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Report of Abstracts

Mini-colloquium
LODY2026
Localization Dynamics in Matter and Waves

Organizers:

Juan F.R. Archilla, Manfried Faber

Masayuki Kimura, Yusuke Doi

https://grupo.us.es/gfnl/talks/2026/lody2026/

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LODY206: LOCALIZATION DYNAMICS IN MATTER AND WAVES

Mini-colloquium in CMD32-ÖPG75, Graz, Sep 2026

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Keywords: Localization, solitons, topological phenomena, nonlinear phenomena

Abstract
Solitons are ubiquitous examples of spatial localization, often in movement. They include discrete breathers as envelope solitons. Striking examples in water are tsunamis and bores, but they appear in many other systems as optical waveguides, Josephson junction arrays, Bose-Einstein condensates, matter waves, and biological molecules, to name a few. Solitons appear both in theory, classical and ab-initio nonlinear dynamics, and experiments. They often have long lives, which may hinder heat evacuation in tokamak fusion reactors. Polarons and solectrons consist of a charge bounded to a local deformation and/or localized vibrational modes. They are often described using semi-classical models within the tight-binding approximation. Localization can also be in momentum as q-breathers, or in time, as rogue waves. Metamaterials allow for the engineering of especial properties including solitons. With time modulation, time crystals appear, as proposed by Nobel Laureate Frank Wilczek in 2012. Space-time metamaterials bring about new properties of localized excitations that appear within the frequency or momentum bandgaps. Electrons have also been described as topological solitons with Coulomb and Lorenz forces as a consequence, in this way, expanding the soliton concept to particle physics. This mini-colloquium intends to review recent advances and unify theories and approaches.

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Levy Sachdev-Ye-Kitaev model

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Abstract
Sachdev-Ye-Kitaev model (SYK) is a paradigmatic quantum disordered many-body model, that is solvable. Its solvability provides multiple insights into physics of many-body interacting quantum problems. The standard model features Gaussian random interactions. Various extensions of the original model were considered in the literature, some solvable, others not. The solvable extensions typically inherit the properties of the original SYK. We introduce the Levy Sachdev-Ye-Kitaev model, discuss its solvability and properties. It shows some interesting properties not present in the original SYK, while maintaining solvability.

Floquet breathers in a time-modulated nonlinear lattice

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Abstract
Floquet discrete breathers are localized periodic solutions that may appear in nonlinear lattices with periodic modulation in space and time. Based in a previous experimental device constructed with cantilevers and with additive time-periodic excitation, we have designed a system with parametric driving that can be modulated in space and time. For that system, we deduce theoretically the changes brought about by the modulation, first in the phonon band and then on breather properties as existence, stability and the numerical methods to obtain them. We have found a large variety of Floquet breathers with equal period of the modulating one, multiplied or divided by an integer and commensurate ones. The results are applicable to a variety of systems and are not limited to the specific model.

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Soliton molecules and roton mediated binding in binary condensates

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Abstract

Localized nonlinear excitations can form long lived bound states whose internal degrees of freedom shape their dynamics. I will present two complementary mechanisms for binding solitary waves in two component Bose-Einstein condensates and their consequences for localization dynamics. In miscible, nondipolar mixtures, polarization (“magnetic”) solitons interact via an effective potential that supports soliton molecules. This framework identifies the conditions for binding and yields an analytic dissociation energy for oppositely polarized pairs, in agreement with full dynamical simulations.

In dipolar mixtures, a roton minimum of the spin excitation branch induces intersoliton forces that oscillate with separation between dark-antidark pairs. The resulting periodic potential supports multiple bound states at distinct separations and generates spatial spin density oscillations around individual solitons—both direct signatures of the spin roton. In collisions, dipolar interactions enforce universal low velocity bouncing, contrasting with the transmit or bounce behavior of nondipolar solitons, offering a realistic path to confirming spin rotons experimentally.

These results show how soft spin modes and spin polarization mediate controllable long range forces that organize the binding and scattering of localized waves.

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R. M. V. Röhrs and R. N. Bisset Phys. Rev. A 113, 033311 (2026)

The Hidden geometry of transport in disordered matter

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Abstract

Transport in disordered media is usually described through spectra, eigenmodes, and localization lengths. Yet finite systems are probed point to point: a source excites a specific realization at a specific frequency, and transmission follows sparse, heterogeneous corridors. We show that the resolvent response defines a source-conditioned communication geometry directly on the medium. Its logarithm acts as a transport potential whose basins, ridges, and saddles organize propagation. Within this geometry, attenuation is controlled not by the cumulative cost along a path, but by the minimax saddle: the lowest pass at which source and target first become dynamically connected. This yields a finite-scale constitutive closure for transmission, with subleading corridor and entropic corrections. Tests on disordered graphene and protein elastic networks show that the saddle systematically outperforms path-based predictors, revealing transport as a threshold- controlled, geometric process in finite disordered matter.

Two-dimensional spectroscopy of quantum sine-Gordon solitons with ultracold atoms

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Abstract
We propose a framework for employing two-dimensional (2D) spectroscopy to investigate the quantum sine-Gordon (QSG) model. Traditionally used to study the structure and dynamics of molecular systems, 2D spectroscopy is increasingly recognized as a powerful tool for exploring collective excitations in quantum many-body physics. By evaluating 2D maps within a Gaussian ansatz, we quantify the QSG system's response to consecutive (time-delayed) perturbations. This approach enables the identification of key features such as the emergence of quantum breather modes, their bound states, signatures of the theory's non-Gaussian nature, and the effects of disorder. Notably, these results are unattainable by means of the traditional linear response paradigm, since the consecutive perturbations bring the system to states with multiple excitations and thus reveal processes such as breather-breather interactions.
The computed maps provide detailed insights on the out-of-equilibrium dynamics of the QSG model, which can be experimentally investigated through platforms like ultracold atoms and superconducting qubits. As an example, we examine the implications of our spectroscopic protocol in a system of two one-dimensional tunnel-coupled superfluids within a double-well potential: a natural realization of the QSG model. Furthermore, our framework is generalizable to the study of collective excitations in other paradigmatic quantum many-body systems.

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A consistent formulation of electrodynamics and the classical electron without singularities.

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Abstract
Millikan's famous experiment revealed a contradiction with Maxwell's electrodynamics, which became known as the "4/3 problem" and the "radiation reaction problem". From today's perspective, these issues seem to have been insufficiently understood. The actual origin of the problems lies in the instability of the classical electron.
Historical approaches to solving the 4/3 problem require more than three degrees of freedom. In a soliton model, only three field degrees of freedom are required to stabilize a purely electrodynamic electron, as was demonstrated 25 years ago but has largely gone unnoticed until now. Precursors to this model are Dirac's magnetic monopoles and their non-Abelian formulation by Wu-Yang. It is shown how solitons with a size of the classical electron radius can reproduce the electromagnetic cross sections of electrons in Compton, Möller, and Bhabha scattering in agreement with the results of QFT, when the Lorentz contraction is taken into account.

Coherent interactions between discrete breathers

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Abstract
Discrete breathers (DBs) are spatially localized vibrational modes ubiquitous in physical systems. Despite decades of research, their mutual interactions represent a fundamental yet unexplored facet of nonlinear dynamics. Here we uncover quantitative interaction laws for DB pairs, encoded in tunable energy beating whose amplitude provides a direct coupling metric shaped by energy mismatch, phase configuration, and a separation yielding exponentially decaying, parity-sensitive coupling. The coupling can be strongly modulated by frequency locking, which emerges only under restricted excitation conditions. A minimal nonlinear dimer encapsulates all salient behaviors across diverse lattice models. These results promote DBs from static energy traps to versatile elements for engineering energy transport, tailoring vibrational spectra, and generating acoustic frequency combs.

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Ergotropy and dynamical signatures of many-body localization and discrete time crystals in disordered Heisenberg chains

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Abstract
Many-Body Localization (MBL) and Anderson Localization (AL) represent a fundamental paradigm of non-ergodic quantum dynamics in disordered systems. MBL and AL are hallmarks of interact- ing and non-interacting systems, respectively. From a quantum-information perspective, MBL phase is uniquely identified by the logarithmic entanglement growth, while in the AL case the entanglement is stationary over time. We investigate anisotropic disordered Heisenberg spin chains through state-of-the-art numerical simulations. We propose local ergotropy - defined as the maximum work extractable via local unitary operations on a small subsystem - as a robust thermodynamic witness of the transition from the ergodic phase to MBL and AL phases. We demonstrate that within the MBL phase, both local ergotropy, reported in Fig. 1a, and its quantum fluctuations exhibit a slow, logarithmic temporal evolution, mirroring the phenomenology of entanglement entropy. Our findings suggest that leveraging local control provides a novel indicator of localization based on extractable work, offering a thermodynamic alternative to standard entropic measures.

Furthermore, we explore the emergence of discrete time crystals (DTC) when an external drive is applied to such localized systems. A DTC is an out-of-equilibrium phase of matter in which continuous time-translation symmetry is spontaneously broken. As a consequence, the system exhibits a subharmonic response, and observables become periodic with a period that is an integer multiple of that of the drive. Figure 2b shows the imbalance time-correlation function, which exhibits oscillations with a period twice that of the drive and remains coherent over time.

While DTC phases have been extensively studied in Ising-like models, we unveil their robustness in disordered Heisenberg chains . By analyzing the dynamics of ergotropy, entanglement, and spin-spin spatial correlations, we identify clear signatures that characterize the transition from the DTC phase to the MBL regime as the driving parameters are tuned. Our results provide new insights into the stability of out-of-equilibrium phases in many-body quantum systems.

Topological soliton pairs with long-range Coulombic interaction

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Abstract
We determine the interaction potential of a solitonic Positronium in the singlet state, modeled as an SU(2) field, using improved lattice simulations of two solitons at varying separations. The potential is extracted from the energy of the two-soliton configuration as a function of distance. At large separations, the interaction reproduces the classical Coulomb potential quantitatively up to an energy shift $\delta E\infty \approx 9$ keV of the fitted asymptotic constant relative to 2mec2, assumed to be related to limited numerical precision on the lattice. At shorter distances, deviations from the Coulomb potential of point-like charges appear, that are in qualitative agreement with the asymptotic formula of perturbative Quantum Electrodynamics, reflecting the running of the fine-structure constant, with the inverse fine-structure constant ($\alpha^{-1} \approx 137$) reproduced.

A nonlinear coupled cantilever array with time-periodic on-site potentials and Floquet breathers

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Abstract
Intrinsic localized modes (ILMs) or discrete breathers (DBs) have been observed experimentally in a coupled cantilever array with nonlinear on-site potentials [1,2]. The on-site potential is introduced via the magnetic interaction between a permanent magnet, which is attached to the free end of the cantilever, and an electromagnet. Since the strength of the interaction can be modulated by the current flowing in the electromagnet, it is rather easy to realize a time-dependent on-site potential. Indeed, an ILM was successfully manipulated by locally changing the current of the electromagnet.
In this talk, we briefly introduce the experimental system and the equation of motion. Afterward, DB solutions are obtained for which the on-site potentials are modulated periodically in time. The stability and bifurcations of the DB solutions, namely Floquet breathers [3], will be discussed.

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Dynamics of localization in two-dimensional nanostructures

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Abstract
Two-dimensional (2D) materials of atomic thickness exhibit rich physics and strong potential for advanced technologies. Following the discovery of graphene, extensive research has explored fundamental properties of 2D materials and inspired analogous developments in photonics, cold atoms, and engineered metamaterials. Progress in electronics, optoelectronics, quantum technologies, catalysis, and energy applications highlights the critical role of edge effects. In this context, edge states have emerged as a key factor in understanding and controlling wave propagation in low-dimensional systems. We present theoretical and computational studies, often supported by experiments, on the structural and electronic properties of 2D nanostructures, emphasizing cases where simplified models successfully capture the essential physics. For the well-studied graphene nanoribbons using a tight-binding model with nearest-neighbor interactions, extended to the discrete nonlinear Schrödinger equation to incorporate interaction-induced nonlinearity, we reveal novel spatially localized states. By analyzing the time evolution of initially localized wave packets, we identify distinct dynamical regimes, ranging from linear spreading to nonlinear self-trapping, or governed by edge geometry and initial conditions. For semiconducting armchair nanoribbons, we demonstrate analytically and numerically the existence of flat band states that remain strictly localized across the ribbon width without spreading along the periodic direction. In zigzag nanoribbons, we construct localized states from partially flat band edge states at the Fermi level, leading to confinement in both transverse and longitudinal directions. The inclusion of strong disorder via random on-site energies results in Anderson localization in all cases. Extensions to related 2D lattices reveal the emergence of robust topological states. These results show that geometry, nonlinearity, disorder, and topology provide multiple localization mechanisms, offering new strategies for controlling transfer of excitations in 2D systems.

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Topological defects in nematic liquid crystals

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Abstract
Topological defects (TDs) appear in all systems reached via a symmetry breaking phase transition and are consequently observed at all physical scales, including particle physics, condensed matter and even cosmology. Liquid crystals (LCs) are particularly adequate edia to study TDs because they exhibit a rich variety of qualitatively different TDs and in them defects could be relatively easily experimentally observed, e.g., using polarizing microscopy. Of particular recent interest are the so-called twist disclinations in nematic LCs which do not carry the 3D topological charge, however, have nonzero 2D charge. Therefore, in 3D they are not topologically stable. Thus, in ordinary conditions they vanish soon after their creation. However, one can stabilize them energetically by imposing appropriate local orientational frustrations. In the lecture I will present basic properties of twist disclinations and general conditions via which they can be stabilized. Furthermore, I will demonstrate their importance from the perspective of basic physics (they might be analogues of the intriguing neutrinos in particle physics) and applications (they could be exploited as reconfigurable paths for controlled transport of appropriate nanoparticles).

Observations of intrinsic localized modes forming polar nanoregions in a relaxor ferroelectric

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Abstract
Relaxor ferroelectrics exhibit broad, diffuse phase transitions, and polar nanoregions (PNRs) in place of the long-range ordering observed in displacive ferroelectrics. While displacive ferro- electrics are explained by the well established soft-phonon theory, a corresponding intrinsic-localized-mode (ILM) theory for relaxors—first introduced by Bussmann-Holder et al. in 2005—has remained elusive experimentally. The challenge largely stems from a "waterfall"effect that obscures the ILM spectral region. In this talk, neutron scattering will be presented on the lead-free uniaxial relaxor ferroelectric strontium barium niobate to reveal evidence of ILMs that form PNRs. In this system the transverse optic (TO) phonon is observed without the waterfall effect, unveiling flat ILM bands below the TO phonon that become increasingly intense upon cooling toward the phase transition and ultimately condense into diffuse elastic scattering associated with PNR formation. Analysis of the ILM intensities supports the idea that they act as a local order parameter for the diffuse relaxor phase transition.

Effective Topological Charge Cancelation Mechanism

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Abstract
Topological defects (TDs) arise almost inevitably during phase transitions that involve continuous symmetry breaking. Owing to their topological nature, their essential characteristics are largely independent of microscopic system details, leading to a wide range of universal behaviors. In this work, we present a numerical investigation of TDs in effectively two-dimensional closed soft films with in-plane orientational order, such as liquid crystalline shells and biological membranes. We introduce the Effective Topological Charge Cancellation mechanism, which governs the localized spatial organization of TDs and describes the formation of defect–antidefect pairs on curved surfaces and in the presence of relevant inhomogeneities (e.g., nanoparticles). We define an effective topological charge, incorporating contributions from real, virtual, and curvature-induced (smeared) charges within surface patches characterized by different spatially averaged values of Gaussian curvature. Our results reveal a strong tendency for effective topological charge to go to zero in regions composed of patches with significantly different values of Gaussian curvature. For cases where effective topological charge does not equal to zero, we estimate a critical depinning threshold for defect–antidefect pair formation using an electrostatic analogy.

Ballistic energy transport in the nonlinear lattice excited by specific symmetry

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Abstract
We propose the one dimensional (1D) nonlinear lattice exhibiting ballistic energy transport.
The 1D nonlinear lattice is constructed to vanish the umklapp processes which disturb smooth thermal transport.
The methodology for construction is based on the symmetry in Fourier space.
The nonlinear potential has non-locality, and the strength coefficient of long-range interaction is determined to satisfy the condition of symmetry.
We also perform numerical simulation to compute the thermal conductivity in the proposed 1D nonlinear lattice.
As a result of numerical simulation, it is shown that the 1D nonlinear lattice supports ballistic energy transport.

Disorder Free Localization

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Abstract

Localization in quantum systems is most commonly associated with disorder: Anderson's seminal result established that quenched randomness in a lattice potential suppresses diffusive transport through destructive interference, a mechanism subsequently extended to the interacting regime by many-body localization theory. Yet localization can emerge in perfectly ordered, translationally symmetric systems when the spectral geometry of the Hamiltonian enforces it—a phenomenon now recognized as disorder-free localization. We begin this talk with an introduction to this mechanism, tracing its appearance across several physical settings: lattice gauge theories with conserved local charges, flat-band systems with macroscopic ground-state degeneracy, and continuous-time quantum walks on fully connected graphs, where maximal connectivity paradoxically confines rather than delocalizes.

We focus on the last of these as a concrete and computationally tractable model. We present an efficient quantum circuit implementation of continuous-time quantum walks that produces disorder-free localization on random graphs from near-full to full connectivity. We then show that localization in this setting can be systematically destroyed by introducing disorder, and that this destruction is controllable. This controllability turns out to be precisely the resource needed to construct quantum batteries from such systems, where disorder acts as a tunable charging mechanism with favorable energetic cost relative to stored ergotropy.

Oscillating ring ferrodark solitons with breathing nematic core in a homogeneous spinor superfluid

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Abstract
We investigate the dynamics of topological solitons in two-dimensions (2D) and find that a ring ferrodark soliton (FDS) exhibits self-sustained oscillations in a homogeneous quasi-2D ferromagnetic spin-1 Bose-Einstein condensate (BEC), rather than expected indefinite expansion. Moreover, along with the ring radius oscillation, the nematic tensor at the magnetization-vanishing FDS core also exhibits periodic motion.

When the ring radius greatly exceeds the FDS width, the motion is nearly elastic and we derive the ring-radius equation of motion (EOM) which can be recast into a form analogous to the inviscid Rayleigh-Plesset equation for spherical bubbles in classical fluids, but with anomalous terms.

Exact solutions to this equation, as well as the oscillation frequency and amplitude, are obtained analytically. In the absence of the magnetic field, the ring radius and the non-zero eigenvalue of the nematic tensor at the core, i.e., the mass superfluid density, become stationary, while oscillations of the nematic tensor components, driven by the ring curvature, persist at the core. Excellent agreements are found between analytical predictions and numerical simulations.

Lifetime of breathers in an all flatband lattice

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Abstract
A lattice of electrical circuits with some specific coupling and three oscillators per unit cell, called the diamond lattice, has the property that the three phonon bands are optical and completely flat.
The addition of a nonlinear on-site hard potential brings about the existence of breathers, that is localized periodic oscillations. The largest vibration can be located in any of the oscillators inside the unit cell, and their frequencies can be in three of the four different phonon forbidden bands. The forbidden band below the lowest flat band has no breathers due to the hardness of the on-site potential.
There are, therefore, nine different types of breathers, with different properties of stability and energy.
We consider the increase of energy in the different oscillators in a thermalized system, and let the system evolve until thermalization is achieved, measuring the thermalization time. We use a function, called the localization function, which has the property that its value at thermal equilibrium is N/2, where N being the number of oscillators in the system.
The different routes to thermalization of the different breathers are described.

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