Book of abstracts: Trends in Quantum Simulation of Gauge Fields and Topological Matter

Invited speakers

Speaker: Alessio Celi (UPC Barcelona)

Scalable quantum simulation/computation of Abelian and non-Abelian gauge theories beyond 1D with finite resources

Performing gauge theories' calculations by realizing their Hamiltonians in controllable quantum systems to complement existing methods like perturbation theory and quantum Montecarlo is promising and challenging endeavor. After a brief and partial review of current successes and challenges, I will focus on the task of achieving continuum limit calculation with finite resources. I will present an efficient scheme to allow to determine the running of the coupling in SU(N) gauge theories by computing the expectation value of plaquette operator for any regime of the coupling with finite resources. I will illustrate the results obtaining for pure SU(2) gauge theory on a minimal torus and discuss the application of the scheme in current quantum computers and tensor-network computations. I will conclude by presenting preliminary tensor network results on U(1) gauge theory in large or infinite 2D lattices.

Speaker: Dalmonte Marcello (ICTP)

Graviton excitations in Fractional quantum Hall synthetic matter

Over the last few years, growing evidence has been reported that the fractional quantum Hall (FQH) carries very specific spectral properties, that had previously been overlooked. An outstanding one is the presence of neutral, chiral, well defined spin-2 excitations induced by quantum geometry, termed gravitons. The generality and phenomenology of such modes is still in its infancy, with most results derived for continuum models, and experimental signatures limited to (challenging) Raman spectroscopy.
In this talk, I will discuss how synthetic quantum systems provide multiple novel perspectives on the problem. First, I will show how graviton modes do exist also in lattice models, a highly non-trivial fact as, on the lattice, well defined excitations are offered multiple decay channels and are thus fundamentally more unstable. In the context of the bosonic Harper-Hofstadter model, I will discuss the field theoretical origin of such modes, corresponding numerical evidence, and specific experimental signatures within a "geometric" quench realizable in cold atom experiments.
I will then follow this up discussing the fate of gravitons for FQH matter embedded in cavities, related to recent experiments in Faist's group. Remarkably, quantum light couples strongly to gravitons, establishing the existence of a new quasiparticle - a graviton polariton - which imprints unique entanglement patterns on the system wave function, and shall be experimentally observable at strong coupling.
Work done in collaboration with Bacciconi, Carusotto, Chanda, Son, and Xavier.

Speaker: Goldman Nathan (Collège de France, International Solvay Institutes and Université Libre de Bruxelles)

Correlated topological matter: news and views from quantum simulation

Considerable efforts are currently focused on realizing correlated topological phases in quantum-engineered systems, with the aim of manipulating their exotic properties within a controlled environment. Important advances in this field recently led to the observation of fractional quantum Hall states, using small ensembles of atoms or photons. This talk will present key aspects of these emerging experimental settings, and discuss new ways to probe and characterize quantum Hall states in ultracold atomic gases.

Speaker: Magnifico Giuseppe (University of Bari)

Tensor Network methods for Gauge Field Theories

Gauge theories lie at the heart of our description of nature's fundamental building blocks and their interactions, ranging from high-energy particle physics to emergent phenomena in low-temperature quantum matter. However, the complete characterization of their phase diagrams and the full understanding of non-perturbative effects are still debated, especially at finite charge density, mostly due to the sign-problem affecting Monte Carlo numerical simulations. In recent years, a complementary numerical approach, Tensor Networks (TN) methods, in synergy with emerging quantum technologies, has found increasing applications for studying Lattice Gauge Theories (LGTs). In this talk, I will present recent results concerning the application of TN algorithms to the study of LGTs including fermionic matter. In particular, I will focus on intriguing dynamical phenomena, such as string-breaking and scattering effects, and equilibrium phase diagrams.

Speaker: Morais Smith Cristiane (Utrecht University)

Topology and Interactions at dimension 1.58

We know how topological insulators behave in 1,2,3 dimensions, but what happens in between? In this talk, I will first present theoretical and experimental results on the behavior of ultranarrow germanene nanoribbons and show the transition from 1D topological edge states into 0D end states as the width of the nanoribbons is reduced below 2 nm [1]. Then, I will discuss the topological properties of electrons in self-formed single-layer bismuth fractals with dimension d = 1.58 on InSb [2]. Finally, I will present theoretical results on the Hubbard model in a fractal geometry [3] and discuss ongoing studies on a fractal made of Rydberg atoms with long-range interactions, trapped by optical tweezers (in preparation).

[1] D. J. Klaassen, L. Eek, A. N. Rudenko, E. D. van't Westende, C. Castenmiller, Z. Zhang, P. L. de Boeij, A. van Houselt, M. Ezawa, H. J. W. Zandvliet, C. Morais Smith, P. Bampoulis, Nature Communications **16**, 2059 (2025).
[2] R. Canyellas , Chen Liu, R. Arouca, L. Eek, G. Wang, Yin Yin, D. Guan, Yaoyi Li, S. Wang, Hao Zheng, Canhua Liu, J. Jia, C. Morais Smith, Nature Physics **20**, 1421 (2024).
[3] M. Conte, V. Zampronio, M. Rontgen, and C. Morais Smith, Quantum **8**, 1469 (2024).

Speaker: Salerno Grazia (University of Pisa)

Topology of light polarization vortices in nanophotonic crystals

The simulation of topological modes offers an important prospect for realizing robust phenomena that are not affected by the external environment. In photonic crystals, this robustness can manifest through the emission of vortex beams with a non-trivial topological charge. Bound states in the continuum (BICs) emerge as light polarization vortices in nanophotonic systems and have extremely high Q factors and low losses. We show that these BIC modes allow lasing emission with non-trivial polarization properties akin to vortex beams [1]. By combining group theory with a careful design of the lattice, we further demonstrate that different BICs with distinct topological charges can lase in various regimes, while our simulations confirm that the modes' quality factors undergo a loss-induced topological transition as the scale of the unit cell changes [2]. We then explore the relation between the symmetry of the photonic structure and the rotationality of the vortex, experimentally demonstrating high topological charges in quasicrystals [3]. By developing an effective non-Hermitian model, we offer insights into the topology of the far-field emission and how it is connected to the standard band topology in the presence of BICs [4].

[1] R. Heilmann, G. Salerno, J. Cuerda, T.K. Hakala, and P. Törmä, ACS Photonics 9, 224 (2022).
[2] G. Salerno, R. Heilmann, K. Arjas, K. Aronen, J.P. Martikainen, and P. Törmä, Phys. Rev. Lett. 129, 173901 (2022).
[3] K. Arjas, J.M. Taskinen, R. Heilmann, G. Salerno and P. Törmä, Nat. Commun. 15, 9544 (2024).
[4] X. Yuan, L. Malgrey, H. Sigurðsson, H. S. Nguyen and G. Salerno, arXiv:2504.05188 (2025).

Speaker: Tarruel Leticia (ICFO Barcelona)

Probing supersolidity through excitations in a spin-orbit-coupled Bose-Einstein condensate

Spin-orbit-coupled Bose-Einstein condensates are a flexible experimental platform to engineer synthetic quantum many-body systems. In particular, they host the so-called stripe phase, an instance of a supersolid state of matter. The peculiar excitation spectrum of the stripe phase, a definite footprint of its supersolidity, had so far remained out of experimental reach. In my talk, I will present our recent experiments on spin-orbit coupled Bose-Einstein condensates, where by leveraging the tunable interaction properties of potassium atoms and a matter-wave optics magnification scheme, we achieve for the first time in situ imaging of the stripes. This allows us to directly observe both superfluid and crystal excitations, investigate superfluid hydrodynamics, and reveal a stripe compression mode. The latter shows that the system possesses a compressible crystalline structure and, through its frequency softening, enables the location of the supersolid transition point. Our results establish spin-orbit-coupled supersolids as a platform of choice to investigate supersolidity and its rich dynamics.

Speaker: Zache Torsten (IQOQI Innsbruck)

Observation of string breaking on a (2+1)D Rydberg quantum simulator

Fundamental forces of nature are described by gauge theories, and the interactions of matter with gauge fields lead to intriguing phenomena like the confinement of quarks in quantum chromodynamics. Separating a confined quark-anti-quark pair incurs an energy cost that grows linearly with their separation, eventually leading to the production of additional particles by an effect that is called string-breaking.
In this talk, I will discuss how similar phenomenology can be probed using Rydberg atom arrays. In particular, I will explain how the Rydberg blockade constraint on a suitable two-dimensional lattice geometry allows us to interpret the native Rydberg Hamiltonian as a confining U(1) lattice gauge theory. In collaboration with QuEra, we have realised this proposal using their device “Aquila”, operating as an analog quantum simulator. I will present both theoretical and experimental results concerning the physics of confinement and string-breaking in this setup, including equilibrium state preparation as well as non-equilibrium quench dynamics.

Contributed speakers

Speaker: Bacciconi Zeno (SISSA)

Local vs Nonlocal Dynamics in Cavity-Coupled Rydberg Atom Arrays

Locality is a transversal principle that governs quantum dynamics of many-body systems. However, for cavity embedded systems, such fundamental notion is hindered by the presence of non-local cavity modes, leaving space for new possible dynamical behaviors. In this talk, I will discuss our recent results [1] on ground state and real-time dynamics of a one dimensional Rydberg atom array coupled to a global cavity mode. The effective Hamiltonian of the system is a Tavis-Cummings-Ising model, whose phase diagram shows competition between a confined phase and U(1) spontaneous symmetry broken phase. I will focus on the low-energy excitations of the confined phase and argue that the non-local nature of the cavity mode drastically affects the emergent meson and string dynamics expected in locally interacting theories. Mesons hybridize coherently with cavity photons, leading to composite meson-polaritons excitations. Strings instead can acquire a finite kinetic energy thanks to non-local cavity-mediated interactions, contrary to standard local theories. In the end, I will address the effect of photon losses and discuss possible concrete experimental regimes.

[1] Zeno Bacciconi, H. Xavier, M. Marinelli, D. Bhakuni, M, Dalmonte; Phys. Rev. Lett. **134**, 213604 (2025)

Speaker: Burrello Michele (University of Pisa)

Poor man's Majorana modes in interacting hybrid superconductor-semiconductor devices

Recent experiments in hybrid semiconductor-superconductor devices demonstrated the possibility of realizing the so called "Poor man's Majorana modes" (PMMs). These are zero-energy modes that fulfill most of the properties of standard Majorana modes in topological superconductors, despite not being topologically protected. PMMs are indeed realized in fine-tuned devices composed by quantum dots and superconducting elements, which mimic minimal Kitaev chains with two sites only. The exquisite control granted by these hybrid systems, however, allow for tuning the cotunneling and Andreev processes between quantum dots, thus enabling a remarkable control over the emerging PMMs. In this talk, I will introduce the platforms used to realize PMMs and present the design of devices with floating superconducting islands which combine PMMs with electrostatic interactions. These devices enable the integration of PMMs with transmons and other superconducting systems, they can be integrated with state-of-the-art sensors for charge and fermionic parity, and allow for the design of two-state systems for the exploration of exotic Kondo problems, including the topological Kondo effect which is considered a hallmark for the non-locality of Majorana modes.

Speaker: Lerose Alessio (University of Leuven)

Analog quantum simulation of continuum (1+1)D gauge-QFT with quasi-1D synthetic quantum magnets

Speaker: Maffi Lorenzo (University of Padua)

Vortex Dynamics in Strongly Interacting Superfluid

Interactions can play a determinant role in low dimensions for topological and chiral states of matter by giving rise to interesting emergent phenomena such as quasiparticle fractionalization and quantum phase transitions. Recent experimental evidence from Floquet engineered ultracold atomic systems, have provided a starting point for observing correlated vortex structures of the Laughlin bosonic Hall effect. Motivated by these experimental advances, we have investigated the quantum dynamics of large vortices in strongly interacting superfluids. For one quantum of flux and close to half-filling, the change in sign of the Hall conductivity suggests an abrupt change in vortex response and dynamics, due to effective strong quantum fluctuations. In this contribution we will present some preliminary results on vortex dynamics in the presence of strong correlations for different filling factors, giving rise to chiral vortex motion and non-trivial trajectories near to half-filling. We provide a mapping to a dual effective free theory explaining our observations. These results motivate novel transport measurements to delve into the phenomenology of single and multi-vortex dynamics in state-of-the-art bosonic platforms.

Speaker: Nardin Alberto (University of Paris Saclay)

Nonlinear dynamics at the fractional quantum Hall edge

One of the hallmark features of fractional quantum Hall liquids is the existence of chirally propagating edge modes at their boundary, whose presence has been an invaluable tool for probing the system's exotic properties, most notably the presence of fractionally charged quasiparticles with anyonic exchange statistics. During this talk, I'll describe how corrections to Wen's chiral Luttinger liquid, the golden-standard for the description of these edge modes, emerge in systems such as anharmonically confined quantum Hall fluids or small atomic fractional quantum Hall states on a lattice. In particular, mode dispersion and non-linearities give rise to intriguing new features, such as solitons propagating along the boundary, quantum blockaded dynamics leading to the possibility of generating non-classical states of the edge, and bistable behaviors.

Speaker: Notarnicola Simone (University of Padua)

Dynamics across quantum phase transitions in Rydberg atom arrays

Neutral atoms are one of the most promising tools for quantum technologies, after recent experiments have proven their capability to prepare quantum many-body states in analog quantum simulations, as well as in digital and logical quantum computations. In particular, two-dimensional atom arrays, in which each atom can be either in its ground or in a higly excited Rydberg state, have been used to investigate exotic spin-wave phases of matter and out-of-equilibrium phenomena. In our work, we study, both numerically and experimentally, the dynamics across the quantum phase transition between the disordered phase (no spin wave) and the ordered striated phase. The striated phase is a genuine quantum phase induced by long-range interactions and the transition from the disorder to the ordered phase is of the first order in the thermodynamic limit, while it is of the second order along the boundary. We find that the interplay between the bulk and the boundary strongly influences the properties of finite-size systems depending on the even or odd size of the lattice, unveiling an intriguing and unexplored phenomenology. We use tree-tensor networks, implemented in the Quantum Green Tea library, to simulate equilibrium and out-of-equilibrium properties in lattices up to 16×16 sites. Moreover, we benchmark our numerical predictions with experiments performed on the Aquila quantum processor realized by the QuERA startup.

Speaker: Tirrito Emanuele (ICTP)

Entanglement and magic in U(1) lattice gauge theory

Quantum resources have played a crucial role in our understanding of many-body systems over the past two decades. While entanglement has been extensively studied, the role of other quantum resources—such as magic, which is essential for quantum computational advantage—remains less explored. Understanding the emergence and dynamics of magic is key to advancing quantum simulators and quantum computing architectures. In this talk, I will show how magic serves as a fundamental bridge between quantum information theory and many-body physics. I will begin by reviewing stabilizer Rényi entropies as a powerful measure of magic and its utility in characterizing complex quantum states. Building on this framework, I will present a thorough investigation of nonstabilizerness in a one-dimensional U(1) lattice gauge theory including matter fields. I show how nonstabilizerness is always extensive with volume, and has no direct relation to the presence of critical points. However, its derivatives typically display discontinuities across the latter: This indicates that nonstabilizerness is strongly sensitive to criticality, but in a manner that is very different from entanglement.

Speaker: Xu Wen-Tao (TUM)

Tensor-Network Study of the Roughening Transition in (2+ 1) D lattice gauge theories

Within the confined phase of (2+1)D lattice gauge theories a roughening transition arises between a weakly confined regime with floppy string excitations and a strongly confined regime with stiff string excitations. In this work, we use an infinite Density Matrix Renormalization Group (iDMRG) algorithm to quantitatively characterize the properties of confined strings. To this end, we stabilize the state with a string excitation by 't Hooft loop operators. While for zero gauge-matter coupling we can use bare 't Hooft loop operators to do so, for finite gauge-matter coupling we have to transform them to emergent ones, which we achieve with an adiabatic protocol. By analyzing the scaling of both a novel order parameter and the entanglement entropy, our approach allows us to accurately determine the roughening transition, even at finite gauge-matter coupling.

Speaker: Zerba Caterina (TUM)

Emergent Fracton Hydrodynamics of Ultracold Atoms in Partially Filled Landau Levels

The realization of synthetic gauge fields for charge neutral ultracold atoms and the simulation of quantum Hall physics have witnessed remarkable experimental progress. Here, we establish key signatures of fractional quantum Hall systems in their nonequilibrium quantum dynamics. We show that in the lowest Landau level the system generically relaxes subdiffusively. The slow relaxation is understood from emergent conservation laws of the total charge and the associated dipole moment that arises from the effective Hamiltonian projected onto the lowest Landau level, leading to subdiffusive fracton hydrodynamics. We discuss the prospect of rotating quantum gases as well as ultracold atoms in optical lattices for observing this unconventional relaxation dynamics.

List of posters

Presenter: Ballini Edoardo (University of Trento)

Error mitigation with post-selection in non-Abelian lattice gauge theories

Non-Abelian gauge theories underlie our understanding of fundamental forces of modern physics. Simulating them on quantum hardware is an outstanding challenge in the rapidly evolving field of quantum simulation. A key prerequisite is the protection of local gauge symmetries against errors that, if unchecked, would lead to unphysical results. One of the simplest yet effective methods for simulations of Abelian theories is postselection based on local gauge invariance. However, applying it to non-Abelian models becomes nontrivial, as the symmetry generators typically do not commute with each other.
In this seminar, I will discuss two methods to adapt postselection techniques for nonabelian gauge groups. The first, dubbed dynamical postselection, uses mid-circuit measurement to enforce gauge invariance during the simulation. I will show its application to a simple Z2 1+1D theory. The second one, post-processed symmetry verification, implements an effective group averaging by cleverly combining measured observables at the end of the simulation. I will illustrate these two methods on the dihedral group D3, the smallest non-Abelian discrete group.

Presenter: Burgher Maxime (Université Libre de Bruxelles)

Fate of chiral order and impurity self-pinning in flat bands with local symmetry

Interacting bosons on a single plaquette threaded by a π flux can spontaneously break time-reversal symmetry, resulting in a chiral loop current. Connecting such bosonic π-flux plaquettes in a dispersive configuration was recently shown to lead to long-range chiral order. Here, instead, we design a chain of π-flux plaquettes that exhibits an all-flat-bands single-particle energy spectrum and an extensive set of local symmetries. Using Elitzur's theorem, we show that these local symmetries prevent the emergence of long-range chiral order. Moreover, projecting the dynamics to a Creutz ladder model with an effective intrarung interaction allows one to derive simple spin Hamiltonians capturing the ground-state degeneracy and the low-energy excitations, and to confirm the absence of chiral order. Nevertheless, we show how to obtain gauge-invariant information from a mean-field approach, which explicitly breaks gauge-invariance. Finally, we observe an impurity self-pinning phenomenon, when an extra boson is added on top of a ground state at integer filling, resulting in a nondispersive density peak. Exact diagonalization benchmarks are also provided, and experimental perspectives are discussed.

Presenter: Catalano Alberto Giuseppe (University of Padua)

Experimental preparation of W-States with Rydberg atoms

W-states are important quantum states possessing both bi-partite and multi-partite entanglement and are necessary for several relevant quantum algorithms. We propose a protocol to generate them with an arbitrary number of qubits on a Rydberg atoms platform, by exploiting the principles of {\it topological frustration}. We experimentally achieve fidelities close to 90\% (for 11 qubits) and show a promising scaling using accurate numerical simulations, with high fidelities for tens of qubits. In this way, not only do we reach an unparalleled accuracy for the generation of these states compared to the existing approaches, but we also show once more how physics principles can overcome traditional barriers and be exploited toward quantum advantage.

Presenter: Cortes Ronald (ICTP-SISSA)

Principal component analysis of absorbing state phase transitions

We perform a principal component analysis (PCA) of two one-dimensional lattice models belonging to distinct nonequilibrium universality classes – directed bond percolation and branching and annihilating random walks with even number of offspring. We find that the uncentered PCA of datasets storing various system's configurations can be successfully used to determine the critical properties of these nonequilibrium phase transitions. In particular, in both cases, we obtain good estimates of the critical point and the dynamical critical exponent of the models. For directed bond percolation we are, furthermore, able to extract critical exponents associated with the correlation length and the order parameter.

Presenter: Cuzzuol Nitya (Politecnico di Torino)

Finite temperature induced interacting symmetry protected topological phases

Topological phases in low-dimensional strongly interacting quantum systems have been widely studied at zero temperatures, revealing that they can emerge due to lattice geometry, interactions, and explicit symmetry-breaking terms. We demonstrate [1] that finite temperature effects can induce new symmetry-protected topological (SPT) phases in systems where magnetic atoms or polar molecules are trapped in optical lattice. Specifically, we analyze both the XXZ spin-1 and the dimerized spin-1/2 Heisenberg Hamiltonians, as well as a fermionic system where particles interact through an antiferromagnetic coupling. In these systems, the presence of distinct gaps in the energy spectra characterized by different amplitudes plays a crucial role in the finite-temperature stability of SPT phases. In particular, the imaginary time evolution of MPS-based purification reveals that when at zero temperature a system is in an ordered phase a SPT phase with novel symmetry features can emerge as the temperature increases. This intriguing and general mechanism results accurately proved by the emergent long-range order of nonlocal string order parameters, even degeneracy of the entanglement spectrum and finite edge states. These findings demonstrate how temperature represents a novel and powerful resource for creating and controlling SPT phases in atomic quantum simulators.

[1] N. Cuzzuol, M. Miotto, A. Montorsi, L. Barbiero. Finite temperature induced interacting symmetry protected topological phases. In preparation.

Presenter: Di Spena Sharon (University of Padua)

Quantum many-body effects in a pi-flux Hubbard model

Frustration induced by pi-fluxes in dimerized lattices enhances quantum many-body effects and can stabilize higher-order topological insulating phases characterized by boundary states localized in lower dimensions. Building on recent two-dimensional studies, we investigate the many-body physics of a three-dimensional generalization of the pi-flux Hubbard model involving bosonic particles on strongly dimerized cubic plaquettes. Using an effective low-energy theory, mean-field analysis, and Gross–Pitaevskii approaches, we characterize the ground-state properties and low-energy excitations, revealing the impact of interactions and degeneracy. Our results are relevant for quantum simulation platforms based on ultracold atoms in synthetic gauge fields.

Presenter: Geraghty Patrick (University of Cologne)

Stability of Fractional Quantum Hall States in Synthetic Dimensions

Recent cold atom experiments using an internal degree of freedom as a synthetic dimension have successfully realized an integer quantum Hall state. A natural next step is the realization of a fractional quantum Hall (FQH) state; however, in this regime, the long-range and anisotropic interactions intrinsic to synthetic dimension systems can no longer be neglected. Using Tree Tensor Network simulations, we demonstrate that these interactions do not necessarily destroy the FQH state. The crucial parameter is \rho_{1D}, the particle density in the physical dimension. Depending on the value of this parameter, the resulting phase is either a trivial density wave (DW) or a non-trivial momentum space DW living in the same universality class as the FQH state. We also study the impact of anisotropy in the hopping amplitude between the physical and synthetic dimensions. We present phase diagrams as a function of \rho {1D} and the hopping anisotropy. Our results unveil a broad parameter regime for the realization of FQH states in synthetic dimensions.

Presenter: Lanaro Maria (University of Padua)

Emergent chiral properties and quantum phase transitions in the BBH model

Chirality is a central concept to describe a large class of phases of matter, including certain topological phases, and quantum simulators provide a unique opportunity to explore the corresponding properties. A particularly interesting case of study is the Benalcazar-Bernevig-Hughes (BBH) model for two-dimensional lattices with pi-flux, which is known to belong to the higher-order insulators family. It has been recently shown that chiral properties and phases resembling those of higher bands emerge in the low-energy physics of this model with bosons at half filling [1], especially in the weakly interacting regime and on the strongly interacting 1D ladder case. Here, we focus on the two-dimensional strongly-interacting case to clarify the quantum phases of the model, the corresponding phase diagram via relevant observables and the low energy spectrum near criticality. We employ variational techniques based on the Gutzwiller ansatz, a local product state ansatz, extended to include short-range correlations, to characterize the emergence of local angular momentum states via symmetry breaking.

Presenter: Liu Jing-Xin (Nanjing University)

Geometric Bloch oscillations and transverse displacement in flat band systems

We investigate transport phenomena and dynamical effects in flat bands where the band dispersion plays no role.
We show that wavepackets in geometrically non-trivial flat bands can display dynamics when inhomogeneous electric fields are present. This dynamics is revealed both for the wavepacket trajectory and for its variance, for which we derive semiclassical equations extended to the non-Abelian case. Our findings are tested in flat band models in one- and two-dimensional lattices where the dynamics is solely determined by geometric effects, in the absence of band dispersion. In particular, in the one-dimensional case, we show the existence of Bloch oscillations for the wavepacket position and for the wavepacket variance, whereas in the two-dimensional case we observe a transverse displacement of the wavepacket in the absence of Berry curvature. This work paves the way for understanding quantum-geometry induced dynamical effects in flat band materials and also opens the possibility for their observation with synthetic matter platforms.

Presenter: Maier Tobias (University of Stuttgart)

Topological order in symmetric blockade structures

The bottom-up design of strongly interacting quantum materials with prescribed ground state properties is a highly nontrivial task, especially if only simple constituents with realistic two-body interactions are available on the microscopic level. Here we study two- and three-dimensional structures of two-level systems that interact via a simple blockade potential in the presence of a coherent coupling between the two states. For such strongly interacting quantum many-body systems, we introduce the concept of blockade graph automorphisms to construct symmetric blockade structures with strong quantum fluctuations that lead to equal-weight superpositions of tailored states. Drawing from these results, we design a quasi-two-dimensional periodic quantum system that – as we show rigorously – features a topological Z2 spin liquid as its ground state. Our construction is based on the implementation of a local symmetry on the microscopic level in a system with only two-body interactions.

Presenter: Majcen Peter (University of Padua)

Cold-atom simulator of a (2+1)D U(1) quantum link model and efficient local basis truncation of Quantum field theories

The modern description of elementary particles and their interactions is formulated in the language of gauge theories, making them of great interest in theoretical physics. However, first-principle calculations for understanding emergent phenomena are not always feasible. Possible solutions to this challenge include formulating a Hamiltonian lattice gauge theory and studying it using tensor network (TN) techniques or quantum simulators that emulate the dynamics of the theory of interest. A suitable platform for such quantum simulators is ultra-cold atoms. In this work, we adopt a quantum link formulation of QED and present a mapping of a U(1) Quantum Link Model (QLM) for spin S=1 in (2+1)D to a bosonic superlattice. We then propose a scheme for the realization of the target QLM on an extended Bose-Hubbard model. To validate the mapping, we demonstrate the stability of gauge invariance and the fidelity between the quench dynamics of the extended Bose-Hubbard model optical superlattice. Using perturbation theory, we derive an effective description of the QLM and relate its parameters to those of the extended Bose-Hubbard model. To validate the mapping, we demonstrate the stability of gauge invariance and the fidelity between the quench dynamics of the extended Bose-Hubbard model and the target QLM over all accessible evolution times.

For both tensor network and quantum simulation approaches, one limitation is the potentially large local Hilbert space for bosonic degrees of freedom. To address this problem, we propose an effective description of the target theory. Using cluster mean-field techniques, we estimate the reduced density matrix and project the theory onto the relevant subspace. We demonstrate this approach in purely bosonic quantum field theories, such as the sine-Gordon model in (1+1)D and the ϕ-4 model in (1+1)D and (1+2)D, where it is particularly effective in symmetry-broken phases and allows for accurate determination of critical exponents. This development improves the scalability of TN simulations in higher dimensions and can also be applied to quantum computation and quantum simulation.

Presenter: Morgavi Mattia (University of Padua)

Real-time simulation of pure Yang-Mills SU(3) glueballs scattering processes with MPS

We introduce a model-independent method to construct Matrix Product Operator (MPO) representations of quasiparticle creation operators acting on the interacting vacuum of (quasi-)one-dimensional quantum many-body systems. This method exploits maximally localized Wannier functions constructed from single-particle states at intermediate system sizes, which provides the building blocks for a generic single-quasiparticle MPO wave-packet creation operator. This enables the preparation of arbitrary input states for real-time scattering simulations. We test this approach on a relevant scenario for Lattice Gauge Theory: the glueball-glueball scattering on a pure Yang-Mills SU(3) ladder, opening a path to real-time simulations of non-abelian scattering processes, a still largely unexplored frontier.

Presenter: Muzzi Cristiano (SISSA)

Quantum many-body integrable systems featuring non-abelian symmetries are know to display superdiffusion even at high temperature, in particular related to Kardar-Parisi-Zhang scaling. However, the impact of broken time reversal symmetry on universality in such systems remains underexplored. This poster explores high-temperature energy and spin transport regimes in an integrable ladder model where both parity and time reversal symmetries are broken.

Presenter: Pavesic Luka (University of Padua)

Constrained dynamics in the 2D quantum Ising model

Presenter: Ritu Ritu (SISSA)
Unravelling Quantum Magic in Topological Phases

Presenter: Sferrazza Giovanni Luca (University of Palermo)
Non-Markovian dynamics of a qubit due to accelerated light in a lattice

Non-Markovian dynamics of a qubit due to accelerated light in a lattice: We investigate the emission of a qubit weakly coupled to a one-band coupled-cavity array where, due to an engineered gradient in the cavity frequencies, photons are effectively accelerated by a synthetic force F.
For strong F, a reversible emission described by an effective Jaynes-Cummings model occurs, causing a chiral time-periodic excitation of an extensive region of the array, either to the right or to left of the qubit depending on its frequency. For weak values of F instead, a complex non-Markovian decay with revivals shows up. This is reminiscent of dynamics induced by mirrors in standard waveguides, despite the absence of actual mirrors, and can be attributed to the finite width of the energy band which confine the motion of the emitted photon. In a suitable regime, the decay is well described by a delay differential equation formally analogous to the one governing the decay of an atom in a multi-mode cavity where the cavity length and time taken by a photon to travel between the two mirrors are now embodied by the amplitude and period of Bloch oscillations, respectively.

Presenter: Tiburzi Edoardo Maria (University of Padua)

Multi-particle bound states dynamics in driven Rydberg atom arrays

Recent developments in the control of Rydberg atoms have shown that Floquet drives, e.g. the WAHUHA protocol, can be successfully employed to manipulate and tune the parameters of the corresponding spin models. Inspired by these results, in this work we investigate the behavior of two- and three-spin bound states arising from second-order effects in Floquet theory. We consider a system initially described by an XY model driven under the WAHUHA protocol and its generalizations. At first order, the effective Hamiltonian corresponds to an XYZ model with tunable anisotropies, while second-order corrections introduce long-range interactions and four-site coupling terms. By appropriately tuning the parameters of the protocol, we show that SO(2) symmetry, i.e. magnetization conservation as for the XY or XXZ models, can be approximately preserved up to 2nd order in spin-spin interactions. We analyze regimes of different magnetic excitations corresponding to single spin-flips, doublons, and triplons which form bound states of the model. We analyze how second-order corrections impact the mobility of these states favouring or suppressing the bound state dynamics and the role of symmetry breaking terms. Furthermore, we discuss how these findings can apply to Rydberg atom arrays interacting via dipole-dipole interactions to enable the observation of multi-particle bound state dynamics.

Presenter: Timisinai Hari (SISSA)
Critical Behavior in One-Dimensional Spin Systems Through Robustness of Magic

Robustness of Magic (RoM) characterizes the usefulness of a given quantum state for non-Clifford operations. RoM quantifies the classical simulation overhead and serves as a well-defined measure of nonstabilizernass (magic) for generic quantum states. It is computed by minimization over the set of all pure stabilizer states. In this contribution, we will present the application of RoM in many-body systems, focusing on the one-dimensional spin models. We will examine a tri-partitioned system of different sizes, where some degree of freedom will be traced out via quantum Monte-Carlo, leaving two disconnected subregions. Results on RoM and mutual-RoM as functions of the transverse field for the ground state and their finite-temperature behavior will be presented. Additionally, we will investigate the critical behavior through finite-size scaling governed by the power-law decay of the RoM.