitation of Tamm Plasmon Polariton Modes with Deep Learning

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Plasmonics-based nanophotonics is a fascinating area of research due to its potential to provide high-end, future-ready optoelectronic technologies. When the metal layer is coated on a distributed Bragg reflector (DBR), the localised mode excited at the metal-DBR interface is known as a Tamm plasmon polariton (TPP). In recent years, TPP has been studied extensively due to its wide range of applications. However, a detailed investigation of different excitation schemes for the TPP mode has not yet been conducted. Here, we investigate the TPP in a silver-DBR structure for unidirectional and simultaneous bidirectional excitations and compare the field confinement under these excitation schemes. We observe that simultaneous bidirectional excitation enhances the field confinement of the TPP mode compared to conventional unidirectional excitation. This enhancement is achieved by controlling the respective phases of the excitation waves. Due to the abundance of parameter combinations for tuning the bidirectional modes of TPP, a deep neural network (DNN) is trained to predict the electric-field confinement within the structure for given wavelength and phase-difference values. The model shows more than 99% accuracy in prediction and would be useful for developing novel optoelectronic devices utilising different excitation schemes of the TPP modes.

Keywords: Tamm plasmon polariton, Distributed Bragg reflector, Bidirectional excitation, Deep neural network.

9. Decoding THz Metasurface Resonances via Multipole Expansion

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The multipole expansion emerged as an effective tool for engineering the electromagnetic response and thereby understanding the optical properties of metamaterials and metasurfaces. It provides a framework for decomposing the electromagnetic response of subwavelength structures into a systematic progression of fundamental radiative sources, including electric and magnetic dipoles and higher-order moments such as electric and magnetic quadrupoles. Hence, rather than saying that a resonance occurs at a particular frequency, the decomposition of multipoles helps identify the core physical mechanism responsible for the metamaterial's electromagnetic response at that frequency. This work presents the realization of THz metasurfaces and the multipole investigation of their electromagnetic response, with special attention to chiral metamaterial designs. The front layers of the designs shown in figure are used to form chiral structures, with their corresponding mirror images rotated by specific angles. The interference between the different multipole moments can significantly modify the optical characteristics, and also this methodology facilitates the design of metamaterial structures exhibiting controlled polarization conversion, asymmetric transmission and near-field enhancement for sensing and nonlinear optical applications.

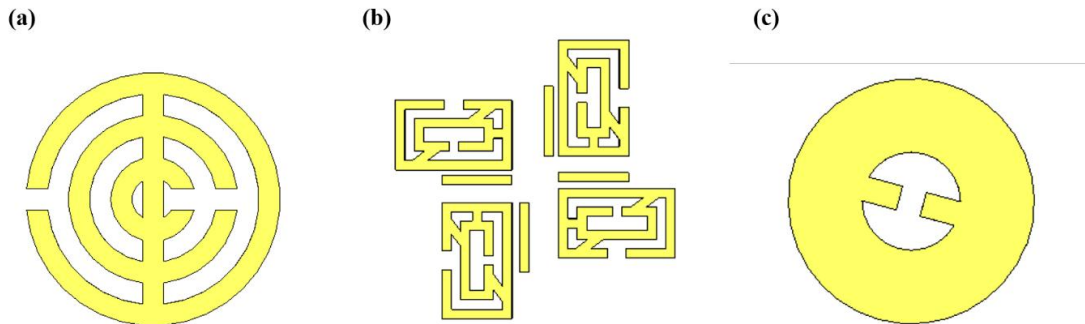


Fig. (a), (b) and (c) are the metal patterns of the realized metamaterials.

10. First Statistical Study of Hard X-ray QPPs in X-Class Solar Flares Using Aditya-L1 HELIOS Data

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Quasi-periodic pulsations (QPPs) are frequently observed in solar flare emissions and provide important diagnostics of energy release and particle acceleration processes. In this study, we present a systematic analysis of QPPs detected in hard X-ray emissions from X-class solar flares observed by the HELIOS instrument onboard the Aditya-L1 mission during 2024–2025. Focusing exclusively on major eruptive events enables us to investigate high-energy flare dynamics under extreme magnetic energy release conditions. Using uniformly processed light curves across multiple hard X-ray energy channels, we identify statistically significant QPP signatures and quantify their temporal characteristics. Particular emphasis is placed on the energy dependence of the modulation depth, allowing us to examine how pulsation amplitude evolves with photon energy. The results reveal a consistent scaling behaviour across events, suggesting a strong connection between non-thermal electron acceleration and the observed periodic intensity variations. The statistical trends obtained from this two-year dataset provide new constraints on the physical origin of hard X-ray QPPs in powerful flares. The observed energy-dependent modulation properties favour scenarios involving periodic or quasi-periodic modulation of accelerated electron populations, rather than purely thermal plasma oscillations. This work represents one of the first systematic hard X-ray QPP studies using Aditya-L1 observations and establishes a foundation for future multi-wavelength investigations combining space and ground-based data.

POSTERS

1. Studying the Epoch of Reionization using the statistics of 21-cm signal

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The ionization of neutral hydrogen by the early ionizing sources serves as a probe of the cosmic history. The Epoch of Reionization (EoR) helps in understanding the properties of ionizing sources, and these characteristics can be probed using the 21-cm signal from neutral hydrogen. Statistical tools are essential for analyzing the 21-cm signal data. The 21-cm power spectrum can give a good idea about the fluctuations due to structure formation. But the two-point statistics can't capture the non-Gaussian features of reionization that arise from the growth and morphology of complex ionized bubbles. Minkowski Functionals (MFs) are the topological tools that explain the morphology of reionization, which includes i) volume fraction, ii) surface area, and iii) Euler characteristics. These tools help in characterizing the geometric properties of the reionization epoch. We apply Minkowski Functionals to simulated Neutral Hydrogen maps to analyze the evolution of the topology and geometry of ionized regions during the Epoch of Reionization. The redshift evolution of the volume fraction, surface area, and Euler characteristic is analyzed to characterize the growth and overlap of ionized bubbles.

2. Cosmological N-Body Simulation

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Cosmological N-body simulation are essential to understand the evolution of structures in our universe. In this work, we develop a computationally efficient method of simulation by using C-Python interface to reduce simulation runtime and visualize data effectively. Using this framework, we compare various cosmological models and see which one of them performs a better fit in order to explain the formation of structures in our universe.

3. Fano-Resonant Microwave Metasurface for Dielectric Characterization and Fuel Composition Sensing

Aleena Antony, M. P. Pranaw, Debabrata Kalita, Isac Antony Babu Vazhappilly and N. Yogesh

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In this work, we present a microwave metasurface engineered to support sharp Fano resonance for high-sensitivity dielectric sensing applications. The metasurface comprises one outer circular split-ring resonator (SRR) with a clear dark-mode resonance frequency of 2.274 GHz and two inner rectangular SRRs that generate a Fano resonance at 3.166 GHz for normal-incidence transverse electric (TE) excitation. The asymmetric coupling between these resonators induces strong interference effects, while the inner SRRs simultaneously generate toroidal dipole moments at the Fano resonance frequency, effectively suppressing radiative losses and enhancing field confinement. Numerical simulation indicates a significant redshift in the Fano resonance frequency as the dielectric constant of the dielectric analyte increases, enabling reliable and precise dielectric sensing. A high sensitivity of 0.0441 GHz per unit change in dielectric constant is achieved, allowing the detection of even small variations in material properties. Moreover, the maximum Q factor of the Fano mode of the metasurface dipped in dielectric is found to be 3000. The metasurface has been successfully fabricated, and experimental characterization is being carried out currently. We attempt to use the proposed metasurface to sense ethanol content in gasoline via dielectric contrast. It is also useful for molecular drug sensing, atmospheric pollutant sensing and gas sensing applications.

Acknowledgments:

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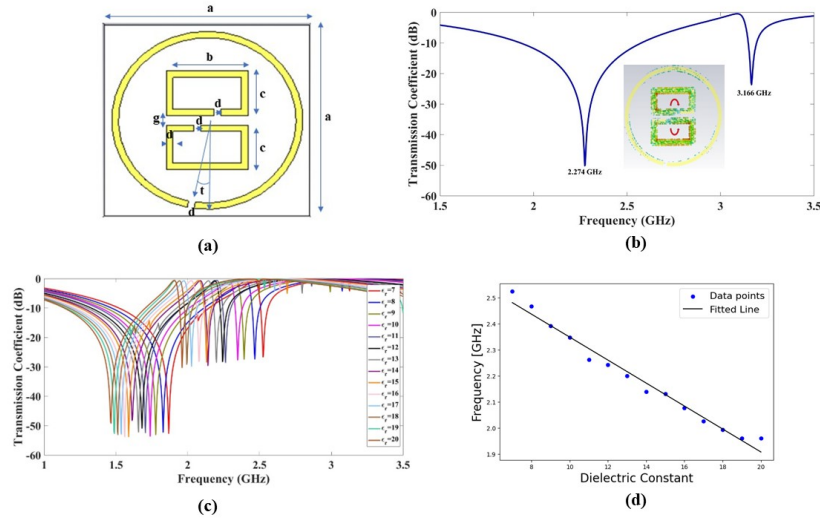


Fig.(a) Design of front layer of the unit cell and the complete geometry. Fig.(b) The transmission plot of the designed unit cell without a sensing dielectric. The inset shows surface current plot at 3.166 GHz, which shows the toroidal moment in the metasurface. Fig.(c) The transmission plot of the designed unit cell for the unit cell dipped in dielectric case. Fig.(d) Sensitivity graph for the metamaterial dipped in dielectric. The sensitivity is found to be 0.0441 GHz per unit change in dielectric constant.

4. Yield of Neutron-Induced Fission Products Using a Residual-Learning ML Model

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Fission-fragment mass distributions is one of the key fission observable for understanding the complex interplay of macroscopic and microscopic effects, such as shell effects, pairing correlations, and collective shape evolution of the compound nucleus (CN). In order to understand the aforementioned effects, accurate predictions of fission product yields are essential. Moreover, these studies are also relevant for nuclear reactor physics, nuclear medicine and imaging, and the management of nuclear waste. In this work, we employed a physics informed machine learning (ML) model, Extremely-randomised Trees (Extra-Trees) for predicting the fission product yield (FPY) of 18 CNs across actinide region. This work covers 3700 individual data-points spanning three different neutron energies: thermal, fast (0.5 MeV), and high energy (14 MeV). General description of Fission Observable (GEF) is used as a theoretical baseline along with the Japanese Evaluated Nuclear Data Library (JENDL) as the experimental evaluated data library. The Extra-Trees is trained to learn the residual between the GEF and

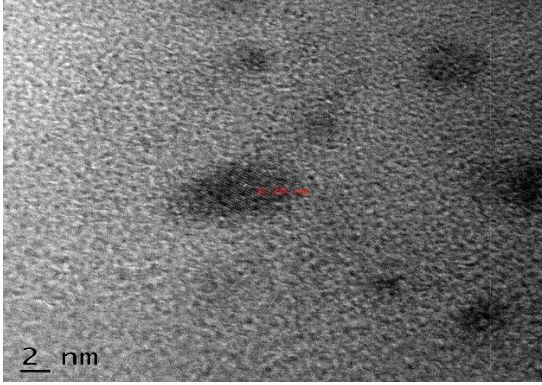
JENDL data with physics-embedded GEF as one of the attributes to the model. The trained model systematically corrects the baseline GEF predictions, leading to better agreement with evaluated experimental yields. Instead of using the standard k-fold cross-validations, we used the Leave-One-Nucleus-Out (LONO) validation strategy to see the performance of the model to unseen nuclei. Both variance based and experimental uncertainty-weighted metrics has been used to assess the predictive accuracy of the model.

5. Chemical-Free Fabrication of Nb₂C MXene Quantum Dots by Pulsed Laser Irradiation in Liquid and Their Nonlinear Optical Response

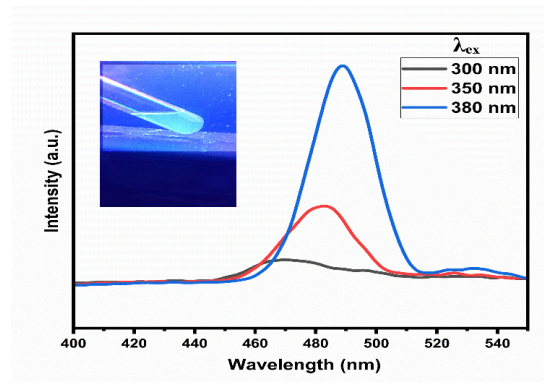
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MXenes, a rapidly expanding family of two-dimensional transition metal carbides and nitrides, have emerged as promising materials for nonlinear photonic applications owing to their strong light-matter interaction and ultrafast carrier dynamics. In this work, Nb₂C MXene quantum dots (QDs) were directly synthesized via pulsed laser irradiation in liquid (PLIL), offering a rapid, single-step, and chemical-free approach to achieve quantum confinement. The intense laser-matter interaction in the liquid medium generates localized plasma and cavitation effects, leading to efficient fragmentation of bulk Nb₂C into ultrasmall, well-dispersed QDs with pulsed laser-induced surface functionalization. The nonlinear optical properties were investigated using the open-aperture Z-scan technique at 532 nm. The Nb₂C QDs exhibit pronounced intensity-dependent absorption characteristics, showing saturable absorption at lower excitation intensities due to ground-state bleaching and state filling, followed by strong reverse saturable absorption at higher input fluences attributed to excited-state absorption and small two-photon absorption. A significant nonlinear absorption coefficient (β) was obtained, confirming a strong third-order nonlinear absorption response. Notably, the dominant reverse saturable absorption at elevated intensities results in efficient optical limiting behavior, demonstrating the suitability of PLIL-synthesized Nb₂C MXene QDs for optical limiting and photonic protection applications. The enhanced nonlinear absorption is attributed to the synergistic effects of quantum confinement, defect-assisted carrier dynamics, and strong intrinsic light-matter interaction within the Nb₂C framework.



(a) TEM image of Nb₂C quantum dots.



(b) PL spectra of Nb₂C quantum dots.

6. Improving 21-cm Inference with Machine Learning & Higher-Order Statistics

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The 21-cm signal from neutral hydrogen is a powerful probe of the early universe, particularly the Epoch of Reionization (EoR). In practice, detecting this signal is extremely difficult because it is faint and heavily contaminated by bright astrophysical foregrounds, motivating analyses based on summary statistics of the 21-cm fluctuations. Most existing work focuses on the power spectrum, but as a two-point statistic, it cannot capture all of the information in the strongly non-Gaussian 21-cm field during reionization. Here we show that adding higher-order information through the bispectrum can substantially enhance parameter inference. We develop machine-learning emulators that rapidly predict both the power spectrum and bispectrum, allowing efficient Bayesian constraints via Markov Chain Monte Carlo (MCMC). By jointly fitting these two statistics, we obtain noticeably tighter constraints on the neutral hydrogen fraction than with the power spectrum alone, demonstrating the value of higher-order statistics for a more complete reconstruction of reionization. In addition, we also demonstrate the model-dependent nature of the neutral hydrogen fraction (x_{HI}) in 21-cm parameter inference.

7. Iron-Decorated VS_2 Nanosheets as a Bifunctional Catalyst for Alkaline Water/Seawater Electrolysis

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Development of resilient, stable, and cost-effective bifunctional electrocatalysts from earth-abundant materials for hydrogen and oxygen evolution reactions (HER and OER) under harsh alkaline and natural seawater conditions has gained significant attention for large-scale electrocatalytic water splitting towards sustainable green hydrogen production and usage technologies. In this work, we report, the synthesis of highly active and durable iron-decorated vanadium sulfide ($Fe - VS_2$) nanosheets, supported on conductive nickel foam (NiF) via a simple one-pot hydrothermal method, as a promising bifunctional electrocatalyst for efficient alkaline/natural seawater electrolysis. The controlled incorporation of iron in VS_2 nanosheets, significantly enhances its bifunctional electrocatalytic activity for both the HER and OER in alkaline and natural seawater electrolytes. The optimized $Fe(10) - VS_2$ electrocatalyst demonstrates low overpotentials of 256 and 216 mV at 20 mA cm^{-2} for HER in 1 M KOH and alkaline seawater ($SW + 1 \text{ M KOH}$), respectively, along with the promising Tafel slope (114 mV dec^{-1} in alkaline natural seawater), close to the benchmark Pt/C catalyst. For OER, in the same electrolyte conditions, $Fe(15) - VS_2$ exhibits overpotentials of only 285 and 340 mV, respectively, at 200 mA cm^{-2} . Further, the overall water splitting using the optimized $Fe - VS_2$ bifunctional electrocatalyst, requires cell potentials of 1.93 V and 1.97 V to achieve a current density of 100 mA cm^{-2} in 1 M KOH and $SW + 1 \text{ M KOH}$, respectively, while maintaining the excellent electrochemical stability under harsh electrolytic conditions. The superior performance arises from the synergistic effects of the nanosheet morphology with abundant active sites, Fe-induced electronic and structural activation of VS_2 and the conductive Ni foam substrate enabling charge transport. Moreover, the one-pot method offers a feasible and economical synthesis route, paving the way for the development of non-noble, low-cost electrocatalysts for industrial scale seawater splitting applications.

Keywords : Bifunctional electrocatalyst, Hydrogen evolution reaction, Oxygen evolution reaction, Seawater electrolysis, VS_2 nanosheets, $Fe - VS_2$.

8. Coexistence of Weyl Nodes and Nodal lines in quaternary Heusler compound FeRuVIn

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We perform a first-principle study of the topological electronic properties of quaternary Heusler alloy FeRuVIn using Density Functional Theory (DFT) and Wannier-based tight-binding analysis. Our calculations reveal the coexistence of Weyl nodes and Nodal lines in the bulk band structure of this non-magnetic system. In the absence of spin-orbit coupling (soc) symmetry-protected Nodal lines are observed and upon inclusion of soc these Nodal lines partially gap out, leading to the emergence of Weyl nodes with opposite chirality. The presence of Weyl nodes confirmed from the Berry curvature calculation which show monopole like source-sink behavior. Surface state calculations on both 001 and 011 reveals both Fermi arc states connecting the projected Weyl nodes and drum-head-like surface states associated with Nodal lines. Our findings shows that FeRuVIn is a non-magnetic topological semimetal hosting multiple types of topological quasi particles, and is a promising material in the class of quantum materials.

9. Numerical and Experimental Investigations of Petrochemical Sensing Using a One-Dimensional Photonic Crystal Cavity Resonator at Microwave Frequencies

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By creating a defect site, a 1-D photonic crystal formed by alternative glass-air slabs is intended to detect petrochemicals in the gigahertz range of frequencies

between 6 and 10 GHz. When an air defect is introduced into the photonic crystal, electromagnetic trapping occurs at 8.45 GHz. Petrol and diesel are poured into the photonic crystal cavity to detect petrochemicals. Differentiating between these analytes is a major sensing challenge due to the low permittivity of petrol and diesel, and their dielectric loss dispersions. Analytes were introduced into the defect cavity region, and full-wave numerical simulations were carried out to assess the sensor response. The findings show that, while the resonance mode considerably weakens or vanishes in the case of diesel due to its significant dielectric loss, the addition of petrol shifts the resonance frequency toward 6.7 GHz. Though the simulated results closely match the experimental results, they do not match exactly. Fabrication tolerances, material losses, minute changes in dielectric characteristics, thickness, and temperature variations are all responsible for the discrepancy between the simulated and experimental results. This work highlights the difficulty of differentiating petrochemical analytes with closely matched permittivities, and the necessity of strong cavity confinement to improve the experimental agreement. Our work is important for the petrochemical industry to rule out sensing discrepancies associated with the photonic crystal cavity method.

10. Isospectral Deformation of Schwarzschild Black Hole in Thermal Potential

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In this study, we apply ideas of supersymmetric quantum mechanics (SUSY QM) to the thermodynamics of Schwarzschild black hole in a thermal potential, where its dynamics map to a Schrödinger-like equation. We demonstrate the equivalence of two SUSY methods, i.e. translation and scaling, for generating isospectral deformed potentials. While translation produces single parameter deformation whereas scaling can produce up to a three parameter deformation. We shown that the translation method emerges as a special case of a more general scaling formalism.

11. Altermagnetism and Topological Properties of NiF_3

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Altermagnets are new class of materials different from ferromagnets and antiferromagnets. The crystal structure and magnetic structures of altermagnets are unique. They are the promising candidates for the next generation devices due to their unique properties like strong spin coherence, high-temperature magnetic ordering etc. One interesting altermagnetic system is NiF_3 with a rhombohedral crystal structure. Experimentally, it is found to be an antiferromagnetic insulator. Plane wave DFT calculations give a ferromagnetic, half-metallic ground state. However, introduction of a Hubbard U term make it an antiferromagnetic insulator, which is also altermagnetic. We study the topological properties of NiF_3 with and without spin-orbit coupling, using a Wannier function based Tight Binding Model.

12. Exceptional Point of Non-Hermitian Electromagnetic Metasurface for THz Waveband Applications

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In conventional electromagnetic design, material loss, for the most part, is viewed as a liability that needs to be minimized. The standard Hermitian metasurfaces are constrained by the conservation of energy. However, non-Hermitian physics can facilitate these losses, inducing phase transitions at singularities called Exceptional Points (EPs). Here, we propose a passive, bilayer metasurface with two orthogonally coupled split-ring resonators (SRRs) to have orthogonal excitation orientations, with the same resonant frequency but different loss coefficients. By precisely modulating the spatial coordinates of the two resonators in the unit cell, we satisfy the necessary symmetry-breaking condition for a PT-

symmetric phase transition that is required to reach the EP. The resulting full-wave simulations are validated against an analytical model that captures the distinct phase transition in the eigenvalue and eigenvector spaces. This transition is characterized by the coalescence of the two eigenvectors into a single degenerate state, highlighting the transition point between the symmetric and broken-symmetric phases. Unlike conventional sensors, which are limited by linear response, the second-order EP exhibits square-root eigenvalue splitting, providing a highly sensitive response to minute perturbations. Consequently, these metasurfaces hold significant potential for applications in biomedical diagnostics.

13. Tsallis Entropy as a Non-Gaussianity Probe of the Epoch of Reionization

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The redshifted 21 cm signal from the Epoch of Reionization (EoR) encodes rich information about the astrophysical processes governing the ionization of the intergalactic medium (IGM). While the dimensionless power spectrum ($\Delta^2(k)$) has been the standard statistical tool for analyzing this signal, it captures only two-point information and is blind to phase correlations, thereby missing a significant fraction of the non-Gaussian information that develops as reionization progresses. In this work, I explore Tsallis entropy (S_q) as an alternative and complementary summary statistic to characterize the non-Gaussian nature of the 21 cm brightness temperature field. My motivation stems from the fact that, from the mid-to late-EoR, the 21 cm brightness temperature field (T_b) can be regarded as a non-extensive system. As ionized regions grow and merge, the field evolves from an initially Gaussian distribution to a highly non-Gaussian one, exhibiting complex morphology and long-range correlations on scales of tens of megaparsecs due to radiative feedback and photon propagation. S_q , a generalized form of entropy designed for non extensive systems, naturally provides a framework to quantify these features. Using simulated T_b maps, I compute S_q over a range of entropic indices (q) and compare its statistical behavior with that of the dimensionless power spectrum. I investigate the covariance structure of both statistics across multiple realizations and employ principal component analysis (PCA) to identify the dominant modes of variance and reduce the effective dimensionality of the data. My preliminary study is to see if S_q captures higher-order and non-Gaussian information that is not accessible through $\Delta^2(k)$

alone, particularly during the mid to late stages of reionization. Further, I aim to perform parameter estimation and Fisher matrix analyses in PCA space, directly comparing the constraining power of S_q and $\Delta^2(k)$ on key reionization parameters, such as ionizing efficiency (ζ) and neutral hydrogen fraction (x_{HI}). This work demonstrates the potential of S_q as a powerful and physically motivated summary statistic for future 21 cm cosmology analyses.

Keywords: Brightness temperature (T_b), Dimensionless power spectrum ($\Delta^2(k)$), Tsallis entropy (S_q), Ionizing efficiency (ζ), Neutral hydrogen fraction (x_{HI}).

14. Fusion in sub barrier energies in $^{19}F + ^{158}Gd$ reactions

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Sub-barrier heavy-ion fusion reactions provide important insight into nuclear structure effects and channel couplings that influence tunnelling through the Coulomb barrier. In many systems, experimentally observed fusion cross sections at energies below the barrier are significantly enhanced compared to predictions of the one-dimensional barrier penetration model (1DBPM), indicating the crucial role of intrinsic nuclear degrees of freedom. In this work, the fusion dynamics of the $^{19}F + ^{158}Gd$ system have been investigated using the coupled-channel formalism implemented in the CCFULL code, with calculations performed around a barrier energy of approximately 80 MeV. The coupled-channel approach incorporates the bare nuclear and Coulomb potentials along with couplings to rotational, vibrational, and neutron transfer channels. The 1DBPM calculations strongly underpredict the fusion cross sections at sub-barrier energies, demonstrating the inadequacy of a single static barrier description. In contrast, inclusion of rotational excitations of the well-deformed target ^{158}Gd leads to significant enhancement of the fusion probability. Rotational couplings fragment the single Coulomb barrier into a distribution of barriers, effectively lowering the barrier height and increasing the tunnelling probability. The enhancement becomes more pronounced as additional rotational states are included. Vibrational couplings further contribute to the sub-barrier fusion enhancement. Inclusion of low-lying vibrational states of $^{158}Gd(2^+, 3^-)$ and the $5/2^+$ state of ^{19}F improves agreement with the enhanced fusion trend. Moreover, the two-neutron pickup transfer channel with a positive Q-value produces a larger enhancement compared to one-neutron transfer and no-transfer cases. The study confirms that sub-barrier fusion in the $^{19}F + ^{158}Gd$

system is strongly governed by coupled-channel effects, with rotational couplings playing a dominant role and vibrational and positive Q-value neutron transfer channels providing additional enhancement beyond the 1DBPM prediction.

15. Study of Transport Coefficients and Characterization of Absorbing Phase Transitions in a Conserved Pair-Factorized Steady State

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In the study of nonequilibrium systems, exactly solvable models are exceptionally rare. One-dimensional conserved-mass transport processes possessing a pair-factorized steady state (PFSS) are a notable exception. We find that for a particular choice of particle hopping rate, the PFSS exhibits an active-absorbing phase transition. Using a novel transfer-matrix formalism, we calculate the critical point, the subsystem particle fluctuations, and the two-point density-density correlation function. Moreover, by extending its dynamics to a symmetric regime, the model conforms to the macroscopic fluctuation theory, rendering its order parameter and transport coefficients analytically accessible. These results allow us to determine the critical exponents and characterize the universality class, which belongs to a completely different class from the existing directed percolation (DP), conserved directed percolation (CDP), and Edwards–Wilkinson (EW) universality classes.

16. Disorder-induced topological properties in Heusler alloys

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Heusler alloys have been of great interest over the last decades due to their multifunctional novel properties. This class of material offers an enormous variety of possibilities for material design since they are known to exhibit tunable

electronic and magnetic properties. Heusler alloys exhibit rich and interesting ground-state properties such as magnetism, unconventional superconductivity, and heavy fermion behavior. The interplay between these properties and the topological order makes Heusler alloys ideal candidate for investigation of novel topological effects, new topological phases, and applications. Here, we present in detail, both theoretically and experimentally, the effect of structural disorder on the electronic, magnetic, and topological properties of quaternary Heusler alloys CoFeCrZ ($Z = \text{Al}$ and Ga). In the ideal Y structure, these alloys exhibit spin gapless semiconducting behaviour. However, the introduction of B2 type disorder destabilizes this phase and drives the system into a magnetic Weyl semimetallic state. Furthermore, topologically protected surface states with Fermi arcs emerge in the disordered phase.

17. Charge Transport and Nonlinear Optical Properties of TS-CuPc Reinforced PEDOT:PSS via Molecular Ordering

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Organic semiconducting polymers/small molecules are extensively studied for their chemical, optical, and charge transport properties. Among these, solution-processable materials are particularly attractive due to their cost-effectiveness in the overall manufacturing of electronic devices. However, the electrical properties of these materials are highly dependent on processing conditions. This dependence calls for a deeper understanding of the charge transport mechanisms in these systems. One promising class of semiconducting materials is small molecules, with the water soluble Copper Phthalocyanine-3,4,4,4-tetrasulfonic acid tetrasodium salt (TS-CuPc), attracts attention for its solution processibility. However, strong intermolecular interactions both between the solute molecules and solute/solvent promotes aggregation and thereby pinhole formation. It has been found that Phthalocyanines tend to form self-assembled structures in acidic medium, enabling ordered alignment of the molecules. Such a morphology is observed in its composite with acidic poly(3, 4 ethylenedioxythiophene)-poly(styrenesulfonate) (PEDOT:PSS), which has better solution processability than the pristine small molecule and a lower pH than PEDOT:PSS. In this study, we investigate the electrical transport and optical properties of the PEDOT:PSS-

TS-CuPc composite, where the TS-CuPc forms leaf-like self assembled patterns through self-assembly promoting $\pi - \pi$ stacking. We report a comprehensive understanding of the transport mechanisms, detailing the temperature and electric field-dependent analysis of mobility in a diode architecture. We investigated the role of trap states in the memristive response by analysing the hysteresis behaviour in the current-voltage characteristics, considering possible contributions from charge trapping/detrapping processes alongside other switching mechanisms. In parallel, light-matter interactions were examined using the Z-scan technique to determine the nonlinear absorption and nonlinear refractive indices of the small-molecule system. Since $\pi - \pi$ stacking influences electronic delocalization and molecular polarizability, its effect on the nonlinear optical response was indirectly assessed through the extracted third-order optical parameters. Finally, a correlation between the electrical switching characteristics and the nonlinear optical properties was explored to understand the interplay between charge transport, trap states, and molecular packing.

18. Partial Focusing Effect Due to a Hyperbolic Medium for Infrared Imaging Applications

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Hyperbolic metamaterials are anisotropic artificially engineered nanostructures that behave as a metal in one direction and as a dielectric in the orthogonal direction. By possessing opposite signs in their principal permittivity tensor components, they exhibit a hyperbolic dispersion over a range of designed frequencies. The negative curvature of hyperbolic dispersion shows negative refraction and partial focusing effect. Since realizing a negative component of dielectric permittivity in one direction is easier than 3-D homogeneous metamaterial, one can explore partial focusing effect of a hyperbolic metamaterial for imaging functionalities especially at infrared (IR) frequency regimes. In this work, we will present a few of our full-wave electromagnetic simulations associated with negative permittivity hyperbolic medium with a demonstration of negative bending, partial focusing, and image resolution. We'll highlight the importance of employing partial focusing effect for IR imaging applications.

19. Multi-Frequency Electromagnetic Transparency via Pseudoanapole Modes Using Pairs of Mirrored Split-Ring Metamaterials

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Electromagnetic transparency, arising from non-radiating states, has attracted significant research due to its major applications in cloaking, sensing, and wave manipulation. The pseudoanapole is such a state which arises when all dominant multipole moments are suppressed, resulting in minimal far-field scattering and near-unity transmission. This work investigates the excitation of pseudoanapole modes in mirrored split-ring resonator (SRR) metasurfaces operating at GHz frequencies. Initially, we demonstrate, through simulations, that the formation of a pseudoanapole can be confirmed by S-parameter analysis and surface current distributions. Building on this, we show that modifying geometrical ring parameters, such as ring width and split width, tunes the pseudoanapole formation frequency. Thereby, upon integrating multiple mirrored SRR pairs with varying geometries within a single unit cell, we realize dual and triple-frequency pseudoanapole states, achieving a bandwidth of high-transmission regimes. The study thus establishes a straightforward geometry-driven strategy to achieve multi-frequency electromagnetic transparency, offering a scalable pathway toward broadband transparent metasurfaces in the high-frequency or microwave domain.

20. Analysis of Doppler Velocity Power Spectra and Magnetic Fields in the Solar Active Region NOAA 13842

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The distribution of acoustic (p-mode) power in solar active regions provides critical insight into the interaction between magnetic fields and solar oscillations. In this study, we examine oscillatory power in NOAA Active Region 13842 using high-resolution Dopplergram data from the Helioseismic and Magnetic Imager (HMI) onboard the Solar Dynamics Observatory (SDO). Time–frequency analysis reveals significant suppression of acoustic power in regions of strong magnetic fields compared to the quiet Sun, consistent with the absorption and damping of p-modes by magnetic structures. These findings demonstrate the complex coupling between magnetic topology, and helioseismic oscillations, advancing our understanding of wave behavior in magnetized solar atmospheres and contributing to the emerging field of flare-helioseismology interactions.