# 6th Quantum Science and Technology Workshop

# 2nd IKUR Quantum Science and Technology Workshop 2023

## Bilbao

October 20, 2023

## Final Program

(last updated: October 19, 2023)

organized by UPV/EHU and DIPC

Donostia International Physics Center

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Universidad del País Vasco

Euskal Herriko Unibertsitatea

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EUSKO JAURLARITZA GOBIERNO VASCO

ikur estrategia

## 1 Program

**09:25** arrival, welcome

**09:30** Maria Gastiasoro (DIPC)

**10:00** Sara Catalano (CFM)

**10:20** Brahmin Lounis (U Bordeaux)

**10:50** Nathan Metraud (UPV/EHU)

**11:10** coffee break & posters

**11:40** Jonathan Wise (U Bordeaux)

**12:10** Aitor Alaña (UPV/EHU)

**12:30** David Novoa (UPV/EHU)

**13:00** Marc Manzano (Sandbox)

**13:20** lunch break and poster session

**15:30** Tobias Grass (DIPC)

**16:00** Nonia Vaquero (DIPC)

**16:20** Mikel Sanz (BCAM)

**16:50** coffee break & posters

**17:10** Nico Lorente (CFM)

**17:30** Roman Orús (DIPC & Multiverse)

**17:50h** conclusion

## 2 Venue and Contact Data

**Organizers:** Enrique Rico, Géza Giedke

**Local organizer:** Enrique Rico

**Contact:**
enrique.rico.ortega@gmail.com

**Website:** `http://dipc.ehu.es/giedke/eusqutech23.html`

**Venue:** Paraninfo of the Science and Technology faculty of the UPV/EHU in Leioa (Barrio Sarriena s/n)

**Sponsors:** The workshop is financially supported by DIPC, by IKUR, and by Euskampus. We thank UPV/EHU for hosting the workshop.

# 3 Invited and Contributed Talks and Posters

## List of Invited Talks

1. Gastiasoro, Maria (DIPC & Ikerbasque, Donostia)
   **Pairing mediated by soft ferroelectric modes in polar metals**

2. Grass, Tobias (DIPC & Ikerbasque, Donostia)
   **Quantum simulation of Hubbard models**

3. Lounis, Brahmin (Université de Bordeaux)
   **Tailoring the degree of entanglement of two coherently coupled quantum emitters**

4. Novoa, David (UPV/EHU & Ikerbasque, Bilbao)
   **Mastering light quanta with synchronous molecular motion**

5. Sanz, Mikel (BCAM, UPV/EHU, & Ikerbasque, Bilbao)
   **Digital-Analog Quantum Computation**

6. Wise, Jonathan (Université de Bordeaux)
   **Nonclassical mechanical states in nonlinear quantum optomechanics**

## List of Contributed Talks

1. Alaña, Aitor (UPV/EHU, Bilbao)
   **Controlling a quantum phase transition manipulating the Modulation Instability**

2. Catalano, Sara (CFM, Donostia)
   **Josephson Junctions with hybrid EuS/Al interfaces: a preliminary study**

3. Lorente, Nicolas (CFM, Donostia)
   **Many-body localization and time crystalline phases in a NISQ experiment**

4. Manzano, Marc (SandboxAQ, USA)
   **What's quantum-resistant cryptography and why does it matter?**

5. Metraud, Nathan (UPV/EHU, Bilbao)
   **Quadratic Fermionic Hamiltonians**

6. ORÚS, ROMAN (DIPC, Ikerbasque & Multiverse, Donostia)
   **Simulating IBM's Eagle Kicked Ising Experiment with Quantum-Inspired Tensor Networks**

7. VAQUERO, NONIA (DIPC, Donostia)
   **Physically Motivated Improvements in Variational Quantum Eigensolvers**

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## List of Posters

1. Alcaine, Jesús Matias (UPV/EHU and BCAM, Bilbao)
   **Symmetry-protected gates on superconducting circuits**
2. Aseguinolaza Aguirreche, Unai (Mondragon Unibertsitatea)
   **Error estimation in current noisy quantum computers**
3. Bercioux, Dario (DIPC & Ikerbasque, Donostia)
   **Topological properties of a non-Hermitian quasi-one-dimensional chain with a flat band**
4. Biswas, Sourav (DIPC, Donostia)
   **Two-channel Kondo problem in coupled interacting helical liquids**
5. Caldevilla Asenjo, David (CFM, Donostia)
   **Characterization of planar Al-based Josephson Junctions proximitized by a ferromagnetic insulator**
6. Capela, Matheus (UPV/EHU, Bilbao)
   **Hybrid classical-quantum algorithms with finite number of measurement outcomes**
7. Carreras, Abel (Multiverse, Donostia)
   **Addressing Statistical Noise in Classical Optimizers for Variational Quantum Eigensolvers**
8. Cobos Jiménez, Jesús (UPV/EHU, Bilbao)
   **Noise-aware variational eigensolvers: a dissipative route for lattice gauge theories**
9. Dastbasteh, Reza (Tecnun, Donostia)
   **Infinite Class of Robust Degenerate Quantum Error-Correcting Codes**
10. D'Emidio, Jonathan (DIPC, Donostia)
    **Lee-Yang zeros at O(3) and deconfined quantum critical points**
11. Edalatmanesh, Shayan (DIPC, Donostia)
    **Topological one-dimensional nanomaterials**
12. Etxezarreta Martinez, Josu (Tecnun, Donostia)
    **Superadditivity effects of quantum capacity decrease with the dimension for qudit depolarizing channels**

13. Garcia de Andoin, Mikel (UPV/EHU, Bilbao)
**Hybrid Quantum-Classical Search Space Reduction Heuristic for Optimization**

14. González Conde, Javier (UPV/EHU, Bilbao & QuantumMads)
**Efficient quantum amplitude encoding of polynomial functions**

15. González Raya, Tasio (UPV/EHU, Bilbao)
**Tavis-Cummings model in gas-filled hollow-core fibres for frequency up-conversion**

16. Ibarrondo, Ruben (UPV/EHU, Bilbao)
**Quantum Genetic Algorithm**

17. Lafuente-Bartolome, Jon (UPV/EHU, Bilbao)
***Ab-initio* theory of polarons at all couplings**

18. Leumer, Nico (DIPC, Donostia)
**Finite size quantization of mid-gap Majorana states of Rashba-nanowires**

19. Ligthart, Rian (Utrecht University)
**Towards topological edge states with artificial electronic lattices: Cs on InAs(111)A**

20. Mena, Arturo (UPV/EHU, Bilbao)
**Preservation of biphoton quantum coherence in frequency up-conversion using gas-filled hollow-core fibres**

21. Mier, Cristina (Tecnalia, Donostia)
**Quantum Simulations of Graphene**

22. Navarro, Javier (BCAM, Bilbao)
**Classical and Quantum Bhattacharyya Bounds**

23. Nguyen, Minh (DIPC, Donostia)
**Valley-polarized edge modes in sliding bilayer graphene**

24. Oliva del Moral, Javier (Tecnun, Donostia)
**Asymmetric Generalized Amplitude Damping Channel**

25. Patra, Siddhartha (DIPC, Donostia)
**Simulating IBM's quantum Ising experiment with PEPS:127, 433, 1121 and infinitely-many qubits**

26. Pellicer Guridi, Ruben (CFM, Donostia)
**Hardware for scalable magnetic field sensing with Nitrogen Vacancy centers: from high spacial resolution with single centers to high sensitivity with centers in bulk**

27. Rahman, Shah Jee (CFM, Donostia)
**Quantum enhanced gyroscopes with optically levitated microparticles**

28. Reichert, Maximilian (UPV/EHU, Bilbao)
**Heisenberg-limited Quantum Lidar for Joint Range and Velocity Estimation**

29. Rodríguez, Pablo Jesus (UPV/EHU, Bilbao)
**Enhancing Lloyd-Mohseni-Rebentrost algorithm with quantum cloning**

30. Veríssimo, Luan (DIPC, Donostia)
**Dissipative Symmetry-Protected Topological Order**

## 3.1 Book of Abstracts: Talks

# Pairing mediated by soft ferroelectric modes in polar metals

Maria Gastiasoro

*DIPC & Ikerbasque, Donostia*

The role of polar fluctuations in correlated electronic phenomena has had a research surge in recent years, with particular focus on the interplay between ferroelectricity, superconductivity and anomalous transport. I will present a pairing mechanism based on a Rashba-like linear coupling between the conduction electrons and soft ferroelectric modes. Our minimal microscopic model [1-2] captures many of the frozen-phonon relativistic ab initio features of this Rashba-like polar coupling, including a dome of the resulting superconducting critical temperature with carrier density. I will discuss our results and their possible relevance in doped bulk STO and recent KTO heterostructures [3-4], which show anomalously large condensate inmunity against applied magnetic fields [5].

[1] M. N. Gastiasoro, M. E. Temperini, P. Barone, and J. Lorenzana, Phys. Rev. B 105, 224503 (2022).
[2] M. N. Gastiasoro, M. E. Temperini, P. Barone, and J. Lorenzana, Phys. Rev. Research 5, 023177 (2023).
[3] G. Venditti, M. E. Temperini, P. Barone, J. Lorenzana, and M. N. Gastiasoro, J. Phys. Mater. 6, 014007 (2023).
[4] C. Liu et al, Nat. Comm 14, 951 (2023).
[5] A. H. Al-Tawhid et al, Nano Lett. 23, 15, 6944-6950 (2023).

# Quantum simulation of Hubbard models

Tobias Grass

*DIPC & Ikerbasque, Donostia*

The Hubbard Model in all its variations plays a central role in the description of strongly correlated many-body systems. Despite its simple form, the solution of the model remains a challenge for analytical and numerical methods. Quantum simulation has been established as an alternative solution method in the last 20 years. My talk takes a comprehensive look at this development and introduces both atomic and electronic many-body systems suitable for quantum simulation of Hubbard models. In particular, the focus is on various extensions of the model, such as long-range interactions, lattices without dispersion, electron-phonon interaction.

# Tailoring the degree of entanglement of two coherently coupled quantum emitters

Brahmin Lounis

*University of Bordeaux, Institut d'Optique & CNRS, France*

The control and manipulation of quantum-entangled non-local states is a crucial step for the development of quantum information processing. A promising route to achieve such states on a wide scale is to couple solid-state quantum emitters through their coherent dipole-dipole interactions. Entangling the electronic states of coherently interacting solid-state emitters is challenging since it requires both a coupling strength larger than the coherence decay rate, implying nanometric distances between the emitters, and quasi-degenerate optical transitions, detuned by less than their coupling strength. Single aromatic molecules embedded in well-chosen solid matrices at liquid helium temperatures are unique candidates to achieve this goal, as they have proven to be test-bench systems for quantum optics. Due to their random spatial distribution in the host crystal and the variety of local matrix environments that span their optical resonances within an inhomogeneous band, fulfilling the requirements of space and transition-frequency proximities of the molecules remains a challenge. Further challenges are to manipulate the degree of entanglement of pairs of molecules having frozen geometries and dipole orientations, and selectively address any quantum entangled state.

We use hyperspectral superresolution imaging in highly doped molecular crystals to reveal pairs of coupled fluorescent molecules. We demonstrate the manipulation of th degree of entanglement of coupled molecules through Stark shifts of their optical resonances. We achieve maximal entanglement with nearly pure subradiant and superradiant Bell states. We also show that delocalized molecular electronic states can extend over distances as large as 60 nm, which opens up attractive perspectives in terms of addressability. Interestingly, optical nanoscopy images of the entangled molecules unveil novel spatial signatures that result from quantum interferences in their excitation pathways.

# Mastering light quanta with synchronous molecular motion

David Novoa

*UPV/EHU & Ikerbasque, Bilbao*

Photons have enabled the vast majority of recent scientific breakthroughs and technological developments in many disparate fields such as biomedicine or high-speed communications. In this regard, while standard linear optical elements permit control over many light-wave degrees of freedom like polarization and orbital angular momentum, the manipulation of others such as the spectral content require nonlinear light-matter interactions to be feasible. To this end, hollow-core microstructured optical fibres filled with gases stand out owing to their reconfigurable optical properties, excellent guidance over broad bandwidths and high damage threshold.

In this talk, we will discuss the science behind hollow anti-resonant fibre technology and present in detail a particularly exotic example of its multiple applications: The exquisite control over all degrees of freedom of micro-confined classical and quantum light fields using specialty waveguides whose molecular core oscillates in a precise choreography.

# Digital-Analog Quantum Computation

Mikel Sanz

*BCAM, UPV/EHU, & Ikerbasque, Bilbao*

Digital-analog quantum computing is a computational paradigm which employs an analog Hamiltonian resource together with single-qubit gates to reach universality. This paradigm has attracted a lot of attention as a roboust alternative in the NISQ era and new theoretical and experimental results have recently come to light. We will revisit the fundamentals of the digital-analog paradigm, explain how to design quantum simulations and quantum algorithms in this paradigm, and briefly review some of the most recent advances.

# Nonclassical mechanical states in nonlinear quantum optomechanics

Jonathan L. Wise*, Clement Dutreix, and Fabio Pistolesi

Université de Bordeaux, CNRS, LOMA, UMR 5798, F-33400 Talence, France

* jonathan.wise@u-bordeaux.fr

Introducing a controlled and strong anharmonicity in mechanical systems is a present challenge of nanomechanics, since the anharmonicity may be exploited to generate nonclassical states of motion. Significant theoretical and experimental effort has been invested in this direction in the field of cavity optomechanics, where the intrinsic nonlinear interaction provides an ideal playground for exploring such physics [1].

While most previous works have focused on the steady state solution [2, 3], we propose here a simple method for generating transient nonclassical mechanical states of an oscillator via driving of the optical cavity. In our procedure the cavity and oscillator are both prepared in coherent states; the subsequent system evolution in the presence of the cavity drive leads directly to the formation of a nonclassical state for the oscillator. A perturbative analytical treatment for weak drive captures well the physics of these states, which resemble quantum superpositions of coherent states. The strong nonclassicality of the oscillator state is manifested by negativity in its Wigner function and is shown via numerical simulation to be robust against weak dissipation.

As well as presenting the above I will also briefly discuss other aspects of the group activity, including a recent proposal for a nanomechanical qubit [4], and a study of molecules coupled via a nanomechanical resonator.

[1] M. Aspelmeyer, T. J. Kippenberg, and F. Marquardt, Rev. Mod. Phys. **86**, 1391 (2014)
[2] N. Lörch, J. Qian, A. Clerk, F. Marquardt, and K. Hammerer, Phys. Rev. X **4**, 011015 (2014)
[3] B. D. Hauer, J. Combes, and J. D. Teufel, Phys. Rev. Lett. **130**, 213604 (2023)
[4] F. Pistolesi, A. N. Cleland, and A. Bachtold, Phys. Rev. X **11**, 031027 (2021)

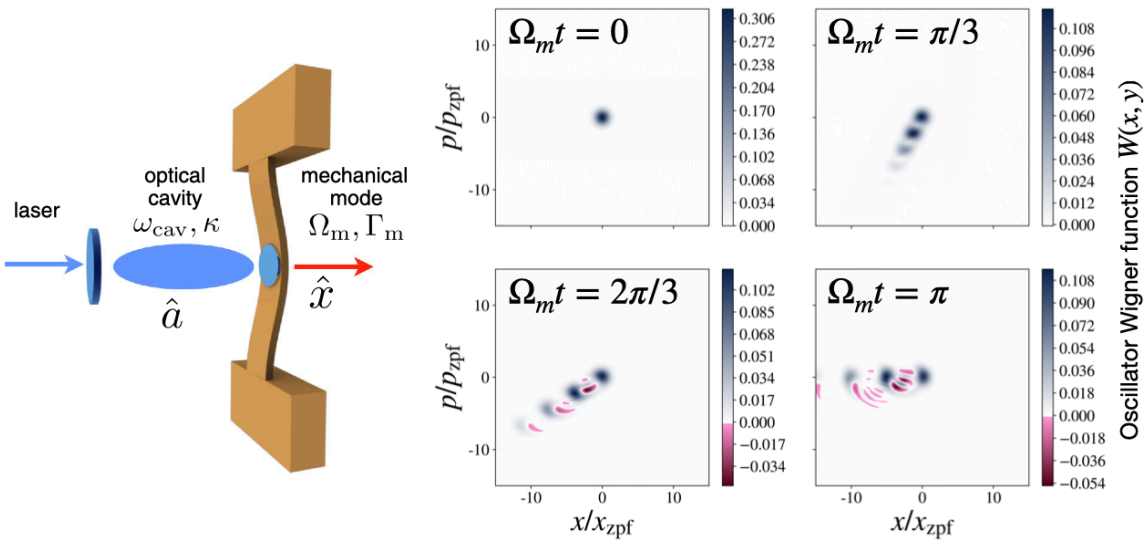


**Figure 1 :** Left: Schematic of the typical optomechanical system considered, where a mechanical mode interacts with an optical cavity that is driven by a laser [1]. Right: Mechanical oscillator Wigner function for different times where negative areas indicate the formation of a highly nonclassical state. The initial state is assumed to be composed of coherent states for both the oscillator and the cavity.

# Controlling a quantum phase transition manipulating the Modulation Instability

Aitor Alaña

*UPV/EHU, Bilbao*

In the framework of a dipolar BEC (specifically an ultracold Dy gas) among others one can find the Superfluid (unmodulated and phase coherent) and the Supersolid (phase coherent but breaking the translational symmetry) states of matter, which are connected by a quantum phase transition driven by Modulation Instability (MI). The knowledge about mechanics behind MI allows for optimized transition schemes which may be interesting for instance to reduce the time required for the transition to happen or to reduce the total excitation (instead of adiabatically driving the system implementing a faster optimized ramp).

# Josephson Junctions with hybrid EuS/Al interfaces: a preliminary study

Sara Catalano

*CFM, Donostia*

Superconducting tunnel junctions (STJ) are key components of quantum circuits and versatile platforms for the study of quantum transport. Their current-voltage characteristic yields a probe of the superconducting density of states, which is typically mapped out by the derivative of the measured current as a function of the applied voltage [1,2]. I will present the transport characteristics of STJs that were recently fabricated and measured, consisting of 12 nm thick aluminum (Al) films separated by a plasma induced AlOx insulating barrier. Additionally, the junctions comprise 12 nm film of the ferromagnetic insulator EuS evaporated on the topmost Al layer, so that an exchange field is applied on one of the superconducting electrodes. The STJs are characterized by DC transport measurements in a dilution fridge with a base temperature below 10mK. The devices are studied as a function of the temperature and magnetic field. Based on the tunnelling transport characteristics, I will discuss the exchange field induced by the EuS film on the topmost superconducting Al layer. Moreover, these STJs exhibit a Josephson supercurrent. The dependence of the Josephson critical current on the applied magnetic field and magnetization of the EuS film will be considered, in light of theory predictions [3].

[1] R. Meservey and P.M. Tedrow, Physics Reports, 238, 4, (1994)
[2] E. Strambini et al., Phys. Rev. Materials 1, 054402 (2017)
[3] F. S. Bergeret and F. Giazotto, Phys. Rev. B 89, 054505 (2014)

# Many-body localization and time crystalline phases in a NISQ experiment

Nicolas Lorente[1], Angel Rodríguez[1], Eric Switzer[1], Nathan Keenan[2], Niall Robertson[2], Sergiy Zhuk[2]

*(1) Centro de Física de Materiales, Donostia-San Sebastián (2) IBM Quantum, Dublin*

A time crystal is a non-equilibrium phase of matter that is characterized by a spontaneous breaking of the time symmetry of the underlying time-dependent Hamiltonian leading to a period that is a multiple of the driving period and to a robust behavior under perturbations and imperfections. It is a steady state under constant driving that does not blow up or heat up until infinite temperatures. The secret to achieve it lies in many-body localization. When the interactions at play are randomly distributed around some mean value, entanglement is greatly diminished and with it the transmission of information and/or heat in the system. As a consequence the new phase presents localization and non-ergodicity. These are keys elements to achieve a time crystal. I will briefly present these exotic states of matter and how they can be emulated in a NISQ computer.

# What's quantum-resistant cryptography and why does it matter?

Marc Manzano

*SandboxAQ, USA*

In this talk, we will give an overview of the state-of-the-art of quantum-resistant cryptography, or so-called Post-Quantum Cryptography. We will specifically focus on the main approaches that have laid the foundation of the upcoming Key Encapsulation Mechanisms and Digital Signatures standards, namely lattice-based cryptography, code-based cryptography and hash-based signatures.
We will also cover the main highlights of the currently ongoing NIST PQC Standardization Competition for Digital Signatures and Key Encapsulation Mechanisms, and then we will describe the new NIST PQC Standardization Competition solely focusing on Digital Signatures, providing an overview of potential leading candidates.
Finally, we will provide insights to justify why we need to worry about this right now, what are the initiatives that Governments are already launching, and we will review the current status of the migration of real world Internet protocols to quantum-resistant cryptography.

# Quadratic Fermionic Hamiltonians

Nathan METRAUD, joint work with Jean-Bernard BRU

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Quadratic Hamiltonians are very important in many-body quantum fields theory. They appear for instance as effective models for superconductivity and superfluidity in the fermionic and bosonic case respectively. Their studies on more general setting, which go back to the sixties, are relatively incomplete for the fermionic case. In this work, we present a method to N-diagonalize quadratic fermionic Hamiltonians under much weaker assumptions than before using a flow equation. We show that we can implement Bogoliubov transformations through this novel elliptic operator-valued non-linear differential equations.

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**AFFILIATION** University of the Basque Country (UPV/EHU) - Basque Center for Applied Mathematics (BCAM)
**DATE** October 2023

# Simulating IBM's Eagle Kicked Ising Experiment with Quantum-Inspired Tensor Networks

Roman Orús

*DIPC, Ikerbasque & Multiverse, Donostia*

Here I will show how 2d Projected Entangled Pair States (PEPS) can be used to simulate numerically a kicked Ising experiment implemented recently on a 127 qubit quantum processor by IBM (Eagle), with noise mitigation (Nature volume 618, p.500-505 (2023)), in a remarkably-efficient way. Furthermore, we provide also calculations for 433 qubits (Orsprey) and 1121 (Condor), as well as for infinitely-many qubits. If time allows, I will also sketch other activities at our group on quantum machine learning and quantum optimization.

# Physically Motivated Improvements in Variational Quantum Eigensolvers

Nonia Vaquero[a], Abel Carreras[b], David Casanova[a,c]

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[b]Multiverse Computing, 20008 Donostia, Euskadi, Spain
[c]IKERBASQUE, Basque Foundation for Science, 48009 Bilbao, Euskadi, Spain

Variational Quantum Eigensolvers (VQEs)[1] are one of the most promising methods for quantum simulation of chemical systems. These are hybrid classical-quantum algorithms that calculate the ground state of a given Hamiltonian by optimizing an ansatz. One of these algorithms is ADAPT-VQE[2], in which the ansatz is progressively grown upon an initially prepared configuration. Analytical simulations have shown that ADAPT-VQE results in shallower circuits and higher chemical accuracy than the canonical Unitary Coupled Cluster approach.

In this work, we apply two strategies from the field of theoretical chemistry to improve ADAPT-VQEs. The first of them is the use of natural orbitals as the basis for the operators and the second one is the use of active space projections. We found that these techniques can reduce the depth of the quantum circuits and the number of required qubits, especially when dealing with strongly correlated systems, approaching the real application of ADAPT-VQEs to solve quantum chemistry problems.

## References

[1] Peruzzo, A., McClean, J. R., Shadbolt, P., Yung, M., Zhou, X., Love, P. J., Aspuru-Guzik, A., & O'Brien, J. L. A variational eigenvalue solver on a photonic quantum processor. *Nat. Commun.*, *5* (2014) 4213.

[2] Grimsley, H. R., Economou, S. E., Barnes, E., & Mayhall, N. J. An adaptive variational algorithm for exact molecular simulations on a quantum computer. *Nat. Commun.*, *10* (2019) 3007.

## 3.2 Book of Abstracts: Posters

# Symmetry-protected gates on superconducting circuits

**Presenter author:**

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**Rest of authors:**

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Juan José García-Ripoll, Instituto de Física Fundamental (IFF-CSIC), Calle Serrano 113b, 28006 Madrid, Spain.

The study of qubit architectures with intrinsic protection against noise has been an ever-growing field of research. The $0 - \pi$ qubit stands out as a very interesting case, owing to its multimode nature and resilience against noise. Here we study the $0-\pi$ qubit phenomenology and propose a novel perspective on single-qubit gates realization, taking advantage of its remarkable symmetry properties.

# Error estimation in current noisy quantum computers

Unai Aseguinolaza Aguirreche

*Mondragon Unibertsitatea*

One of the main important features of the noisy intermediate-scale quantum (NISQ) era is the correct evaluation and consideration of errors. In this work, we analyze the main sources of errors in current (IBM) quantum computers and we present a useful tool (TED-qc) designed to facilitate the total error probability expected for any quantum circuit. We propose this total error probability as the best way to estimate a lower bound for the fidelity in the NISQ era, avoiding the necessity of comparing the quantum calculations with any classical one. In order to contrast the robustness of our tool we compute the total error probability that may occur in three different quantum models: 1) the Ising model, 2) the Quantum-Phase Estimation (QPE), and 3) the Grover's algorithm. For each model, the main quantities of interest are computed and benchmarked against the reference simulator's results as a function of the error probability for a representative and statistically significant sample size. The analysis is satisfactory in more than 99% of the cases. In addition, we study how error mitigation techniques are able to eliminate the noise induced during the measurement. These results have been calculated for the IBM quantum computers, but both the tool and the analysis can be easily extended to any other quantum computer.

# Topological properties of a non-Hermitian quasi-one-dimensional chain with a flat band

Dario Bercioux

*DIPC & Ikerbasque, Donostia*

We investigate the spectral properties of a non-Hermitian quasi-one-dimensional lattice in two possible dimerization configurations. Specifically, we focus on a non-Hermitian diamond chain that presents a zero-energy flat band. The flat band originates from wave interference and results in eigenstates with a finite contribution only on two sites of the unit cell. To achieve the non-Hermitian characteristics, we introduce non-reciprocal intrasite hopping terms in the chain. This leads to the accumulation of eigenstates on the boundary of the system, known as the non-Hermitian skin effect. Despite this accumulation of eigenstates, for one of the two possible configurations, we can characterize the presence of non-trivial edge states at zero energy by a real-space topological invariant known as the biorthogonal polarization. We show that this invariant, evaluated using the destructive interference method, characterizes the non-trivial phase of the non-Hermitian diamond chain. For the other possible non-Hermitian configuration, we find that there is a finite quantum metric associated with the flat band. Additionally, we observe the skin effect despite having the system a purely real or imaginary spectrum. For both configurations, we show that two non-Hermitian diamond chains can be mapped into two models of the Su-Schrieffer-Heeger chains, either non-Hermitian and Hermitian, in the presence of a flat band. This mapping allows us to draw valuable insights into the behavior and properties of these systems.

# Two-channel Kondo problem in coupled interacting helical liquids

Sourav Biswas

*DIPC, Donostia*

We study the two-channel Kondo problem in the context of two interacting helical liquids coupled to a spin-1/2 magnetic impurity. We show that the interactions between the two helical liquids significantly affect the phase diagram and other observable properties. Using a multichannel Luttinger liquid formalism, we analyze both the Toulouse limit, where an exact solution is available, and the weak coupling limit, which can be studied via a perturbative renormalization group (RG) approach. We recover the results for the 'decoupled' limit (interactions between the helical liquids switched off) and point out deviations from the known results due to this coupling. The model under study is mapped to a model of two effectively decoupled helical liquids coupled to an impurity. The perturbative RG study shows that each of these channels can flow to either a Ferromagnetic (FM) or an Anti-Ferromagnetic (AFM) fixed point. We obtain the phase diagram of the coupled system as a function of the system parameters. The observable consequences of the interaction between the two channels are captured using linear response theory. We compute the negative correction to the conductance due to the Kondo scattering processes and show how it scales with the temperature as a function of inter-channel interaction.

# Characterization of planar Al-based Josephson Junctions proximitized by a ferromagnetic insulator

David Caldevilla Asenjo

*CFM, Donostia*

A ferromagnetic insulator in contact with a superconductor induce an effective exchange field in the latter, emulating the effects of applying an external magnetic field on one superconducting electrode. This, results in a spin splitting of the BCS density of states [1,2]. In this work, we fabricate and study planar Josephson Junctions made in Ultra High Vacuum conditions using the shadow mask method. These junctions consist of 12nm thick aluminum (Al) layers separated by plasma-induced AlOx layers. On top of the junction, a 12nm thick of europium sulfide (EuS), a ferromagnetic insulator with a Curie temperature of 16.7K, is deposited. We characterize the junctions through transport measurements performed at temperatures below 10 mK. We explore the tunnelling current as a function of temperature and magnetic field, observing both quasiparticle and supercurrent components, which attests to the high-quality of the fabricated interface. Our experimental setup provides a means to validate predictions of an enhanced critical Josephson current in junctions featuring spin-split superconductors [3].

[1] R.Meservey and P.M.Tedrow, Phys. Rep. 238, 173 (1994).
[2] E.Strambini et al., Phys. Rev. Materials, 1, 054402 (2017).
[3] F.S. Bergeret and F. Giazotto, Phys. Rev. B, 89, 054505 (2014).

# Hybrid classical-quantum algorithms with finite number of measurement outcomes

Matheus Capela

*Department of Physical Chemistry and EHU Quantum Center, UPV/EHU, Bilbao*

It is proposed a discussion on whether it is possible to determine formal limitations for hybrid classical-quantum algorithms running under the constraint of finite quantum measurement outcomes.

# Addressing Statistical Noise in Classical Optimizers for Variational Quantum Eigensolvers

Abel Carreras
Multiverse Computing, 20014 Donostia, Euskadi, Spain

Variational Quantum Eigensolver[1] (VQE) based algorithms have emerged as a promising approach for solving quantum chemistry problems using quantum computers. A critical component of these algorithms is the classical optimizer, as its efficiency impacts on the overall computational cost. Among classical optimizers employed in VQE, COBYLA[2] is one of the most widely used. It exhibits robust performance when the energy evaluation at each step is determined analytically. However, when employing sampled energy evaluations, which include inherent statistical noise, the energy convergence becomes notably more challenging. This is particularly pronounced in algorithms like adaptVQE, which rely on successive optimizations of a growing ansatz.

In this work, we analyze the behavior of COBYLA when utilized in conjunction with sampled energy evaluations. Using this information we propose a set of modifications to the conventional adaptVQE implementation that aim to improve the algorithm's efficiency by minimizing the number of shots required to attain a desired level of precision. These developments are expected to contribute to the practical utility of VQE-based approaches on noisy quantum hardware.

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# Noise-aware variational eigensolvers: a dissipative route for lattice gauge theories

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We propose a novel variational ansatz for the ground state preparation of the $\mathbb{Z}_2$ lattice gauge theory (LGT) in quantum simulators (QSs). It combines dissipative and unitary operations in a completely deterministic scheme with a circuit complexity that does not scale with the size of the considered lattice. We find that, with very few variational parameters, the ansatz is able to achieve $> 99\%$ fidelity with the true ground state in both the confined and deconfined phase of the $\mathbb{Z}_2$ LGT. We benchmark our proposal against the unitary Hamiltonian variational ansatz (HVA), and find a clear advantage of our scheme, especially for few variational parameters as well as for large system sizes. After performing a finite-size scaling analysis, we show that our dissipative variational ansatz is able to predict critical exponents with accuracies that surpass the capabilities of the HVA. Furthermore, we investigate the ground-state preparation algorithm in the presence of circuit-level noise and determine variational error thresholds, which determine error rates $p_L$, below which it would be beneficial to increase the number of layers $L \to L + 1$. Comparing those values to quantum gate errors $p$ of state-of-the-art quantum processors, we provide a detailed assessment of the prospects of our scheme to explore the $\mathbb{Z}_2$ LGT on near-term devices.

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Basque Quantum Science and Technology Workshop
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# Infinite Class of Robust Degenerate Quantum Error-Correcting Codes

**Reza Dastbasteh**[1], **Josu Etxezarreta Martinez**[1], **Pedro Crespo Bofill**[1], **Andrew Nemec**[2]

Quantum error-correcting codes, often referred to as quantum codes, play a crucial role in protecting quantum information against the adverse effects of noise and decoherence within quantum channels. Among the extensively studied quantum codes, stabilizer codes stand out. They are constructed using specific classical codes, presenting a powerful tool in quantum error correction. One of the fundamental challenges in quantum error correction is designing constructions of practical quantum codes that offer robust error control while maintaining ease of implementation.

In this study, we introduce a novel method for constructing binary quantum stabilizer codes using specific families of algebraic codes over the quaternary field. Our approach yields an infinite set of binary quantum codes that are easy to implement, inherit numerous algebraic features, and possess the following remarkable property:
For any $\delta > 0$, an infinite series of binary quantum codes exists with a non-zero asymptotic rate and a minimum distance of at least $\delta$. Furthermore, we demonstrate that this class of quantum codes contains an infinite subset of degenerate codes, which, in general, do not require active error correction. Additionally, we establish that our constructed quantum codes satisfy a square root type minimum distance lower bound. To illustrate the practicality of our approach, we provide numerical examples of good degenerate and, in some instances, record-breaking binary quantum codes resulting from our construction.

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# Lee-Yang zeros at O(3) and deconfined quantum critical points

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Lee-Yang theory, based on the study of zeros of the partition function, is widely regarded as a powerful and complementary approach to the study of critical phenomena and forms a foundational part of the theory of phase transitions. Its widespread use, however, is complicated by the fact that it requires introducing complex-valued fields that create an obstacle for many numerical methods, especially in the quantum case where very limited studies exist beyond one dimension. Here we present a simple and statistically exact method to compute partition function zeros with general complex-valued external fields in the context of large-scale quantum Monte Carlo simulations. We demonstrate the power of this approach by extracting critical exponents from the leading Lee-Yang zeros of 2D quantum antiferromagnets with a complex staggered field, focusing on the Heisenberg bilayer and square-lattice J-Q models. The method also allows us to introduce a complex field that couples to valence bond solid order, where we observe extended rings of zeros in the J-Q model with purely imaginary staggered and valence bond solid fields.

# Topological one-dimensional nanomaterials

Shayan Edalatmanesh

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Engineering low bandgap Π-conjugated polymers is an emerging area in basic and applied research, with the main synthetic challenge being in the solubility of the materials during the chemical synthesis. Here we report a comprehensive study of the on-surface synthesis of various topological low-bandgap molecular wires on Au(111) using scanning tunneling microscopy (STM), non-contact atomic force microscopy (nc-AFM), density functional theory (DFT) and complementary AFM/STM simulations [1].

The on-surface chemical reactions of molecular precursors on a pristine Au(111) surface result in the formation of long, defect-free, Π-conjugated polymers featuring a topologically non-trivial SSH [2] quantum phase, with a very low bandgap due to the proximity to the point of topological transition and electronic transformation of the Π-conjugated polymers [3,4].

Our results not only introduce a ground-breaking chemical protocol to design pi-conjugated polymers based on oligoacene precursors, but also shed light upon the aromatic-quinoid transition in named systems and the transformation of ethynylene bridge bonds between polyacene moieties. Thus contributing to the development of the field of on-surface science and the design of modern low bandgap polymers useful in the future of electronics and spintronics.

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# Superadditivity effects of quantum capacity decrease with the dimension for qudit depolarizing channels

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(Dated: October 10, 2023)

Quantum channel capacity is a fundamental quantity in order to understand how well quantum information can be transmitted or corrected when subjected to noise. However, it is generally not known how to compute such quantities since the quantum channel coherent information is not additive for all channels, implying that it must be maximized over an unbounded number of channel uses. This leads to the phenomenon known as superadditivity, which refers to the fact that the regularized coherent information of $n$ channel uses exceeds one-shot coherent information. Here, we study how the gain in quantum capacity of qudit depolarizing channels relates to the dimension of the considered systems. We make use of an argument based on the no-cloning bound in order to prove that the possible superadditive effects decrease as a function of the dimension for such family of channels. In addition, we prove that the capacity of the qudit depolarizing channel coincides with the coherent information when $d \to \infty$. We also discuss the private classical capacity and obtain similar results. We conclude that when high-dimensional qudits experiencing depolarizing noise are considered, the coherent information of the channel is not only an achievable rate, but essentially the maximum possible rate for any quantum block code. The results obtained have implications for quantum error correction and quantum communications when the noise is strongly correlated among the qubits of a block.

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# Hybrid Quantum-Classical Search Space Reduction Heuristic for Optimization

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Reducing the time to solve constrained combinatorial optimization problems is one of the objectives at which the quantum computing research is aiming. One of the main difficulty of these problems is efficiently accessing the set of allowed states, and then performing the optimization within that space. As an approximate solution, we propose a hybrid quantum-classical heuristic for solving problems whose constraints can be classified into two classes: global and partial constraints. The new approach consists of two main subroutines. In the first step, we employ a quantum subroutine to sample feasible partial solutions by imposing the partial constraints of the problem. Then, we generate full solutions by imposing the global constraints and we search for the optimum solution. A key feature of this new approach is the fact that we employ a quantum subroutine to reduce the search space for the classical subroutine. Furthermore, the quantum resources employed are greatly reduced compared to a fully quantum optimizer, making it more appropriate for the NISQ era. For validating our results, we show the performance of our heuristic for solving the one-dimensional Bin Packing Problem and a the Electric Vehicle Routing and Routing Problem.

# Efficient quantum amplitude encoding of polynomial functions

Javier González Conde

*UPV/EHU, Bilbao & QuantumMads*

Loading functions into quantum computers represents an essential step in several quantum algorithms, such as in the resolution of partial derivative equations. Therefore, the inefficiency of this process leads to a major bottleneck for the application of these algorithms. Here, we present and compare two efficient methods for the amplitude encoding of real polynomial functions. The first one relies on the matrix product state representation, where we study and benchmark the approximations of the target state when the bond dimension is assumed to be small. The second algorithm combines two subroutines, initially we encode the linear function into the quantum registers with a swallow sequence of multi-controlled gates that loads its Hadamard-Walsh series expansion, followed by the inverse discrete Hadamard-Walsh transform. Then, we use this construction as a building block to achieve a $\mathcal{O}(n)$ block encoding of the amplitudes corresponding to the linear function and apply the quantum singular value transformation that implements the corresponding polynomial transformation to the block encoding of the amplitudes.

# Tavis-Cummings model in gas-filled hollow-core fibres for frequency up-conversion

Tasio González Raya

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Recent experiments with gas-filled hollow-core fibres achieved frequency up-conversion of single photons by harvesting optical phonons generated by stimulated Raman scattering. Using the Tavis-Cummings model, we attempt to describe the process of stimulated Raman scattering in a hydrogen gas, where an electromagnetic mode acting as a pump activates a Stokes signal, while it also induces vibrational excitations in the hydrogen molecules. This represents the first stage. Once coherence is developed in the gas, an incoming photon can take part of this coherence and change colour, if phase matching conditions between it and the coherence wave are satisfied. We present an effective Hamiltonian for the system and attempt to diagonalize it in order to study the effects of frequency up-conversion in entangled states.

# Quantum Genetic Algorithm

Ruben Ibarrondo

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Genetic Algorithms (GAs) are extremely successful bioinspired optimization algorithms, which emulate the natural selection process. Merging GAs with quantum computation is an old ambition which has been considered as a potential source of new heuristic optimization methods. However, only restricted results have been achieved up to now due to the limitations imposed by quantum mechanics for cloning or erasing information. Here, we develop a fully quantum genetic algorithm (QGA) and study different subroutines for cloning or breeding by means of both a thorough numerical analysis and quantum-channel techniques. This approach paves the way for a new type of optimization quantum algorithm which, additionally, can be straightforwardly parallelized among different quantum processors.

# *Ab-initio* theory of polarons at all couplings

Jon Lafuente-Bartolome

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State-of-the-art ab initio theories to describe polarons in materials currently fall into two separate categories: the weak coupling perturbative methods that describe phonon-induced band structure renormalization, and the strong coupling adiabatic techniques that capture polaron self-trapping effects. The transition region between these regimes remains unclear. In this work we present a self-consistent many-body theory of polarons that captures both limits and the intermediate regime within a single unified framework. A connection with previous literature on polaron models will be established, and practical first-principles calculations of the zero-point renormalization of band gaps including polaron localization effects will be presented.

# Finite size quantization of mid-gap Majorana states of Rashba-nanowires

Nico Leumer

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Propelled by new fabrication techniques, research on the rich physics of unconventional magnetic features, so called Π-magnetism, of graphene derivatives developed into an attractive field [1,2] The repulsion of former unpaired, localized electrons (pinned energetically close to the Fermi level) is the physical origin. Although these electrons may or may not manifest generally non-trivial topological character of the host material, the formation of edge states in magnetization noticed recently hints to it [3]. Within the literature and rather familiar to researchers of the Majorana community, terms such as "hybridization" or "spatial overlap" are frequently met. Concerning Majorana zero modes, these expressions describe the energy splitting away from zero to exponentially small energy states (w.r.t. the Fermi level) and their subsequent transformation into Majorana fermions residing at the system's edges.
Although overlap arguments satisfy our most fundamental intuition, there is more beneath the surface as first meets the eye. Based on past experience [4,5], the "overlap" masks quite interesting finite size effects in allegiance with open boundary conditions. Similarities between the theoretical description of Π-magnetism and Majorana fermions, hints at the same being true for the former as well.
In my contribution I will (shortly) motivate my reasoning. Turning to Majorana fermions, I will report on newest results on finite size effects on the mid-gap states imposed by open boundary conditions for the experimental relevant semi conducting Rashba nanowires and how the wave functions spatial profile impacts quantum transport. In the same way, we might expect interesting quantization effects for the lowest electron excitations in Π-magnetism systems.

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# Towards topological edge states with artificial electronic lattices: Cs on InAs(111)A

Rian Ligthart

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Artificial electronic lattices are a promising tool to study topology on an atomic scale. The Scanning Tunnelling Microscope (STM) allows to build the topological lattices by manipulating single atoms with nanoscale precision and to probe their electronic properties. Here, the semiconductor InAs(111)A surface with adsorbed Cs atoms is studied. Vertical and lateral manipulation allow to place multiple Cs-adatoms in vicinity of each other. Lines of positively charged Cs atoms create a potential well that confines the surface state electrons of InAs due to local band bending. The confined state acts as an artificial atom and can be used to construct dimers and other structures. [1] Artificial atoms can therefore be used to study the topological properties of the model systems such as the SSH [2] and trimer chain.

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# Preservation of biphoton quantum coherence in frequency up-conversion using gas-filled hollow-core fibres

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We propose an experimental verification of the preservation of biphoton quantum coherence in the frequency up-conversion of one of the photons in the pair using a hollow anti-resonant fibre filled with hydrogen. Raman coherence waves excited in the gas permit threshold-less spectral shifting of arbitrary quantum sources. Under the right conditions, this process can be very efficient, while keeping the fragile quantum correlations and overall coherence present in the original biphoton pair unaltered. We analyze how this situation could be assessed using two-photon Hong-Ou-Mandel interferometry. This work might have implications for modern quantum technologies relevant in communications, information processing and sensing.

# Quantum Simulations of Graphene

Cristina Mier

*Tecnalia, Donostia*

Quantum computing represents an emergent technology with exciting applications. Among these, quantum simulation offers a natural framework for studying quantum pheomena. In systems where dimension grows exponentially, the problem of finding the eigenvalues becomes extremely inefficient for classical computers. In this project we investigate the simulation of a tight-binding Hamiltonian that models a honeycomb lattice. Appling a variational quantum eigensolver (VQE), we find the ground energy and ground state of graphene-based finite structures.

# Classical and Quantum Bhattacharyya Bounds

Javier Navarro

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Quantum parameter estimation consists in obtaining the value of a parameter $\theta$ by measuring a quantum state $\rho_\theta$ codifying it. If we have an accurate knowledge about the prior value of the parameter, the quantum Fisher information (QFI) gives a bound for the minimal variance in the estimation of $\theta$ through the quantum Cramer-Rao bound (QCRB). This necessary prior knowledge makes QCRB impractical in many realistic parameter estimation problems. Bhattacharyya bounds provide limits to the minimal variance in the estimate of the parameter while reducing the dependence of the experiment on the true value of the parameter. In this poster, we study some features of these useful bounds.

# Valley-polarized edge modes in sliding bilayer graphene

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Besides the conventional electronic charge and spin, valley degrees of freedom are an additional feature of electrons that can be used to encode and process information [1]. In this work, we theoretically propose that propagating valley-polarized edge states exist in sliding bilayer graphene [2]. For some specific stacking configurations of the bilayer graphene, the Dirac cones of the two layers at a valley are separated and shifted in energy. As a result, the topological edge states connecting the two Dirac points and protected by the winding number have nonzero group velocity, giving rise to propagating edge modes.

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# Asymmetric Generalized Amplitude Damping Channel

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Generalized Amplitude Damping Channel (GADC) is a quantum channel which characterizes amplitude shifts suffered by a qubit when it interacts with the environment. Is is usually derived from a basic model where a Two-level System (TLS) interacts with its environment composed by a thermal bath, allowing us to study the absorption, the emission and the stimulated emission. However, a qubit within a quantum computer interacts with its environment in a more complex way, and, hence, its dynamics are not well-defined only by the GADC derived from a TLS and thermal bath. Moreover, a quantum computer is composed by many qubits and thousand of gates are applied to them in order to run an algorithm or to implement a Quantum Error Correction Code (QECC). Hence, a small asymmetry in the GADC could have a huge effect in quantum computers. In this poster we will introduce new interactions to the qubit Hamiltonian and prove that they form a Completely Positive and Trace Preserving (CPTP) map, i.e. a quantum channel, called the Asymmetric GADC (AGADC), where the different transitions probabilities between the qubit states are not equal.

# Simulating IBM's quantum Ising experiment with PEPS: 127, 433, 1121 and infinitely-many qubits.

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In this paper we show how quantum-inspired 2d tensor networks can be used to efficiently and accurately simulate the dynamics of a complex quantum many-body system. In particular, we simulate the kicked Ising experiment considered recently by IBM in his 127-qubit "Eagle" quantum processor (Nature 618, p. 500–505 (2023)), by using graph-based Projected Entangled Pair States (gPEPS) as proposed by some of us in PRB 99, 195105 (2019). Our results show that simple tensor updates are already sufficient to achieve very large accuracies with remarkably low computational resources for this model. We also extend our results to larger lattices, namely to 433 and 1121 qubits corresponding respectively to "Orsprey" and "Condor" IBM quantum processors, setting then a benchmark for those machines. In fact, we use as well our techniques to provide accurate numbers for infinitely-many qubits. Our results show that gPEPS are a natural tool to efficiently simulate quantum computers that have a lattice-based qubit connectivity, such as all quantum processors based on superconducting qubits.

# Hardware for scalable magnetic field sensing with Nitrogen Vacancy centers: from high spacial resolution with single centers to high sensitivity with centers in bulk.

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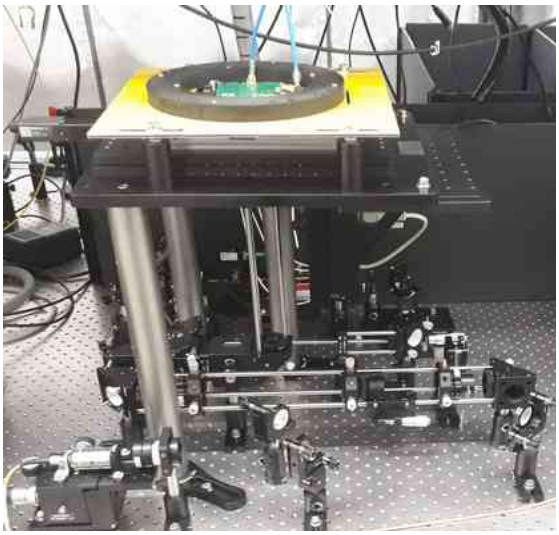
## Introduction:

Nitrogen Vacancy (NV) centers in diamond are a versatile host for electron and nuclear spin states. These show long coherence times even at room temperature, and can accurately detect ambient parameters such as magnetic fields, strain, temperature or electric fields. NV centers offer different benefits when addressed individually or in bulk, and one is preferred over the other depending on the application. On the one hand, being able to interrogate NV centers individually enables, for example, sensing with nanometer resolution, gaining insight in spin behavior to create advanced sensing sequences or employing electron and nucleus as quantum bits and quantum gates [1]. On the other hand, the signal to noise ratio of the measurement improves with increasing number of NV centers being interrogated concurrently. At the Quantum Nanophotonics Lab we have developed two complementary systems: the first one is entitled MaGNiFi 1D and has been designed for interrogating NVs individually with nanometer size resolution and employs a fixed external magnetic field; the second one is called MaGNiFi 3D and is meant to run measurements with large populations of NV centers and can generate an external magnetic field that can be rapidly switched in amplitude and direction.

## Methods & Results:

*MaGNiFi 1D prototype*: This system consists of a) two optical paths for excitation and readout of the response from NV centers independently, b) a nano- and a micro- positioning station, c) a custom made microwave (MW) resonator, d) a MW signal generation and amplification chain, e) an array of permanent magnets that generate a homogeneous magnetic field, f) a commercial data acquisition card, g) an FPGA that controls the timing of pulse sequences, and h) the master PC with home-built control software. The two optical paths guide a green laser beam (515 nm) and the red fluorescence (650-800 nm) to overlap at the diamond and use a microscope objective with high numerical aperture (0.8) to create a diffraction limited confocal setup. The green beam is used to initialize the electron spin state and induce its state revealing fluorescence. The red path carefully carries the fluorescence signal to the photodetectors, which are fiber coupled for rapid switching between a single photon detection module used with individual NVs and an analogue photo detector employed with larger ensembles of NVs. The combination of the positioning stations concurrently allows a movement that covers a volume of (25x 25 x 25 $mm^3$) but at the same time features nanometer resolution. The custom-made microwave antenna can host large volume diamond samples (3x3x0.5 $mm^3$) and generate a high (34 Am/Watt) but highly homogeneous magnetic field. The antenna also can generate a circularly polarized MW field that allows selective coupling of either $m_s$ = -1 or +1 spin states with the 0 state even with near zero external magnetic field, condition at which -1 and +1 states are degenerate. The external magnetic field points axially, orthogonal to the MW fields, and can be adjusted between 0.2 mT and 5 mT by adding or removing permanent magnet pairs. The



# Quantum enhanced gyroscopes with optically levitated microparticles

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Optically levitated particles have a great potential to form the basis of novel quantum enhanced sensors. Researchers around the world are using them as a platform to study cutting-edge physics phenomena. These systems have been used to demonstrate force sensing up to 10-21N [1]. Optical levitation is very well suited for inertial sensing as the particles are completely isolated from thermal environment and have no particle-substrate interaction. In our setup we use a high numerical aperture objective lens to optically trap spheres in the direction of gravity. We cool the center-of-mass (CoM) motion of particles by modulating the intensity of the trapping beam in real-time by using an AOM (Acoustic Optical Modulator) [2]. The frequency-shifted trapping beam is then diffracted by a spatial light modulator (SLM) to create different orders of Laguerre-gaussian beams for trapping the particle in the centre of the beam or in the ring. Furthermore, we can control the rotational degree of freedom through the use of waveplates [3]. Rotors in the quantum regime exhibit strong interference effects that have no counterpart in the classical regime and no analogue in the CoM motion of the object. These rotors can be used to study rotational superpositions and next generation ultra-precise torque sensors [4].

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# Heisenberg-limited Quantum Lidar for Joint Range and Velocity Estimation

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We propose a quantum lidar protocol to jointly estimate the range and velocity of a target by illuminating it with an unentangled pulsed beam of squeezed light. We consider experimentally feasible homodyne and heterodyne reception as measurements. We show that for homodyne reception combined with a local estimation strategy, the mean error of range and velocity estimates are inversely proportional to the number of signal photons, attaining the Heisenberg limit simultaneously and thus quantum advantage. We consider photon loss and other imperfections and demonstrate the protocol's resilience, providing significant quantum advantage for round-trip transmissivities above 85% for the homodyne protocol, and significant advantage above 50% transmissivity for the heterodyne protocol. This, and the feasibility of the probe state and measurement with current state of the art technology make the protocol highly promising for near-term implementation.

# Enhancing Lloyd-Mohseni-Rebentrost algorithm with quantum cloning

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Classical information loading is an essential task for many processing quantum algorithms, constituting a cornerstone in the field of quantum machine learning. In particular, the embedding techniques based on Hamiltonian simulation techniques enable the loading of matrices into quantum computers. A representative example of these methods is the Lloyd-Mohseni-Rebentrost protocol, which efficiently implements matrix exponentiation when multiple copies of a quantum state are available. However, this is a quite ideal set up, and in a realistic scenario, the copies are limited and the non-cloning theorem prevents from producing more exact copies in order to increase the accuracy of the protocol. Here, we propose a method to circumvent this limitation by introducing imperfect quantum copies that significantly enhance the performance of previous proposals.

# Dissipative Symmetry-Protected Topological Order

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Topological phases of matter[1] have emerged last decades as an important research area in condensed matter physics owing to further paradigms on the classification of novel quantum phases of matter beyond the Landau-Ginzburg-Wilson theory. Also, the interplay of quantum physics and the environment opens the possibilities to interesting physics phenomena, where the role of dissipation on the topological order is important given the possibilities of applications in material science[2] and topological quantum computing[3]. In this work, we implement tensor networks [4,5] modern algorithms to investigate the effects of dissipation on the symmetry-protected topological order. We considered the Affleck-Kennedy-Tasaki-Lieb spin model under dissipation due to the interaction with the environment where the time evolution of the system is given by the Lindbladian master equation. We numerically solve the Lindbladian dynamics by adapting the infinite time-evolving block decimation method for mixed-states[5] which allows us to treat a translational-invariant system and time-evolve the density matrix that describes the mixed-state of the system until reaching the non-equilibrium steady state. In this way, we have considered two types of dissipation in which the conservation of time-reversal symmetry is seen as central in the establishment of topological order under Lindbladian dynamics. We compute typical non-local string parameters, purity, and the singular values of the tensor network decomposition of the reduced density matrix to detect the topological order. For the non-symmetric dissipation, we see the Lindbladian dynamics leading to a disordered pure state without any spontaneous local or string orders. Considering the symmetric dissipation, we observed the Marvokian dynamics leading to a mixed state with typical signatures that characterize a topological order, such as finite string parameters and more interestingly, a degeneracy pattern of singular values in the tensor network decomposition of the reduced density matrix. Our work [6] opens the possibility of a broader and more practical definition of symmetry-protected topological order for mixed states induced by dissipation. Extensions of this work are also presented.

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