2024 INTERNATIONAL CONGRESS

QUANTUM OPTICS X

December 9 to 13, Puerto Varas, Chile

Celebrating 100 years of Quantum Mechanics

Organizers

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INDEX

WELCOME NOTE

Quantum Optics is a conference that periodically gathers leading scientists in the fields of optics and quantum optics from different regions of the world.

Held for the first time under the organization of the University of Rochester, New York, in the 1960s, this first edition was attended by leading figures in this area of study in the United States, such as physicists Leonard Mandel and Emil Wolf.

In Latin America, the first of these meetings was held in Santiago, Chile, in 2000. Since then, these meetings have been held every two years, which brings us to Quantum Optics X, in the city of Puerto Varas, in the Los Lagos region of Chile.

This year, the conference aims to reunite diverse members of academia to facilitate research collaboration and the exchange of key knowledge for the international development of Quantum Optics but also seeks to recognize the trajectory of Chilean researcher **Miguel Orszag**, who organized the first edition of the congress.

PROGRAM

	Monday	Tuesday	Wednesday	Thursday	Friday
08:30	Luiz Davidovich	Paul Lett	Berge Englert	Morgan Mitchel	Luis Sánchez-Soto
09:15	Adán Cabello	Akira Furusawa	Peter Zoller	Juan García-Rippol	Irina Novikova
10:00	Coffee Break				
10:30	Marcin Pawłowski	Janos Bergou	Cecilia Cormick	Kanu Sinha	Guillermo Romero
	Andrey Jarmola	Polina Sharapova	Alexei Ourjoumtsev	Gabriel Araneda	Jerónimo Maze
11:00	Aaron Z. Goldberg	Igor Jex	Fabricio Toscano	Tomás Ramos	Vitalie Eremeev
	Sebastião Pádua	Elohim Becerra	Daniel Felinto	Asaf Paris-Mandocky	Antonio Khoury
11:30	Omar Jimenez	Andrei Klimov	Simon Balthasar Jäge	Nara Rubiano da Silva	Dardo Goyeneche
	Alberto Marino	Barry Garraway	Arturo Lezama	Raul Celestrino Teixeira	Sébastien Gleyzes
12:00	Marcelo Terra Cunha	Fernando Lombardo	Paula Mellado	Marcelo França Santos	Gustavo Lima
	Pablo Barberis-Blostein	Zdenek Hradil	Philippe Courteille	Johan Triana	
12:30	Lunch				
14:30	Sponsors	Marco Genovese			
15:15		Juan Pablo Paz		Paulo Nussenzveig	
16:00	Coffee Break			Coffee Break	
16:30	Poster Session	Gonzalo Carvacho		Alfred U'Ren	
		Luciano Pereira		Melissa Maldonado	
17:00		Ariel Norambuena		Renné de Araújo	
		Gabriel Aguilar		Gustavo Cañas	
17:30		Francisco Albarrán		Rocío Jáuregui	
		Dominique Spehner		Birger Seifert	
19:00				Social Event	

Salón Puerto Varas   Salón Puerto Varas   Salón Puerto Octay

PLENARY SPEAKERS

Adan Cabello, Universidad de Sevilla

Experimental tests excluding nonlocal, superdeterministic and retrocausal explanations of quantum theory

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The violation of Bell inequalities implies that at least one of the assumptions in Bell's theorem fails in nature. Existing experiments are inconclusive about which is the assumption that fails. As a consequence, possible explanations of Bell non-locality include theories with different amounts of instantaneous actions at a distance, different degrees of measurement dependence (that may occur due to limitations to freedom of choice or to retrocausal influences), and combinations thereof. Here, we drastically narrow down the possibilities. Our first result is a proof that any non-local hidden-variable (HV) theory with outcome independence (OI) and arbitrary joint relaxation of measurement independence (MI) and parameter independence (PI) can be experimentally excluded in a Bell-like experiment on specific high-dimensional entangled states. Our second result is a proof that any non-local HV theory with MI, PI and arbitrary relaxation of OI can also be experimentally excluded using specific qubit-qubit entangled states.

These results show that Bell's theorem is just the tip of an iceberg: quantum theory does not only offer advantage in information processing, communication and computation with respect to local models, but also with respect to any model that allows partial instantaneous actions at a distance or that only partially constrain freedom of choice or only allow for partial retrocausal influences.

Quantum Sensing of Open Systems: Beyond the Classical Limits of Precision

Luiz Davidovich[a]

[a] Universidade Federal do Rio de Janeiro

Quantum sensors allow the estimation of parameters with precision higher than that obtained with classical strategies. Devices based on quantum physics have allowed the precise estimation of the gravitational field, the detailed imaging of the brain, the detection of gravitational-wave sources more than 400 million light years away, and an ever-increasing precision in the measurement of time. Quantum metrology is the conceptual framework that encompasses all these devices. This talk reviews recent developments in this field, leading to precision bounds for noisy systems [1,2,3], with applications to the quantum speed limit [4] and the estimation of absorption [5,6] and depolarization of light [7].

[1] B. M. Escher, R. L. de Matos Filho, and L. Davidovich, Nature Physics 7, 406 (2011)
[2] B. M. Escher, R. L. de Matos Filho, and L. Davidovich, Braz. J. Phys. 41, 229 (2011)
[3] C. L. Latune, B. M. Escher, R. L. de Matos Filho, and L. Davidovich, Phys. Rev. A 88, 042112 (2013)
[4] M. M. Taddei, B. M. Escher, L. Davidovich, and R. L. de Matos Filho, Phys. Rev. Lett. 109, 050402 (2013)
[5] J. Wang, L. Davidovich, and G. S. Agarwal, Physical Review Research 2, 033389 (2020)
[6] J. Wang, R. L. de Matos Filho, G. S. Agarwal, and L. Davidovich, Physical Review Research 6, 013034 (2024)
[7] L. Davidovich and R. L. de Matos Filho, Physical Review A 108, 042612 (2023)

Uncertainty Relations: 97 Years Later

Berge Englert [a,b,c]

[a] Beijing Institute of Technology, China
[b] Centre for Quantum Technologies, Singapore
[c] QuTalent, Singapore

In addition to reviewing the history of uncertainty relations, starting with Heisenberg's work in 1927, the talk will discuss how all the standard inequalities — for products or sums of variances — follow from one basic equation.

[1] arXiv:2310.05039; Phys. Lett. A 494, 129278 (2024).

Optical quantum computers with quantum teleportation

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[b] RIKEN Center for quantum computing

We did the first experiment of unconditional quantum teleportation at Caltech in 1998 [1]. Then we did various related experiments like quantum teleportation network [2], teleportation of Schrödinger's cat state [3], and deterministic quantum teleportation of photonic qubits [4]. We invented the scheme of teleportation-based quantum computing in 2013 [5]. In this scheme, we can multiplex quantum information in the time domain and we can build a large-scale optical quantum computer only with four squeezers, five beam splitters, and two optical delay lines [6].

For universal quantum computing with this scheme, we need a nonlinear measurement and we invented the efficient way [7]. We recently succeeded in the realization [8]. Our present goal is to build a super quantum computer with 100GHz clock frequency and hundred cores, which can solve any problems faster than conventional computers without efficient quantum algorithms like Shor's algorithm. Toward this goal we started to combine our optical quantum computer with 5G technologies [9].

For the realization of fault-tolerance with our optical quantum computers, we use Gottesman-Kitaev-Preskill (GKP) qubits [10]. We recently succeeded in the generation [11] and invented an efficient way for the generation [12]. We built a real machine of optical quantum computer in Riken and will put it on the cloud in October, 2024. We launched a new start-up company OptQC in September, 2024 which is working on building a large-scale neural network based on optical quantum computers.

[1] A. Furusawa et al., Science 282, 706 (1998).
[2] H. Yonezawa et al., Nature 431, 430 (2004).
[3] N. Lee et al., Science 332, 330 (2011).
[4] S. Takeda et al., Nature 500, 315 (2013).
[5] S. Yokoyama et al., Nature Photonics 7, 982 (2013).
[6] W. Asavanant et al., Science 366, 375 (2019).
[7] K. Miyata et al., Phys. Rev. A 93, 022301 (2016).
[8] A. Sakaguchi et al., Nature Communications 14, 3817 (2023).
[9] A. Inoue et al., Appl. Phys. Lett. 122, 104001 (2023).
[10] D. Gottesman, A. Kitaev, and J. Preskill, Phys. Rev. A 64, 012310 (2001).
[11] S. Konno et al., Science 383, 6680 (2024).
[12] K. Takase et al., Phys. Rev. A 110, 012436 (2024).

Waveguide QED for Superconducting Quantum Networks

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One avenue to scale up quantum computers is to connect quantum processors with quantum links that transport information as flying qubits [1]. This paradigm of quantum links and state transfer has been demonstrated in various platforms, including superconducting quantum circuits. This platform has the advantage that static qubits (transmons) and flying qubits (microwave photons) are the same particles: plasmonic excitations of the superconductor hybridized with the electromagnetic field. This enables strong light-matter interactions and multiple ways to interface scalable quantum processors with said quantum links at macroscopic distances that defy local models [2]

In this talk, I will describe our efforts to realistically model the design and operation of superconducting quantum links, exploring performance limits and their origin in the waveguide properties [3], overcoming those limitations with clever photon engineering [4], analyzing the ultimate bandwidth limitations of superconducting channels in multiplexed scenarios [5] and putting together these ingredients to support scalable entanglement distribution protocols in generic topologies [6].

[1] Quantum State Transfer and Entanglement Distribution among Distant Nodes in a Quantum Network, J. I. Cirac, P. Zoller, H. J. Kimble, and H. Mabuchi, Phys. Rev. Lett. 78, 3221 (1997)
[2] Loophole-free Bell inequality violation with superconducting circuits, S. Storz et al. Nature 617, 265-270 (2023).
[3] Universal Deterministic Quantum Operations in Microwave Quantum Links, Guillermo F. Peñas, Ricardo Puebla, Tomás Ramos, Peter Rabl, and JJGR, Phys. Rev. Applied 17, 054038 (2022)
[4] Improving quantum state transfer: correcting non-Markovian and distortion effects, G. F. Peñas, R. Puebla, JJGR, Quantum Science and Technology 8, 045026 (2023).
[5] Multiplexed quantum state transfer in waveguides, G. F. Peñas, R. Puebla, JJGR, arXiv: 2403.12222
[6] Deterministic multipartite entanglement via fractional state transfer across quantum networks, G. F. Peñas, JJGR, R. Puebla, arXiv:2408.01177

Quantum Imaging

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In the last years the specific properties of quantum states (as entanglement), for long time considered as peculiarities discussed by the restricted community of physicists interested in the foundations of quantum mechanics, became a fundamental resource for the development of new technologies (as quantum communication, computation and imaging), collectively dubbed "quantum technologies". In this talk, I will introduce the new possibilities in imaging and optical sensing offered by quantum measurements [1] and, in particular, of photon number correlated states. Then, I will discuss in more detail some of these new protocols, in particular exploiting quantum photon number correlations, as quantum lithography [2], ghost and sub shot noise imaging (both in absorption and phase [3]) and quantum illumination [4], the contribution of INRIM having been particularly significant for the last two. In particular, I will discuss practical applications. For instance, these range, for ghost imaging, to imaging in turbulent or diffusive media to imaging in cryogenic situations, while for sub shot noise imaging (and other techniques) can be relevant for biological /medical applications (e.g. retinography).

[1] M.Genovese, Journal of Optics, 18 (2016) 073002.
[2] M.D'Angelo, M.V. Chekhova, and Y.Shih Phys. Rev. Lett. 87, 013602 (2001)
[3] G. Brida, M. Genovese, I. Ruo Berchera, Nature Photonics 4, 227 (2010). G. Ortolano, A. Paniate, P. Boucher, C. Napoli, S. Soman, S. F. Pereira, I. Ruo-Berchera, M. Genovese, Light: Science & Applications 12, 171 (2023)
[4] E.Lopaeva, I.Ruo Berchera, I.Degiovanni, S.Olivares, G. Brida, M. Genovese, Phys. Rev. Lett. 110, 153603 (2013).

Generation of hypercubic cluster states in 1-4 dimensions in a simple optical system

Paul D. Lett[a], Zhifan Zhou[a], Luís E. E. de Araujo[a,b] , Matt Dimario[a], Jie Zhao[a], Jing Su[a], Meng-Chang Wu[a], B. E. Anderson[c], Kevin M. Jones[d]

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Measurement-based quantum computing for continuous variables has been proposed for optical quantum information processing. This one-way quantum computing technique uses cluster graph states, where the initial state and the entanglement required for computation are built into the constructed quantum state, and a series of (possibly conditional) measurements is carried out that encodes the computational program [1]. Error correction in measurement-based quantum computing schemes will require the construction of cluster states in at least 3 dimensions. Here we generate 1-, 2-, 3-, and 4-dimensional optical frequency-mode cluster states by sending broadband 2-mode vacuum-squeezed light through an electro-optical modulator (EOM) driven with multiple frequencies. We create the squeezed light using 4-wave mixing in Rb atomic vapor and mix the sideband frequencies (qumodes) using an EOM, as proposed by Zhu et al. [2]. This produces a pattern of entanglement correlations that constitute continuous-variable graph states containing up to several hundred qumodes. We verify the entanglement structure by using homodyne measurements to construct the covariance matrices and evaluate the nullifier expressions. This technique enables scaling of optical cluster states to multiple dimensions without increasing loss. Using sawtooth waveforms to drive the EOM allows for simpler 50/50 beamsplitting, larger state mixing, and simplifies the nullifier expressions from those derived for the sine-wave case.

[1] H. Briegel, D. Browne, W. Dür, R. Raussendorf, M. Van den Nest, Measurement-based quantum computation. Nat. Phys. 5, 19 (2009).
[2] X. Zhu et al., Hypercubic cluster states in the phase-modulated quantum optical frequency comb. Optica 8, 281 (2021).

Atom-based quantum sensors

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For decades atoms have been the heart of precision measurement experiments. They make natural candidates for optical quantum sensors thanks to exquisite understanding of light-atom interactions and quantum control [1,2]. In this talk I will discuss the status of hot atom-based sensors and will speculate on the potential quantum enhancement of their performance and associated challenges. I will also briefly review atom-based sources of non-classical light and their pros and cons for quantum sensing applications.

[1] C. L. Degen, F. Reinhard, and P. Cappellaro, "Quantum sensing," Rev. Mod. Phys. 89, 035002 (2017).
[2] Jun Ye and Peter, "Essay: Quantum Sensing with Atomic, Molecular, and Optical Platforms for Fundamental Physics", Phys. Rev. Lett. 132, 190001 (2024)

Paulo Nussenzveig

(tbu)

Quantum limits of field sensing with ordinary and ultracold matter and application to fundamental physics

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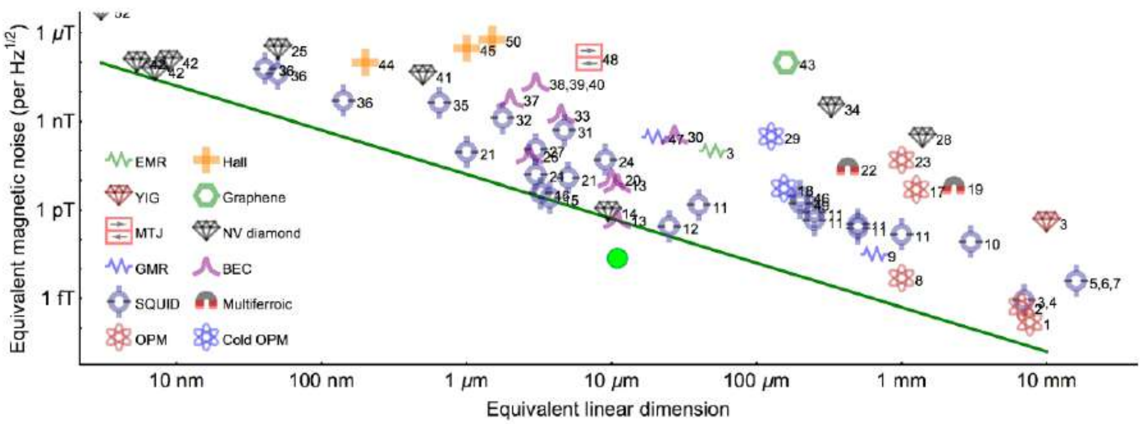

The search for new physics is an application that motivates new methods of detecting tiny fields and forces. We describe recent results on the quantum limits of field sensing, with a focus on magnetic and magnetic-like fields. We describe and explain the “energy resolution limit” that limits today's highest-performing field-sensing technolgies, consider (and discard) possible universal principles limiting sensor “energy resolution” to Planck’s constant hbar, and suggest new technologies to improve sensitivity [1]. One of these technologies is a spinor Bose-Einstein condensate (SBEC). We describe the quantum optical limits of such a sensor using a phase-space picture, show that it beats the hbar limit that constrains other sensors [2], and describe the potential of the SBEC to detect new forces mediated by the (virtual) axion, a well-motivated dark matter candidate [3].

[1] M. W. Mitchell and S. Palacios Alvarez. Colloquium: Quantum limits to the energy resolution of magnetic field sensors. Rev. Mod. Phys., 92, 021001 (2020)
[2] S. P. Alvarez, P. Gomez, S. Coop, R. Zamora-Zamora, C. Mazzinghi, and M. W. Mitchell. Single-domain Bose condensate magnetometer achieves energy resolution per bandwidth below $\hbar$. Proceedings of the National Academy of Sciences, 119, e2115339119 (2022)
[3] P. Gomez, F. Martin, C. Mazzinghi, D. Benedicto Orenes, S. Palacios, and M. W.
Mitchell. Bose-einstein condensate comagnetometer. Phys. Rev. Lett., 124, 170401 (2020)

Quantum Optics with Superconducting circuits: How to build and use a controlled squeeze gate?

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In this talk we review a recent proposal to build a controlled squeeze gate with superconducting circuits [1]. When combined with single qubit operations, Gaussian operations on a resonator and single qubit measurements, this is a new universal type of gate that induces the squeezing of the state of a resonator depending on the state of a qubit. We show how to use this type of gate to encode quantum information in the state of the resonator in a way that makes the most common source of errors (the ones induced by photon losses) easily detectable by a parity measurement. Along the way, we discuss interesting properties of states which are superposition of states squeezed along orthogonal directions.

[1] "A controlled-squeeze gate in superconducting quantum circuits", N. Del Grosso, F. C. Cortiñas, P.I. Villar, F.C. Lombardo y J.P. Paz, arXiv preprint arXiv:2408.08404 (2024), https://doi.org/10.48550/arXiv.2408.08404

Measuring impossible parameters with indefinite causal order

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Quantum theory promises sensors with significantly enhanced precision compared to classical systems, but this advantage is often undermined by noise. Indefinite causal order— a quantum phenomenon where the sequence of events exists in a superposition—can boost communication capacity even in noisy environments. In this study, we experimentally show that indefinite causal order allows for probing noisy channels and a target channel in a way that remains robust against arbitrarily high levels of noise [1]. This holds true even when the probe is completely mixed and one of the noisy channels entirely erases all information.

[1] A. Z. Goldberg, L. L. Sánchez-Soto, K. Heshami, Phys. Rev. Res. 5, 033198 (2023).

Quantum Simulation with Atoms and Ions

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[b] IQOQI, Austrian Academy of Sciences, Innsbruck, Austria

Quantum simulation seeks to efficiently solve quantum many-body problems using programmable quantum devices, and quantum optical systems of atoms and ions provide one of the most promising ways to implement quantum simulators in the laboratory. In this talk, we highlight recent advancements in both analog and digital quantum simulations, covering topics from condensed matter physics to high-energy physics. We begin with a brief overview of atomic platforms and the engineering of many-body Hamiltonians. Next, we provide examples of recent research that includes programming and verifying quantum simulators through Hamiltonian learning [1], investigating large-scale entanglement [2], and simulating lattice gauge theories [3,4]. We conclude with a forward-looking perspective on quantum simulators as programmable quantum sensors [5].

[1] M. Joshi et al., unpublished
[2] M.K. Joshi, C. Kokail, R. van Bijnen, F. Kranzl, T. V. Zache, R. Blatt, C. F. Roos & P. Zoller, Nature 624, 539 (2023)
[3] M. Meth, J. F. Haase, J.L. Zhang, C. Edmunds, L. Postler, A. Steiner, A. J. Jena, L. Dellantonio, R. Blatt, P. Zoller, T. Monz, P. Schindler, C. Muschik, M. Ringbauer, arXiv:2310.12110
[4] D. Gonzalez-Cuadra et al., unpublished
[5] C. D. Marciniak, T. Feldker, I. Pogorelov, R. Kaubruegger, D. V. Vasilyev, R. van Bijnen, P. Schindler, P. Zoller, R. Blatt & T. Monz , Nature 603, 604 (2022)

INVITED SPEAKERS

Gabriel Aguilar, Universidade Federal do Rio de Janeiro

Quantum Reality Erasure with Spacelike-Separated Operations

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In 1935, Einstein, Podolsky, and Rosen argued that quantum mechanics is incomplete, based on the assumption that local actions cannot influence elements of reality at a distant location (local realism). In this work, using a recently defined quantum reality quantifier, we show that Alice's local quantum operations can be correlated with the erasure of the reality of observables in Bob's causally disconnected laboratory. To this end, we implement a modified optical quantum eraser experiment, ensuring that Alice's and Bob's measurements remain causally disconnected. Using an entangled pair of photons and quantum state tomography, we experimentally verify that, even with the total absence of any form of classical communication, the choice of quantum operation applied by Alice on her photon is correlated with the erasure of a spatial element of reality of Bob's photon. In this case, it is shown that Bob's photon can entangle two extra non-interacting degrees of freedom, thus confirming that Bob's photon path is not an element of physical reality.

Noise reduction via optimal control in a light-matter quantum system

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Quantum noise reduction below the shot noise limit is a signature of light-matter quantum interaction. A limited amount of squeezing can be obtained along the transient evolution of a two-level system resonantly interacting with a harmonic mode, in the well-known Jaynes-Cummings model. The role of squeezing in quantum technologies involve quantum teleportation [1], continuous variable quantum computing [2], quantum error correction [3], and quantum metrology, where one of the most impressive applications was the gravitational wave detection [4].

In this work [5], we propose the use of optimal quantum control over the two-level system to enhance the transient noise reduction in the harmonic mode in a system described by the Jaynes-Cummings model. Specifically, we propose the use of a sequence of Gaussian pulses in a time window where the dissipative effects can be neglected. We find that the correct choice of pulse times can reduce the noise in the quadrature field mode well below the shot noise, reaching reductions of over 80%. As the Jaynes-Cummings model describes a pivotal light-matter quantum system, our approach for noise reduction provides an experimentally feasible protocol to produce a non-trivial amount of squeezing with current technology in several platforms like superconducting circuits or trapped ions.

[1] A. Furusawa, J. L. Sørensen, S. L. Braunstein, C. A. Fuchs, H. J. Kimble, and E. S. Polzik. Science 282, 706 (1998).
[2] N. C. Menicucci, P. van Loock, M. Gu, C. Weedbrook, T. C. Ralph, and M. A. Nielsen. Phys. Rev. Lett. 97, 110501 (2006)
[3] T. Aoki, G. Takahashi, T. Kajiya, J.-i. Yoshikawa, S. L. Braun- stein, P. van Loock, and A. Furusawa. Nat. Phys. 5, 541 (2009)
[4] T. L. S. Collaboration. Nat. Phys. 7, 962 (2011).
[5] F. Albarrán-Arriagada, G. Romero, E. Solano, and J. C. Retamal. arXiv: 2406.18693 [quant-ph]

Distributed Quantum Computing between Two Ion-Trap Nodes in a Quantum Network

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Trapped ions are a leading platform for quantum computing due to their long coherence times, precise control over both internal and external degrees of freedom, and inherent full qubit connectivity. High-fidelity single- and multi-qubit operations (>99.9%) have enabled the realization of small-scale universal quantum computers. However, scaling up to larger systems remains a significant challenge. A promising solution is to connect smaller quantum computers via entanglement, creating a cluster of interconnected quantum processors.

In our work, we aim to demonstrate the first operational and fully controllable two-node quantum computer, where each node functions as a small-scale quantum processor linked by photonic entanglement. We use two ion trap systems that confine mixed chains of Strontium and Calcium ions. The Ca ion offers exceptional qubit coherence, while the Sr ion is optimized for efficient photonic entanglement generation. Remote entanglement between nodes is established by utilizing 422 nm photons emitted by the Sr ions.

Recently, we achieved a remote remote entanglement fidelity of 96.0(2)% at a rate of 100 entangled events per second, and an average CHSH violation of 2.677(6). In this presentation, I will discuss our recent experimental progress in the use of remote entanglement between two trapped-ion quantum processors, separated by meters, to execute deterministic distributed quantum computing tasks. These include teleported quantum gates and basic instances of distributed quantum algorithms [1]. Additionally, I will showcase how this elementary quantum network has been used for proof-of-concept experiments in secure quantum communication [2] and quantum sensing [3].

[1] https://arxiv.org/abs/2408.01177
[2] Nature 609, 689–694 (2022)
[3] Nature 607, 682–686 (2022)

Usefulness of quantum entanglement for enhancing precision in frequency estimation

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We investigate strategies for reaching the ultimate limit on the precision of frequency estimation when the number of probes used in each run of the experiment is fixed. That limit is set by the quantum Cramér-Rao bound (QCRB), which predicts that the use of maximally entangled probes enhances the estimation precision, when compared with the use of independent probes. However, the bound is only achievable if the statistical model used in the estimation remains identifiable throughout the procedure. This in turn sets different limits on the maximal sensing time used in each run of the estimation procedure, when entangled and independent probes are used. When those constraints are taken into account, one can show that, when the total number of probes and the total duration of the estimation process are counted as fixed resources, the use of entangled probes is, in fact, disadvantageous when compared with the use of independent probes. In order to counteract the limitations imposed on the sensing time by the requirement of identifiability of the statistical model, we propose a time-adaptive strategy, in which the sensing time is adequately increased at each step of the estimation process, calculate an attainable error bound for the strategy and discuss how to optimally choose its parameters in order to minimize that bound. We show that the proposed strategy leads to much better scaling of the estimation uncertainty with the total number of probes and the total sensing time than the traditional fixed-sensing-time strategy. We also show that, when the total number of probes and the total sensing time are counted as resources, independent probes and maximally entangled ones have now the same performance, in contrast to the non-adaptive strategy, where the use of independent is more advantageous than the use of maximally entangled ones.

Optical phase estimation with optimized measurements

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Optimized quantum measurements play a central role in metrology, which is at the core of many areas in physics and engineering. Among diverse metrological tasks, optical phase estimation uses the interaction of an optical probe state with a physical system to learn about a specific parameter of the system. In this process, the information about this parameter is mapped to the phase of the optical probe, and an optimal (or near-optimal) measurement of the optical phase then allows for inferring the property of the system under study. The ultimate limit for the precision of optical phase estimation depends on the quantum state used as the probe, and it can be achieved by the optimal phase measurement on the probe. However, while theoretically the optimal phase measurement exists, for most quantum states there are no known physical realizations of such optimal measurements. The task is therefore to find quantum measurements optimized for a particular quantum state that can approach the performance of the ideal optimal measurement for optical phase estimation. In this talk, I will discuss recent advancements in optimized quantum measurements for optical phase estimation for various quantum probes: coherent states [1,2], squeezed states [3], and single photons. We consider measurements based on single photon counting, homodyne measurements, and optimized adaptive strategies. We find that these optimized adaptive strategies can allow for optical phase estimation for different optical probe states with precisions surpassing the conventional measurement limits, and in some cases approaching the quantum bounds.

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Average concurrence and entanglement swapping

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We discuss the role of average concurrence in entanglement swapping in quantum networks [1]. First, we focus on qubit pure states and present a very simple rule that governs the propagation of average concurrence in multiple swaps. We find a similarly simple rule for average concurrence when creating a Greenberger-Horne-Zeilinger state from three entangled pairs. We then look at examples of mixed qubit states and find that the relation for pure states gives an upper bound on what is possible with mixed states. Next, we consider entanglement swapping of qudits, where we find that I-concurrence plays a central role. The situation is more complex than for qubits, but in some cases relatively straightforward results can be obtained. We also look at additional limitations arising from linear optical implementations, which is relevant in linear optical networks.

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Perfect Vortex Beams for Enhanced Classical and Quantum Communication

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This research explores the innovative use of perfect vortex (PV) beams for coupling into ring-core optical fibers (RCFs) to enhance spatial multiplexing in classical and quantum communications. Traditional Laguerre-Gaussian (LG) beams are limited by variable coupling efficiency that depends on the orbital angular momentum (OAM) value, which can hinder transmission efficiency. PV beams, with their consistent beam shape regardless of OAM value, offer nearly perfect and uniform coupling efficiency across all supported OAM modes. This makes PV beams especially beneficial for multiplexing large numbers of OAM channels within a single fiber, simplifying optical setups and boosting transmission systems. Experimental results reveal that PV beams significantly outperform LG beams, providing higher coupling efficiency, lower power demands, and reduced variability in bit error rates. Additionally, the successful high-fidelity transmission of 4-dimensional quantum states encoded in PV beams indicates a promising path for high-dimensional quantum communication through space-division multiplexing in RCFs. These findings highlight the potential of PV beams in advancing both classical and quantum optical communication technologies.

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Gonzalo Carvacho, Sapienza Università di Roma

Polarization-encoded photonic quantum-to-quantum Bernoulli factory based on a quantum dot source

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A Bernoulli factory is a randomness manipulation routine that takes as input a Bernoulli random variable, providing as output another Bernoulli variable whose bias is a function of the input bias [1]. Recently proposed quantum-to-quantum Bernoulli factory schemes encode both input and output variables in qubit amplitudes. This primitive could be used as a subroutine for more complex quantum algorithms involving Bayesian inference and Monte Carlo methods.

Given the broad applicability of such a problem, in recent years, quantum counterparts to the BF problem were theoretically introduced [2,3]. Here, we report an experimental implementation of a polarization-encoded photonic quantum-to-quantum Bernoulli factory recently published [4]. We present in Fig.1 three interferometric setups implementing the basic operations of an algebraic field (inversion, multiplication, and addition), which, chained together, allow for the implementation of a generic quantum-to-quantum Bernoulli factory. These in-bulk schemes are validated using a quantum dot–based single-photon source [5] featuring high brightness and indistinguishability, paired with a time-to-spatial demultiplexing setup to prepare input resources of up to three single-photon states.

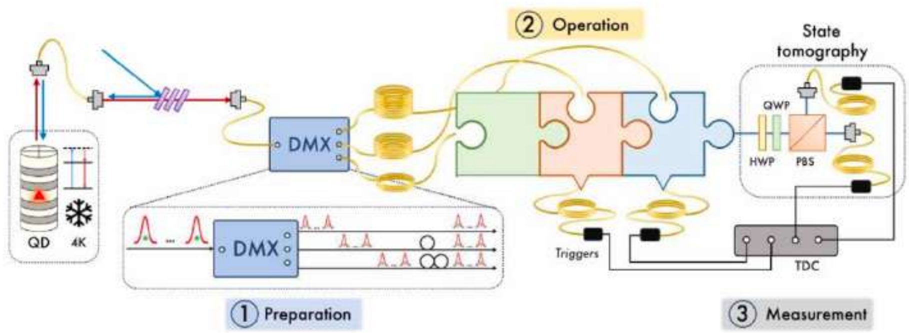

Figure 1 Full experimental apparatus: We use a Qd single-photon source kept in a cryostation at 4 K and operatednonresonantly in the so-called lA phonon–assisted configuration (38). the output of the Qd source is connected to a time-to-spatial dMX, which distributes the single-photon stream in bunches of ~180 ns toward three output modes: here, temporal synchronization is achieved via finely tuned in-fiber delay loops. the three-photon re-source states are then input to the modular QQBF setup: At its output, the set of projective measurements required for state reconstruction is performed with a sequenceof QWPs, hWPs, and PBS.

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Observation of Space-Dependent Rotational Doppler Shifts with a Single Ion Probe

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We present an experiment [1] investigating the rotational Doppler effect using a single trapped ion excited by two copropagating vortex beams. The setup isolates the azimuthal gradients of the fields, eliminating longitudinal and curvature effects. We achieve a thorough characterization of the phenomenon by deterministically placing a single ion across the beams and measuring fluorescence spectra with sharp “dark resonances” that depend on the angular velocity of the ion and the difference of helicity between the two beams. The interpretation of the measurements is supported by numerical simulations and by a simplified analytical model. Our results reveal key properties of the rotational Doppler effect, showing that it increases approaching the center of the beam and that it is independent of the waist of the beam. The experiment offers insights into the feasibility of super-kicks or super-Doppler shifts for sensing and manipulating atomic motion transverse to the beams’ propagation direction.

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Quantum correlations in ultracold atomic clouds driven by dissipative cavities

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Cold atoms represent an ideal platform for the implementation of second-generation quantum technologies. Particularly interesting opportunities emerge from a coherent coupling of the atoms to single-mode light fields enabled by resonant optical cavities. I will present experimental and theoretical studies of the interaction of ultracold strontium atoms with a ring cavity in parameter regimes suitable for the creation of non-classical collective states of the atomic cloud with possible application in Heisenberg-limited interferometry or superradiant lasing.

Vitalie Eremeev, Universidad Diego Portales

Dual phonon-photon lasing in an optomechanical system

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The interdisciplinary field as cavity optomechanics bridges quantum optics and nanomechanics and has found applications in high-precision measurement, quantum information processing, as well as in the exploration of fundamental quantum mechanics at macroscopic scales [1]. In recent years, one fascinating phenomenon explored in hybrid optomechanical systems (OMS) is the possibility of achieving simultaneous lasing of photons and phonons [2,3].

Here we propose a theoretical study to achieve simultaneous lasing of photons and phonons in OMS driven by a two-tone field. We specifically focus on the condition where the frequency difference between the drive tones is tuned to match the mechanical frequency of the system. Our analysis delves into the dynamical processes induced by the two-tone drive, which enhances the optomechanical interaction and facilitates coherent energy transfer between the mechanical and optical modes. The model demonstrates that when the frequency difference condition is satisfied, both photon and phonon populations can attain steady-state coherent oscillations, resulting in dual lasing. Numerical simulations support our analytical findings, indicating that this frequency condition maximizes amplification for both optical and mechanical modes. This study provides a comprehensive understanding of the mechanisms underlying dual lasing and presents a new strategy for optimizing optomechanical interactions through tailored driving fields. Our setup, consisting of a single optomechanical cavity, is simpler than previous realizations of dual lasing. The phenomenon of dual lasing may significantly influence the development of advanced OMS, including applications in quantum information processing, high-precision sensing, and hybrid photonic-phononic devices.

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Quantum and classical regimes for four-wave mixing in an ensemble of cold two-level atoms

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Here we report experiments exploring different regimes of four-wave mixing in ensembles of cold rubidium atoms prepared in a pure two-level system. Out of resonance, we observe quantum correlations at short time scales, which win over regular Rayleigh scattering without filtering. These quantum correlations are verified by the violation of the classical bound of a Cauchy-Schwarz inequality on the normalized second order correlation functions of the scattered light. As they result from the competition between scattering on sidebands and on the excitation frequency, these correlations are enhanced by spectral filtering. On longer timescales, the correlations lose their purely quantum traces and reflect the decay of excitation gratings on the external degrees of freedom of the ensemble's ground state. At resonance, however, we observe a different regime, without violating any classical bound, in which all correlations disappear on a very short time scale, on the order of the natural linewidth of the transition. We also present some first theoretical analysis for our various observations. As a whole, our investigation opens the way to use purely cycling transition for the generation of quantum light.

Abstract Matter-wave rings and shells: experiment and theory with radio-frequency fields

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The motivations behind this work are the analysis of systems that may be used to make Sagnac interferometers [1,2,3] for rotation measurements, and the analysis of idealized shell states of a Bose-Einstein condensates. For the latter case, experiments on the Cold Atom laboratory in space, or CAL [4,5], have stimulated wide interest in the creation and physics of bubbles of quantum gas [6]. This includes the collapse and expansion of bubbles, vortices on closed surfaces, and vibration of the shell. In this presentation an introduction and overview will be given.

We have developed techniques for the analysis of wave packet dynamics in 2D and 3D. We use a Gaussian approximation to a wave-packet in a ring potential and show how the orientation of the wave-packet changes as it propagates around the ring. Further to this, a method to obtain corrections to the Gaussian wave-packet is obtained by transforming the Hamiltonian of the system to a local co-moving and rotating harmonic basis [7].

Further, by using a method of representing a wave-function by a swarm of Gaussian wave-packets we also analyse the dynamics of matter-wave rings and shell states expanding in free space. This uses simplified expansions based on a method inspired by quantum optics.

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Sébastien Gleyzes,

(tbu)

Entanglement, loss, and quantumness: When balanced beam splitters are best

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Entanglement generation by beam splitters lies at the heart of quantum optics, from the Hong-Ou-Mandel effect to boson sampling. Yet, the conjecture that maximal entanglement is generated by beam splitters with equal reflection and transmission probabilities has remained unproven for almost two decades, despite overwhelming positive evidence [1]. We report on our recent proof of this conjecture [2]. Our results yield corollaries from inequalities for quasiprobability distributions to properties of states undergoing photon loss to measures of quantumness. One can now definitively state: the more balanced a beam splitter, the more entanglement it can generate.

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State tomography in quantum computers with minimal local resources

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In the current state of the art of quantum computing [1], the full state reconstruction of a quantum computer is a challenging task even for a small number of qubits. This is primarily because existing protocols (see e.g. [2-5]) necessarily involve at least one of the following quantities growing exponentially with the number of qubits: number of projective measurements, number of ancillary systems, number of non-local gates, depth circuit in the measurement stage, and postprocessing time. In this talk, we introduce a method that overcomes all these challenges by using a fixed set of 2n rank-one projective measurements to univocally reconstruct the state of n-qubit systems, offering an explicit reconstruction formula and eliminating the need for postprocessing operations. Additionally, the measurement stage involves only a single local Pauli gate applied to each qubit. Moreover, a subset of these projectors enables us to define a tomographic protocol using just a fixed set of five rank-one projective measurements, complemented with classical communication between the qubits. As a result, we push the boundaries of state tomography, achieving high fidelities for genuinely entangled quantum states with systems exceeding 10 qubits.

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Quantum Theory of Rotor-Like Systems

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The talk will cover the theoretical foundations of quantum technologies that utilize complementary quantities, with a focus on exploring previously overlooked degrees of freedom. Rather than the commonly used position, momentum, or spin variables, we will concentrate on a quantum rotor, characterized by complementary quantities such as angular momentum and the unitary exponential of the angle operator [1,2]. The developed quantum theory encompasses the design of uncertainty measures based on the moment of inertia, the formulation of relevant uncertainty relations, the derivation of optimal conditions for simultaneous measurements, the identification of extremal states, and phase space representation. The theory will be demonstrated through experiments on optimal pulse shaping and detection at the ultimate quantum limit. Additionally, we will reformulate tight uncertainty relations in the time-frequency domain and present an optimal tomography scheme to retrieve complete information about the pulse at the quantum limit.

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Lindblad Master Equations for Quantum Systems Coupled to Dissipative Bosonic Modes

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We present a general approach to derive Lindblad master equations for a subsystem whose dynamics is coupled to dissipative bosonic modes. The derivation relies on a Schrieffer-Wolff transformation which allows to eliminate the bosonic degrees of freedom after self-consistently determining their state as a function of the coupled quantum system. We apply this formalism to the dissipative Dicke model and derive a Lindblad master equation for the atomic spins, which includes the coherent and dissipative interactions mediated by the bosonic mode. This master equation accurately predicts the Dicke phase transition and the correct steady state. We also discuss further applications of the Lindblad master equation to time-periodically driven systems and to interaction and dissipation engineering.

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Rotation sensing with nuclear spins in diamond

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Diamonds doped with nitrogen-vacancy (NV) centers are a promising solid-state platform for rotation sensing [1,2] capable of operating in a broad range of environmental conditions. In our previous work [3], we demonstrated a solid-state rotation sensor based on 14N nuclear spins intrinsic to NV centers in diamond. This type of sensor detects rotation by measuring the shift in the precession rate of nuclear spins, analogous to vapor-based NMR devices. The sensor employs direct optical polarization and readout of the 14N nuclear spins and a radio-frequency double-quantum Ramsey interferometric scheme that monitors 14N nuclear spin precession, and it does not require microwave pulses resonant with the NV electron spin transitions. However, these types of sensors are sensitive to variations in the magnetic field, temperature, and amplitude of the applied RF pulses, limiting the long-term stability of the device. To improve the robustness of the sensing technique, we develop and implement a generalized version of the Ramsey interferometric scheme, employing stimulated Raman adiabatic passage (STIRAP) techniques to perform the required nuclear-spin-state manipulation with high fidelity [4]. The enhanced robustness of the STIRAP-based Ramsey scheme to variations in the pulse parameters is experimentally demonstrated, showing good agreement with theoretical predictions. Our results pave the way for improving the long-term stability of diamond-based sensors, such as gyroscopes and frequency standards.

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Effects of collective coupling on four-wave mixing in atomic samples

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Optimization of non-linear optical responses of multilevel atoms and the coherent control of light is better accomplished when microscopic models are taken into account. These models are traditionally based on single-atom effects that are parametrically extrapolated to include collective effects, such as an enhanced response or propagation within atomic media. In this work we present a systematic analysis of the cooperative effects arising in driven systems composed of multilevel atoms coupled via a common electromagnetic environment. The analysis is based on an interplay between dressed states induced by the driving field and photon exchanges, and collective decay channels. This theory is applied to the case of four wave mixing induced by a pair of lasers acting on atoms with internal levels in the diamond configuration. Three regions of operation are identified: (i) laser-dominated; (ii) intermediate; and (iii) dipole-dominated. Single and two-photon correlations are shown to exhibit a transition from a Lorentz-like dependence on the two-photon detuning —with general features that can be obtained in an isolated atom scheme —to a two-peaked distribution when the dipole-dipole interactions become relevant. For weak Rabi frequencies whose value is smaller than the highest collective decay rate, the atoms are trapped inside their ground state as they approach each other. It is found that the anisotropy of the dipole-dipole interaction and its wave nature are essential to understand the behavior of the photons correlations. Signatures of these processes are identified for existing experimental realizations.

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Open quantum dynamics and quantum networks

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We give a summary of our work on the dynamics of open system dynamics given by iterated quantum maps and give several examples of possible applications. Among others we discuss how the properties of the network can determine the asymptotic dynamics and point out the link between the asymptotic dynamics and the Jaynes principle.

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Quantum resources for assisted optimal state discrimination

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Optimal unambiguous quantum state discrimination assisted by an auxiliary system has been studied in the context of the underlying resources required to perform the task. The design of the problem led to the assumption that entanglement was such resource. However, to discriminate between two nonorthogonal states, it has been shown that entanglement is not necessary at all, whereas quantum dissonance may or may not be required, depending on the relationship between the overlap and the a priori probabilities of the inputs Zhang et al. [1]. Here, we resume this discussion and show that, regardless of this relationship, coherence [2] and purity [3] are required resources for the task and, therefore, more fundamental than dissonance. Coherence is analyzed based on its generalized resource theory [4], which allowed us to find the scenario that generates the maximal cryptographic randomness gain in the protocol. Purity, on the other hand, is shown to be greater than coherence, including the extreme cases of orthogonal and parallel states, where the latter is zero. Therefore, purity is the most elementary resource for assisted optimal state discrimination, in accordance with the known hierarchy among resources for quantum information processing [3].

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Recognition of light orbital-angular-momentum superpositions for quantum communication

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We study the tomography of spatial qudits encoded on structured light photons in the space of fixed order transverse modes. While direct position measurements with cameras do not provide an informationally complete Positive Operator Valued Measure (POVM), this property is achieved with the use of astigmatic transformation, allowing full characterization of the spatial quantum state from simple intensity measurements in both the intense and in the low photocount regimes. These methods are useful for classical and quantum communication with structured light. Here we deal with two regimes: in the first, we treat intense beams, which are equivalent to measurements on many copies of a quantum system and, therefore, one has reliable estimates for the probabilities of each experimental outcome. Then, we explore the low photocount regime, which is more subtle, as one cannot determine with certainty the state being observed. This fact is considered by some tomographic techniques, such as maximum likelihood [1,2] or the variational tomography method [3,4]. Here we will employ Bayesian inference [5,6], where one assigns a probability for each possible state. This probability is updated with each new observation, being initially broad when one has performed a low number of measurements, and then concentrating around a particular state as more and more data is used to update our knowledge.

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Detection of multipartite correlation transfer via discrete Rényi entropy

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We show that the total amount of correlation stored in N-qubit systems, as characterized by the discrete Rényi entropy, can be effectively employed to detect the presence of N-partite correlations within the framework of deterministic measurements. An associated optimization procedure can be analytically performed for a broad range of N-qubit states, encompassing both symmetric and nonsymmetric ones. This analytical approach enables the analysis of the asymptotic limit N>>1. It is proved that the appropriately normalized quadratic discrete Rényi entropy always decreases in the process of deterministic measurements. This allows us to introduce a robustness parameter for assessing the stability of pure multipartite states under the protocol of measurement-induced optimal correlation transfer.

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Cold Rydberg atoms in the presence of light and Microwave

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Rydberg atoms have long been considered as a promising support for the study of collective effects and quantum information protocols implementation [1]. I will describe experiments and theoretical modeling of cold ^{87}Rb trapped in a magneto optical trap and optically excited to the $55D_{3/2}$ Rydberg state in the presence of a microwave (RF) field. The RF frequency is tuned between 12 and 15 GHz covering three different transitions to neighboring Rydberg states. The EIT signal of the exciting light as a function of RF frequency shows structures at frequencies detuned from the Rydberg transitions by several hundred MHz. We argue that these spectral features are indicative of mechanical effects induced by the RF which result in the removal of atoms from the interaction region and elaborate on the use of such effects for the coherent manipulation of Rydberg atom pairs.

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Device-Independent Certification of Qudit Generalized Quantum Measurements

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Quantum measurements are essential for understanding and applying quantum theory. Traditionally, they have been viewed as projections of a quantum system but modern understanding enables more general, non-projective, measurements that go beyond the traditional textbook concept. These generalized measurements are conceptually intriguing and they are becoming increasingly important in quantum information science.
However, generalized measurements present two major challenges. (i) They are difficult to implement faithfully because they require control of auxiliary degrees of freedom. (ii) It is difficult, from both a theoretical and experimental standpoint, to certify the operational advantage of generalized measurements without making considerable extra assumptions.

In our work, we present a versatile platform for faithful implementation of generalized quantum measurements. For the first time, we go beyond the simplest, two-dimensional qubit, scenario and show how one can perform these measurements on higher-dimensional systems, while achieving a quality high enough to certify them as a useful quantum information resource beyond traditional measurements even under minimal assumptions. This is achieved by developing technology for multiport beamsplitters that are built inside multicore optical fibers operating at telecom wavelengths. This platform achieves a very high measurement quality, without compromising the faithfulness of the implementation.

Shortcut to adiabaticity in a superconducting cavity with moving mirrors

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Shortcuts to adiabaticity constitute a powerful alternative that speed up time evolution while mimicking adiabatic dynamics. In this talk we describe how to implement shortcuts to adiabaticity for the case of a massless scalar field inside a cavity with a moving wall. The shortcuts take place whenever there is no dynamical Casimir effect. We obtain a fundamental limit for the efficiency of an Otto cycle with the quantum field as a working system, that depends on the maximum velocity that the mirror can attain. We describe possible experimental realizations of the shortcuts using superconducting circuits.

Melissa Maldonado, Pontificia Universidad Católica de Chile

Nonlinear Optical Characterization of Layered Transition Metal Dichalcogenides in the Femtosecond and Nanosecond Regimes

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Atomically thin 2D materials, including metallic, semimetallic, semiconducting, insulating, and superconducting, are of significant scientific interest due to their unique properties. Layered transition metal dichalcogenides (TMDs) possess tunable bandgaps, making them promising candidates for optoelectronic devices such as solar cells and photodetectors. In this talk, we investigate the excitation dynamics of TMDs—specifically metallic NbS2, semimetallic ZrTe2, and semiconducting MoS2—using optical Z-scan and photoacoustic Z- scan techniques across different temporal regimes.

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Scalable Generation of Continuous Variable Multipartite Entangled States of Light

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Multipartite entanglement is a valuable resource in quantum information science, as it is at the center of applications such as distributed sensing and quantum computing. We present a scheme based on a parametric amplifier (PA) network to generate scalable multipartite continuous variable (CV) entangled states of light [1]. We show that the symmetry of the PA network makes it possible to demonstrate the scalability of the proposed scheme to an arbitrary number of 2N entangled parties through different entanglement measurements, such as the positive partial transpose (PPT) criteria or α-entanglement of formation. We leverage the spatial multimode nature of four-wave mixing in Rb vapor [2, 3] to implement the proposed scheme in a compact and scalable configuration. We present initial results that show the presence of quantum correlations between all expected mode pairs for quadripartite and octapartite quantum states [4].

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Optical properties of Vanadium Oxide Phthalocyanine and phonon longitudinal relaxation of electronic spins for quantum technologies

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Single emitters in molecules and large bandgap materials are nowadays on demand as controllable systems for quantum applications and electro-optical devices. A deep understanding of their properties and interaction with their environment is crucial for their implementation in quantum technologies. In this presentation, I will discuss about the internal
structure of a single emitter hosted in the molecule vanadium oxide phthalocyanine (VOPc) and how it determines their optical properties and interaction with phonons [1]. VOPc is an organic molecule with sub nanoseconds excited state lifetime and presents a large emission intensity under red excitation. At the single molecular level, it shows a clear response to the polarization of optical excitation which allows to unravel details of its internal structure and interaction with vibrations. We will also discuss about the phonon longitudinal relaxation for this molecule in terms of recent findings for the longitudinal relaxation of the electronic spin associated to the nitrogen-vacancy center in diamond, for which we have found that its zero- field splitting plays a crucial role in making this electronic spin robust in a phonon environment [2]. These aspects are important for defect engineering with desired optical properties for quantum photonics and quantum metrology.

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Renné Medeiros de Araújo,
(tbu)

Photoinduced Floquet topological magnons in Kitaev magnets

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We study periodically driven pure Kitaev model and ferromagnetic phase of the Kitaev- Heisenberg model on the honeycomb lattice by off-resonant linearly and circularly polarized lights at zero magnetic field. Using a combination of linear spin wave and Floquet theories, we show that the effective time-independent Hamiltonians in the off- resonant regime map onto the corresponding anisotropic static spin model, plus a tunable photoinduced magnetic field along the [111] direction, which precipitates Floquet topological magnons and chiral magnon edge modes. They are tunable by the light amplitude and polarization. Similarly, we show that the thermal Hall effect induced by the Berry curvature of the Floquet topological magnons can also be tuned by the laser field. Our results pave the way for ultrafast manipulation of topological magnons in irradiated Kitaev magnets, and could play a pivotal role in the investigation of ultrafast magnon spin current generation in Kitaev materials.

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Physics-informed neural networks for quantum control

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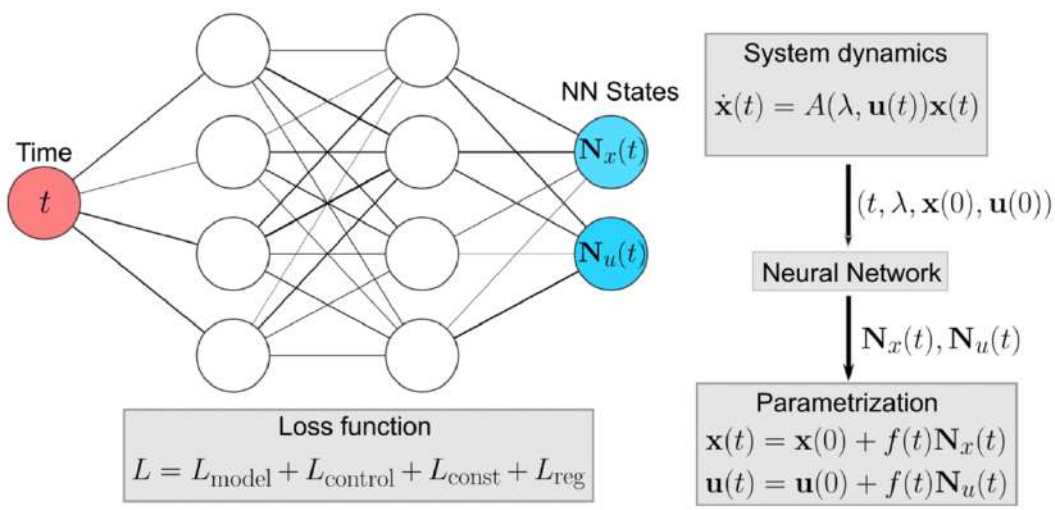
Quantum control is a ubiquitous research field that has enabled physicists to delve into the dynamics and features of quantum systems, delivering powerful applications for various atomic, optical, mechanical, and solid-state systems. In recent years, traditional control techniques based on optimization processes have been translated into efficient artificial intelligence algorithms. In particular, physics-informed neural networks (PINNs) have been introduced as a new artificial intelligence paradigm that only requires the model itself [1,2]. Here, we introduce a computational method for optimal quantum control problems via PINNs [3]. We apply our methodology to open quantum systems by efficiently solving the state-to state transfer problem with high probabilities, short-time evolution, and using low-energy consumption controls. Furthermore, we illustrate the flexibility of PINNs to solve the same problem under changes in physical parameters and initial conditions, showing advantages in comparison with standard control techniques.



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Entangled Two-Photon Absorption Cross Section in Cesium Atoms

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The two-photon absorption processes driven with entangled photon pairs (ETPA) has been of great interest due to its linear dependence with the photon flux. This dependence opens new possibilities to study ETPA in, e,g,. biological samples with a reduced probability of destroying them in the process. The ETPA cross section has been measured in different molecules. Results presented until now are in discussion due to the difficulty to distinguish the ETPA signal in organic molecules in experiments using a coincidence detection scheme. An alternative to clarify the origin of the signal is to study the ETPA process in atomic systems. The first step towards this goal is the quantification of the TPA cross section in atoms. Here we present the theoretical and experimental results the TPA cross section in the transition in cesium atoms. From these results the ETPA cross section for the transition is calculated using the density operator formalism. These results are the input to design ETPA experiments in Cesium based on a coincidence detection scheme.

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Quantum engineering of light with intracavity Rydberg superatoms

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I will describe our efforts towards using Rydberg superatoms coupled to an optical cavity [1] as a platform for quantum engineering of light enabling strong photon-photon interactions. Using this system, we prepared Wigner-negative free-propagating states of light by mapping the internal state of an intracavity Rydberg superatom onto an optical qubit encoded as a superposition of 0 and 1 photons [2]. This approach allows us to reach a 60% photon generation efficiency in a well-controlled spatio-temporal mode, while maintaining a strong photon antibunching. By changing the qubit rotation angle, we observe an evolution from quadrature squeezing to Wigner negativity. I will show that, like single-atom-based setups, this system can be accurately modeled from first principles, and I will present our recent progress towards increasing the number of manipulated qubits.

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Experimental quantum interference of force with pothons

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Aharonov et al. discuss the radiation pressure that photons exert on mirrors in an interferometer using the weak value concept [1]. One conclusion is that the superposition of a positive photonic radiation pressure with a null radiation pressure may result in a negative photonic radiation pressure in a mirror, a non-intuitive behavior. Inspired in the results of [1], the quantum interference of force effect was introduced in [2]. It was shown that the quantum superposition of a positive force with a null force on a quantum particle may result in a negative momentum transfer to it. As a consequence, an ensemble of quantum particles may receive an average momentum in the opposite direction of the applied force [2] and charges of the same sign may suffer an effective electrostatic attraction in an interferometer [3], non intuitive behaviors. These intriguing effects were not experimentally verified so far.

Here we show experimentally an implementation of a quantum interference of force experiment using entangled photons. Although photons are massless particles, they have linear momentum, and we experimentally show that the quantum superposition of a positive momentum transfer with a null momentum transfer may result in a negative momentum transfer to an ensemble of photons, a behavior with no classical analogue. Also, the momentum transfer to each photon is defined by the result of a polarization measurement performed in another photon, initially entangled with it.

We use entangled photons generated by spontaneous parametric down-conversion (SPDC) to implement a quantum interference of force experiment in the present work. Paired type I BiBO crystals with orthogonal optic axes are pumped by a continuous wave laser (CW) at 405 nm polarized at 45o producing photon pairs with wavelength at 810 nm. Photon pairs (signal and idler) are entangled in momentum [4] and polarization. Photons are reflected by a spatial light modulator (SLM) that subjects the horizontal polarization component of the signal photon in path 1 to a linear grating, which causes a shift in momentum, and the horizontal component of the idler photon in path 2 to a uniform phase mask, in order to maximize the destructive spatial interference in the coincidence rate after projection in the diagonal polarization basis. Photon signal is the one that will be subjected to a quantum interference of force. Due to the system entanglement, its quantum state depends on projective measurements performed on the momentum and polarization of photon idler and the negative momentum transfer to photon signal can be controlled nonlocally by the projection in photon idler. We acknowledge the support of CAPES, CNPq, National Institute of Quantum information (INCT-IQ), and FAPEMIG.

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Quantum Nonlinear Optics Mediated by Rydberg Atoms

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Exciting atoms in dilute cold gases to highly excited Rydberg states introduces an amplification mechanism where single photons can significantly impact the optical properties of surrounding atoms. By leveraging this phenomenon, a large ensemble of individual atoms can be transformed into a collective system that behaves like a single two- level emitter, exhibiting enhanced coupling to the optical driving field. This approach allows for strong, coherent interactions at the few-photon level, even in free space.
In this talk, we present tools that exploit this principle to manipulate light at the few-photon level. Additionally, we will discuss the ongoing development of an experiment in Mexico aimed at placing a cloud of cold atoms inside a low-finesse cavity to further explore the light-matter interaction through the collective atomic response.

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Extending loophole-free nonlocal correlations to arbitrarily large distances

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One of the most striking features of quantum theory is that it allows distant observers to share correlations that resist local hidden variable (classical) explanations, a phenomenon referred to as Bell nonlocality. Besides their foundational relevance, the nonlocal correlations enable distant observers to accomplish classically inconceivable information processing and cryptographic feats such as unconditionally secure device-independent key distribution schemes. However, the distances over which nonlocal correlations can be realized in state-of-the-art Bell experiments remain severely limited owing to the high threshold efficiencies of the detectors and the fragility of the nonlocal correlations to experimental noise. Instead of looking for quantum strategies with marginally lower threshold requirements, we exploit the properties of loophole-free nonlocal correlations, which are experimentally attainable today, albeit at short distances, to extend them over arbitrarily large distances. Specifically, we consider Bell experiments wherein the spatially separated parties randomly choose the location of their measurement devices in addition to their measurement settings.

We demonstrate that when devices close to the source are perfect and witness extremal loophole-free nonlocal correlations, such correlations can be extended to devices placed arbitrarily far from the source, with almost-zero detection efficiency and visibility. To accommodate imperfections, close to the source, we demonstrate a specific analytical tradeoff: the higher the loophole-free nonlocality close to the source, the lower the threshold requirements away from the source. We utilize this analytical tradeoff paired with optimal quantum strategies to estimate the critical requirements of a measurement device placed away from the source and formulate a versatile numerical method applicable to generic network scenarios.

The talk is based on paper [1].

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Quantum Tomography for Pure States: Minimal orthonormal bases and Adaptive Fisher Symmetric Measurements

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Quantum state tomography [1], the process of experimentally determining the complete description of a quantum system, is essential for numerous applications, ranging from quantum information processing to quantum computing. Tomographic protocols for pure states have become an alternative for increasing the scalability and precision of those methods. In this talk, we present two tomographic methods for pure states. First, we present an analytical method to estimate pure quantum states using a minimum of three measurement bases in any finite-dimensional Hilbert space [2,3]. This is optimal as two bases are insufficient to construct an informationally complete positive operator-valued measurement (IC-POVM) for pure states [4]. We demonstrate our method using a binary tree structure, providing an efficient algorithmic path for implementation. Second, we introduce an adaptive tomography method with Fisher Symmetric measurements. They can estimate a pure quantum state with the ultimate precision given by the Gill-Massar bound [5], using the minimal number of outcomes. However, FSMs are limited in their effectiveness to the vicinity of a known fiducial state, thus restricting their usability for completely unknown states. We demonstrate that by combining a single-shot measurement on a computational basis with three adaptive FSMs, we can estimate any pure state with precision close to the Gill-Massar bound.

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Improving quantum measurement and amplification in superconducting quantum devices

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The current generation of quantum machines can perform universal quantum logic operations, but the number of successive operations is limited by noise, imperfections, and decoherence. My work focuses on improving the quality of qubit measurement in superconducting circuits, which currently induces the largest error per process.

I will first review the standard procedure for dispersive qubit readout and then discuss new approaches to improve it. In particular, I will present new tomographic methods to experimentally reconstruct the complete quantum process describing a quantum non- demolition (QND) measurement [1,2]. This provides valuable information to identify measurement errors, and we show how to use this to improve the calibration of multi-qubit readout, quantifying more precisely the QND-ness, back-action, and cross-talk of the measurement.

I will also comment on a fundamentally new way of performing directional and broadband parametric amplification of quantum microwave signals based on an array of Josephson junctions with topological properties [3,4,5].

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Controlling nonequilibrium many-body dynamics via two-tone Floquet engineering

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We report on the control of spin pair fluctuations using two-tone Floquet engineering. We consider a one-dimensional spin-1/2 lattice with periodically modulated spin exchanges using parametric resonances. The stroboscopic dynamics generated from distributed spin exchange modulations lead to spin pair fluctuations reaching quasi-maximally correlated states and a subharmonic response in local observables, breaking the discrete-time translational symmetry. We present a protocol to control the interacting many-body dynamics, producing spatial and temporal localization of correlated spin pairs via dynamically breaking correlated spin pairs from the edges towards the center of the lattice. Our result reveals how spin fluctuations distribute in a heterogeneous lattice depending on parametric resonances. These two-tone Floquet protocols may open new routes for exploring distinct nonequilibrium states of matter.

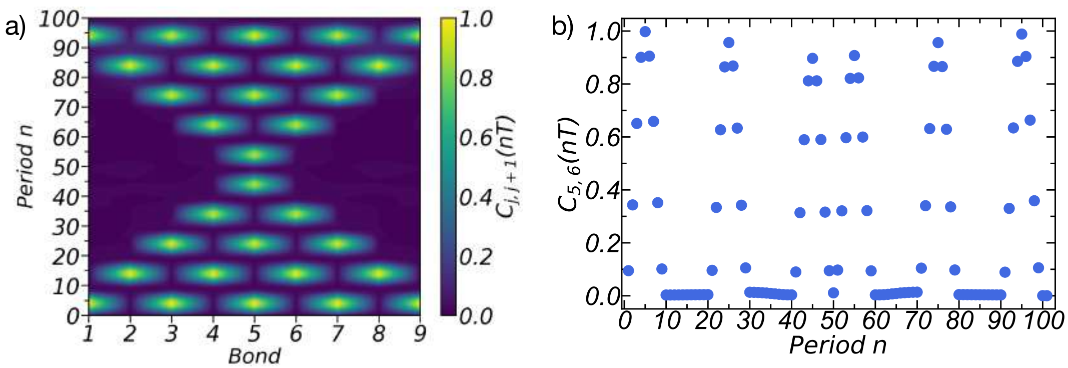

Figure 1. Nearest-neighbor correlation functions $C_{j,j+1}(nT)$ as a function of stroboscopic time T following the two two-tone Floquet protocols for a spins lattice of size L=10. b) Correlation $C_{5,6}(nT)$ function between central spins, whose maximum value reaches 0.9977 at t=5T.

Light shapes in nonlinear optics and linear algebra

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Light may be structured in intensity, phase and/or polarization. In this talk, I will present our recent research on structured light for rather opposite purposes. From a fundamental point of view, we use structured light beams to reveal the underlying physics of nonlinear conversion phenomena. In particular, we investigate the selection rules and polarization-controlled generation of optical modes in stimulated parametric down-conversion [1-3], and further demonstrate the identification of optical vortex topological charge by the modulation of light by light [4]. Then, from an application perspective, we show that structuring light can be a tool for data processing via the optical computation of linear algebra operations. We propose an optical scheme to solve a NP-hard problem reformulated in a matrix formalism [5], and an ongoing implementation of one-time-pad encryption of binary information contained in a modulated light beam. Through theoretical description and experimental validation, we advance the ever-growing number of technical and fundamental uses of structured light.

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Entanglement from which process indeterminacy

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Raman processes consist of an inelastic light scattering where an incoming photon is converted into an outgoing one with less (Stokes) or more (anti-Stokes) energy due to the creation or absorption of a vibrational quantum of the material.

Sometimes, both photon conversions take place simultaneously and a correlated Stokes- anti-Stokes (SaS) photon pair may be generated. Despite being explored for decades in the semi-classical intense fields regime, the intrinsic quantum aspects of SaS pairs have only gained momentum after being directly related to corrections of the extraction of temperature through SaS spectroscopy [1]. Time, spatial and polarization correlations were predicted and experimentally demonstrated in the last few years for different transparent materials [2-6]. However, many important open questions remained. Two of the most relevant ones concerned whether SaS pairs could be entangled in polarization and why the spectrum of SaS coincidence counts displayed an asymmetry, being severely suppressed for detections beyond the Raman resonance peaks.

In this work, we answer both questions and show that they originate from the same phenomenon. More specifically, we calculate theoretically and demonstrate experimentally that SaS pairs emitted by diamond can be entangled in polarization. More than that, we show that such entanglement originates from a “which process” indeterminacy, where the quantum interference of Raman scattering and electronic four wave mixing collaborate to form the entangled pairs. Furthermore, this very same interference also explains the rate of pair production as a function of the energy of the photons, finally solving a decade long open puzzle [7-8].

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Fast Femtosecond Pulse Measurements for Quantum Processes and Applications

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Ultrashort pulses are essential for quantum information processing in the long term due to their high power and coherence. With ultrashort pulses, quantum states can be easily manipulated and entanglement can be generated using nonlinear processes. Femtosecond quantum communication and processing based on quantum frequency combs is just one example. In general, ultrashort pulses will be used in quantum computing, quantum cryptography and quantum networks with secure communication protocols. Quantum processes such as tunnel ionization in the generation of high-order harmonics only work optimally with ultrashort pulses. Femtosecond pulses can also carry orbital angular momentum. Spin-orbit torque generated by femtosecond pulses can be used in optical tweezers for particle trapping. Devices such as broadband oscillators, amplifiers, OPAs and fiber compressors are often used for quantum applications. For this and for the quantum processes mentioned above, the temporal pulse shape and phase must be precisely defined and measured.

Femtosecond pulse measurement techniques are available as scanning versions and as single- shot versions, the latter not requiring mechanically moving parts [1,2]. Single-shot versions are robust, easy to adjust and require few components, which also reduces systematic measurement errors, and finally they are practical and therefore currently preferred over scanning versions. When comparing interferometric and non-interferometric methods, it should be noted that the latter do not require fringe analysis techniques. There are currently only two robust non-interferometric single-shot methods, namely frequency-resolved optical gating (FROG) and dispersion scan (d-scan) [3]. The latter is convenient because the pulses do not have to be synchronized to generate a delay axis. This means that single-shot d-scan is not alignment sensitive, which is also referred to as inline setup. This contribution presents a new single-shot d-scan variant with which not only short fs pulses (<60 fs) can be measured, but also long ones [4].

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Nonlinear squeezing generation based on multimode PDC and squeezing characterization via direct intensity measurement

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The rich potential of quantum modes of light in generating cluster states has been the subject of extensive study due to its promising applications in quantum computing and quantum information processing [1, 2]. To increase the number of generated modes, promising resources are multimode squeezed states, which allow accelerating the generation of cluster states [3]. However, for universal quantum computing, it is necessary to accompany the Gaussian large-scale quantum resources with non-Gaussian elements. At the same time, non-Gaussian resources and operations are quite challenging in quantum optics [4]. An example of such an operation is cubic nonlinearity [5], a low-order operation that produces a nonlinear transformation in the Heisenberg picture and can produce non-Gaussian states.

We present a method based on a multimode parametric down-conversion (PDC) process and quantum optical catalysis technique to generate quantum states that carry nonlinear squeezing. In such a system, a multimode PDC is seeded by multimode coherent light followed by detection in the idler channel. To maximize the nonlinear squeezing, a proper detection basis (shape of the local oscillator) should be chosen. Therefore, it is of great importance to know the mode structure of the multimode PDC. However, the existing methods of its characterization (homodyne detection, projective filtering) are technically complicated, and in the best case, deal with a single mode at a time. Therefore, we present a method [6] based on a cascaded system of nonlinear crystals to simultaneously measure squeezing in different spatial modes. In such a system, the second crystal serves as an amplifier/deamplifier for the squeezed light generated in the first crystal (squeezer), while the direct intensity measurement of light after the amplifier allows us to reconstruct its squeezing.

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Non-Markovian Collective Atom-Photon Interactions in Waveguide QED

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The interaction between a collection of atoms and light can be cooperatively modified via quantum correlations between the atoms. Such cooperative light-matter interaction can be understood as a constructive or destructive interference between the atomic dipoles and the emitted radiation, which manifests as an enhancement (superradiance) or suppression (subradiance) of the total spontaneous emission from the atomic ensemble. I will present an overview of collective atom-field interactions going from short interatomic separations to distances comparable to coherence length of the emitted photons, wherein the memory effects of the intermediary electromagnetic environment become pronounced. We demonstrate that such a system can exhibit surprisingly rich non-Markovian dynamics, with collective spontaneous emission rates exceeding those of Dicke superradiance ('superduperradiance'), formation of highly delocalized atom-photon bound states and spontaneous generation of emitter-emitter entanglement in the presence of delay. Our results are pertinent to analyzing retardation effects in quantum networks and distributed quantum information protocols based on long-distance emitters.

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Bures geodesics and quantum metrology

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We study the geodesics on the manifold of mixed quantum states for the Bures metric. It is shown that these geodesics correspond to physicalnon-Markovian evolutions of the system coupled to an ancilla. Furthermore, we argue that geodesic evolutions are of interest in quantum metrology. In fact, if the unknown parameter is a phase shift proportional to the time parametrizing the geodesic, the estimation error obtained by processing the data of measurements on the syste alone is equal to the smallest error that can be achieved from joint detections on the system and ancilla. This means that the ancilla does not carry any information about the parameter. The estimation error can saturate the Heisenberg bound. In addition, the measurement on the system bringing most information on the parameter is parameter-independent and can be determined in terms of the intersections of the geodesic with the boundary of quantum states.

Marcelo Terra Cunha

(tbu)

Quantum thermodynamics for general bipartite interacting autonomous systems

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The internal energy of individual subsystems is not well defined in interacting quantum systems, leading to ambiguities in the definition of thermodynamic quantities. Applying the Schmidt basis formalism to general bipartite autonomous quantum systems, we demonstrate that the master equation describing subsystem evolution adheres to the principle of minimal dissipation. This enables to define internal energy of each subsystem in a consistent way. Moreover, by utilizing general aspects of open quantum systems, we show that this master equation is unique. We analyze heat and work for each subsystem as derived from this formalism, providing deeper insights into the thermodynamics of interacting quantum systems.

Quantum optics for mid-infrared molecular nanophotonics

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Light-matter interaction between nanoscale infrared resonators and molecular modes appears as new devices for studying cavity quantum electrodynamics at room temperature. Infrared (IR) nanoantennas combined with tip nanoprobes can be manipulated to enhance nanometer spatial and femtosecond temporal resolution by coupling the vacuum field with molecular vibrations. However, the requirements to design accurate protocols for reaching the desired goal represent a challenge both theoretically and experimentally. To advance in the design of quantum nanophotonic devices in the mid-IR, we study different light-matter systems with Kerr nonlinearities driven by mid-IR femtosecond laser pulses. We propose alternative schemes to improve tip-design rules for the experimental manipulation of vibrational strong coupling and Fano interference effects in open infrared resonators [1]. In addition, we describe an approach to transfer the molecular anharmonicity to the infrared vacuum, which generates stationary power-dependent nonlinear shifts [2]. Our findings demonstrate the implementation of phase control in the weak coupling regime, in contrast with conventional cavity-QED schemes that require strong light-matter interaction. Our work paves the way to advance in the development of quantum platforms at the infrared regime and contributes to the design of future experimental implementations using current nanophotonic technology.

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Alfred U'Ren,

(tbu)

POSTER SESSION

Maritza Ahumada, Universidad de Santiago de Chile

Spin-wave control via Floquet engineering

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Periodic driving of quantum many-body systems can drastically change their properties, giving rise to exotic nonequilibrium states of matter with no static analogue. In this poster, we introduce a Floquet-engineered transverse field Ising model designed to control the one- dimensional propagation of spin waves. The proposed mechanism leverages high-frequency driving and characteristic parametric resonances in the spin-lattice. This approach provides a method for controlling spin-wave propagation and realizing a quantum switch. Our schemes have possible applications in quantum batteries, quantum thermal engines, and state transfer in quantum many-body systems.

All-in-Fiber Dynamically Reconfigurable Orbital Angular Momentum Mode Sorting

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Optical communications have proven to be the technology of choice for maximizing bandwidth and data processing speeds in modern telecommunications networks, enabling massive flows of information between users worldwide. Each year, this data volume continues to grow exponentially, and unfortunately, attacks on critical telecommunications infrastructure are becoming increasingly frequent.

Quantum communication, grounded in fundamental principles of natural science, has emerged as a promising solution to provide high-level security for these infrastructures. For instance, numerous government and industrial entities consider quantum communications to be a crucial layer for ensuring information security in the coming decades. However, integrating quantum technologies into current optical networks and industrial systems presents significant challenges: Many existing quantum optical systems rely on free-space optical devices or do not easily integrate with optical fiber networks, which limits the scalability and adaptability of the quantum systems in use.

In this work, we present an all-fiber optical platform capable of performing a wide range of tasks aimed at advancing the generation and detection of photonic states. Among its key features is the generation and detection of photonic quantum states carrying orbital angular momentum. The platform can also be configured to generate random numbers based on quantum mechanical measurements, a central component for future information technologies.

Our approach utilizes cutting-edge space-division multiplexing (SDM) technologies, such as few-mode fibers and photonic lanterns. It is scalable to high dimensions, operates in the 1550 nm telecommunications band, and uses only commercially available components. We offer a viable alternative that ensures compatibility between current optical networks and future quantum communication technologies.

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Photophysics of a Single Quantum Emitter Based on Vanadium Phthalocyanine Molecules

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Single quantum emitters are crucial for advancing quantum technologies, including quantum repeaters and quantum information processing. The ability to isolate individual molecules with stable optical properties at room temperature is key for these applications. Vanadium-oxide phthalocyanine (VOPc) molecules have emerged as promising candidates due to their long coherence times, previously measured at the ensemble level [1], a detectable EPR signal[2] and has shown to couple to microwave photons [3].

In this work [4], we study the optical properties of isolated VOPc molecules, enabling the determination of its lifetime under two different detectors, resulting in approximately 1.27 and 0.8 nanoseconds. Our findings reveal that the optical properties of the molecule remain stable under controlled laser illumination matching a pyramidal C4v symmetry and, additionally, the equipment's highly precise instrument response function (90 picosecond resolution) allowed us to observe previously unreported anomalies in the molecule's lifetime, consisting of a series of oscillations and a plateau behavior on the aforementioned. These results highlight the potential of single VOPc molecules to act as quantum emitters, with robust stability and measurable intrinsic properties at room temperature.

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Role of Quantum Coherence in Counterdiabatic drivings

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The Adiabatic Quantum Computing (AQC) [1] is a promising candidate for solving mathematical and physical problems encoded in a many-body system Hamiltonian, such as QUBO problems, through the adiabatic evolution of a Hamiltonian from an initial state to a final one that encodes the solution of the problem. However, slow evolution is necessary to ensure high fidelity in the solution, which makes it difficult to implement on current noisy devices. To circumvent this problem, the use of counterdiabatic (CD) protocols to speed up adiabatic evolution has been proposed in recent years [2], presenting a promising paradigm for quantum computing and quantum technologies in general. In this work, we calculate the quantum coherence generated during an adiabatic evolution with different CD terms. Specifically, we consider QUBO Hamiltonians, p-local Hamiltonians, and non-stochastic Hamiltonians. We explore quantum coherence production across different regimes: the impulse regime (short evolution time), the middle regime, and the adiabatic regime (long evolution time), demonstrating how each regime is characterized by a different hierarchy of CD terms [3]. This work paves the way for a better understanding of CD terms and how various quantum resources are produced and consumed during an adiabatic evolution enhanced by counterdiabatic approximations

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Generating MUBs via Photonic Chips - Multiport Beam Splitter based on Silicon Nitride for 3 and 4 dimensions

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This project looks toward the generation of Mutually Unbiased Bases (MUBs) in photonic chips through the combination of Mach Zehnder's interferometers and phase controllers aiming to implement experimentally quantum information protocols based on qudits (d-level quantum system). We will use multiport beam splitters to perform unitary operations necessary to implement the protocols. Even though they do not allow us a universal gate, they can be used to implement the operations needed only with phase control. The design will be based on silicon nitride ($Si3N4$) wave-guides and silicon dioxide ($SiO2$) cladding at the wavelength of interest 795 nm, close to Alkali atom lines.

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A review of the weak value amplification effect

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The concept of the weak value of an observable was introduced by Aharanov, Albert, and Vaidman in 1988 [1]. In general, weak values are complex numbers that appear when the outcomes of independent repetitions of an experiment are averaged. For weak values to emerge, experiments should include three key ingredients: initial system state preparation, weak measurements (that is, weak interactions between the measurement apparatus and the measured system), and final state post-selection, which is a probabilistic process that selects a final system state. In this statistical sense, weak values are analogous to expectation values. However, they may be complex quantities or lie outside the eigenvalue range of the observable being measured, in which case the weak values are said to be anomalous. In such situations, the effect of the measured system on the measurement apparatus is amplified, a phenomenon often referred to as weak value amplification. This amplification arises from the post-selection of a final state, which comes at the cost of losing data when post-selection fails. Indeed, there is a trade-off between amplification and data retention.

Weak values have found applications in various areas. On the one hand, they have inspired a technique for measuring a quantum state (called weak state tomography), which has been compared to conventional state tomography [2]. From a more fundamental perspective, weak values have been useful for analyzing quantum experiments that lead to paradoxes when analyzed in a counterfactual manner [3]. On the other hand, the weak value amplification effect has been used in precision metrology for the estimation of small effects such as beam deflections or phase shifts, among many others, allowing, for example, the measurement of beam displacements on the order of angstroms [4]. In this poster [5], we will describe the weak value amplification effect, with an emphasis on its application and progress in the field of precision metrology under different noise scenarios.

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A 2D Bose gas to study quantum hydrodynamic instabilities

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Hydrodynamic instabilities in classical fluids, often characterized by the exponential growth of a well-defined pattern, are encountered in many mundane situations. Increasing our understanding of the underlying mechanisms of such instabilities has a strong impact in modeling fluids dynamics in a broad scenario and in fundamental problems such as the transition from laminar to turbulent flow. In the context of quantum fluids, quantum hydrodynamic instabilities (QHI) are related to the superfluid properties of these systems offering a new approach when studying superfluidity [1,2]. Thanks to their high degree of control and simple detection techniques, ultracold atomic gases are ideal platforms to engender and observe such QHI. In this work, we present the current status of the construction of a new experimental setup capable to address the specific conditions for the onset of different hydrodynamic instabilities in a 2D Bose gas.

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Optimizing Data Transfer Rates in Free-Space Optical Communication through Squeezed States

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Free-space optical communication (FSOC) is a promising method for improving data transmission over long distances. Nevertheless, its potency is diminished due to atmospheric turbulence which leads to, among other things, a change in the refractive index of the transmittance´s medium, and therefore, adds a not negligible amount of scattering, noise and degradation. In order to address these challenges, this research explores the use of bright two- mode squeezed state (bTMSS) as a method to enhance data transfer rates within FSOC systems. By using binary Pulse Position Modulation (PPM) [1] and On-Off Keying for encoding information, this work aims to leverage the quantum properties of bTMSS to achieve an improvement in the signal-to-noise ratio (SNR). This enhancement is primarily attributed to the reduction of quantum noise in specific quadratures, which is expected to lead not only to a more efficient data transmission but also enhance the security of the communication, making a more resilient FSOC system. The main objective of this study is to demonstrate that, under certain conditions, the use of bTMSS can lead to an improvement in the data transfer performance in optical communication systems. This research also intended to serve as a foundation for eventual developments of the next generation of FSOC networks.

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Synchronizing Quantum Computers using Crosscorrelation Fidelity Estimation

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We introduce a method to iteratively approach the quantum state of one quantum computer to the state of another, which we call “synchronizing”. We use the gradient-free optimization procedure over the complex variable domain introduced in [2], in order to optimize the fidelity between the first system and the second system (or subsystems of the two quantum computers). This fidelity can be calculated using only local measurements in randomized product bases communicated classically between computers [1]. We show that the fidelity is bounded by the precision induced by the number of unitaries and measurements used at each step to estimate it.

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In-line polarization controller in multi-core fiber

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Polarization control is essential in the fields of fiber optic communication and fiber optic sensors. One of the elements that allows this control is the fiber squeezer, or in-line polarizer. While their effects on polarization have been studied in various types of fibers, such as single-mode fibers [1] and hollow-core photonic bandgap fibers [2], their influence on multi-core fibers has not yet been studied. We characterize the unitary operation performed by the in- line polarization controller (IPC) on each core of a multi-core fiber.

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Investigating Temperature Effects on Phase Quadrature Noise. on Integrated X^3 - Based Optical Parametric Oscillators

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This research explores the impact of temperature on phase quadrature noise in a microchip-based optical parametric oscillator (OPO). By examining how phase quadrature noise varies with temperature, the study aims to enhance the OPO's performance for applications like generating entangled light.

Recent advancements in silicon chip technology have facilitated the generation of squeezed light states and enabled quantum protocols such as boson sampling [1]. On-chip χ(3) platforms are capable of producing squeezed states in both single-mode [2–4] and two-mode [5, 6] configurations. In earlier research [7], we achieved 2.30(3) dB of squeezing in the amplitude difference quadrature of a two-mode state generated by a silicon-nitride OPO chip. However, excess noise in the phase sum quadrature hindered the observation of entanglement.

We investigated how phase quadrature noise in a χ(3)-based OPO varies with the OPO's temperature. Using integrated microheaters, we precisely adjusted the cavity resonance to match the pump frequency, altering the microring's size and refractive index via the thermo-optic effect. This method allows the micro-resonator to maintain a resonant optical path for each temperature, determined by the pump wavelength. A locking system was em- ployed to drive the heater into resonance, enabling temperature selection for examining its impact on the phase quadrature under resonant conditions using a tunable pump laser.

The measurement setup (see Figure 1-(a)) uses a tunable diode laser in a Littrow configuration, amplified by an Erbium-Doped-Fiber-Amplifier (EDFA). The pump light is meticulously filtered to minimize amplitude and phase noise before being coupled to the chip through a tapered fiber. On the chip, a high-Q silicon-nitride microresonator OPO ($Q \approx 1 \times 106$) is maintained at the desired temperature using a Ditter-Locking system, ensuring alignment with the pump field resonance. The wavelength of the transmitted field is analyzed using an Optical Spectrum Analyzer (OSA), while quadrature noise in both phase and amplitude is measured via a Resonant Assisted Homodine Detection scheme.

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Role of seeding in the generation of polarization squeezed light by atomic Kerr medium

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Quantum state production and characterization are fundamental elements for many quantum technological applications. In this paper, we studied the generation of polarization quantum states by interacting light with a Kerr medium and the dependency of the outcome on orthogonal polarization seeding. Starting from coherent states produced by Ti:Sapphire laser, interaction with a 87Rb warm vapor cell led to noise compression of −5.2 ± 0.5 dB (6.4 ± 0.6 dB after correction of the detection quantum efficiency). Experimental characterization of the effect of an orthogonal polarization light seed on squeezing is shown to agree with the theoretical model.

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One-time-pad protocol using polarization-based optical processing

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This work presents an implementation of the One-Time Pad cryptographic protocol using an optical processor based on encoding information in light polarization to intensity [1]. We exploit the properties of polarization and spatial light modulators (SLMs) to perform the One-Time Pad protocol. The XOR operation, fundamental to this protocol, is achieved through an SLM that alters the polarization of light from diagonal to anti-diagonal, corresponding to bits 0 and 1, respectively.

The system utilizes a pair of SLMs: the first encodes the message in the transverse profile of the light, and the second contains the random key, determining whether the light's polarization remains unchanged (encoding a 0) or is inverted (encoding a 1). This process effectively executes the XOR operation between the message and the key, ensuring that the encrypted message is entirely secure. As the One-Time Pad protocol guarantees, the encryption is theoretically unbreakable when paired with a truly random, single-use key. The process can be repeated by re-encoding the encrypted message in the first SLM and the key in the second.

After the polarization-based XOR operation, the result is visualized through light intensity using a projection system involving a half-wave plate and a polarizing beam splitter (PBS). This setup translates the encoded polarization into an intensity pattern that can be measured, revealing the encrypted message or its XOR combination with the key.

Our experiments demonstrate that this optical method guarantees secure communication and significantly improves processing speed and parallelization compared to traditional electronic techniques. We discuss the system's efficiency in distributing and applying keys using light polarization and assess its robustness against potential attacks. The findings suggest that optical processing offers a promising solution for implementing high-security encryption, particularly for high-speed communication networks.

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Multipartite entanglement via pulses in quantum computers

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Efficient qubit control is crucial for quantum computing and its applications. In particular, preparation of highly entangled states in the smallest possible time represents a major challenge in currently existing quantum devices [1]. A possible way to achieve such a fine tuning control of quantum correlations in multi-qubit systems is by considering a series of electromagnetic pulses [2] instead of using predefined gates. In this work, we certify the preparation of genuine multipartite entangled quantum states by applying local and bipartite pulses to three and four qubit systems. Our results are tested on quantum computers provided by IBM.

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Variational Quantum Eigensolver in Quantum Chemistry Applications

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With the emergence of new technologies, quantum computing opens up a new World of possibilities, capable of tackling computationally complex problems, such as optimization [1], cryptography [2] and molecular simulations [3]. One of the current challenges is the noise and intermediate scale of quantum computers in the NISQ era, where errors from quantum phenomena hinder many algorithms from reaching their full potential. A way to harness the power of current quantum computers is through the Variational Quantum Eigensolver [4], a quantum-classical algorithm able to compute the minimum energy of the electronic structure for molecules. By mapping fermionic systems to qubits, we use this algorithm to obtain the equilibrium energy and the geometric configuration of diatomic molecules such as H_2H2, LiH, and HF, and for the triatomic molecules H_2OH2O and O_3. A further study includes the simulation of isomerization reactions for the C_4H_8 C4H8 molecule.

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Twist Conservation of Partially Coherent Beams in Nonlinear Optical Three-Wave Mixing Process

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Partial coherence beams have gained notoriety in optical research due to some advantages over fully coherent beams under turbulence [1]. Furthermore, this class of beams has been studied in parametric down-conversion in order to explore both the advantages of the process and the partial coherence [2,3]. Here, we perform an experimental investigation about the conservation of twist phase when Twisted Gaussian Schell Model (TGSM) beams interact in both up and down conversion three wave mixing nonlinear processes. TGSM beams are generated independently and prepared with several different twist parameters. They are used for pumping and seeding the nonlinear interactions and the beams generated in the processes are analyzed in order to determine their twists. Our results show that the up and down converted beams have twists that depend on the twists of the pumping and seeding beams. They also indicate that the twist phase is conserved in the process, in qualitative agreement with the theoretical predictions. This research is motivated by the growing potential applications for TGSM beams.

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Quantum switch with continuous control

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Quantum mechanics allows for the application of two quantum operations in a superposition of orders, coherently controlled by an ancillary system. This transformation, known as the "quantum switch" [1], is an example of a causally nonseparable process. The quantum switch has been proposed also as a way to study the interface between quantum mechanics and gravity. For example, an indefinite causal structure could arise from the superposition of two different geometries associated to a massive body prepared in a superposition of two distinct states [2]. However, the state of a physical system is usually described by a wave function whose domain is continuous. Hence, a more realistic scenario should consider a causal structure controlled by an infinite-dimensional quantum system. In this work we revisit the quantum switch and introduce a new definition of it, allowing for a continuous control. Then, we provide a study case built on a periodic Hamiltonian and a cyclic control of the time ordering operator. Finally, we propose a photonic simulation of this process. Although we do not apply our definition to a gravitational scenario, our proposal could inspire new research on the superposition of causal structures.

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Quantum advantage in spoofing detection using non classical light

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We have proposed the following scenario based on the protocol described in reference [1]. The transmitter randomly chooses between two quantum states, $|\alpha\rangle$ or $|\beta\rangle$, with equal probability. It then emits the state encoded in an electromagnetic signal. Afterward, the signal reflects off the target and is directed to the receiver, who knows the quantum state chosen by the transmitter. Upon arrival, the receiver can obtain information about the target, such as its position and velocity, through the time of arrival or the Doppler effect, among other properties. However, there is a possibility that the target might perform spoofing by emitting a false signal that alters the information. The only way for the receiver to determine if the information has been falsified is by analyzing whether the encoded state has been perturbed.

We derive an upper bound for spoofing detection when two quantum states are randomly encoded in an electromagnetic signal and demonstrate that it can be achieved using coherent states. We also analyze how encoding squeezed states in the signal affects the detection probability and examine the implications when the spoofer's capability is limited solely to generating coherent states [2].

Our analysis shows that the quantum advantage in spoofing detection is independent of the number of photons, eliminating the need for low-photon constraints in experimental demonstrations. We optimize the probability of discrimination between two arbitrary states and identify the optimal states that saturate the success bound for spoofing detection. Furthermore, when squeezed states are encoded, the detection probability approaches 100% if the spoofer can only generate coherent states.

Finally, we conclude that a significant quantum improvement in spoofing detection is achievable using both coherent and squeezed states, surpassing classical limits. We highlight its potential in practical applications where quantum security is crucial.

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Pseudospectral method for solving PDEs using Matrix Product States

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This research focuses on solving time-dependent partial differential equations (PDEs), in particular the time-dependent Schrödinger equation, using matrix product states (MPS) [1]. We propose an extension of Hermite Distributed Approximating Functionals (HDAF) [2] to MPS, a highly accurate pseudospectral method for approximating functions of derivatives. Integrating HDAF into an MPS finite precision algebra, we test four types of quantum inspired algorithms for time evolution: explicit Runge-Kutta methods, Crank-Nicolson method, explicitly restarted Arnoli iteration and split-step. The benchmark problem is the expansion of a particle in a quantum quench, characterized by a rapid increase in space requirements, where HDAF surpasses traditional finite difference methods in accuracy with a comparable cost. Moreover, the efficient HDAF approximation to the free propagator avoids the need for Fourier transforms in split-step methods, significantly enhancing their performance with an improved balance in cost and accuracy.
Both approaches exhibit similar error scaling and run times compared to FFT vector methods; however, MPS offer an exponential advantage in memory, overcoming vector limitations to enable larger discretizations and expansions. Finally, the MPS HDAF split-step method successfully reproduces the physical behavior of a particle expansion in adouble-well potential, demonstrating viability for actual research scenarios [3].

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Quantum state tomography beyond ten qubits

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Resources required to reconstruct the global state of a quantum computer typically scale exponentially with the number of involved qubits, namely number of quantum circuits, number non-local gates and postprocessing time. Despite many quantum state tomography protocols are known, see e.g. [1-5], none of them optimize all the above mentioned aspects, as far as we know. In this work, we provide a tomographic method that considers 2n + 1 quantum circuits for n-qubit systems, each of them composed by a single Pauli gate in each qubit, in the measurement stage. As further advantages, we provide an explicit reconstruction formula, whereas postprocessing is not required to estimate a valid quantum state. This protocol has been tested on IBM quantum computers obtaining high fidelities for genuinely entangled states up to 12 qubits. These results push forward the boundaries of state tomography in quantum computers beyond 10 qubits in the NISQ era [6].

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High-Resolution Magnetic Resonance Imaging using Magnetic Force Microscopy and NV centers in Diamond

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Nitrogen-vacancy (NV) centers in diamond are renowned for their exceptional quantum sensing capabilities, making them valuable in fields such as metrology and life sciences. In this work, we demonstrate the use of shallow NV centers as quantum sensors for nanoscale nuclear magnetic resonance (nano-NMR) applications [1].

We can selectively target and detect signals from specific nuclear spins by applying magnetic field gradients, resulting in distinct spin resonance frequencies. This capability is further enhanced by employing magnetic force microscopy (MFM) with cobalt-coated scanning probes [2, 3], which generate a spatially varying magnetic field gradient. This approach allows for high-resolution detection of nuclear spins, even within dense spin samples.

Our technique provides a novel approach to achieving high-resolution nano-NMR and nanoscale magnetic resonance imaging (nano-MRI) using NV centers. This advancement holds significant potential for applications in materials science, biomedical imaging, and quantum information processing.

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Scalable Quantum Dynamics Simulation Using Machine Learning

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Simulating the time evolution of quantum systems remains a critical challenge in the field of quantum information, especially for complex Hamiltonians. Traditional methods often face computational limitations, particularly as system size grows. In this work, we introduce a machine learning-based model designed to efficiently simulate the dynamics of a small quantum system composed of two qubits, governed by a specific Hamiltonian. Given an initial quantum state, the model predicts its evolution at a desired time t.

Our approach involves an encoder that maps the input state to a latent space, capturing key features of the system. A scalar parameter is then introduced in this latent space to guide the model for the correct construction of the output state at time t. Architectures based on Convolutional layers, used commonly for image-to-image reconstruction [1], give us good results in terms of Fidelities between model and theoretical predictions. The incorporation of the scalar parameter is included in the latent space that, the input density matrix, is reduced after the action of an encoder.

The goal of this the methodology is to demonstrate the adaptability of machine learning models for quantum simulations, like [2] where an autoencoder is used to solve the marginal problem. With deeper architectures, this approach can be scaled to larger systems, highlighting the potential of machine learning as a powerful tool for constructing scalable quantum simulations.

The significance of this work is underscored by recent achievements in the field; this year's Nobel Prizes in Physics and Chemistry were awarded for research intrinsically related to the use of neural networks. This recognition underscores the growing importance of machine learning, especially as an adaptive tool capable of supporting diverse scenarios by reducing costs and solving complex problems.

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Transport of squeezed light mediated by topological domain walls in a SSH photonic lattice

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In this work [1] we present a study of a photonic waveguide model featuring topological walls. By bending one waveguide in the array, which is the one where the domain wall is present, it is possible to guide light across the lattice (see Figure 1c) with a high transmission. Remarkably, the topology of the system is crucial for this phenomenology since a trivial domain wall cannot achieve the same behavior (see Figure 1d,e). We used this system to propagate non classical states, like squeezed light and we characterized the dynamics of this system. Interestingly, we found that when two domain walls interact, this interaction can be seen as an effective two port beam splitter for quantum light.

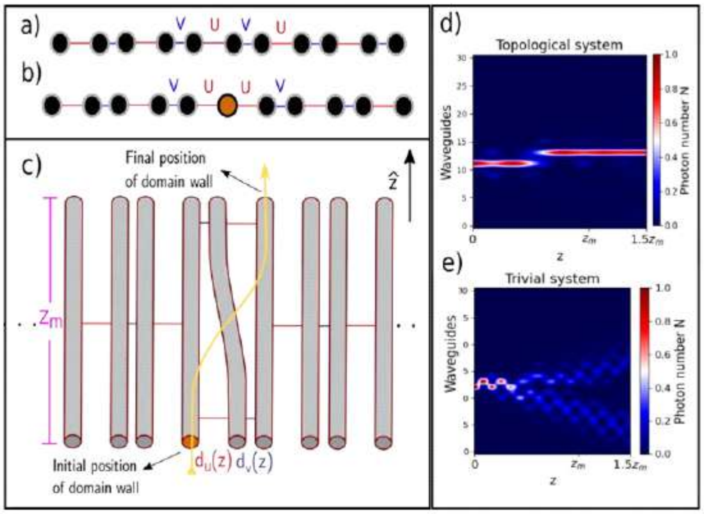

Figure 1. a) scheme of a SSH array. b) scheme of a SSH array with a domain wall. c scheme of a domain wall and its transport across the lattice. d) and e) numerical simulation of the dynamics for the topological and trivial case, respectively.

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Characterization of non-Gaussian coherent states: Intensity-Field correlation function and Entanglement Criteria

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Generalized coherent states (GCS) are generated through the nonlinear interaction between a coherent state and a medium [1]. These states retain key properties of coherent states, such as Poissonian photonic statistics and coherence as defined by the correlations functions $g^{(n)}$ at all n orders. However, unlike traditional coherent states, GCS exhibit distinct quantum behavior in phase space, as evidenced by negative values in their Wigner representation. While this characteristic enhances their potential for different application (like quantum metrology), it also presents challenges in directly identifying their quantum properties through correlation functions alone.
To overcome this limitation, we propose using a quantum/classical criterion based on the intensity-field correlation function $g^{(3/2)}$ to check if the GCS states break the classical inequalities associated with this function [2], which sets a classical bound and provides a more comprehensive approach to identifying quantum behavior in GCS. Furthermore, we investigate the entanglement [3] properties of GCS—absent in regular coherent states—by applying entanglement criteria such as von Neumann [4] and Shannon entropies [5] after the states pass through a beam splitter. Preliminary results indicate that these criteria offer a robust method for determining whether a state exhibits quantum characteristics, even when these cannot be discerned solely through standard correlation functions.

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One-dimensional Bose Polarons across harmonically confined optical lattices

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The progress in realising ultracold atomic mixtures has greatly revitalised the interest in studying impurities immersed in quantum mediums [1]. Amongst them, Bose polarons, i.e. impurities immersed in bosonic baths, have attracted increased attention since their experimental realisation in 2016 [2, 3]. Following these developments, and motivated by the possibility of trapping ultracold atoms in optical lattices [4], the theoretical study of impurities in lattice configurations has emerged as a new platform for studying polaron physics. In this direction, in the past few years, different studies of lattice Bose polarons have revealed intriguing features across the superfluid-to-Mott insulator transition [5-7].

In this work, we study an impurity interacting with a bosonic bath and immersed in a harmonically confined optical lattice. The harmonic confinement enables us to model a realistic scenario and study polaron physics across superfluid and Mott domains. We consider a one-dimensional configuration and study the system theoretically with DMRG simulations for a large number of particles. We reveal that baths with Mott domains produce an enlargement of the polaron cloud and the onset of a sudden orthogonality catastrophe of the polaron quasiparticle.

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Testing alternative space-time metric theories using Quantum state discrimination

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This project aims to explore the possibility of distinguishing between space-time metric theories in terms of the post-Newtonian parameters (PPN) [1], through quantum state discrimination techniques [2], and therefore constitutes an instance of hypothesis testing. To determine the most suitable hypothesis—that is, which alternative theory is correct—an experiment is proposed. To perform this task, we employ massive particles with internal degrees of freedom that act as quantum clocks [3], and use Wigner polarization rotation in the case of photons [4]. Both quantum resources enable the distinction between several PPN theories using unambiguous state discrimination among other discrimination strategies.

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Intra-cavity laser-assisted solar-energy conversion

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The conversion of solar energy into electrical energy is a crucial point in the quest for sustainable environmental solutions and our research presents an innovative method that utilizes laser light amplification to optimize the solar energy conversion process [1]. This involves modeling the effects of introducing a photovoltaic cell(PVC) or a thermoelectric cell within the optical cavity of a laser generated by sunlight, as itis shown in Fig. 1. Although these converters have low efficiency (around 5%), their environmentally friendly production processes make them highly sustainable.

The process involves concentrating sunlight in the optical cavity of a laser, which is then generated in an active medium, such as Nd:Cr:YAG. A key aspect of the study is the collection of laser light through a converter, enhancing net efficiency due to the quantum amplification of light. By analyzing the laser dynamics and applying the laser rate equationsfor a four-level gain medium, we calculate the overall power-conversion efficiency. Our findings demonstrate a significant net efficiency of 45% in converting solar energy to electricity, as is shown in Fig. 2, comparable to commercial silicon cells.

It is demonstrated that this technology has the potential to achieve the same efficiency usingmore sustainable processes. The combination of advanced optics and fundamental laser theory shown the great potential of optics in developing innovative solutions to the critical issues faced by today's society.

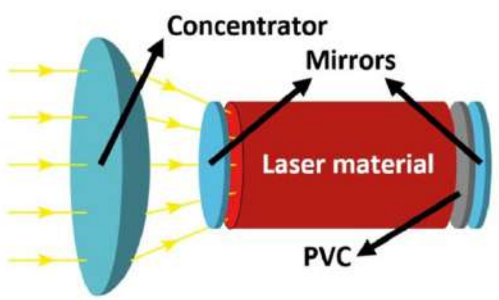

Figure 1. Representation of the proposed system, where a PVC is included between the mirrors.

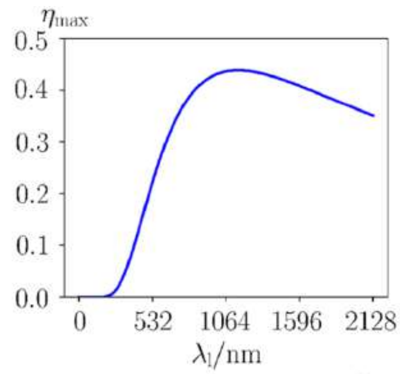

Figure 2. Maximum achievable efficiency is shown as a function of the laser wavelength [1].

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Torus bifurcation of a dissipative time crystal

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In driven non-linear systems, various kinds of bifurcations can be observed. From the evolution of Floquet multipliers one can extract information which serves as a precursor for phase transitions and dynamical instabilities. This method is applied in classical non-linear physics, for example, to obtain early warning signals. Utilising the control over an atom-cavity platform, we are able to prepare our system in various dynamical regimes and study the bifurcation experimentally in a quantum gas to obtain insights that could potentially be applied to more complex systems. We prepare a Bose-Einstein condensate inside the centre of a cavity and pumping it perpendicular to the cavity axis with a standing wave light field. Upon crossing a critical pump strength, we observe a pitchfork phase transition from a normal to a steady state self-organized phase [1]. Employing an open three- level Dicke model, this transition can be understood as a transition between two fixpoints, indicating a pitchfork bifurcation. If the pump strength is increased further, the system undergoes a Hopf bifurcation. This causes limit cycles, which have time crystalline properties, to emerge [2]. In this regime, our model no longer shows fixpoints but stable attractive periodic orbits [3]. For strong pumping, we observe a second bifurcation, in our case a Neimark-Sacker bifurcation. Its main characteristics is an oscillation with two incommensurate frequencies and using the language of many-body physics, this may indicate the formation of a continuous time quasicrystal. In contrast to the limit cycle regime, the system is not confined on a loop in phase-space but samples a torus [4]. Finally, in the regime of very strong pumping, we observe chaotic dynamics with many contributing frequencies.

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Displacement sensing with stabilized GKP states

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We theoretically show how, in the estimation of isotropic displacements [1], single-mode stabilized GKP states [2] can be used to surpass the gaussian limits of sensing [3]. This is the case even when the gaussian approach is allowed to use an infinite number of photons. Concretely, we show how the quantum-error-correction stabilization protocol implemented in Refs. [4, 5] can be adapted to sense weak displacements. Importantly, at all times during the metrology protocol the photon number is bounded, improving over a previous proposal [1] using GKP states to beat the Heisenberg limit of sensing at the cost of an exponential increase in the photon number with time. In summary, our protocol beats the gaussian limits of sensing, is robust against noise sources, and can be implemented in current architectures.

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Relaxation of nitrogen-vacancy centers in diamond with modified environmental charge configuration for quantum metrology

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Diamond nitrogen-vacancy (NV) centers have been the object of various studies in the last few years due to their unique properties that make them promising for applications related to quantum metrology and quantum computation. This defect can be found in three different charge states: negatively charged (NV^-), neutrally charged (NV^0), and positively charged (NV^+), of which the former is usually utilized for metrology applications. The main defining characteristics of NV centers are their long coherence times and an easily readable and optically preparable spin state, suitable for temperature and magnetic and electric fields sensing [1]. Nevertheless, implementation of sensor technologies based on NV centers is usually limited due to the need for the defect to be near the diamond surface and therefore being prone to a reduction of relaxation times due to an increasing number of interactions with surface impurities of various kinds, including other NV defects. An arising question is then whether it is possible to increase the relaxation time of NV centers by direct manipulation of the surrounding environment.

For this purpose, we propose an experimental approach based on the implementation of a confocal setup and lasers of different wavelengths (532 nm, 594 nm, and 633 nm) to modify and read the charge state of NV centers surrounding a singular NV. The charge state of surrounding NV centers can be modified by a series of laser pulses and an optical vortex (used to isolate a particular defect) to exploit the ionization and recombination processes related to the energy structure of the defect, allowing the creation of both negatively and neutrally charged environments with 532 nm and 633 nm pulses, respectively, while the charge state readout is carried out by 594 nm pulses that do not dramatically affect the charge state of defects [2,3].

It is expected that given the total spin number of neutrally and negatively charged NV's (S=1/2 and S=1 respectively), an increase in relaxation times compared to the natural environmental state would be observed for a neutrally charged environment given a reduction in hyperfine interaction between the sensing NV spin and the surrounding environment, while a reduction of this time would be observable for a mainly negative environment. For this reason, studying the impact of the surrounding environment on the coherence dynamics of NV centers could be a gateway to improve the main limiting factors in future implementation of technologies based on this defect.

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New spectral entanglement asymmetry in optical parametric amplification by hot alkali atoms

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In order to fully harness quantum correlations into quantum communication and quantum processing applications [1], a complete state reconstruction of the quantum state is desired. Quantum correlated sources in the continuous variable domain (CV), offer different configurations which open broad set of applications. For instance, optical parametric oscillators (OPOs) below or above threshold can be used to generate squeezed states and entangled state.
For most of these systems the spectral quantum state reconstruction is done by either direct intensity measurement or homodyne detection. Such kind of detection is sufficient for complete tomography of light sources with symmetric emission spectra, in which the upper and lower sideband modes around the carrier frequency present energy balance. Nevertheless, the photocurrent spectrum cannot discriminate the contribution of upper and lower sidebands in general, leading to an incomplete information of the state. Thus, the state can only be reconstructed, by manipulating these sidebands prior to detection [2].

In this work we present the interesting case where entanglement involving the standard combination of sidebands is not observed, but the detailed analysis of their sidebands structure present entanglement. This work open ups the possibility for optimization of quantum resources when performing a detailed quantum operation involving specific modes. In order to demonstrate that case, we study the entanglement produced by a four wave mixing (4WM) process in an isotopically selected ^{85}Rb vapor cell [3]. The full state tomography of individually addressed frequency modes associated to each beam is done by using the dispersive response of an auxiliary resonator [2], achieving the complete reconstruction of the two-beam covariance matrix. Due to the spectral narrow bandwidth of the 4WM process, we are able to measure the asymmetry of entanglement in a 4WM system, demonstrating a hidden entanglement that can not be observed in solid state systems or chips.
We support our experimental observations through a theoretical model based in the microscopical description of 4 level system proposed in ref. [4]. Our theoretical model describes the correlations in the twins beams of the 4WM process, predicting to some degree the asymmetry of the quantum correlations between the pair of sidebands.

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Resonance of Vector Vortex Beams in a triangular Optical Cavity

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Vector Vortex Beams (VVB) have an inhomogeneous distribution of polarization in their transverse profile. They have been explored in several applications, such as imaging, optical traps, communication protocols (classical and quantum) and even the use in non-linear optics. In [1], we show that triangular cavities can also be used to analyze and discriminate vector vortex beams.

In cavities with an odd number of mirrors, in addition to the Gouy phase accumulated in every round trip, modes that present horizontal antisymmetry acquire an extra π phase compared to those displaying horizontal symmetry, due to the odd number of reflections. For polarization, a similar phenomenon occurs: horizontally polarized modes gain an extra π phase compared to the horizontally polarized ones. Therefore, describing VVBs as linear combinations of Hermite-Gaussian modes with different polarizations allows us to analyze how VVBs behave in a triangular optical cavity.

For the two first-order VVBs, radial and azimuthal modes, we have experimentally demonstrated that resonance is reached for separate cavity lengths, suggesting that such cavity may be used as a VVB mode sorter. We have tested this by sending a mode of spiral polarization to the cavity and observing one resonance peak for each VVB it is composed of: radial and azimuthal modes. Additionally, we are building a Mach-Zehnder interferometer with an extra mirror to also use as a mode sorter, according to the same principle explained here. Our intuition is to compare these two methods.

The cavity and the Mach-Zehnder interferometer use mirrors with piezoelectric material to scan their lengths. For them to act as legitimate mode sorter, their lengths must be fixed at a resonance peak, so that one mode is transmitted and the other is reflected. Since these systems lack stability, our group developed an electronic circuit capable of locking the interferometers fixed at constructive interference.

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Exploring entanglement dynamics in an optomechanical cavity with a type-V qutrit and quantized two-mode field

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The main objective of this work is to measure the degree of interaction of a type-V qutrit with a two-mode quantized field in an optomechanical cavity [1]. We first deduce the Hamiltonian in the interaction picture to identify the oscillatory terms and then obtain the effective Hamiltonian analytically. By selecting initial conditions for the atom, the two-mode field, and the moving mirror, we can determine the state vector of the entire system through a first-order approximation of the effective Hamiltonian. With this information, we proceed to solve the Schrödinger equation, generating a coupled set of differential equations that is solved numerically based on the initial conditions. The atomic von Neumann entropy allows us to obtain the temporal evolution of the degree of entanglement of the qutrit in the cavity and the atomic population inversion. The results indicate that entanglement in this tripartite system, composed of the qutrit and the mirror-field subsystems, as well as the population inversion, can be manipulated by the initial state conditions of the system, the qutrit-field and mirror-field coupling coefficients, the pump field, and the dissipation rates of the two-mode field and the movable mirror, respectively.

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Frequency Multimode State Generation Via Four-Wave Mixing in Hot Alkali Atoms

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Parametric processes, such as those occurring in optical parametric oscillators (OPOs) and optical parametric amplifiers (OPAs), are well-established for their ability to produce non-classical states of light through interaction with non-linear materials. These processes are crucial for the development of quantum technologies, including quantum computing, where properties like entanglement play a key role. To implement a quantum network capable of processing and sharing information, it is necessary to generate a significant number of entangled modes, with atoms acting as nodes and entanglement as the communication channels [1].

In order to create a network of multimode entangled states, also referred to as cluster states, different groups presented proposals for their generation. Examples are Olivier Pfister's group that used an OPO based on PPKTP crystal to generate 15 entangled modes [2], and that of Laboratorio Kastler Brossel that used an OPO with synchronized short-pulse laser pumping [3]. More recently, the group of Jietai Jing has used hot alkali atoms to produce spatial multimode states [4]. They produce this state using two pumps with the same wavelength and an angle between them. All the different states obtained in these experiments present their advantages and disadvantages.

Our proposal aims to generate, instead of spatial, a frequency multimode state through the four-wave mixing (FWM) process. In order to produce such a state, we employ two superposed pump fields with a relative frequency of the order of MHz that interact with rubidium 85 atoms in an OPA. Now, in the multimode FWM process we can have the annihilation of two photons from the first pump, or two from the second or even one from each. This leads to a cascade that can create different frequencies photons for the probe and conjugate.

With this configuration we are able to generate and characterize a frequency multimode state with tunable frequency separation between the modes in the probe and conjugate beams. This work paves the way to characterize the quantum correlations among the generated frequency modes and study the multimode properties to determine whether it is a cluster state for developing a quantum network.

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Optimal qubit selection for error mitigation in quantum computers

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Currently existing quantum computers belong to the so-called Noisy Intermediate Scale Quantum (NISQ) Era [5]. This generation of computers is good enough to star solving problems in areas like molecular optimization [1-2], materials design [2] or drug discovery [4]. However, codifying these problems in quantum computers typically requires to consider several qubits and circuits with large depth. A fundamental step to make such implementations possible is to select the required subset of qubits in the best possible way, in the sense of maximizing connectivity and mitigating propagation of errors. In this work, we introduce a method to choose the best possible subset of qubits for the implementation of a given quantum algorithm and show that it outperforms the transpiler optimization tool (level 3, with IA) provided by IBM [3].

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Unitary logic gates for quantum computing on classical photonic system

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Simulation of quantum devices with classical resources is a highly interesting topic in the current Era of quantum computing [1]. This poster demonstrates the efficient emulation of fundamental unitary operations for quantum computing by encoding quantum bits in classical photonic waveguides, offering a practical approach to understanding and simulating quantum behavior.

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Nonlinear Effects of Bragg Lattices on Atomic Vapors

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The need to control the flow of light has an important impact in optical information processing. Research groups have focused their efforts into high speed optical switches, which has pointed in the direction of non linear switching effects for their implementation into optical systems. The study of nonlinear optical effects in atomic vapors is then crucial for the development of advanced optical devices. In this research, we investigate the nonlinear effects present in Bragg lattices on atomic vapors, leveraging the unique nonlinear properties of atomic systems, and explore the potential bistability within the system. Previous studies have identified nonlinearities in the response of the system, originating in the third kerr coefficient; yet the bistability of such configurations remains unexplored. Through our research, we aim to characterize this bistability and uncover its origins. This could lead to the development of all-optical switches and optical diodes, which are vital components in the design of integrated optical systems and future quantum networks. Our findings could thus pave the way for new applications in optical signal processing and communication technologies.

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Multiqubit quantum circuit for transfering unitary operator information

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We study a multiqubit quantum circuit that operates on a chain of N qubits as target and 2N qubits as control states. The circuit is composed of a sequence of unknown unitary operators, U. The design, inspired from [1], enables the transfer of information from the unitary operator U - represented in the Weyl-Heisenberg basis - to the control states without loss of information, while remaining independent of the target state. This approach is then extended to explore its applications in unitary tomography and its potential in quantum metrology.

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Exploring Precision Enhancement in Multiport Interferometers

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In a standard interferometer where two waves interfere, the precision of phase shift measurements can surpass the Standard Quantum Limit (SQL) using quantum resources [1]. In this work, we explore multiport interferometers with the aim of identifying configurations and input states that enhance precision measurement and enable the parallel determination of multiple parameters [2,3].

We analytically examine the phase shifts induced in multiport Mach-Zehnder interferometers, focusing on the 3-input, 3-output and 4-input, 4-output configurations. Our approach utilizes various input arrangements combining coherent states, squeezed states of light, and single photons, alongside the measurement of different system operators to optimize the use of available information. Preliminary results indicate that it is feasible to measure multiple phase shifts simultaneously with enhanced precision.
Our findings so far suggest that multiport systems with different configurations and input states provide an interesting pathway to improve multi-parameter estimation beyond conventional limits and configurations.

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All-Gaussian Quantum Neural Network

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Continuous-variable quantum computing (CV-QC) is a paradigm of quantum information processing that exploits the continuous nature of bosonic systems for analog computation. Although recent research both theoretically and experimentally paves the way to the fault-tolerant CV-QC with optical components [1], current technologies have yet to realize universal quantum computing. In the upcoming era of noisy intermediate-scale devices, it is crucial to find experimentally feasible use cases for practical computation. In the qubit regime, variational quantum circuits (VQCs) [2] are vigorously investigated as promising candidates for applying quantum devices. Although previous papers [3, 4] have partially extended this framework to CV-QC, these proposals raise numerous challenges for experimental implementation including high-demanding photon interactions and a lack of analysis on sampling cost.

To overcome these obstacles, we present an experimentally feasible ansatz for CV quantum machine learning. As illustrated in Fig. 1, the VQC employed here consists only of Gaussian gates, enabling a straightforward implementation by a measurement-based quantum computation scheme using cluster states. The trick is to insert data-dependent layers into the quantum circuit, introducing a nonlinear transformation against input data that serves as an activation function of classical neural networks. As is shown in Fig. 2, this ansatz can be successfully trained for multiple tasks such as curve fitting and binary classification. We further analyze the sampling cost under a realistic noise model on cluster states and discuss potential techniques to boost its performance such as parameter- shift gradient estimation [5] and nonlinear feedforwarding.

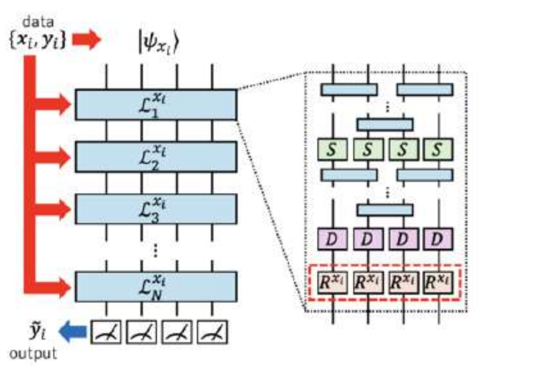

Fig. 1 All-gaussian VQC ansatz. Red dotted layer on the right denotes input-dependent gates.

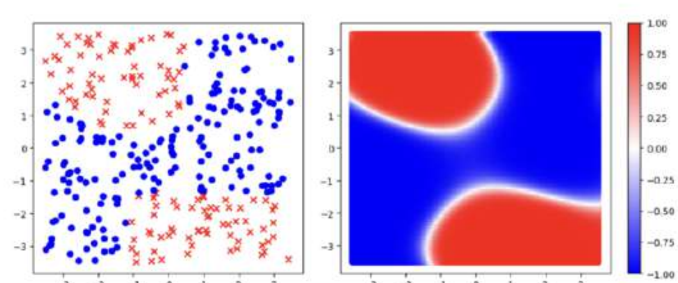

Fig. 2 Training data of binary classification on 2D plain (left) and training result on our VQC (right).

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Long-distance photonic device-independent quantum key distribution

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Device-independent quantum key distribution (DIQKD) offers the strongest form of quantum security for two fully uncharacterized users. However, its implementation, especially over long distances, poses significant challenges as losses make Bell test difficult to conduct successfully. In this work, we propose a photonic realization of DIQKD that offers significant advantages with respect to existing proposals [1]. In particular, our scheme leads to positive key rates over distances of hundreds of kilometers for state-of-the-art parameters, making the proposed setup a promising candidate for securing long-distance communication in quantum networks.

Results have been obtained and the manuscript is nearing completion; we anticipate publication on arXiv prior to the conference. Further details will be provided during the presentation.

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Gauge quantum thermodynamics of time-local non-Markovian evolutions Title

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Dealing with a generic time-local non-Markovian master equation, we define current and power to be process-dependent as in classical thermodynamics. Each process is characterized by a symmetrical transformation, a gauge of the master equation, and is associated with different amounts of heat and/or work. Once the symmetry requirement fixes the thermodynamical quantities, a consistent gauge interpretation of the laws of thermodynamics emerges. We also provide the necessary and sufficient conditions for a system to have a gauge-independent thermodynamic behavior and show that systems satisfying quantum detailed balance conditions are gauge-independent. Applying the theory to quantum thermal engines, we show that gauge transformations can change the machine efficiency, however, yet constrained by the classical Carnot bound.

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Subtracting Four Photons from Squeezed Light

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Quantum optics is a promising platform for realizing quantum computers in the continuous variable (CV) system. One of the main technical obstacles is the experimental difficulty of efficiently generating non-Gaussian states and operations. Using a beamsplitter with low reflectance to tap the light and measuring the number of photons is known to be a good approximation of annihilation operation (non-Gaussian operator) on the quantum state. The number of detected photons corresponds to the number of annihilation operators. This method is called photon subtraction, and it effectively introduces non-Gaussianity to otherwise Gaussian states, using the quantum entanglement and the non-linearity of the photon number resolving detectors (PNRD). For more than a decade, the number of subtracted photons from squeezed light was limited to three [2,3], due to various technical difficulties. This severely limited the kind of operation and state generation that could be used in experiments. In this research, we experimentally demonstrated the first four annihilation operations on squeezed light with four-photon detections. The output state was measured with a homodyne detector. The Wigner function obtained from tomography revealed negativity without loss correction, which is a strong indicator of the non-classicality of the output state. This experiment was enabled by a low-loss optical parametric amplifier, fine-tuning of various parameters, fast and efficient PNRD, and high stability of the system. This research is a state-of-the-art quantum optics experiment that demonstrates more free manipulation of the quantum state, paving the way for full engineering of the quantum state for optical quantum computers.

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Theoretical and numerical approach for the conversion of squeezed light from single mode to two mode in optical lattice

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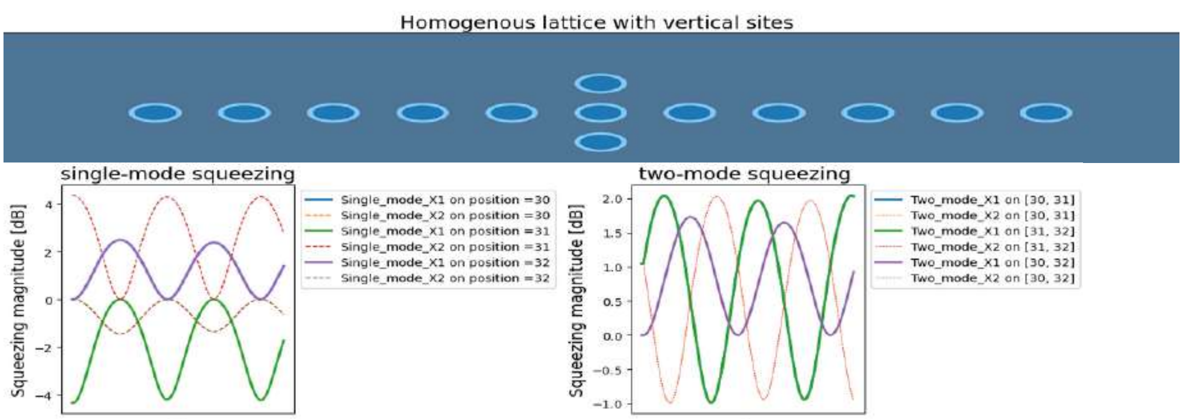
Squeezed light is a quantum state with diminished uncertainty on one quadrature at the expense of gaining uncertainty at the orthogonal quadrature. This property allows for application in areas such as metrology, quantum information, quantum computation, among many others [1]. The conversion from single-mode to sole two-mode can be done by injecting two single-mode states into a beam splitter [2] or a waveguide dimer [3] but currently, and up to our knowledge, there are no setups that can convert one single-mode into a sole two-mode, and vice-versa. Understanding what kind of properties a platform has to have to allow this kind of conversion will help with the manipulation, generation and flexibility of squeezed light inside photonic devices.

Our investigation focuses on the theoretical and numerical study of different optical lattices in the search of the condition for the generation of sole two-mode from one single-mode state which, if found, should also be reversible allowing the conversion of two-mode into sole single-mode. We show a numerical method capable of handling any linear Hamiltonian with time-dependent coefficients, and different characterization of this system which can give a path for a better conversion of modes.



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Strongly Regular Graphs from Quantum Computers

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Strongly Regular Graphs (SRGs) find important applications in coding theory [1], design of error-correcting codes [2], and network security protocols [3]. In this work, we develop an algorithm suitable for quantum annealing [4,5] to construct SRGs, which is a NP-hard problem [1] for classical computing. As a result, we find all inequivalent classes of SRG up to 16 vertices, offering a promising new application of mathematical problems that quantum computers can solve.

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Spatial correlation measurement of photons pairs generated by type II SPDC using an EMCCD Camera

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Spontaneous parametric down-conversion (SPDC) in nonlinear crystals generates photon pairs exhibiting correlations. We investigate spatial anticorrelation in photon pairs produced by type II SPDC using an electron multiplying CCD camera (EMCCD). The experiment employs a He-Cd laser to pump a BBO crystal, generating photon pairs at 650 nm. After rigorous filtering and capturing over 1,000,000 frames, using an algorithm that we developed we identify and quantify spatial anticorrelation. Our results confirm that correlated photons appear in opposite regions of the detection plane, demonstrating spatial anticorrelation. By the nature of the measurement this result is shown for every pixel of the Region of Interest (ROI) which allows us to identify in a more precise way the behavior of this phenomenon.

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Degenerate optical parametric oscillator based on four wave mixing process in hot alkali atoms

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Optical Parametric Oscillator (OPO) is a typical source to produce squeezed light [1] and entangled beams in continuous variables [2]. Recently it has been shown [3] the realization of a nondegenerate OPO based on four wave mixing in hot alkali atoms vapors, producing entangled beams above threshold. In this work, we have implemented the generate version of such kind of OPO in atoms. Here we present the characterization of the output power as a function of the input power. From this characterization, we observed a soft transition between below and above threshold oscillation as the finesse of the OPO cavity is reduced. Furthermore, we present intensity noise measurements of the beam produced by the OPO through balanced detection. Moreover, we study the intensity noise of the generated beam for different finesse of the OPO cavity and different pump power. Our preliminary results show that in the degenerate operation we obtained excess noise in intensity of the output beam. Nevertheless, our results show the rich spectral structure of the system, in which the finesse of the OPO cavity allows us to observe the atomic contribution to the output spectrum. In particular, we observed that for low finesse the spectrum of the atoms is more visible and thus the power broadening effect is more evident.

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Designing POVM for quantum computers

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Positive Operator-Valued Measure (POVM), the most general kind of measurements allowed in quantum mechanics [1], finds applications in entanglement detection [2], tomography [3] among others. In this work, we find some general constraints for entanglement in multipartite POVM. In particular, we focus on a special kind of quantum measurements knows as Equiangular Tight Frames [4]. Finally, we derive some families of POVM that can be implemented in quantum computers with low depth circuits.

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Experimental Noise-Resilient Quantum Random Access Code

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A $n^d \overset{p}{\to} 1$ 1 Quantum Random Access Code (QRAC) is a communication task where Alice encodes n classical bits into quantum states of dimension d and transmits them to Bob, who performs appropriate measurements to recover the required bit with probability p. In the presence of a noisy environment, the performance of a QRAC is degraded, losing the advantage over classical strategies. We propose a practical technique that enables noise tolerance in such scenarios, recovering the quantum advantage in retrieving the required bit. We perform a photonic implementation of a $2^2 \overset{p}{\to} 1$ QRAC using polarization-encoded qubits under an amplitude damping channel, where simple operations allow noise robustness showing the revival of the quantum advantage when the noisy channel degrades the performance of the QRAC. This revival can be observed by violating a suitable Dimension Witness (DW) inequality, which is closely related to the average success probability of the QRAC. This technique can be extended to other applications in the so-called prepare and measure scenario, enhancing the semi-device independent protocol implementations.

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Exploiting spatial correlations of entangled light beams for a Four-Wave Mixing neural network

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We propose an optical neural network inspired by recent advancements in deep physical neural networks trained with backpropagation, but now utilizing the spatial correlations of entangled light beams. Our approach exploits a four-wave mixing (FWM) process, which is a nonlinear interaction between four modes of the field and an atomic medium. Here a high-power pump beam, interacts with a hot atomic vapor and generates two temporally entangled probe and conjugate beam with low power, which describe a two-mode squeezed state (TMSS). A seed probe beam is used to stimulate the process (fig. 1).

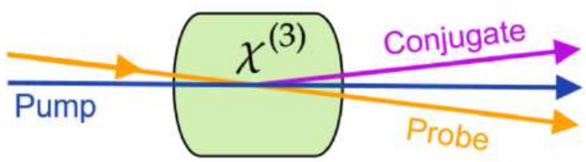

Fig. 1: Scheme of the FWM process.

In our proposed framework, FWM serves as the nonlinear component of the neural network, with the momentum of the pump encoding the network's weights and biases, while the seed beam's momentum functions as the input. The computational output is then encoded in the cross-correlations between the far-field probe and conjugate beams. This configuration allows us to exploit their quantum correlations in the spatial domain, encoding the neural network's computation results in a way that ensures secure data sharing, as the results cannot be fully accessed by observing only one of the beams, making them suitable for secure information processing between untrusted parties.

The most recent works showing control over the shapes of the correlation only used first-order approximation and a Gaussian seed [1]. Our work extends the theoretical understanding of the FWM by moving beyond first-order approximations, aiming to accurately model the complex cross-correlations of the probe and conjugate beams using higher-order terms with any arbitrary shape for the seed field distribution. Preliminary results suggest that the shapes of the pump and probe fields significantly influence these correlations, indicating a method to manipulate and control the neural network's output. The long-term goal of this research is to experimentally build a physical neural network exploiting the FWM process, thus bridging the fields of quantum optics, quantum information and artificial intelligence.

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Controlling directional propagation of photons in driven-dissipative lattices

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Studying the propagation of photons in structured media or lattices is of great interest in the photonic community because these systems enable the control or manipulation of their flow, which is rather challenging in homogeneous media [1]. A number of geometries have been implemented in photonic lattices to engineer different band structures, so that reaching a quite precise control over the photon propagation [2]. More recently, in the context of quantum emitters coupled to photonic-lattice baths, directional photon emission has been theoretically predicted when the emitters are in resonant with certain energies within the band [3]. However, these latter findings have yet to be implemented.

In this work, we demonstrate that directional propagation of photons can be achieved purely optically in any 2D photonic lattice presenting inflection points in its band structure. To demonstrate so, we use as a testbed a square lattice, where we show that a single external drive at the energy of these inflection points (resonant laser excitation) produces an anisotropic propagation. We then present a unitary-driving configuration (UDC) that generates propagation along specific lattice directions, resulting in a quasi-1D propagation. The addition of an extra drive allow us to route this propagation towards a desire direction. Finally, we show how localized states can be also generated when using multiples UDCs aligned along the predominant directions of propagation. Our numerical result can be readily implemented in experiments using, for instance, lattices of coupled micropillars [4].

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Non-canonical steady state of two interacting oscillators in the strong coupling regime

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The dynamics of open-quantum system is typically modelled by local-Lindblad terms that describes the effects of the baths in the system. This kind of modelling is valid when the system elements are weakly interacting. However, for strongly interacting elements the system dynamics can be derived in a consistent microscopic way through a global master equation. This local and global approaches have shown differences in entanglement production and temperature dependence of system coherence [1,2].

In this work, we microscopically derive a master equation for two interacting harmonic oscillators in the strong coupling regime. The derivation uses Redfield equation that considers weak coupling and Born-Markov approximation for the interaction between the oscillators and the thermal baths. The obtained global master equation contains local terms, that describes independent relaxation processes, and non-local terms, due to the inclusion of the coupling strength in the derivation.

Results show that the dynamics of the system is well described by local-Lindblad and global approaches. However, in the steady state, the non-local terms in the global approach lead the system to a canonical state. When these non-local terms are neglected, the system have a non-canonical steady state, where the observables have a resonant behavior as in local Lindblad modelling. Possible connections and coexistences of local-Lindblad and global approaches are discussed, including regimens of temperature and oscillator energy detuning, and the inclusion of non-linear system bath interactions.

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Exploring Wigner Phase Rotation as a Tool for Quantum Sensing

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In this work, we explore how the Wigner phase rotation [1], induced by a gravitational field on photon polarization, can be employed as a tool for quantum sensing. We focus on the weak field and slow rotation limit of the Kerr metric to calculate the rotation parameter. Within this framework, we analyze how temporal time dilation and polarization rotation could be employed as resources for quantum metrology. These results can be compared with those in [2], where gravitational time dilation was considered as a tool for quantum sensing, but for particles with internal degrees of freedom.

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Adaptive Phase Estimation with Squeezed Vacuum States

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Optical phase estimation is an essential task for applications such as communication, sensing, and quantum information processing. The precision of an estimator is ultimately limited by the Quantum Cramér-Rao Bound (QCRB). For classical light states, the QCRB scales as $O(1/n)$, where n is the average photon number. This limit is known as the Standard Quantum Limit (SQL). In contrast, squeezed states, which show quantum noise below the shot noise in one field quadrature, can achieve the Heisenberg scaling, where the QCRB scales as $O(1/n^2)$. One approach to achieving the Heisenberg scaling involves encoding the unknown phase θ within the range $[0,\pi/2)$ into squeezed vacuum states and using homodyne measurements. When the phase matches a specific optimal value determined by the squeezing strength, homodyne measurements on these states can achieve the QCRB. However, deviations from this optimal phase can cause the precision of estimators based on these measurements to be even worse than the SQL. To address this issue, a two-step strategy is typically employed: initially, homodyne measurements on independent squeezed vacuum states provide a coarse phase estimate, which is then refined through additional measurements. While this strategy can achieve the QCRB near the optimal phase, its precision decreases as the phase deviates, although it generally remains better than the SQL. Consequently, the ongoing challenge is to develop strategies that achieve the QCRB for squeezed vacuum states across the entire range of phase values.

In this work, we present a multi-step adaptive Gaussian estimation strategy for optical phase estimation using squeezed vacuum states. The strategy begins with homodyne measurements to implement a series of locally optimal POVMs, which are then refined through adaptive optimization using the Maximum Likelihood Estimator. However, strategies based only on homodyne measurements are limited to phases within $[0, \pi/2)$ because the probability distribution of the outcomes is $\pi/2$-periodic. This periodicity restricts the asymptotic efficiency of the strategy to this range. To overcome this limitation, our strategy incorporates heterodyne measurements, allowing the estimator to achieve optimal performance for phases within $[0, \pi)$, which is the full range that can be encoded into squeezed vacuum states [2]. Furthermore, by incorporating squeezed displaced states as quantum probes, our protocol extends the phase estimation range to cover the full-period of $[0,2\pi)$.

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Stochastic resonant behaviours and steady state control in harmonic systems

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Brownian motion and parametric resonance are two paradigmatic phenomena particularly taking place on harmonic dynamical systems, covering a plethora of branches in science. While the former gives a pathway to include dissipation and noise (additive noise) in asystem, the latter stands for a physical mechanism that supplies energy to a system by exploiting the resonant variation of the characteristic frequency. Both aspects find their syncretism in the so-called stochastic resonance, where the competition between dissipation and the strength of the fluctuations in the characteristic frequency of the system (multiplicative noise) defines whether the system undergoes exponential growth (as in parametric resonance) or stabilises in a steady state in the long-time limit[1]. Typically, the impact of this competition is neglected due to relatively high dissipation rates that overcome resonant effects. However, the development of harmonic systems with increasingly quality factors makes this competition to come into play, raising as a potential limiting factor but also as a possibility for a novel control mechanism. In this talk, I will introduce the basics of the mentioned dynamical phenomena to quantify its impact on experimental setups, such as optically levitated nanoparticle. Moreover, I will also show how these concepts enter interacting harmonic systems, giving place to enhanced resonant behaviours in the steady state. The latter can be exploited, for instance, for heat transport and thermalisation[2].

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Modelling the excited state lifetime of vanadium phthalocyanine single molecules for quantum applications

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Single molecules are promising candidates for applications in quantum technologies [1] and some of them present large coherence times at room temperature [2]. Vanadium-Oxide Phthalocyanine (VOPc) has proven to be a system with interesting characteristics at the single molecular level, showing optical stability [3]. VOPc has an energy structure consisting of a first optically excited state (doublet) and two other sets of excited states (doublet and quartet) arising from the geometry. This configuration allows for electronic transitions upon laser excitation that can be studied when measuring the lifetime of the excited state, showing interesting behaviors such as oscillations, upon changes in the laser power. A theoretical study of the different models that can explain the decaying paths in the lifetime of VOPc is presented. Starting from the basis of the two-level system interacting with a photonic bath, we seek to construct a model that by considering all sets of excited states and possible orientations of their interacting electric dipole moments can explain the decay and simulate the observed experimental results.

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Parameter independent quantum alternating operator anzats

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We propose a hybrid classical-quantum optimization algorithm that involves the digitization of an optimized adiabatic process, with a particular focus on optimized schedule functions. This approach serves as the digital counterpart to the recently introduced Variational Coherent Quantum Annealing (VCQA) algorithm [1, 2]. What distinguishes our algorithm is its ability to produce a parameter-independent quantum alternating operator ansatz, similar to the Quantum Approximate Optimization Algorithm (QAOA) [3]. However, unlike QAOA, our version maintains a constant number of parameters regardless of the number of layers. This allows us to reduce digital error (due to a large number of layers) without increasing the complexity of the classical optimizer, helping to avoid barren plateaus [4], one of the major challenges in hybrid algorithms. Specifically, we demonstrate that our approach can achieve results comparable to or better than QAOA using fewer variational parameters, reducing the cost of the classical optimizer and potentially decreasing runtime. This opens the door to a new generation of variational algorithms, minimizing the role of the classical subroutine and making it ideal for tackling large optimization problems on current quantum devices.

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Manipulating the light-matter coupling of a plasmonic nanosphere and a dipole emitter with laser fields

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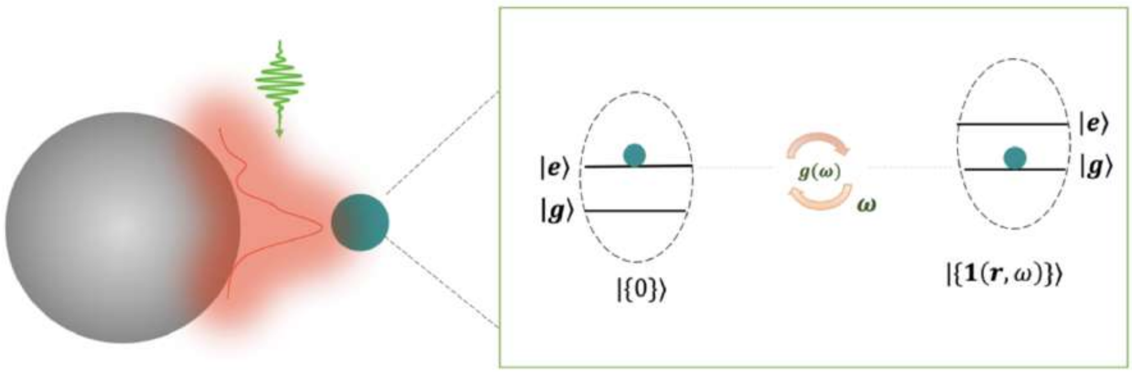
Near field plasmonic resonances that happen in metallic nanostructures provide a fascinating way to en- gineer the interaction between light and matter [1]. It has been demonstrated that the coupling between the cavity field and matter can lead to strong coupling with a single emitter in plasmonic cavities [2]. We study the strongly coupled dynamical processes of a dipole emitter coupled to near-field modes of a plasmonic nanosphere using macroscopic quantum electrodynamics (QED) and explore the possibility of manipulating the photonic local density of states by driving the system with narrowband laser sources. To achieve this, we develop a pseudo-mode representation of the electromagnetic dyadic Green's tensor of a nanosphere with dipolar and higher-order plasmonic resonant modes, to build semi-analytical solutions of the set of coupled non-Markovian integro-differential equations (IDE) that describe the laser-driven dynamics of material dipoles and photonic degrees of freedom. We solve for experimentally relevant photonic and dipolar observables for a single dipole emitter in a resonant optical nanocavity and compare the results with recent phenomenological Markovian models developed for molecular polaritons [3].



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High-dimensional decoy-state quantum key distribution over 1.2km installed multicore fibers

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Multicore fibers have attracted attention in telecommunications due to their higher transmission capacity compared to single-core fibers, owing to a method known as space-division multiplexing [1]. In the context of quantum communication, they allow the generation of higher-dimensional quantum states by encoding data in the relative phases of light sent through each core. However, when coherent states are used for quantum key distribution (QKD) with the BB84 protocol, they are vulnerable to photon number splitting attacks, which limits the maximum range at which secure communication is achievable [2]. This problem is solved by the decoy state protocol, in which the intensity of each state is randomly changed and Alice announces the intensity information of each state after the measurement stage but before the sifting (basis reconciliation) stage [3].

In this poster, we report a decoy state quantum key distribution (QKD) experiment with numerically optimized signal and decoy intensities [4] over 1.2km of four-core optical fiber installed in a realistic environment. Our multicore optical fiber network presents advantages over using four single-core fibers in a transmission channel, particularly its robustness against phase fluctuations between cores owing to them being in the same cladding [5]. We achieved a transmission rate of $3.6 \cdot 10^{-4}$ bits/ns at a frequency of 2 MHz, and our theoretical analysis shows that QKD with our setup is possible at distances of over 100 km.

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Quantum Detector Tomography of a Single Photon Detector based on a Nanophotonic Parametric Amplifier

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Integrated photonic quantum information processing (QIP) has advanced rapidly due to progress in various nanophotonic platforms [1, 2]. Single photon detectors have been the subject of intense study due to their ubiquity for state measurement and manipulation in QIP systems [3, 4], yet many state-of-the art detectors operate at cryogenic temperatures under vacuum and suffer from long dead times [5]. We propose and demonstrate a single photon detection scheme based on optical parametric amplification in nanophotonic lithium niobate (LN) combined with a macroscopic photodetector. We use quantum detector tomography and experimentally demonstrate an efficiency of 26.5% with a 2.2% dark count rate. We show that by improving the nonlinearity-to-loss ratio in nanophotonics and using homodyne detection on a squeezed pump, the detector can achieve 69% efficiency with 0.9% dark count rate. The detector operates at room temperature, has no intrinsic dead time, and is readily integrated in LN nanophotonics, in which many other components of photonic QIP are available. Our results represent a step towards all-optical ultrafast photon detection for scalable nanophotonic QIP.

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High-dimensional counterdiabatic quantum computing

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The interest in quantum computing has increase in the last year, with the advance in proposed to algorithms, mainly based in qubits. Among the different approaches, adiabatic quantum computing [1] has emerged as a significant candidate for solving optimization problems by leveraging the adiabatic theorem to obtain the solution encoded in the ground state of a Hamiltonian that represents the problem. Building on this approach, the digital version of adiabatic quantum computing, enhanced by counterdiabatic driving [2], known as digitized counterdiabatic quantum computing [3], emerges as a promising paradigm.that opens the door to fast and shallow-depth quantum algorithms. In this work, we extend this paradigm to high-dimensional quantum systems, specifically focusing on qutrits—three-level quantum systems—in the context of three-partition classification problems and quadratic optimization.

We study the Multiway Number Paritioning problem, Max 3-cut problem and Portfolio Optimization, deriving the Hamiltonian representations for qutrits in each case and calculating the corresponding counterdiabatic drivings using approximate gauge potentials. Our study compares the performance of these algorithms in qutrit systems to their qubit-based counterparts, revealing superior results in terms of success probabilities and energy minimization in the qutrit case. Furthermore, we explore the potential for physical implementation of these algorithms via digitalization on quantum platforms that support qutrits, employing gate-based techniques.

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Time non-local memory effects in optomechanical system

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Memory effects in a physical system are intrinsically linked to its non-equilibrium dynamical properties [1]. Optomechanical (OM) systems have emerged as novel platforms for exploring the interplay between photonic and phononic degrees of freedom [2]. In this work, we present a theoretical model that explains time non-local memory effects in periodically pulsed OM systems, utilizing different time-dependent electric field amplitudes. We establish the optimal conditions for maximizing these memory effects through a geometrical characterization using a mean-field approximation [3] and optimization techniques. By treating the electric field amplitude as an input (x(t)) and the mean number of photons or phonons as an output (y(t)), we calculate the area A and perimeter P of the closed curve (x(t), y(t)), optimizing the form factor F = 4πA/P2. Through the optimization of pulse parameterssuch as amplitude, width, and frequencyusing both sinusoidal and Gaussian models, we demonstrate that optomechanical hysteresis curves exhibit a time non-local memristive behavior [4] with an optimal form factor. Our numerical simulations further indicate that the proposed control protocol can be adapted to OM systems with varying coupling strengths, resonator frequencies, and dissipation rates.

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Deterministic Generation of Multi-Photon Added Coherent States

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In this work, we propose a deterministic approach to generate photon-added coherent states [1], which effectively bridge the gap between Fock states and coherent states while exhibiting interesting nonclassical features. We employ a Kerr-type nonlinearity [2] within a cavity that is excited by a classical field, allowing us to observe the emergence of photon blockade [3]. This phenomenon allows for the modulation of the photon distribution, enabling us to achieve an optimal distribution that retains the essential characteristics of photon-added coherent states. Our methodology provides a robust mechanism for controlling the addition of multiple photons through the adjustment of model parameters, which is crucial for enhancing quantum properties and advantages across various applications [4]. These findings pave the way for innovative strategies in the generation and manipulation of photon-added coherent states, contributing to the advancement of quantum state engineering.

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Machine Learning approach for the quantum marginal problem

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In this work, we propose a machine learning approach for the quantum marginal problem. Our method consists in training convolutional denoising autoencoders to find a global density matrix compatible with a given set of quantum marginals. Features of the density matrix, such as hermiticity, positivity and normalization, are imposed through the loss function during the training stage. Numerical simulations show that this architecture performs this task with high accuracy. We speculate that future advances in the field of machine learning and artificial intelligence can open the way to extracting knowledge from this kind of architecture, which may help find new theoretical discoveries in the problem.

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Adaptive Quantum tomography with Fisher Symmetric Measurements

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Fisher Symmetric Measurements (FSM) [1] can estimate a pure quantum state with the ultimate precision, as defined by the Gill-Massar bound [2], using a minimal number of outcomes. However, FSMs are limited in their effectiveness to the vicinity of a known fiducial state, thus restricting their usability for completely unknown states. In this work, we demonstrate that by combining a single-shot measurement on a computational basis with two adaptive FSMs, we can estimate any pure quantum state. Numerical simulations indicate that this approach outperforms other tomographic methods for pure states [3], although it falls short of reaching the Gill-Massar bound. Furthermore, we establish that by introducing a third or more adaptive FSM, we can estimate any pure state with precision close to the Gill-Massar bound. Numerical simulations support our results, and we provide a quantitative analysis of the precision scaling.

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Pushing resource efficiency to the limit in quantum state tomography

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The process of reconstructing the global state of a quantum computer is challenging. Informationally complete sets of measurements are known [1,2], but typically a large number of quantum circuits is required to fully recover the information of the quantum state from these protocols. Also, post-processing procedures typically consume resources that increase exponentially with the number of qubits. Among those protocols that sort out these problems, see e.g. [3,4], the consideration of non-local gates considerably reduces the fidelity of the reconstruction process even for a relatively small number of qubits. Intriguingly, for every known tomographic method there seems to be a trade-off relation between the number of quantum circuits required to implement state tomography process and the amount of non-local gates required to implement in the measurement stage of those circuits. e.g. see [1-5]. In our work, we break such a paradigm by introducing a protocol that reconstructs the global state of a quantum computer by requiring a fixed set of five quantum circuits without ancillas, regardless the number of considered qubits, involving local operations and classical communications only in the measurement stage. Furthermore, an explicit reconstruction formula is provided. This protocol is the first of its kind, as far as we know.

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Physical consequences of gauge optimization in quantum open systems evolutions

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On its own, the invariance by gauge transformations of Markovian master equations has mostly played a mathematical or computational role in the evaluation of quantum open system dynamics. So far, the fixation of a particular gauge has only gained physical meaning when correlated with additional information such as the results of measurements carried on over the system or the environment in so-called quantum trajectories. Here, we show that gauge transformations can be exploited, on their own, to optimize practical physical tasks. To do so, first, we describe the inherent structure of the underlying symmetries in quantum Markovian dynamics and present a general formulation showing how they can be used to change the measurable values of physical quantities. We then analyze examples of optimization in quantum thermodynamics and, finally, we discuss the practical implementation of the optimized protocols in terms of quantum trajectories.

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Transmission of optical communication signals through ring core fiber using perfect vortex beams

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Orbital angular momentum can be used to implement high capacity data transmission systems that can be applied for classical and quantum communications [1,2]. Here we experimentally study the generation and transmission properties of the so-called perfect vortex beams and the Laguerre-Gaussian beams in ring-core optical fibers. Our results show that when using a single preparation stage, the perfect vortex beams present less ring-radius variation that allows coupling of higher optical power into a ring core fiber. These results lead to lower power requirements to establish fiber-based communications links using orbital angular momentum and set the stage for future implementations of high-dimensional quantum communication over space division multiplexing fibers [3].

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Effective Liouvillians of a Non-degenerated Optical Parametric Oscillator using a Perturbative Approach

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Parametric amplification is a nonlinear optical process used for frequency conversion from a pump mode to both a signal mode and an idler mode, as well as for generating a squeezed state. Recently, coherent XY machines have utilized nondegenerate parametric oscillators to simulate large XY spin models using 5,000 signal modes [1] and 47,740 signal modes [2]. While the microscopic model includes three times more modes (pump, idler, and signal), constructing a reduced model of a nondegenerate optical parametric oscillator can simplify the description of the machine dynamics and aid in further understanding of these machines. Although several studies in the literature have proposed several effective models, they use phase space representation [3] and number representation [4] of the density matrix, which can make it challenging to grasp the physical meanings from these models.

In this study, we construct effective models represented in the Liouville-Fock space using the time-convolutionless Nakajima-Zwanzig projection operator method. Assuming weak interactions among the pump, signal, and idler modes, we derive an effective Liouvillian of the quantum master equation for the signal and idler modes of a nondegenerate optical parametric oscillator within the 4th order perturbation. The Liouvillian includes a two-mode squeezing term and a two-body loss term involving the signal and idler modes. Additionally, we derive an effective Liouvillian for the signal mode, which corresponds to the Scully-Lamb laser model within the 4th order. In the presentation, we also provide numerical analysis of these Liouvillians using exact diagonalization.

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