IQIS2014 – 7th Italian Quantum Information Science Conference

e-book of Abstracts

The Conference includes 3 special guest lecturers, 5 keynote speakers, 61 among invited and contributed talks and 18 posters.

To reduce the use of paper we have decided to present the Conference abstracts as a stand-alone pdf file saved on participants' USB keys.

Each abstract can be reached by clicking on the contributor name either from the programme overview or from the detailed programme of the corresponding session.

Details of the sessions are linked from the programme overview.

START BROWSING

Conference Programme at a glance

	Monday	Tuesday	Wednesday	Thursday	Friday
Time	**Session 1**	**Session 3**	**Session 5**	**Session 7**	**Session9**
09.00	*Welcome*	**Joerg Wrachtrup**	**Karol Zyczkowski**	**Christof Wunderlich**	**Stephan Ritter**
	Julien Laurat	Luca Pezze'	Barbara Kraus	Giovanna Morigi	Valentina Parigi
	Filippo Caruso	Daniela Buono	Leonardo Ferro	Marco Barbieri	Michele Dall'Arno
	Michele Avalle	Marco Cianciaruso	Roberto Pierini	Matteo Rizzi	Paolo Villoresi
10.35 (Mon. 10.30)	Coffe Break (30')				
	Mauro Paternostro	Wojciech Roga	Marcello Dalmonte	Philipp Hauke	Giuseppe Bimonte
	Francesco Marin	Tony John George Apollaro	Luca Tagliacozzo	Alessia Allevi	Stefano Pirandola
	Alessandro Farace	Pino Falci	Matteo Bina	Francesco Vincenzo Pepe	Giuseppe Luca Celardo
	Cosmo Lupo	Pasquale Scarlino	Alessio Avella	Leonardo Mazza	Massimo Palma
12.25 (Mon. 12.20)	LUNCH (on site)				
	Session 2	**Session 4**	**Session 6**	**Session 8**	
14.30 (Wed. 14.15)	Alessandro Zavatta	Geza Toth	Fabrizio Illuminati	**Frank Pollman**	
	Dominique Spehner	Salvatore Marco Giampaolo	**Francesco Guerra**	Pietro Silvi	
	Marco Genoni	Lorenzo Maccone	David Vitali	Virginia D'Auria	
	Marcus Cramer	Paola Verrucchi Sandro Donadi	Rosario Fazio	Elsa Passaro	
15.50 (Tues. 16.10, Thur. 16.05)	Coffe Break (30')				
	Claudia Benedetti	***POSTER SESSION***	**Giorgio Parisi**	Chiara Macchiavello	
	Sabrina Maniscalco		Paolo Mataloni	Davide Vodola	
	Ebrahim Karimi		Alessio Serafini	Francesco Ciccarello	
	Filippo Cardano		Matteo Paris	Nicolò Spagnolo	
			Saverio Pascazio		
Ending time	17.40	18.20	18.15	17.55	
			CONFERENCE DINNER (Starts 20.00)		

Bold names – keynote and special guests (30'+5' discussion)
Regular speakers (20' including discussion)

Conference Programme

MONDAY 15/9

Morning session 9.00 – 12.20
Afternoon session 14.30 – 17.40
Registration desk will be open the all day since 8.30

9.00	9.15	Welcome addresses	
9.15	9.50	**Optical Hybrid Quantum Information**	**Julien Laurat**
9.50	10.10	Suppression of quantum locking and momentum rejuvenation as super-boosts for quantum transport	Filippo Caruso
10.10	10.30	State and energy transfer through noisy quantum cellular automata	Michele Avalle
10.30	11.00	***Coffee break***	
11.00	11.20	Non-interferometric Test of Collapse Models in Optomechanical Systems	Mauro Paternostro
11.20	11.40	Opto-mechanics toward quantum physics	Francesco Marin
11.40	12.00	Steady-state entanglement activation in optomechanical cavities	Alessandro Farace
12.00	12.20	From quantum data locking to the quantum enigma machine	Cosmo Lupo
12.20	14.30	***Lunch break (on site)***	
14.30	14.50	Generating continuous variables qubits using arbitrary quantum superpositions of single- photon operations	Alessandro Zavatta
14.50	15.10	Geometric quantum discords	Dominique Spehner
15.10	15.30	Stochastic unravelling of the thermal master equation	Marco Genoni
15.30	15.50	Scalable Quantum State Tomography	Marcus Cramer
15.50	16.10	***Coffee break***	
16.10	16.30	Decoherence, non-Markovianity and quantum estimation in qubit systems subject to colored noise	Claudia Benedetti
16.30	16.50	Non-Markovian quantum dynamics: when the past comes back	Sabrina Maniscalco
16.50	17.10	Structured light: concepts and applications	Ebrahim Karimi
17.10	17.40	Twisted photons for simulating quantum walks and probing their effective band structure	Filippo Cardano

Conference Programme

Tuesday 16/9

Morning session 9.00 – 12.25
Afternoon session 14.30 – 18.30
Registration desk will be open 8.30 – 11.05

9.00	9.35	**Quantum information processing and metrology using diamond spins**	**Joerg Wrachtrup**
9.35	9.55	Useful Entanglement in Quantum Metrology	Luca Pezze'
9.55	10.15	Gaussian Quantum Discord: Theory and Experiments	Daniela Buono
10.15	10.35	Understanding freezing of quantum correlations from first principles	Marco Cianciaruso
10.35	11.05	***Coffee break***	
11.05	11.25	Geometric measures of quantum correlations: characterization, quantification, and comparison by metrics and operations	Wojciech Roga
11.25	11.45	Quantum State Routing and many-qubit Quantum State Transfer via a single channel	Tony John George Apollaro
11.45	12.05	Lambda Scheme for Population Transfer in Superconducting Qutrits	Pino Falci
12.05	12.25	Electrical control of a long-lived spin qubit in a Si/SiGe quantum dot	Pasquale Scarlino
12.25	14.30	***Lunch break***	
14.30	14.50	Detecting multiparticle entanglement of Dicke states	Geza Toth
14.50	15.10	Quantum Frustration in complex systems	Salvatore Marco Giampaolo
15.10	15.30	Entanglement and complementarity	Lorenzo Maccone
15.30	15.50	Quantum environment for a longer coherence time	Paola Verrucchi
15.50	16.10	Radiative properties of matter in collapse models	Sandro Donadi
16.10	16.40	***Coffee break***	
16.40	18.30	***POSTER SESSION****	

* A list of the posters is available on a separate sheet

Conference Programme

Wednesday 17/9

Morning session 9.00 – 12.25
SPECIAL SESSION 14.15 – 18.15
Registration desk will be open
8.30 – 9.30

9.00	9.35	**On entropic uncertainty relations**	**Karol Zyczkowski**
9.35	9.55	Certain aspects of multipartite entanglement	Barbara Kraus
9.55	10.15	Origin of spontaneous symmetry breaking: classicality, monogamy, and convertibility	Leonardo Ferro
10.15	10.35	Preserving Information from the Beginning to the End of Time in a Robertson-Walker Universe	Roberto Pierini
10.35	11.05	***Coffee break***	
11.05	11.25	The cold atom lattice gauge toolbox: emergent nuclear physics in Bose mixtures	Marcello Dalmonte
11.25	11.45	Gauge theories and Tensor Networks	Luca Tagliacozzo
11.45	12.05	Real-time phase monitoring for quasi-optimal coherent-state receiver	Matteo Bina
12.05	12.25	Absolute calibration of an EMCCD camera from the analog to single photon regime	Alessio Avella
12.25	14.15	***Lunch break***	
Special session on the occasion of Silvio De Siena's 65th birthday			
14.15	14.35	Introduction to the special session	Fabrizio Illuminati
14.35	15.10	**Heisenberg uncertainty principle in the stochastic interpretation of de Falco-De Martino-De Siena**	**Francesco Guerra**
15.10	15.30	Certified entanglement between distant microwave fields with opto-electro-mechanical systems	David Vitali
15.30	15.50	Non-equilibrium dynamics and thermalisation of string order in quantum spin-1 chains	Rosario Fazio
15.50	16.20	***Coffee break***	
16.20	16.55	**Statistical mechanics of maximally entangled states**	**Giorgio Parisi**
16.55	17.15	3-dimensional integrated photonic quantum simulation	Paolo Mataloni
17.15	17.35	General diffusive conditional dynamics	Alessio Serafini
17.35	17.55	Single- and two-mode quantumness at a beam splitter	Matteo Paris
17.55	18.15	Quantum typicality	Saverio Pascazio

Conference dinner: ***at 20.00 a bus service leaving from the center of Salerno will take all the participants to the Restaurant "La Fattoria" located in the village of Dragonea. Dinner will start around 20.30. The buses will take participants back to the city center at the end of the dinner.***

Conference Programme

Thursday 18/9

Morning session 9.00 – 12.25
Afternoon session 14.30 – 17.55
Registration desk will be open 8.30 – 9.30

9.00	9.35	**Elements of Quantum Simulations with Trapped Ions using MAGIC**	**Christof Wunderlich**
9.35	9.55	Quantum crystals of photons and atoms	Giovanna Morigi
9.55	10.15	Multimode state characterization by weak-field homodyning	Marco Barbieri
10.15	10.35	Optimal persistent currents for interacting bosons on a 1D ring with a gauge field	Matteo Rizzi
10.35	11.05	***Coffee break***	
11.05	11.25	Many-body localization and ergodicity in disordered long-range Ising models	Philipp Hauke
11.25	11.45	Schmidt modes description of the radiation field produced by high-gain parametric down conversion	Alessia Allevi
11.45	12.05	Interference in a Bose-Einstein condensate is typical	Francesco Vincenzo Pepe
12.05	12.25	Out-of-equilibrium dynamics and thermalization of string order	Leonardo Mazza
12.25	14.30	***Lunch break***	
14.30	15.05	**Characterizing topological orders in quantum matter**	**Frank Pollman**
15.05	15.25	Simulating Lattice Gauge field theories with Tensor Networks	Pietro Silvi
15.25	15.45	Ultrafast quantum optics based on telecommunication technologies	Virginia D'Auria
15.45	16.05	Randomness evaluation and certification in a steering scenario	Elsa Passaro
16.05	16.35	***Coffee break***	
16.35	16.55	Randomized Graph States and their Entanglement Properties	Chiara Macchiavello
16.55	17.15	Kitaev chains with long-range pairing	Davide Vodola
17.15	17.35	Measuring the reservoir spectral density via photon scattering	Francesco Ciccarello
17.35	17.55	Efficient experimental validation of photonic Boson Sampling	Nicolò Spagnolo

Conference Programme

Friday 19/9

Morning session 9.00 – 12.30

9.00	9.35	**A quantum gate between a flying optical photon and a single trapped atom**	**Stephan Ritter**
9.35	9.55	Photonic States Manipulation In Atomic Ensembles	Valentina Parigi
9.55	10.15	Accessible Information of Quantum Ensembles and Informational Power of Quantum Measurements	Michele Dall'Arno
10.15	10.35	Extending the Quantum Communications toward the Space exploiting Satellite Links	Paolo Villoresi
10.35	11.05	***Coffee break***	
11.05	11.25	The Casimir effect: present status, theoretical puzzles and future perspectives	Giuseppe Bimonte
11.25	11.45	A quantum information approach to the black-hole information paradox	Stefano Pirandola
11.45	12.05	Robustness of collective properties to disorder: the case of Superradiance. Applications to light harvesting systems	Giuseppe Luca Celardo
12.05	12.25	Transitionless quantum driving in open quantum systems	Massimo Palma
12.25	12.30	***Concluding remarks***	

Conference Programme

POSTER LIST

Tuesday 16.40 – 18.30

Adeline Orieux	Experimental recovery of entanglement by local operations
Carlo Ottaviani	Measurement-device independent quantum cryptography with continuous variables: security of the symmetric configuration
Fulvio Flamini	Efficient experimental validation of photonic Boson Sampling
Gaetana Spedalieri	Quantum Hoeffding bound for Gaussian states
Giuseppe Vallone	Finite-size QKD and Quantum Randomness from the Uncertainty Principle
Luca Taddia	Dynamics of entanglement entropy and entanglement spectrum crossing a quantum phase transition
Maria Maffei	Observation of topological phenomena in photonic quantum walk with twisted light
Mario Arnolfo Ciampini	Path-polarization hyperentanglement characterization on chip
Michele Dall'Arno	Universal Optimal Quantum Correlator
Nicola Malossi	Electro-opto-mechanics with SiN membrane
Salvatore Lorenzo	Correlations and Heat fluxes in a collisional model
Stefano Olivares	About the use of fidelity to assess quantum resources
Stefano Pirandola	Towards end-to-end quantum cryptography
Giuseppe Buonaiuto	Quantum entanglement and quantum discord dynamics in non-Markovian channels
Sara Di Martino	Strong Monogamy of Entanglement
Martí Cuquet	Entanglement and nonclassical properties of hypergraph states
Gaetano Nocerino	Experimental Entanglement birth in the mixing of Guassian states: a matter of Fidelity
Thomas Bromley	The universal freezing phenomenon of geometric bipartite correlations

State and energy transfer through noisy quantum cellular automata

Michele Avalle
Department of Physics & Astronomy, University College London, Gower street, London WC1E 6BT, United Kingdom
michele.avalle.11@ucl.ac.uk

Abstract

I will present a class of noisy quantum cellular automata (QCA) on a one-dimensional lattice of qubits that allows to embed classical Markov chains within the formalism of quantum operations (CP maps), providing a framework in which a quantum and a purely classical stochastic dynamics can be simply and fairly compared.
I will then show how this approach is capable to reproduce and isolate non trivial coherent quantum effects when applied to a relevant and currently widely investigated field of research such as energy transfer in biological processes [1].
Finally, I will discuss the performance of this framework in the context of quantum state transfer, showing a way to extend the dynamics in order to accommodate transport of initial coherences, besides excitations.

References

[1] M. Avalle and A. Serafini, "Noisy Quantum Cellular Automata for Quantum versus Classical Excitation Transfer", Phys. Rev. Lett. 112, 170403 (2014).

(Presenting author)		

Decoherence, non-Markovianity and quantum estimation in qubit systems subject to colored noise

Claudia Benedetti
Dipartimento di Fisica, Università degli Studi di Milano, Via Celoria 16, 20133 Milano, Italy
claudia.benedetti@unimi.it

Abstract

In this talk I consider a qubit system coupled to a stochastic classical field generating random telegraph noise or colored noise characterized by a $1/f^{\alpha}$ spectrum ($0.5 < \alpha < 2$). I address the decoherence and non-Markovianity induced by the external noise as well as the spectral characterization of the classical field by quantum-limited measurement on the qubit

The unavoidable interaction of quantum systems with their complex environments usually destroys its coherence and quantumness. The fragile quantum information encoded in an open quantum system is lost due to the presence of the environment that continuously monitor the system. Decoherence may be induced by classical or quantum bath. The classical description becomes progressively more reliable as far as the environment has many degrees of freedom or when the interaction between a quantum system and a classical fluctuating field is taken into account. We consider a system consisting in two non-interacting qubits initially prepared in maximally entangled state and interacting with a classical colored noise generated by non-Gaussian processes. In particular, we focus on two relevant classes of noise: random telegraph noise generated by a single bistable fluctuator and the colored noise with $1/f^{\alpha}$ power spectrum, generated by a collection of N random bistable fluctuator ($N \geq 1$). We thus analyse the dynamics of quantum correlations between the two qubits. We also discuss the evaluation of non-Markovianity, in the sense of information backflow, of the induced dynamical map. We found that, for the considered system, the presence of revivals of quantum correlations corresponds to information backflow to the system.

The precise characterization of the stochastic process generating the classical noise, possibly using minimal resources, is a crucial ingredient for the design of high-precision measurements and reliable communication protocols. To this purpose, we address a complementary analysis, that is the characterization of the spectral parameters of classical noise by quantum probes, e.g. a qubit. I consider a system coupled to the stochastic process generating the noise and explore the performances of quantum measurements on the qubit to extract information about the spectral properties of the noise. Upon maximizing the quantum signal-to-noise ratio over the preparation of the probe, the interaction time and the measurement at the output, we show that the optimal characterization of the noise strongly depends on the structure of the environment.

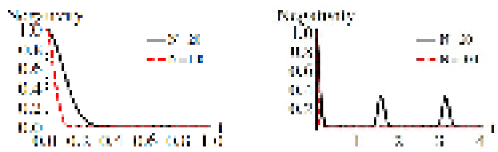

Fig. 1. *Entanglement dynamics between two qubits interacting with a classical noise with power spectrum $1/f^{\alpha}$, with (left panel) $\alpha=1$ and (right panel) $\alpha=1.5$.*

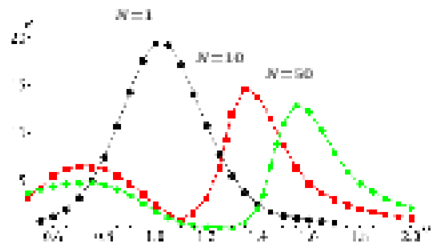

Fig. 2. *Quantum signal-to-noise ratio for different numbers of random bistable fluctuators as a function of the spectral parameter α*

References

[1] C. Benedetti, F. Buscemi, P. Bordone, M. G. A. Paris, Phys. Rev. A 87, 052328 (2013).

[2] C. Benedetti, M.G. A. Paris, S. Maniscalco, Phys. Rev. A 89, 012114 (2014).

[3] C. Benedetti, F. Buscemi, P. Bordone, M. G. A. Paris, Phys. Rev. A 89, 032114 (2014).

[4] C. Benedetti, M.G. A. Paris, Int. J. Quantum Inform. 12, 1461004 (2014).

Twisted photons for simulating quantum walks and probing their effective band structure

Filippo Cardano[1,*], Francesco Massa[1], Hammam Qassim[2], Maria Maffei[1], Ebrahim Karimi[2], Sergei Slussarenko[1], Domenico Paparo[3], Corrado de Lisio[1], Fabio Sciarrino[4], Enrico Santamato[1], Robert W. Boyd[2], and Lorenzo Marrucci[1,3]

[1]*Dipartimento di Scienze Fisiche, Università degli Studi di Napoli Federico II, Complesso Universitario di Monte Sant'Angelo, Via Cintia, 80126, Napoli, Italy*

[2]*Department of Physics, University of Ottawa, 150 Louis Pasteur, Ottawa, Ontario, K1N 6N5 Canada*

[3]*CNR-SPIN, Complesso Universitario di Monte Sant'Angelo, Via Cintia, 80126, Napoli, Italy*

[4]*Dipartimento di Fisica, Sapienza Università di Roma, Roma 00185, Italy*

*filippocardano@gmail.com

Abstract

Quantum walks (QW) [1] were introduced as the quantum counterpart of the classical phenomenon known as random walk. In recent years, it has been demonstrated that search algorithms and universal quantum computation can be based on this quantum process. On the other hand, QWs can be exploited to simulate topological phases and several phenomena occurring in complex systems. Stimulated by this wide applicability, a large effort has been focused, in the last decade, towards implementing stable and scalable protocols for the simulation of a QW. This process has been experimentally realized in variety of physical systems, such as trapped ions or atoms, NMR systems and photons. Photonic approaches have hitherto mainly focused on multi-path schemes, requiring interferometric stability and a number of optical elements that scales quadratically with the number of steps. In contrast, we have experimentally demonstrated [2] a quantum walk taking place in the orbital angular momentum space of light, both for a single photon and for two simultaneous indistinguishable photons. The whole process develops in a single light beam, with no need of interferometers, and requires optical resources scaling linearly with the number of steps. An explicit advantage of this approach is the possibility of manipulating the walker initial state, which can be prepared in any superposition of different lattice sites. In this experiment we prepared Gaussian wavepackets with a finite quasi-momentum, which propagate without a significant change in their shape. Manipulating the coin state and the quasi-momentum in the irreducible Brillouin zone, we probed the underlying dispersion relation and the effective band structure, as resulting by the strong spin-orbit coupling which characterizes the system. Our demonstration introduces a novel versatile photonic platform for implementing quantum simulations, based on exploiting the transverse modes of a single light beam as quantum degrees of freedom.

References

[1] J. Kempe, "Quantum Random Walks: An introductory overview", *Contemp. Phys*, 44, 4 (2003)

[2] F. Cardano *et al.*, "Quantum walks and quantum simulation of wavepacket dynamics with twisted photons", arXiv:1407.5424.

Suppression of quantum locking and momentum rejuvenation as super-boosts for quantum transport

Filippo Caruso
LENS & Dipartimento di Fisica ed Astronomia, Università di Firenze, 50019 Sesto Fiorentino, Italy
QSTAR, Largo Enrico Fermi 2, I-50125 Firenze, Italy
filippo.caruso@lens.unifi.it

Abstract

Transport properties play a crucial role in several fields of science, as biology, chemistry, sociology, information science, and physics. The behavior of many dynamical processes running over complex networks is known to be closely related to the geometry of the underlying topology, but this connection becomes even harder to understand when quantum effects come into play.

Here, we exploit the Kossakoski-Lindblad formalism of quantum stochastic walks [1] to investigate the capability to quickly and robustly transmit energy (or information) between two distant points in very large complex structures, remarkably assisted by external noise and quantum features as coherence – see Fig. 1. An optimal mixing of classical and quantum transport is, very surprisingly, quite universal for a large class of complex networks [2]. This widespread behaviour turns out to be also extremely robust with respect to geometry changes.

In some cases, this can be better understood by means of the notion of invariant subspaces introduced in Ref. [3]. The latter are defined as set of eigenstates of the system Hamiltonian that are orthogonal with the site connected to the sink (quantum locking effect), i.e. they are not affected by the open-system dynamics and their evolution is purely coherent and described by just a global phase. These invariant (trapped) states can be systematically found for any network with some degeneracy, as geometrical symmetries corresponding to large degenerate eigenspaces, and the more they are, the larger is the amount of energy trapped in the system. These subspaces are, hence, suppressed when dephasing noise is added in the dynamics and so the transport becomes more efficient.

However, for some ordered networks, as regular 1D and 2D lattices, there are no invariant subspaces or they are very small, but still the additional presence of noise remarkably enhances the transport efficiency. Therefore, we present a new, simple and intuitive explanation for the intriguing observation that optimally efficient networks are not purely quantum, but are assisted by some interaction with a 'noisy' classical environment. Indeed, by considering the system's dynamics in both the site-basis and the momentum-basis, we show that the effect of classical noise is to sustain a broad momentum distribution, countering the depletion of high mobility terms which occurs as energy exits from the network [4]. This picture predicts that the optimal level of classical noise is reciprocally related to the linear dimension of the lattice; our numerical simulations verify this prediction to high accuracy for regular 1D and 2D networks over a range of sizes up to thousands of sites [5].

Finally, this insight leads also to the discovery that dramatic further improvements in performance occur when a driving field targets noise at the low mobility components.

These results might pave the way for designing optimal bio-inspired geometries of efficient transport nanostructures that can be used for solar energy and also quantum information and communication technologies.

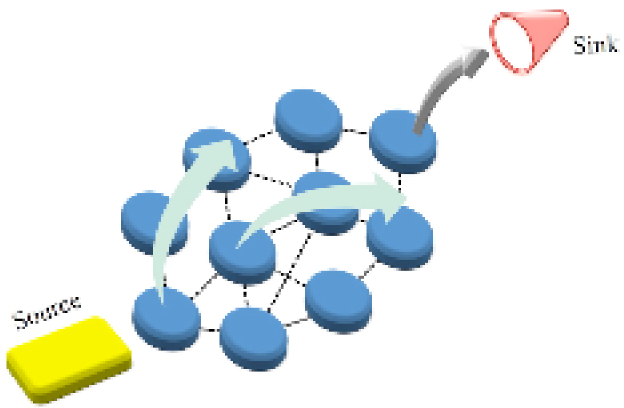

Fig. 1. Energy transfer over a quantum complex network from a source (e.g., light-harversting antenna) to an external trapping site or sink (e.g., reaction center in natural photosynthetic complexes).

References

[1] J.D. Whitfield, C.A. Rodriguez-Rosario, and A. Aspuru-Guzik, "Quantum stochastic walks: A generalization of classical random walks and quantum walks", Phys. Rev. A 81, 022323 (2010).

[2] F. Caruso, "Universally optimal noisy quantum walks on complex networks", New J. Phys. 16, 055015 (2014).

[3] F. Caruso, A.W. Chin, A. Datta, S.F. Huelga, and M.B. Plenio, "Highly efficient energy excitation transfer in light-harvesting complexes: The fundamental role of noise-assisted transport", J. Chem. Phys. 131, 105106 (2009).

[4] Y. Li, F. Caruso, E. Gauger, S.C. Benjamin, "'Momentum rejuvenation' underlies the phenomenon of noise-assisted quantum energy flow", Eprint arXiv:1405.7914 (2014).

[5] The numerical code for ordered networks in [4] is openly available at: http://figshare.com/articles/Quantum_Classical_Hybrid_Transport_Simulations/1050158.

Scalable Quantum State Tomography

M.Cramer
Institut für Theoretische Physik, Albert-Einstein-Allee 11, Universität Ulm, D-89069 Ulm, Germany
marcus.cramer@uni-ulm.de

Abstract

Recent contributions in the field of quantum state tomography have shown that, despite the exponential growth of Hilbert space with the number of qubits, tomography of quantum systems may still be performed efficiently by tailored reconstruction schemes. We discuss some of these (certifiable) scalable methods to reconstruct (pure) mixed states. Scalability relies on the fact that the discussed schemes only require local information about the state.

References

1. T. Baumgratz, D. Gross, M. Cramer, M.B. Plenio, "Scalable reconstruction of density matrices," Phys. Rev. Lett. 111, 020401 (2013).
2. T. Baumgratz, A. Nüßeler, M. Cramer, M.B. Plenio, "A Scalable Maximum Likelihood Method for Quantum State Tomography," New J. Phys. 15, 125004 (2013).
3. M. Cramer, M.B. Plenio, S.T. Flammia, D. Gross, S.D. Bartlett, R. Somma, O. Landon-Cardinal, Y-K. Liu, D. Poulin, "Efficient quantum state tomography," Nat. Commun. 1, 149 (2010).

(Presenting author)

Steady-state entanglement activation in optomechanical cavities

Alessandro Farace[1], Francesco Ciccarello[2], Rosario Fazio[1] and Vittorio Giovannetti[1]
1)NEST, Scuola Normale Superiore and Istituto Nanoscienze-CNR,
(Piazza dei Cavalieri 7, I-56127, Pisa, Italy)
2)NEST, Istituto Nanoscienze-CNR and Dipartimento di Fisica e Chimica,
(Università degli Studi di Palermo, via Archirafi 36, I-90123, Palermo, Italy)
alessandro.farace@sns.it

Abstract

Quantum discord [1], and a number of related indicators, are currently raising a relentless interest as a novel paradigm of non-classical correlations beyond entanglement. Beside merely fundamental aspects, various works have shown that discord is a valuable - so far largely unexplored - resource in quantum information processing. Along this line, quite a striking scheme is entanglement activation [2]. An initial amount of discord between two disentangled parties A1 and A2 of a multipartite system A1 ⊗ A2 ⊗ ... ⊗ AN affects the dynamics so as to establish entanglement across the bipartition (A1 ⊗ A2)(A3 ⊗ ... ⊗ AN), which would not arise otherwise. To date, such a process was proven to be achievable only dynamically, i.e., with no guarantee of a stationary entanglement output in the presence of noise.

Here [3], we discover a discord-activated mechanism yielding steady-state entanglement production in a realistic continuous-variable setup. This comprises two coupled optomechanical cavities [4], where the optical modes (OMs) communicate through a fiber. We first use a simplified model to highlight the creation of steady-state discord between the OMs. We show next that such discord improves the level of stationary optomechanical entanglement attainable in the system, making it more robust against temperature and thermal noise.

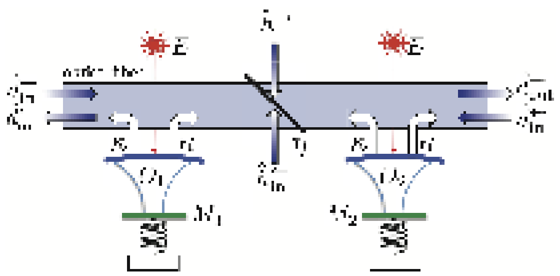

Fig 1. Sketch of the system: two laser-driven optomechanical cavities coupled to an optical fiber. This indirect coupling creates discord between the two optical modes, which is transformed into optomechanical entanglement.

References

[1] L. Henderson and V. Vedral, "Classical, quantum and total correlations", J. Phys. A: Math. Gen. **34**, 6899 (2001).
H. Ollivier and W. Zurek, "Quantum discord: a measure of the quantumness of correlations", Phys. Rev. Lett. **88**, 017901 (2001).
K. Modi et al, "The classical-quantum boundary for correlations: discord and related measures", Rev. Mod. Phys. **84**, 16551707 (2012).

[2] M. Piani et al, "All nonclassical correlations can be activated into distillable entanglement", Phys. Rev. Lett. **106**, 220403 (2011)
L. Mazzola and M. Paternostro, "Activating optomechanical entanglement", Sci. Rep. **1**, 199 (2011)

[3] A. Farace et al, "Steady-state entanglement activation in optomechanical cavities", Phys. Rev. A **89**, 022335 (2014)

[4] M. Aspelmeyer, T. J. Kippenberg, F. Marquardt, "Cavity optomechanics", arXiv:1303.0733 (2013)

Stochastic unravelling of the thermal master equation

Marco G. Genoni
Department of Physics & Astronomy, University College London, Gower Street, London, WC1E 6BT, United Kingdom
marco.genoni@ucl.ac.uk

Stefano Mancini
School of Science and Technology, University of Camerino, I-62032 Camerino, Italy
INFN, Sezione di Perugia, I-06123 Perugia, Italy

Alessio Serafini
Department of Physics & Astronomy, University College London, Gower Street, London, WC1E 6BT, United Kingdom
Scuola Normale Superiore, I-56126 Pisa, Italy

I. Abstract

We analyse the unravelling of the quantum optical master equation at finite temperature, due to direct continuous, detection of the environment. We start by defining the Positive Operator Valued Measure (POVM) corresponding to general-dyne detection, by also presenting a corresponding feasible measurement scheme able to implement it. Then, we derive the stochastic master equation obtained by considering the interaction between the system and a reservoir at thermal equilibrium, which is measured according to the POVM previously determined. Further, drawing from the notion that the thermal state of the environment may be regarded as the local state of a lossy and noisy two-mode squeezed state, we consider conditional dynamics ("unravellings") resulting from the homodyne detection of the two modes of such a state. Thus, we identify a class of unravellings parametrised by the loss rate suffered by the environmental two-mode state, which interpolate between direct detection of the environmental mode (occurring for total loss, whereby no correlation between the two environmental modes is left) and full access to the purification of the bath (occurring when no loss is acting and the two-mode state of the environment is pure). We finally shed some light on the counterintuitive result according to which a larger degree of squeezing is obtainable by continuous measurement and feedback, by increasing the temperature of the environment: such optimal values can be indeed obtained only when a fully purified bath is accessible, whereas direct detection of the environment is not able to reach the maximal steady-state squeezing.

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Vibrations, Quanta and Biology

S. F. Huelga[1]

[1] *Institute for Theoretical Physics, Albert-Einstein-Allee 11, University Ulm, D-89069 Ulm, Germany*

Abstract

Quantum biology is an emerging field of research that concerns itself with the experimental and theoretical exploration of non-trivial quantum phenomena in biological systems [1, 2]. In this overview talk we aim to bring out fundamental assumptions and questions in the field, identify basic design principles and develop a key underlying theme – the dynamics of quantum dynamical networks in the presence of an environment and the fruitful interplay that the two may enter. In particular, we will discuss dynamical processes of relevance in photosynthesis. Photosynthetic architectures generally comprise pigment-protein complexes (PPC) to harvest sunlight that is subsequently transferred in the form of excitonic energy across the PPC and reaction centers to convert electronic excitations into a stable charge separated state. We will show that the non-trivial spectral structures of the environmental fluctuations and particularly the presence of discrete, underdamped vibrational modes lead to the generation and sustenance of both oscillatory energy transport and electronic coherence on timescales that are comparable to excitation energy transport [3]. These results, together with the recent observation of coherent effects in the process of charge separation in the Photosystem II reaction center [4], give ground to the possibility that there could exist a quantitative link between coherent dynamics and efficient biological function.

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Structure light: concepts and applications

Ebrahim Karimi and Robert Boyd
Department of Physics, University of Ottawa, 150 Louis Pasteur, Ottawa, Ontario, K1N 6N5 Canada
ekarimi@uottawa.ca

Abstract

Since the first observation by Johannes Kepler, it has been well understood that a light beam carries linear momentum upon propagation. However, physicists needed much more time to realize and demonstrate that a light beam also possesses angular momentum, which originates from two different types of rotation: spin angular momentum (SAM) and orbital angular momentum (OAM) [1]. These two different forms of rotation are associated with two different features of light: the vectorial nature of the electromagnetic field, and the phase-front of the beam, respectively. Optical beams with twisted phase-front possess a well-defined integer value of OAM and have an essential singularity at their beam origin, where an optical vortex is located [2]. The phase of the optical beam around this point of zero intensity is undefined, and light around this point possesses angular momentum. John Nye and Sir Michael Berry observed those points and called them points of phase dislocation [3], but later they were named phase singular points [4]. More recently, our research team showed that the radial index (the forgotten quantum number) of the paraxial wave associated with the radial phase and intensity distribution of the optical mode [5,6] can be used to label a single photon in addition to the degrees of freedom already known [7]. This opens up a new route toward implementing quantum algorithms with single beam radial masks. Furthermore, optical beams with specific transverse modes and polarisation states result in complex space-varying polarisation and intensity distributions known as vector beams and in some particular cases reduces into vector-vortex beams [8,9]. Surprisingly, such a beam in the single photon regime leads to a single photon multi-degrees of freedom entangled state suitable for novel quantum applications such as dense-coding and implementing novel quantum protocols [10-12]. This quite novel branch of optics gives promising opportunities to develop devices to control fluid flow on a micro-scale, improve resolution on micro and astronomical scales, increase the information capacity in classical and quantum communication, and quantum computation and metrology.

The fundamental physics of phase and vector singularities, linear and angular momentum, and the radial momentum of light will be the subject of my talk. Applications of these modes in modern physics will also be discussed.

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(Presenting author)	

Optical Hybrid Quantum Information

Julien Laurat

Laboratoire Kastler Brossel, Université P. et M. Curie,

Ecole Normale Supérieure and CNRS, 4 place Jussieu, 75252 Paris Cedex 05, France

julien.laurat@upmc.fr

Abstract

Quantum information protocols are commonly based on two different kinds of encoding. Some experiments are performed with 'discrete-variables', where the information is encoded in a two-dimensional Hilbert space, for instance on the polarization of single photons. Other experiments focus on the 'continuous-variable' approach, where the information is encoded in an infinite-dimensional Hilbert space, for instance on the quadrature components of light. Both encodings have advantages and drawbacks when they come to sophisticated protocols. Mixing the two approaches has recently led to a so-called 'hybrid quantum information' aiming at merging the properties of both [1]. I will illustrate this approach by some recent experiments, well-suited for long-distance networking and where discrete and continuous variables are combined.

After a general overview, including a quantum repeater architecture based on this approach [2], I will first report on quantum state engineering experiments with high-fidelity, e.g. the generation of single-photon and two-photon Fock states and superposed coherent states based on continuous-wave optical parametric oscillators [3,4]. Such efficient generation is a requisite for implementing further experimental protocols.

The second part of the talk will then focus on a hybrid protocol for witnessing single-photon entanglement in a large-scale network [5,6]. Such entanglement constitutes the simplest form of entanglement. Yet it provides a valuable resource in quantum information science. It lies at the heart of quantum networks, as it can be used for quantum teleportation, swapped and purified with linear optics. The main drawback of such entanglement is the difficulty in measuring it. The proposed operational witness uses homodyne measurements and is based on a Bell-type scenario. Significantly, it does not need postselection, uses local measurements only, and does not rely on assumptions about the dimension of the measured state. We demonstrated this witness, and its robustness with losses. This test highlights the potential of optical hybrid methods, where discrete entanglement is efficiently characterized via continuous-variable measurements, in verifying the proper functioning of future quantum networks.

Finally, I will present the generation of entanglement between optical qubits of different types, i.e. particle-like and wave-like, located at distant places and connected by a lossy channel [7], as sketched on Figure 1. Such hybrid entanglement of the form |+>|α >+|->|-α>, which is a key resource for a variety of recently proposed schemes, including quantum cryptography and computing, enables to convert information from one Hilbert space to the other via teleportation and therefore connect remote quantum processors based upon different encodings. Beyond its fundamental significance for the exploration of entanglement and its possible instantiations, the realized optical circuit opens the promises for heterogeneous network implementations, where discrete and continuous-variable operations and techniques can be efficiently combined.

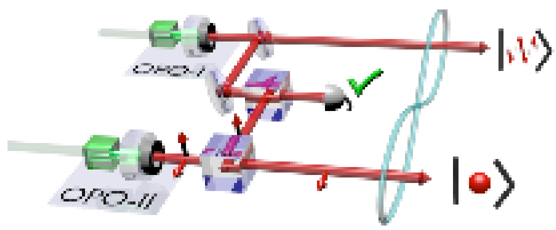

Fig. 1. Hybrid entanglement of light, a resource to connect remote quantum nodes based on different information encodings.

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From quantum data locking to the quantum enigma machine

Cosmo Lupo, Massachusetts Institute of Technology

July 11, 2014

One major contemporary application of quantum mechanics is within cryptography. In quantum key distribution, the goal is to distribute secret keys among two legitimate parties. Once a secret key is shared, it is used to encrypt a message on a public channel, where a third party has negligible probability of successful decryption. A drawback, however, is that the key and the message must have equal length. This yields a major challenge for quantum key distribution, i.e., the distribution of secret keys at bit rates comparable to standard communication technology.

To explore alternative scenarios, we consider the phenomenon of quantum data locking. According to this unique quantum phenomenon, a small secret key can be used to "lock" an exponentially longer message, if this message is suitably encoded into a quantum system. This resembles the XX century enigma machine, a cipher that used a short secret key to encrypt a much longer message. Unlike the classical enigma machine, our "quantum enigma machine" is provably secure. The reason for that is that quantum data locking violates the famous theorem of Shannon's, according to which the secure encryption of a message of n classical bits requires a secret key of at least n bits.

We answer several questions about the possibility of applying quantum data locking for cryptography. One of them concerns the locking of information through noisy channels. We put the problem of quantum data locking of quantum channels on a solid theoretical ground. We formally define the locking capacities of a quantum channel, and prove bounds and results concerning these quantities.

The power of quantum data locking originates from a large gap existing between two security criteria for quantum cryptography quantified by two entropic quantities: the Holevo and the accessible information. We show that the latter becomes a sensible security criterion if an upper bound on the coherence time of the eavesdropper's quantum memory is known. Under this condition we introduce protocols for key distribution through a memoryless qudit channel. For channels with enough symmetry, such as the d-dimensional erasure and depolarizing channels, these protocols allow secret key distribution at an asymptotic rate as high as the classical capacity (that is, the rate of classical communication without any privacy requirement) minus one bit.

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Non-Markovian quantum dynamics: when the past comes back

Quantum systems interacting with their external environment are generally investigated to understand the detrimental effects of noise on their quantum properties. Reservoir engineering techniques combined with increasingly sophisticated theoretical approaches to open systems dynamics, however, nowadays allow to ask new kinds of questions: which types of frequency spectra are best suited to securely send information along a noisy quantum channel? Which characteristics of the environment mostly favour efficient transport along quantum networks? Are reservoir memory effects useful for quantum devices?

In this talk I will give partial answers to some of these questions, opening up new perspectives on the noise-induced limiting factors of quantum technologies and how to overcome them. I will firstly discuss how reservoir engineering can be used to optimise channel capacities and even obtain length-independent finite-capacity channels [1].
I will then present a formal analogy between open system dynamics and entanglement theory and, building from this analogy, I will introduce a hyerarchy of non-Markovianity measures and discuss the concept of entanglement witnesses [2].

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Opto-mechanics toward quantum physics

F. Marin[a,b,c], M. Bonaldi[d,e], A. Borielli[d,e], F.S. Cataliotti[a,b,c], L. Marconi[a], F. Marino[c,f], G. Pandraud[g], A. Pontin[a,c], G.A. Prodi[e,h], P.M. Sarro[g], E. Serra[e,g,i]

[a] Dipartimento di Fisica e Astronomia, Università di Firenze, via Sansone 1, 50019 Sesto Fiorentino (FI), Italy
[b] European Laboratory for Non-Linear Spectroscopy (LENS), via Carrara 1, 50019 Sesto Fiorentino (FI), Italy
[c] Istituto Nazionale di Fisica Nucleare (INFN), Sezione di Firenze, via Sansone 1, 50019 Sesto Fiorentino (FI), Italy
[d] Institute of Materials for Electronics and Magnetism, Nanoscience-Trento-FBK Division, 38123 Povo, Trento, Italy
[e] INFN, Trento Institute for Fundamental Physics and Application, 38123 Povo, Trento, Italy
[f] CNR-INO, L.go Enrico Fermi 6, 50125 Firenze, Italy
[g] Delft University of Technology, DIMES Technology Centre, Feldmanweg 17, 2628 CT Delft, The Netherlands
[h] Dipartimento di Fisica, Università di Trento, 38123 Povo, Trento, Italy
[i] Center for Materials and Microsystems (CMM), FBK, 38123 Povo, Trento, Italy
marin@fi.infn.it

Quantum opto-mechanics is rapidly evolving field with a strong potential impact both in the analysis of fundamental aspects of quantum physics, and for applications. Even the domain of quantum communications is likely to benefit from such research. For instance, a micro-oscillator can be used to store quantum information (taking advantage from the weak decoherence of high-Q oscillators), or to connect microwave to optical channels in hybrid systems. A crucial preliminary task is producing opto-mechanical systems fully working in the quantum regime, i.e., getting rid of classical noise sources such as thermal fluctuations. Such a major breakthrough have been recently achieved in few key experiments, that have obtained nano-mechanical oscillators with occupation number below unity, and squeezed light produced by opto-mechanical interaction.

We will present the development of Micro-Opto-Mechanical Systems (MOMS), based on silicon wafer technology, that achieve very high levels of mechanical quality (i.e., high mechanical Q, yielding weak coupling with the background and low thermal fluctuations) and optical quality (allowing their use in high Finesse optical cavities). As a preliminary step toward the production of non-trivial quantum state in macroscopic systems, we will also present the confinement of a MOMS in a squeezed thermal state, obtained by parametric modulation of the optical spring. In a recent work [1], we have indeed proposed and implemented an experimental scheme based on parametric feedback control of the oscillator, which stabilizes the amplified quadrature while leaving the orthogonal one unaffected. This technique allows us to surpass the -3dB limit in the noise reduction, associated to parametric resonance, with a best experimental result of -7.4dB. While the present experiment is in the classical regime, in a moderately cooled system the technique can be efficiently exploited to produce strong squeezing of a macroscopic mechanical oscillator below the zero-point motion.

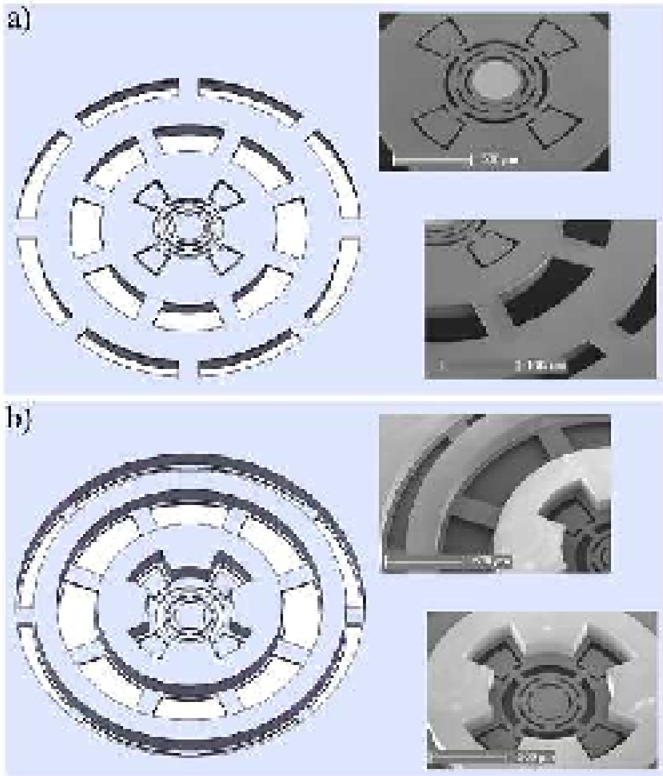

Fig. 1. CAD drawings and SEM details of two opto-mechanical oscillators with resonant frequency of the main mode 117 kHz and 150 kHz. a) Front side with the elastic structure etched in the device layer and the circular mirror deposited over the central disk. b) Back side with the circular frame etched in the handle layer.

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Non-interferometric Test of Collapse Models in Optomechanical Systems

The test of modifications to quantum mechanics aimed at identifying the fundamental reasons behind the un-observability of quantum mechanical superpositions at the macro-scale is a crucial goal of modern quantum mechanics. Within the context of collapse models, current proposals based on interferometric techniques for their falsification are far from the experimental state-of-the-art. In this talk I will discuss an alternative approach to the testing of quantum collapse models that, by bypassing the need for the preparation of quantum superposition states might help us addressing non-linear stochastic mechanisms such as the one at the basis of the continuous spontaneous localisation model.

Geometric quantum discords

Dominique Spehner
Université Grenoble Alpes, Institut Fourier, F-38000 Grenoble, France and
CNRS, LPMMC, F-38000 Grenoble, France

The geometric quantum discord is a measure of quantum correlations which has similar properties than the quantum discord proposed by Ollivier and Zurek [1] and Henderson and Vedral [2] to quantify the degree of non-classicality in a bipartite system. It is defined as the minimal distance of the system state to a classical state with respect to one subsystem, that is, to a state with zero quantum discord [3]. It is also of interest for applications in irreversible dynamical processes to determine the closest classical state(s) to a given state. We will review in this talk some recent results on the geometric discord and closest classical states when the distance on the set of quantum states is either the Bures or the quantum Hellinger distance. For pure states, the corresponding discords reduce to known entanglement-monotone measures. For mixed states, the discord with Bures distance coincides with the optimal success probability of an ambiguous quantum state discrimination task [4]. We will show some general relations and inequalities between the discords for the Bures, quantum Hellinger, and Hilbert-Schmidt distances and argue that analytical explicit expressions can be obtained at least when the measured subsystem is a qubit [5, 6].

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Generating continuous variables qubits using arbitrary quantum superpositions of single-photon operations

A. Coelho, L.S. Costanzo, A. Zavatta & M. Bellini
Istituto Nazionale di Ottica (INO-CNR), Florence, Italy.
and LENS and Department of Physics, University of Florence, Florence, Italy.

Full quantum state engineering can be efficiently accomplished by the experimental application of single-photon addition and subtraction operations and their arbitrary superpositions to light states [1]. Besides demonstrating important quantum information tasks like noiseless amplification, by exploiting the action of such operations on different spatio-temporal modes it is possible to generate a new type of hybrid entanglement between a single-photon and a coherent state [2]. Recently, hybrid entanglement in a free-traveling field was identified as a useful resource for optical quantum information processing [3].
Based on such schemes, the realization of a new kind of qubit for quantum information encoding with continuous variables will be presented.

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Quantum State Routing and many-qubit Quantum State Transfer via a single channel

Tony J. G. Apollaro[1,2,3]

[1]Dipartimento di Fisica, Università della Calabria, 87036 Arcavacata di Rende (CS), Italy

[2]INFN sezione LNF-Gruppo collegato di Cosenza, Italy

[3]Centre for Theoretical Atomic, Molecular, and Optical Physics, School of Mathematics and Physics, Queen's University Belfast, BT7 1NN, United Kingdom

tonyapollaro@fis.unical.it

Abstract

The transfer of an unknown quantum state (QST), from a sender to a receiver, is one of the main requirements to perform quantum information processing tasks (QIP). In this respect, QST of a single qubit by means of spin chains has been widely discussed, and many protocols aiming at performing this task have been proposed (for a review see Refs.[1] and references therein). Nevertheless, the state transfer of more than one qubit has not been properly addressed so far. The possibility of using a single quantum channel to implement different QIP tasks, such as, e.g., quantum state routing or the transfer of the state of n qubits, would offer significant advantages with respect to the use of multiple quantum channels, each one specifically devoted to a single QIP task.

In this talk quantum state routing (QSR) and the transfer of the quantum state of n>1 qubits (n-QST) by means of spin-1/2 chains is addressed, in the framework of minimal engineering settings.

In the case of QSR, the aim is to design a transfer scheme such that the sender is in condition to choose the receiver (of the state to be transferred) among several spins on a lattice by means of local operations. In Fig.1, a sketch of the protocol fulfilling QSR is depicted [2].

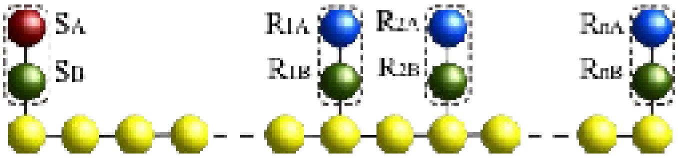

Fig. 1. Qubit S_A (red) embodies the sender and qubits {R_{1A}, R_{2A},...,R_{nA}} (blue) the receivers. By tuning the magnetic field on S_B to one of the value of the (different) magnetic fields on R_{kB} (green), the quantum state on S_A is resonantly transferred to qubit R_{kA}.

The transfer of a quantum state of n>1 qubits (n-QST) consists in achieving a high-fidelity transfer of the quantum state of many qubits via the use of a single spin chain. To this aim, a modified version of the 1-QST scheme proposed in Ref.[3] is adopted. In Fig.2 an instance of such a protocol is depicted in the case of 2-QST between the two pairs of qubits located at the edges of a spin-1/2 chain.

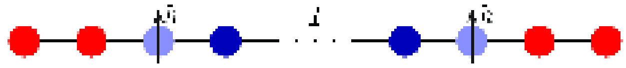

Fig. 2. The first and last two qubits (red) of the open chain embodies the sender and receiver, respectively. They are coupled to a single quantum channel Γ (blue). The first and last spins of Γ (light blue) experience a strong magnetic field that induces Rabi-like oscillations of the excitations between the sender and the receiver block, yielding a high-quality state transfer for arbitrary 2 qubit states.

For the 2-QST, an analytical expression of the average fidelity as a function of the allowed excitations transfer amplitude are derived and, hence, theoretical investigations on the search and optimization of other QST protocols may be triggered [4].

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Gaussian Quantum Discord: Theory and Experiment

D. Buono[1], W. Roga[1], G. Nocerino[2], A. Porzio[3] and F. Illuminati[1,4,5]

[1] Dipartimento di Ingegneria Industriale, Università degli Studi di Salerno, via Giovanni Paolo II 132, I-84084 Fisciano (SA), Italy

[2] Trenitalia spa, DPR Campania, Ufficio di Ingegneria della Manutenzione, IMC Campi Flegrei, via Diocleziano 255, 80124 Napoli, Italy

[3] CNR—SPIN, Unita di Napoli, Complesso Universitario Monte Sant'Angelo, I-80126 Napoli, Italy

[4] CNISM Unità di Salerno, I-84084 Fisciano (SA), Italy and

[5] INFN, Sezione di Napoli, Gruppo collegato di Salerno, I-84084 Fisciano (SA), Italy

danielabuono@yahoo.com

Abstract

We define the Gaussian discord of response as the distance between the state and its closest image under Gaussian local unitary transformations. We analyze the properties of such new measure under different metrics, that induce well defined quantum correlation measures, as Hellinger, Bures, and trace distance [1]. We present explicit formulas and numerical results.

We also present experimental tests that confirm the theoretical findings [2].

Moreover, we show that the Gaussian discord of response has a natural operational interpretation related to the reading efficiency in a quantum reading protocol [3]. In fact, the amount of quantum correlation in a given transmitter, as quantified by Gaussian discord of response, is directly related to the probability of error in a Gaussian protocol of quantum reading.

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Understanding freezing of quantum correlations from first principles

Marco Cianciaruso[1,2], Thomas R. Bromley[1], and Gerardo Adesso[1]
[1]School of Mathematical Sciences, The University of Nottingham, University Park, NG7 2RD, United Kingdom
[2]Dipartimento di Fisica "E. R. Caianiello", Università degli Studi di Salerno, Via Ponte don Melillo, I-84084 Fisciano (SA), Italy
cianciaruso.marco@gmail.com

I. Abstract

Bipartite mixed states can manifest quantum correlations more general than entanglement. The quantification of these correlations relies on so called bona fide discord-like measures, which all satisfy a set of necessary requirements but, in general, are not equivalent. Nevertheless, all the known bona fide discord-like quantifiers agree on the fact that general quantum correlations are more robust than entanglement against noise. In particular, they all manifest freezing under local non-dissipative decoherent evolutions, provided that specific initial conditions are set, whereas entanglement undergoes the well-known sudden death. This freezing phenomenon is quite appealing since it implies that every communication protocol relying on general quantum correlations as a resource will run with a performance unaffected by noise in the specific dynamical conditions. Therefore, it is natural to ask whether freezing just happens as a mathematical accident or it bears a deeper physical meaning which should manifest independently of the adopted measure. Answering to this question is the objective of our work.

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(Presenting author) *Marco Cianciaruso*	

Radiative properties of matter in collapse models

Authors Name/s: Sandro Donadi

Affiliation 1: Department of Physics, University of Trieste, Strada Costiera 11, 34151 Trieste, Italy

Affiliation 2: Istituto Nazionale di Fisica Nucleare, Trieste Section, Via Valerio 2, 34127 Trieste, Italy.

e-mail addresses: sandro.donadi@ts.infn.it or sandrodonadi@yahoo.it

I. Abstract

Collapse models are phenomenological models, proposed to solve the measurement problem, where the evolution of the state vectors is driven by a non-linear and stochastic equation [1-4]. These models make predictions different from quantum mechanics hence, they can be tested. For example, collapse models predict emission of radiation also from systems that should not emit radiation according to standard quantum mechanics [5-9].

In this talk, after a general introduction on collapse models, we discuss about the bounds set by radiation emission on the parameters of collapse models and about possible ways to improve them.

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Lambda Scheme for Population Transfer in Superconducting Qutrits

G. Falci, E. Paladino, A. D'Arrigo, A. La Cognata, M. Berritta and P. Di Stefano
Dipartimento di Fisiaca e Astronomia, Università di Catania
& CNR-IMM-MATIS, Catania & CSFNSM, Catania
gfalci@dmfci.unict.it

Abstract

The implementation of a Lambda scheme in superconducting "artificial atoms" could allow detection of STimulated Raman Adiabatic Passage (STIRAP) and other quantum manipulations in the microwave regime. Despite many theoretical proposals this problem is still experimentally unsettled. We have shown [1] that implementing an efficient Lambda system in a "qutrit" depends on the tradeoff between efficient coupling and non-Markovian (low-frequency 1/f [2]) components of noise. Indeed protection from noise and suppression of pump coupling depend on the same symmetry and are conflicting issues. Substantial efficiency can be achieved within present fabrication technology which allows to exploit tunable symmetry breaking. We find a number of results [2] uniquely due to non-Markovianity of noise, namely: (a) the efficiency for STIRAP depends essentially on noise channels in the "qubit" trapped subspace; (b) a simple physically motivated figure of merit for evaluation of design and operating prescriptions is derived; (c) a scheme of effective dynamical decoupling related to symmetries of the three-level band-structure of the device is found [3].

We next introduce two important ingredients towards the implementation of population transfer and quantum state engineering in solid-state Circuit-QED or nanoelectromechanichal architectures. The first is a 2+1-photon scheme allowing for a Lambda configuration at the symmetry point [3]. Pump coupling and noise protection now both increase for increasing Josephson energy, this advantage being however limited by leakage from the three-level subspace for a more and more harmonic spectrum.

The second issue is a protocol where usual two-photon STIRAP is triggered by a suitable modulation of detunings, allowing to operate with an always on field. The absence of an exact dark state makes the phenomenon of distructive interference untrivial. This operation mode may allow to switch couplings to quantized modes in solid-state architectures.

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(Presenting author)

Quantum Frustration in complex systems

S. M. Giampaolo[1], B. Hiesmayr[1] and F. Illuminati[2]

1 University of Vienna, Faculty of Physics, Boltzmanngasse 5, 1090 Vienna, Austria

2 Dipartimento di Ingegneria Industriale, Università degli Studi di Salerno, Via Ponte don Melillo, I-84084 Fisciano (SA), Italy

smgiampaolo72@gmail.com

Abstract

The dynamics of a many body system is governed by an Hamiltonian that is the sum of local terms, i.e. terms that act only on a subset of the elements of the system. Following the principle of minimal energy, each one of these terms acts to minimize the energy. However, when the subsystems overlap, there may be conflicting interactions that forbid the existence of a configuration able to reach the minimum simultaneously. This physical phenomenon is known as frustration. While for classical systems, frustration is associated to some non trivial geometric property, due to quantum non-commutativity and entanglement, classically unfrustrated systems may admit frustrated quantum counterparts. Recently it was introduced a measure able to quantify the frustration that provides a unified treatment of both classical and quantum system and relate quantitatively the frustration to the entanglement and shared classical correlations.

In the present talk we wish to illustrate some new results about the behavior of the quantum frustration in a large class of spin-1/2 models, i.e. the anisotropic Heisenberg models without any restriction on the range of interaction or on the geometry of the lattice. Such class of models or at least a part of it, can be efficiently simulated, nowadays, using many experimental device as trapped ions, ultracold atoms loaded in optical lattices or NMR devices. Because the Hamiltonian that we are considering can be see as a sum of two body terms, we can naturally individuate as elementary subsystems, the pairs of directly interacting spins. For such elementary subsystems we introduce a classification between classical and quantum frustration based on the degeneracy of the local ground space. For the elementary subsystems that show quantum frustration, we will prove that there exist a relation between frustration and concurrence. Because the frustration is associated to the entanglement between the sub-system S and the rest of the system while the concurrence is a measure of the entanglement in S, such relation drive us to the formulation of a new expression of the entanglement monogamy. We will then focus on models characterized by the presence of both classical and quantum frustration and we show that, in such cases, the frustration pattern must depend on the Hamiltonian parameters and when they vary we may obtain a transition between two or more different frustration patterns We also connect such kind of transition to experimentally observable quantities that average the system proprieties as the quasi momentum distribution in the optical lattices.

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Presenting Authors: S. M. Giampaolo	

Entanglement and complementarity

L. Maccone
Università di Pavia

Abstract

We show that states that have more correlations among complementary observables must be entan- gled. The reverse is false: general entangled states do not have more correlations on complementary observables than separable ones. We show that this is true for different measures of correlation: mutual information, the Pearson correlation coefficient, and the sum of conditional probabilities. This can be used as a state-independent test of entanglement and as entanglement measure. We also show that states with nonzero discord typically have less correlation than classically correlated states.

Useful Entanglement in Quantum Metrology

Luca Pezze' and A. Smerzi
QSTAR, INO-CNR and LENS, Largo Enrico Fermi 2, 50125 Firenze
luca.pezze@ino.it

Abstract

Entanglement is the key quantum resource for improving measurement sensitivity beyond classical limits. Yet, not all entangled states are equally useful for metrological purposes: the "useful" ones are those, and only those, which have a Fisher information larger than the number of particles (or qubits) [1,2]. It is thus clear that devising model-independent theoretical tools to guide the experimental extraction of the Fisher information is of crucial interest in quantum metrology. In this talk I will review the theory and discuss a recent experiment with Bose-Einstein condensates of a large number of atoms [3] where the Fisher information has been obtained via particle counting and without access to the full density matrix.

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(Presenting author)

Geometric measures of quantum correlations: characterization, quantification, and comparison by metrics and operations

Wojciech Roga
Dipartimento di Ingegneria Industriale, Università degli Studi di Salerno, Via Giovanni Paolo II 132, I-84084 Fisciano (SA), Italy

The geometric measure of quantum correlations can be defined through the distance between a given state and the set of states with the classical correlations only (geometric discord) [1], but also through the reaction of a given bi-partite state on a local measurement (measurement induced geometric discord) [2] or through the response of the state on a local unitary perturbation (discord of response) [3]. The Bures distance, trace distance and Hellinger distance defining geometric measures of quantum correlations are analyzed. Several recently obtained relations between the discord of response and the other types of geometric discords are discussed for different metrics [4]. Due to these relations the trace or the Bures geometric discords which were computed earlier for several classes of states automatically provide the analytical formulas for the discord of response defined by the respective distances. On the other hand the known value of Hellinger discord of response can be used to compute the Hellinger type geometric discord. The maximally quantum correlated states with respect to the discord of response induced by different norms are discussed as well.

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Electrical control of a long-lived spin qubit in a Si/SiGe quantum dot

P. Scarlino[1†], E. Kawakami[1†], D. R. Ward[2], F. R. Braakman[1,3], D. E. Savage[2], M. G. Lagally[2], Mark Friesen[2], S. N. Coppersmith[2], M. A. Eriksson[2], and L. M. K. Vandersypen[1]

[1]Kavli Institute of Nanoscience, TU Delft, Lorentzweg 1, 2628 CJ Delft, The Netherlands.

[2]University of Wisconsin-Madison, Madison, WI 53706, USA.

[3]Current address: Department of Physics, University of Basel, 4056 Basel, Switzerland

Nanofabricated quantum bits permit large-scale integration but usually suffer from short coherence times due to interactions with their solid-state environment. The outstanding challenge is to engineer the environment so that it minimally affects the qubit, but still allows qubit control and scalability. Here we demonstrate a long-lived single-electron spin qubit in a Si/SiGe quantum dot with all-electrical two-axis control (*1*). The spin is driven by resonant microwave electric fields in a transverse magnetic field gradient from a local micromagnet (*2*), and the spin state is read out in single-shot mode (*3*). Electron spin resonance occurs at two closely spaced frequencies, which we attribute to two valley states. Thanks to the weak hyperfine coupling in silicon, a Ramsey decay timescale of 1us is observed, almost two orders of magnitude longer than the intrinsic timescales in GaAs quantum dots, while gate operation times are comparable to those reported in GaAs. The spin single Hahn echo decay time is around 70us and can be extended till 300us applying a CPMG 32 echo pulses sequence, possibly limited by intervalley scattering. These advances strongly improve the prospects for quantum information processing based on quantum dots.

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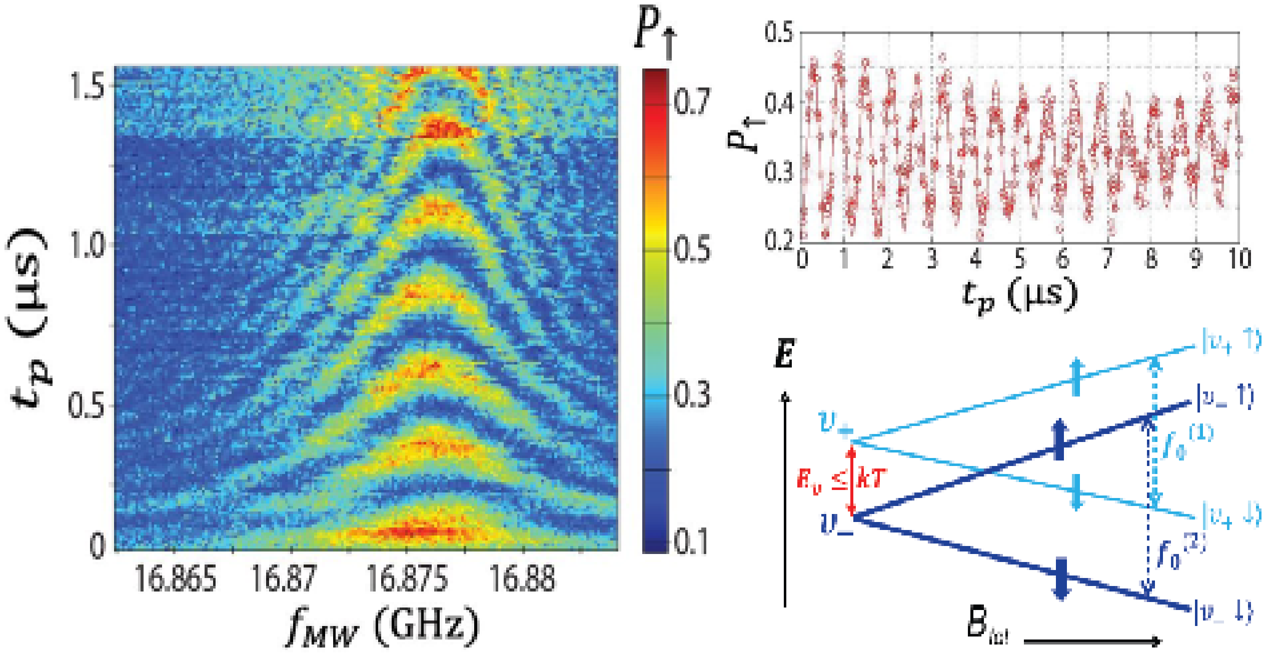

(left and upper right) Rabi oscillations for the single electron spin confined in a single depletion quantum dot defined in Si/SiGe; (lower right) Energy level diagram of the spin transition involved in the driving process;

Detecting multiparticle entanglement of Dicke states

Géza Tóth[1,2,3*] and Giuseppe Vitagliano[1]

[1]Department of Theoretical Physics, University of the Basque Country UPV/EHU, P.O. Box 644, E-48080 Bilbao, Spain

[2]IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao, Spain

[3]Wigner Research Centre for Physics, Hungarian Academy of Sciences, P.O. Box 49, H-1525 Budapest, Hungary

[*]toth@alumni.nd.edu, http://www.gtoth.eu

There have been many experiments aiming at preparing larger and larger entangled quantum states. Recently, it has been realized that apart from Greenberger-Horne-Zeilinger (GHZ) states and cluster states, symmetric Dicke states of the type

$$|D_N^{(N/2)}\rangle = \binom{N}{N/2}^{-\frac{1}{2}} \sum_k \mathcal{P}_k(|0\rangle^{\otimes N/2} \otimes |1\rangle^{\otimes N/2}), \tag{1}$$

have advantageous properties. (Here the summation is over all distinct permutations.)

First of all, the squared overlap of (1) with biseparable states is ½ for large particle numbers [1]. Only cluster states and GHZ states known to have this property, for other states the overlap is larger. This makes symmetric Dicke states good candidates for experiments creating many-particle entanglement, as only a fidelity larger than ½ is required to detect genuine multipartite entanglement.

The symmetric Dicke state (1) also has optimal metrological properties. It maximizes the sum of three quantum Fisher information terms [2-3]

$$F_Q[\varrho, J_x] + F_Q[\varrho, J_y] + F_Q[\varrho, J_z],$$

similarly to GHZ states.

Finally, the state (1) can be created naturally in photonic systems [4-5] and also in cold gases [6-7]. The state (1) is also more robust to noise than GHZ states.

In our contribution, we present entanglement conditions detecting entanglement close to the symmetric Dicke state (1). They are based on collective measurements, thus can be applied in an ensemble of very many particles.

First, we present a spin squeezing parameter that can detect entanglement close to Dicke states [8-9]

$$\xi_{Os}^2 := (N-1)\frac{(\Delta J_z)^2}{\langle J_x^2\rangle + \langle J_y^2\rangle - \frac{N}{2}}.$$

Then we discuss how to detect multipartite entanglement close to such states with a nonlinear condition [11].

Finally, we show experimental results for an ensemble of 8000 cold atoms, in which 28 particle entanglement is detected, even allowing for an uncertainty of 2 standard deviations in the measured values [11]. (See Fig. 1.)

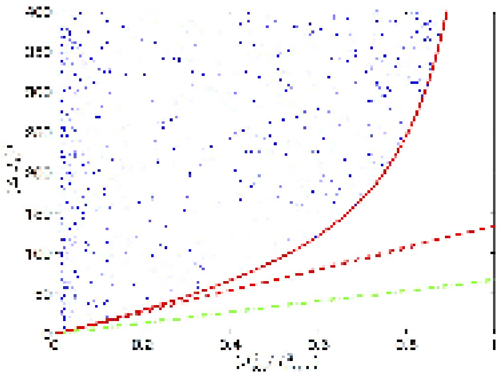

Fig. 1. *Detection of multipartite entanglement for N=8000 particles. Points corresponding to states with at most 28-particle entanglement are above the curve. Any state below the curve has a multiparticle entanglement of more than 28 particles.* $J_{eff}=J_x^2+J_y^2$, $J_{max}=N/2$. *For the description of the linear conditions, see Refs. [10,11].*

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(Géza Tóth

Quantum environment for a longer coherence time

P. Liuzzo Scorpo [1], A. Cuccoli [1,2], P. Verrucchi [3,2,1]

1 : Dipartimento di Fisica, Universita' di Firenze, Via G.Sansone 1, I-50019 Sesto Fiorentino (FI), Italy
2 : Istituto Nazionale di Fisica Nucleare, Sezione di Firenze, Via G.Sansone 1, I-50019 Sesto Fiorentino (FI), Italy
3 : Istituto dei Sistemi Complessi CNR, Via G.Sansone 1, I-50019 Sesto Fiorentino (FI), Italy

pietro.liuzzo.scorpo@gmail.com , cuccoli@fi.infn.it , verrucchi@fi.infn.it

Abstract

Decoherence is one of the main obstacles placed in the way of the correct functioning of quantum devices. It is an ubiquitous phenomenon, due to the unavoidable interaction between a quantum principal system and its environment, which becomes particularly disruptive when quantum properties are to be exploited and controlled. Despite being an ordinary effect, decoherence is not easily describable in a general framework, as it depends on several details of the physical setup. In this work, we make use of a recently proposed method [1] for studying the dynamical evolution of a generic quantum system subject to decoherence. From such treatment, an analytical expression for a consistent measure of the coherence time, emerges, and formally shows how, and why, decoherence depends on the number of dynamical variables of the environment. Based on this result we propose a strategy for effectively reduce decoherence, and finally implement it in two exemplifying situations where decoherence must be kept under control.

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Quantum information processing and metrology using diamond spins

J. Wrachtrup
3rd Institute of Physics, University of Stuttgart, Germany

Abstract

Diamond spins are promising systems for spin-based quantum information processing. Recent progress includes entanglement between nano positioned diamond defects as well as entanglement storage in nuclear spins. Error correction using a three qubit majority vote algorithm has been shown as well as quantum chemical simulations using a single electron and nuclear spin. Diamond defect centers are also known to be excellent probes for magnetic and electric fields as well as parameters like pressure and temperature. Their versatility comes from various quantum control techniques which, for example, allow for controlling quantum states such that they get maximally sensitive to certain quantities like e.g. temperature while being insensitive to other parameters like magnetic fields (clock transitions). The talk will describe a novel method, namely using quantum memories and quantum lock-in techniques, to enhance measurement sensitivity and specificity. Enhanced capabilities will be demonstrated on magnetic resonance imaging of nm-sized sample volumes.

Absolute calibration of an EMCCD camera from the analog to single photon regime

A. Avella, I. Ruo Berchera, A. Meda, I. P. Degiovanni, G. Brida, M. L. Rastello, M. Genovese.
INRIM, Strada delle Cacce 91, 10135 Torino, ITALY

a.avella@inrim.it

I. Abstract

The development of quantum metrology and sensing [1-5] based on quantum optical states and, on the other hand, the project of refining the photometric unit, the candela [6], on single photon counting [7-9] demand for precise calibration of detectors in mesoscopic analog regime. Quantum correlations in twin beams offer an opportunity for reaching this goal, as discussed in [11-14], in analogy to photocounting Klyshko's method [15-21] and its developments [22-25].
Here, we present the absolute calibration of a EMCCD camera by exploiting quantum correlations. In [26] we realized the first absolute calibration of a CCD camera by exploiting bright squeezed states. In [27] we improved such techniques to reach a level of uncertainty suitable for demonstrating the validity of the method for metrological purpose. Here we generalize the method for the single photon regime and we apply this technique to a EMCCD working in analogical and single photon regime.

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Real-time phase monitoring for quasi-optimal coherent-state receiver

M. Bina[1], A. Allevi[2], M. Bondani[3] and S. Olivares[1]

[1]Dipartimento di Fisica, Università degli Studi di Milano, I-20133 Milano, Italy

[2]Dipartimento di Scienza e Alta Tecnologia, Università degli Studi dell'Insubria, Via valleggio 11, 22100 Como, Italy

[3]Istituto di Fotonica e Nanotecnologie, CNR, Via valleggio 11, 22100 Como, Italy

matteo.bina@gmail.com

Abstract

In binary phase-shifted-keyed (BPSK) communication schemes information is encoded in coherent states with opposite phases. A standard and optimal scheme usually employed is the Kennedy receiver, where the discrimination of the two input coherent states, interfering at a beam splitter with a local oscillator (LO), is performed by means of on/off detectors. Setting the relative phase between the input signals and the LO is a crucial task for this discrimination protocol, where a minimal error probability is desirable. Moreover, a common source of errors arises from phase noise which affects the input coherent state preparation and the subsequent communication protocol.

In this framework we propose a method to monitor in real-time the relative phase between the input signals and the LO, based on Bayesian strategies enhanced by the employment of photon number resolving (PNR) detectors [1]. In particular we show, both theoretically and experimentally, how to optimally extract information about the phase reference by processing the same data used to discriminate, shot by shot, between the signals. We demonstrate that it is possible to achieve the minimum uncertainty of the estimated phase parameter, given by the inverse of the Fisher information associated with the statistics of few thousands of the M collected data.

In this work we thoroughly investigate, with both numerical analysis and tests on experimental data, the performances of our method with respect to other approaches, like the inversion of the Fano factor of the output photon number statistics. Furthermore, we include an ad-hoc model of phase noise, thus demonstrating ther reliability of our method in more realistic conditions.

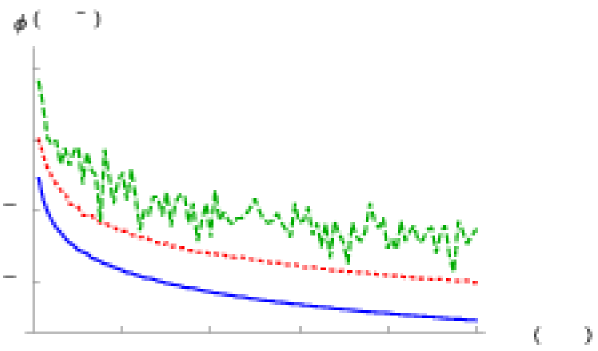

Fig. 1. Logarithmic plot of the variance Varϕ, in numerical simulations, given by the Bayesian method for DD detectors (red, dotted) and PNR detectors (blue, solid), and by the method of inversion of the Fano factor (green, dashed).

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The cold atom lattice gauge toolbox: emergent nuclear physics in Bose mixtures

M. Dalmonte
University of Innsbruck

Abstract

Lattice gauge theories constitute a valuable formalism which has lead to notable progresses on the way towards the understanding of fundamental interactions underlying particle physics. However, the computational complexity of dynamical processes and finite-density regimes is usually biased by the so called sign problem, which strongly reduces its applicability on classical machines. In this talk, we will show how lattice gauge theories can be realised in synthetic systems of ultra-cold atoms in optical lattices. After a general introduction, we will show how lattice gauge models which share qualitative features with high density QCD, such as the formation of stables baryons, can be engineered in ultra cold gases of Bose mixtures. We will the present a general phase diagram, which displays regions of binding and chiral symmetry breaking, and show how the model can be related in an exact fashion to a class of quantum spin chains.

Non-equilibrium dynamics and thermalisation of string order in quantum spin-1 chains

Rosario Fazio

Abstract

We investigate the equilibration dynamics of non-local order in a one-dimensional quantum system. After initializing a spin-1 chain in the Haldane phase, the time evolution of string correlations following a sudden quench is studied by means of matrix-product-state-based algorithms. Thermalization occurs only for scales up to a horizon which grows at a well defined speed, due to the finite maximal velocity at which string correlations can propagate, related to a Lieb-Robinson bound. The persistence of string ordering at finite times is related to the symmetries of the quenched Hamiltonian in a non-trivial way. Our results are suitable to experimental testing in present coldatom setups.

Work done in collaboration with Leonardo Mazza, Davide Rossini, and Manuel Endres.

(Presenting author)	

Classical nature of ordered phases: origin of spontaneous symmetry breaking

M. Cianciaruso,[1,4] **L. Ferro**,[3,4] S. M. Giampaolo,[2] W. Roga,[3] and F. Illuminati[3,4,5]

[1] Dipartimento di Fisica "E. R. Caianiello", Università degli Studi di Salerno, I-8408 Fisciano (SA), Italy
[2] University of Vienna, Faculty of Physics, Boltzmanngasse 5, 1090 Vienna, Austria
[3] Dipartimento di Ingegneria Industriale, Università degli Studi di Salerno, I-84084 Fisciano (SA), Italy
[4] INFN, Sezione di Napoli, I-80126 Napoli, Italy
[5] CNISM Unità di Salerno, I-84084 Fisciano (SA), Italy

Abstract

I will investigate the nature of spontaneous symmetry breaking in complex quantum systems by conjecturing that the maximally symmetry-breaking ground states are the most classical ones among all possible ground states in an ordered phase. I make this argument quantitatively precise by showing that the ground states that realize the maximum breaking of the Hamiltonian symmetries are the only ground states that:

I) are always locally convertible, i.e. can be obtained from all the other ground states by local operations and classical communications, while the reverse is never possible;

II) minimize the monogamy inequality for bipartite entanglement;

III) minimize quantum correlations for all pairs of dynamical variables and are the only ground states for which the pairwise quantum correlations vanish asymptotically with the intra-pair distance.

Francesco Guerra

Dipartimento di Fisica, Università di Roma "La Sapienza"
Istituto Nazionale di Fisica Nucleare, Sezione di Roma

Abstract

We review some aspects of the stochastic formulation of quantum mechanics, in the Nelson approach. In particular we discuss the interpretation of the Heisenberg position-momentum uncertainty principle, as given by de Falco-De Martino-De Siena, and compare with the usual operator formulation.

Certain aspects of multipartite entanglement

Barbara Kraus

Abstract

Many applications of quantum information rely on multipartite entanglement. Thus, the qualification and quantification of entanglement is one of the central topics within quantum information. Due to the exponential growths of the dimension of the state-space (as a function of the number of considered systems), however, many very fundamental questions in this context are still unanswered.

In this talk, I will focus on some aspects of multipartite entanglement. I will present a generalization of the notion of maximally entangled bipartite states to the multipartite case and will demonstrate a new approach of quantifying entanglement of few-partite systems.

(Presenting author)

3-dimensional integrated photonic quantum simulation

Paolo Mataloni

Dipartimento di Fisica, Sapienza Università di Roma,
Piazzale Aldo Moro, 5, I-00185 Roma, Italy

Recent technological improvements in realizing integrated waveguide structures make feasible complex quantum circuits characterized by an intrinsic phase stability and able in principle to solve critical problems in terms of scalability and reliability. Using the mobility of photons it is possible to create arbitrary interconnections within interferometric arrays fabricated on single integrated platforms and to realize complex optical architectures performing basic quantum logic gates and algorithms.

Recent experiments, built on complex 3-dimensional integrated architectures written in a glass by femtosecond laser pulses, able to support both polarization and path degrees of freedom of photons, has opened to novel advanced applications of these systems in photonic quantum simulation. The advantages of implementing quantum simulation in integrated photonic circuits derive mainly from the mobility, as said, and from the high immunity to decoherence of the photons. In particular, quantum walk circuits, enabling photon propagation over complex circuit architectures jumping between different waveguides, have been used to study the role of quantum symmetries in particle diffusion, thus revealing the different behaviour of bosons and fermions when propagating through ordered and disordered structures.

Other kinds of laser-written integrated devices (such as integrated waveplates, enable further capabilities for processing of the photon degrees of freedom, and disclose new possible scenarios even for quantum simulation.

The main results of recent quantum simulation experiments performed in our Laboratory in Rome, based on these integrated systems, will be presented in this talk.

Paolo Mataloni
Dipartimento di Fisica
Sapienza Università di Roma
P.le A. Moro 2 - 00185 ROMA
tel: +39-06-49913478
fax: +39-06-4463158
email: paolo.mataloni@uniroma1.it
homepage: http://quantumoptics.phys.uniroma1.it/

Statistical mechanics of maximally entangled states

Giorgio Parisi (Università di Roma la Sapienza)

I will present some work done on the statistical mechanics of maximally entangled states. The aim is to understand which is the maximum value of entanglement that can be reached in the case of a large system. We are far from having a complete understanding, but some reasonable conjectures can be done, supported by analytic computations.

Single- and two-mode quantumness at a beam splitter

Alessandro Ferraro, Matteo Brunelli
School of Mathematics and Physics, Queen's University Belfast, Belfast BT71NN, UK

Claudia Benedetti, Stefano Olivares and **Matteo G. A. Paris**
Dipartimento di Fisica, Universita` degli Studi di Milano, I-20133 Milano, Italy
matteo.paris@fisica.unimi.it

Abstract

The quantum-to-classical transition for a single-mode bosonic system may be fully characterized by the properties of its Glauber-Sudarshan P-function in the phase-space and the rate of decoherence is quantified by relating it to the decay rates of various, complementary measures of the quantum nature of a state, such as the purity [1]. On the other hand, for two-mode states, quantumness may be recognized either by the presence of nonclassical correlations [2,3,4] or in terms of its phase-space distribution [5,6]. The resulting notions of nonclassicality, termed C- and P-nonclassicality, have been shown to be maximally inequivalent [7], the set of states satisfying both criteria being of zero measure. Here we address the generation of both types of two-mode nonclassical states by the linear mixing of a single-mode Gaussian state with a thermal state at a beam splitter, and explore the relationships between the nonclassical features of the single-mode input and the P- and C-nonclassicality of the two-mode outputs. In particular, input P-classicality and output separability single out two thresholds which coincide only for the case of linear mixing with the vacuum, whereas they are connected in a non trivial way for linear mixing with a thermal state [8]. In turn, we introduce a novel measure of nonclassicality for single-mode states, termed effective non-classicality, which quantifies the capacity of creating entanglement even when mixed with a thermal state, and show that it is a function of the nonclassical depth. We also found that almost every P-classical input state generates C-nonclassicality, i.e., discordant output states, the only exception being provided by the mixing of two identical Gaussian states. Finally, we analyze in some details the effects of the beam splitter transmissivity, and the relationships between entanglement and discord generated in our scheme, providing some insight on their typical values.

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Quantum typicality

Saverio Pascazio

Dipartimento di Fisica, Universita' di Bari
and INFN, Sezione di Bari

Abstract

Typicality is becoming an important concept in quantum mechanics. It plays a key role in the analysis of entanglement and interference. We focus here on the latter. When a Bose-Einstein condensate is divided into two parts that are subsequently released and overlap, interference fringes are observed. Such interference is typical, in the sense that most wave functions of the condensate, randomly sampled out of a suitable ensemble, display interference. We make no hypothesis of decoherence between the two parts of the condensate.

Preserving Information from the Beginning to the End of Time in a Robertson-Walker Universe

Stefano Mancini[1,2], Roberto Pierini[1,2], and Mark M. Wilde[3]

[1]School of Science and Technology, University of Camerino, 62032 Camerino, Italy

[2]INFN Sezione di Perugia, 06123 Perugia, Italy

[3]Hearne Institute for Theoretical Physics,
Department of Physics and Astronomy, Center for Computation and Technology,
Louisiana State University, Baton Rouge, Louisiana 70803, USA

stefano.mancini@unicam.it
roberto.pierini@unicam.it
wilde@lsu.edu

I. Abstract

Preserving information stored in a physical system subjected to noise can be modeled in a communication-theoretic paradigm, in which storage and retrieval correspond to an input encoding and output decoding, respectively. The encoding and decoding are then constructed in such a way as to protect against the action of a given noisy quantum channel. This paper considers the situation in which the noise is not due to technological imperfections, but rather to the physical laws governing the evolution of the universe. In particular, we consider the dynamics of quantum systems under a Robertson-Walker spacetime and find that the noise imparted to them is equivalent to the well known amplitude damping channel. Since one might be interested in preserving both classical and quantum information in such a scenario, we study trade-off coding strategies and determine a region of achievable rates for the preservation of both kinds of information. As a byproduct we also determine a trade-off between achievable rates of classical and quantum information preservation when entanglement assistance is available.

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(Presenting author)

General diffusive conditional dynamics

Where we present an alternative derivation of conditional dynamics driven by general-dyne detection.

Gauge theories and Tensor Networks

Luca Tagliacozzo, A. Celi, M. Lewenstein (L. *Tagliacozzo*)
ICFO The Institute of Photonic Sciences
Parc Mediterrani de Tecnlogia Av. K. F. Gauss n 3
08860 Castelledefels Spain
luca.tagliacozzo@icfo.es

Abstract

I discuss how to formulate lattice gauge theories in the Tensor Network language. In this way one obtains both a consistent truncation scheme of the Kogut-Susskind lattice gauge theories that can be used in cold atoms experiments [2,3] and a Tensor Network variational ansatz for gauge invariant states that can be used in actual numerical computation [1,4]. The construction is also applied to the simplest realization of the quantum link models/gauge magnets and provides a clear way to understand their microscopic relation with Kogut-Susskind lattice gauge theories. I also introduce a new set of gauge invariant operators that modify continuously Rokshar-Kivelson wave functions and can be used to extend the phase diagram of known models. As an example we characterize the transition between the deconfined phase of the Z2 lattice gauge theory and the Rokshar-Kivelson point of the U(1) gauge magnet in 2D in terms of entanglement entropy. The topological entropy serves as an order parameter for the transition but not the Schmidt gap.

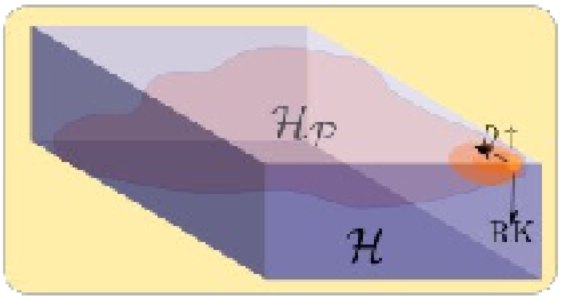

Fig. 1 Illustration 1: The Physical Hilbert space of a lattice gauge theory is embedded into the constituent Hilbert space. Its low energy sector can be described by a Tensor Network ansatz.

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(Presenting author)

Certified entanglement between distant microwave fields with opto-electro-mechanical systems

D. Vitali
School of Science and Technology, Physics Division,
University of Camerino, via Madonna delle Carceri, 9,
I-62032 Camerino (MC), Italy, and INFN, Sezione di Perugia, Italy

We propose a protocol able to prepare two remote and initially uncorrelated microwave modes in an entangled stationary state, which is certifiable using only local optical homodyne measurements. The protocol is an extension of continuous variable entanglement swapping, and exploits two hybrid quadripartite opto-electro-mechanical systems in which a nanomechanical resonator acts as a quantum interface able to entangle optical and microwave fields. The proposed protocol allows to circumvent the problems associated with the fragility of microwave photons with respect to thermal noise and may represent a fundamental tool for the realization of quantum networks connecting distant solid-state and superconducting qubits, which are typically manipulated with microwave fields. The certifying measurements on the optical modes guarantee the success of entanglement swapping without the need of performing explicit measurements on the distant microwave fields.

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On entropic uncertainty relations

Karol Życzkowski* (*Jagellonian University, Institute of Physics, Cracow*)
ul Reymonta 4, 30-052 Krakow, Poland
and
Center for Theoretical Physics, Polish Academy of Science, Warsaw
karol@cft.edu.pl

I. Abstract

Uncertainty relations may be considered as a hallmark of quantum theory. We review the standard 1927 approach of Heisenberg-Kennard, based on the product of variances of the probability distribution in two different representations and advocate an alternative 1957 approach of Hirschman, followed in 1957 by Bialynicki-Birula, Mycielski and independently by Beckner, in which the sum of two entropies characterizing both distributions is investigated.

Entropic uncertainty relations for infinite and a finite-dimensional Hilbert space are recalled. After reviewing the 1983 bounds of Deutsch and stronger 1988 bounds of Maassen and Uffink we discuss possibilities to improve and generalize them. Two new bounds for the sum of an arbitrary number of M entropies characterizing outcomes of M measurements of an N-dimensional state taken in M arbitrary basis are presented.

One of the new bounds is shown to be stronger for any state than the bound obtained independently by two groups in 2013 with help of the majorization techniques. The other complementary result improves the 2013 bound of Coles and Piani, stronger than the Maassen-Uffink relation. Results obtained can be applied for various problems in quantum information theory, including the description of multipartite entanglement, estimation of mutual information and capacity of quantum channels.

* Joint work with Zbigniew Puchała and Łukasz Rudnicki

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(Karol Życzkowski)

Schmidt modes description of the radiation field produced by high-gain parametric down conversion

Alessia Allevi[1,2], Ottavia Jedrkiewicz[3,2], Enrico Brambilla[1,2], Alessandra Gatti[3,2], Jan Peřina Jr.[4], Ondřej Haderka[4], Radek Machulka[4], and Maria Bondani[3,2]

1: Dipartimento di Scienza e Alta Tecnologia, Università degli Studi dell'Insubria, Via Valleggio 11, I-22100 Como (Italy)
2: CNISM UdR Como, Via Valleggio 11, I-22100 Como (Italy)
3: Istituto di Fotonica e Nanotecnologie, CNR, Via Valleggio 11, I-22100 Como (Italy)
4: RCPTM, Joint Laboratory of Optics of Palacký University and Institute of Physics of Academy of Sciences of the Czech Republic, Faculty of Science, Palacký University, 17.listopadu 12, 77146 Olomouc, Czech Republic
alessia.allevi@uninsubria.it

I. Abstract

Travelling-wave parametric down-conversion (PDC) in bulk nonlinear crystals generates twin-beam and squeezed states of light that are naturally multi-mode both in spectrum and space (see Fig. 1).

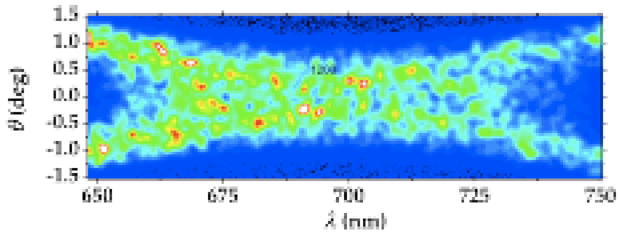

Fig. 1. Single-shot image recorded with an EMCCD camera, in which the typical multi-mode pattern of PDC in the spatio-spectral domain is clearly evident.

In the extensively explored single-photon regime, such features have been described also in terms of Schmidt mode decomposition of the radiation field [1-3]. Here we show that, by extending this description to the high-gain regime up to pump depletion, it is possible to explain the non-trivial evolution of the coherence properties of very bright twin beams (see Fig. 2) [4]. To this aim, we used an imaging spectrometer and an EMCCD camera.

In spite of the very different intensity regimes spanned by our experiment, further investigations, performed by means of photon-number resolving detectors and suitable neutral density filters, allowed us to conclude that the photon- number statistics of the twin beams remains multi-mode thermal [5].

Moreover, we demonstrate that, in the macroscopic domain, the investigation in terms of Schmidt modes can be exploited to optimize the production of single-mode squeezed vacuum states, which can be used in quantum communication protocols and for quantum state engineering [6].

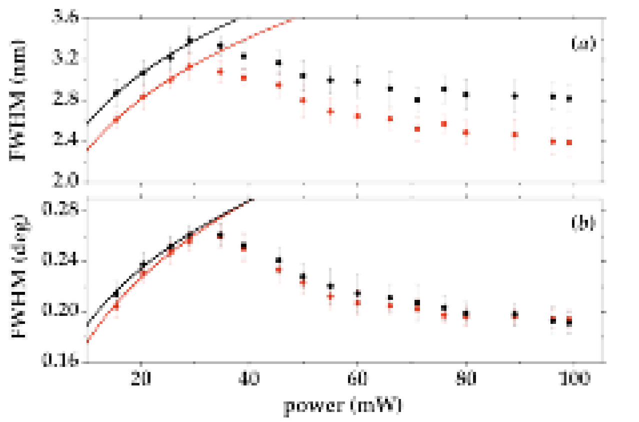

Fig. 2. Evolution of the spectral (a) and spatial (b) full-width half-maximum (FWHM) size of the second-order auto-correlation (red data) and cross-correlation (black data) functions at different values of pump mean power. Lines: fourth-square root fitting functions.

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Multimode state characterization by weak-field homodyning

Gaia Donati[1], Mihai-Dorian Vidrighin[2,1], Tim J. Bartley[1], Xian-Min Jin[1,3], Andreas Eckstein[1], Dylan J. Saunders[1], Animesh Datta[1], Marco Barbieri[1,4], and I.A. Walmsley[1]

[1]Ultrafast group, Department of Physics, University of Oxford, Oxford, UK

[2]QOLS, Blackett Laboratory, Imperial College London, London, UK

[3]Department of Physics and Astronomy, Shanghai Jiao Tong University, Shanghai 200240, China.

[4]Dipartimento di Scienze, Università Roma Tre, Rome, Italy

Marco.barbieri@uniroma3.it

I. Abstract

Characterization is a delicate stage for validating quantum resources. Optical detection techniques offer precise tools for this task, homodyne being an interesting option for multi-particle states. However, the need for a high-flux local oscillator might pose some problems in the perspective of adopting integrated structures.

For this purpose, weak-field homodyne has been proposed and demonstrated; in this case, the strong local oscillator is replaced by a field whose intensity is comparable to that of the signal [1,2]. Further, linear detectors are replaced with photon-number resolving detectors. In this talk, we will discuss on-going progress in the use of weak-field homodyne for full state reconstruction.

We will present its application for the observation of cross mode coherence in a two-mode squeezed state and in a split single-photon mode. Future paths for state reconstruction based on either data pattern functions or direct Wigner function reconstruction will be illustrated.

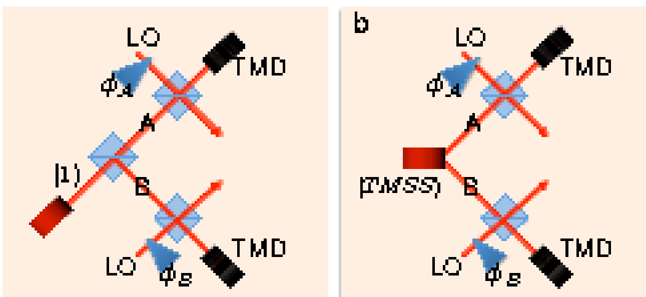

Fig. 1: (left) a single photon is produced by a heralded source bsed on parametric down-conversion. This is then split in order to generate entanglement across two separate spatial modes on which the weak-field homodyne is applied. (right) the same operation is performed on the two modes of a squeezed state. Time multiplex detectors (TMDs) are used as pseudo number resolving detectors.

A. Two-mode coherence.

We investigated the signatures of the coherence between Fock layers across two-mode entangled states by using weak-field homodyne [3]. In our experiment, we demonstrated the oscillations of an array of multiphoton coincidence counts when a split single photon state and a two-mode squeezed state are observed (Fig.1).

B. Future directions.

Bt using multiple intensity settings for the local oscillator, our setup can be adopted for the direct measurement of the Wigner function [2]. Further improvement on the reconstruction can be obtained by employing a maximum-likelyhood algorithm based on data pattern functions, as recently demonstrated for commonplace strong-field homodyne [4].

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Measuring the reservoir spectral density via photon scattering

Francesco Ciccarello

NEST, Istituto Nanoscienze-CNR and Dipartimento di Fisica e Chimica, Università degli Studi di Palermo, via Archirafi 36, I-90123, Palermo, Italy

francesco.ciccarello@unipa.it

Abstract

An environmental model where an open quantum system (OQS) is in dissipative contact with a continuous reservoir is known to be fully specified by the spectral density (SD) function. This is, in particular, the key quantity that shapes the OQS's dynamics. We discover a simple method for measuring the SD based on one-dimensional single-photon scattering from the OQS [1]. The SD profile is shown to be a universal simple function of reflectance and transmittance. As such, it can be straightforwardly inferred from photon's reflection and transmission spectra.

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Ultrafast quantum optics based on telecommunication technologies

L.A. Ngah[1], O. Alibart[1], L. Labonté[1], V. D'Auria[1], and S. Tanzilli[1]

1.Laboratoire de Physique de la Matière Condensée, CNRS UMR 7336, Université de Nice Sophia Antipolis, Parc Valrose, 06108 Nice Cedex 2, France

virginia.dauria@unice.fr

Abstract

For the past thirty years, quantum entanglement has evolved from a merely fundamental concept to a useful, applicable resource for quantum information science (QIS). In particular, the use of entangled photons generated at telecom wavelengths allows implementing QIS protocols compatible with long distance operation via optical fibers.

In most of experiments, pairs of telecom photons originate from the non-linear conversion of optical pulses at ≈ 780 nm generated by solid state mode-locked lasers [1] with repetition rate limited to few hundreds of MHz. Conversely, ultra-fast fiber lasers with repetition rates up to a few tens of GHz are available in the C-band of telecom wavelengths. At the same time, high efficiency periodically poled lithium niobate waveguides (PPLN/w) can be combined to obtain a cascade non-linear processes. We propose here to exploit both state-of-the-art telecom laser technology and guided-wave non linear optics for generating telecom entangled photon at the ultra-high repetition rates: in our scheme, optical pulses emitted by a fiber laser with a repetition rate of 10 GHz are sent to a PPLN/w to be converted from 1540 nm to 770 nm via second-harmonic generation (SHG), and then used to pump a second PPLN/w so as to generate, via spontaneous parametric down conversion (SPDC), photon pairs at 1540 nm. Subsequently, the paired photons are deterministically separated using a combination of a wavelength division multiplexer (DWDM) and a fiber Bragg grating (FBG) filter, in complementary standard telecom channels (ITU 43 and ITU 50).

We characterized the quality our source with a conditional scheme: the detection of photons in one channel, performed by a superconducting single photon detector (SSPD), able to handle 10 GHz repetition rate, will herald the presence of complementary photon in the other arm of the setup: the scheme is an implementation of an "heralded single photon source" (HSPS). The use of a 10 GHz pulsed laser associated with non-linear optics and of standard telecom components allows us obtaining high quality heralded photons at an high rate and with negligible multi-photon events. More specifically, in our experiment, single photons at 1540 nm are announced with an heralding efficiency of ≈40%. Thanks to the laser high repetition rate, we observe heralding rate as high MHz while keeping the mean number of photon-pairs generated per pump pulse well below 0.1. This result is confirmed by a standard Hanbury Brown and Twiss (HBT) measurement who certifies the high quality of our single photons in terms of the autocorrelation function $g^{(2)}(0)$, namely of the (low) probability of unwanted multi-pairs events against single-photon pair ones.

These performances are crucial ingredients demanded for both fast and secure quantum communication protocols and make our source a promising candidate for future quantum networking applications. To conclude we stress that the implemented configuration is highly suitable to long distance entanglement teleportation [2], where a common telecom laser emitting optical pulses at 1550 nm can be distributed to two remote locations and locally used to generate via SPDC photon-pairs with high timing accuracy. In this framework, high repetition rate telecom lasers act as a tool for fighting the low success rates of the quantum protocols due to probabilistic photon pair generation via SPDC process in suitable non-linear crystals. So far, promising results have been obtained, gauging the quality of our approach. Next step is to perform a two-photon interference experiment with GHz repetition rates. This should demonstrate the effectiveness of our high-speed photon pair sources for practical quantum teleportation operation.

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Title:

Many-body localization and ergodicity in disordered long-range Ising models

Philipp Hauke, Peter Zoller, Markus Heyl
Affiliation 1: Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Technikerstr. 21A, A-6020 Innsbruck, Austria
Affiliation 2: Institut für Theoretische Physik, Universität Innsbruck, Technikerstr. 25, A-6020 Innsbruck, Austria
philipp.hauke@uibk.ac.at

I. Abstract

Although a quantum version of the classical ergodic theorem has been put forward already by von Neumann in 1929 [1], a general understanding of quantum ergodicity has not yet been achieved [2]. Recently, it has been proposed that a general framework for quantum ergodicity could be given by the concept of many-body localization [3]. Moreover, since in a many-body localized phase all eigenfunctions are localized, these phases may be inherently robust against local errors and could be useful in the context of quantum memory devices [4]. However, compared to single-particle localization, many-body localization suffers from an increased complexity, making it challenging to derive the localization properties of a given system and finding suitable, experimentally accessible quantities for their characterization.

In this talk, we present recent analytical and numerical results for the many-body localization of an Ising model with variable-range interactions and with disorder in the transverse-field [5]. As seen in the statistics of tunnelling resonances as well as renormalization-group analyses [6] and exact diagonalizations, this model enters a many-body localized phase at any non-vanishing disorder strength (see Fig. 1).

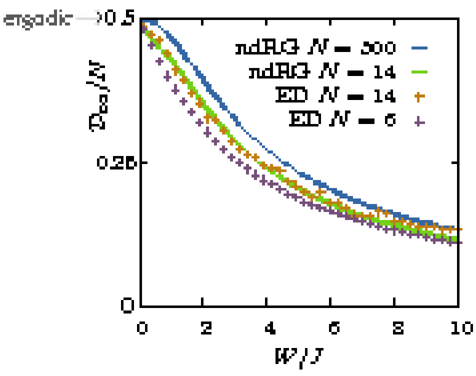

Fig. 1. The observable D_{eq} can be simply measured via the magnetization, and it allows characterizing ergodicity of the system. D_{eq}<0.5 identifies non-ergodicity, which occurs in the long-range interacting Ising-model for all disorder strengths W/J>0. The data is calculated using a nonequilibrium dynamical renormalization group (ndRG) and exact diagonalizations (ED), which show very good agreement. Already small system sizes N capture the essential ergodicity properties.

Furthermore, we discuss how this model can be implemented in state-of-the-art trapped-ion experiments [7], with a simple protocol for state initialization, evolution, and read-out. Importantly, we identify a general measure for quantum ergodicity that can be obtained through experimentally accessible, single-particle observables (i.e., the magnetization). Our proposal thus provides a straightforward roadmap to observe many-body localization phenomena in on-going experiments.

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Philipp Hauke

Randomized Graph States and their Entanglement Properties

C. Macchiavello
University of Pavia

Abstract

We introduce a class of mixed multiqubit states, that correspond to a randomized version of graph states. Such states arise when a graph state is prepared with noisy or imperfect controlled-Z gates. We study the entanglement features of these states by investigating both bipartite and genuine multipartite entanglement. The results presented are reported in [1].

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Out-of-equilibrium dynamics and thermalization of string order

Leonardo Mazza[1], Davide Rossini[1], Manuel Endres[2], and Rosario Fazio[1]
[1]NEST, Scuola Normale Superiore & Istituto Nanoscienze-CNR, I-56126 Pisa, Italy
[2]Max-Planck-Institut für Quantenoptik, D-85748 Garching, Germany
leonardo.mazza@sns.it

Abstract

Quantum phases of matter are characterized by the correlations of the underlying many-body wavefunction of the system. Although they are typically captured by a local order parameter, it has been shown that a broad class of systems, e.g. topologically ordered ones, possesses a non-local form order. I will begin by showing that such non-local order can be experimentally observed, as reported in some recent work on string order in 1D optical lattices [1, 2].

Afterwards, I will discuss the equilibration dynamics of string order in one-dimensional quantum systems. The problem is rather intriguing, as string order is a non-local quantity, and cannot be framed into the well-established picture of equilibration of local order parameters.

After initializing a spin-1 chain in the Haldane phase, the time evolution of non-local correlations following a sudden quench is studied by means of matrix-product-state-based algorithms. It is observed that thermalization occurs only for scales up to a horizon growing at a well defined speed, due to the finite maximal velocity at which string correlations can propagate, related to a Lieb-Robinson bound (which can also be formulated for string order).

The persistence of string ordering at finite times is non-trivially related to symmetries of the quenched Hamiltonian. A complete classification of when string order persists to a Hamiltonian global quench is given; the result is interestingly related to the concept of "symmetry protected topological order" [3].

A qualitatively similar behavior is found for the string order of the Mott insulating phase in the Bose-Hubbard chain. This paves the way towards an experimental testing of our results in present cold-atom setups.

Finally, it is discussed how to extend this work to the study of the out-of-equilibrium dynamics of topological order, addressing the dynamics of the entanglement spectrum in one-dimensional symmetry protected systems.

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Quantum crystals of photons and atoms

Giovanna Morigi, Saarland University

In this talk I will discuss several examples of selforganization of atoms inside a single-mode resonator. When a laser transversally pumps the atom, photon scattering into the resonator depends on the atoms density distribution within the cavity, and in turn determines the strength of the mechanical forces of light on the atoms, hence the atomic density. The dynamics is thus nonlinear and can lead to ordered atomic structures when the laser intensity exceeds a threshold determined, amongst other, by the rate of cavity losses. I will first discuss the dynamics of selforganization in the semiclassical regime, in which the atomic motion is cooled by the photon scattering processes which pump the cavity. I will then consider the quantum regime, where the atoms are ultracold bosons. The atoms are confined by an external optical lattice, whose period is incommensurate with the cavity mode wave length, and are driven by a transverse laser, which is resonant with the cavity mode. While for pointlike atoms photon scattering into the cavity is suppressed, for sufficiently strong lasers quantum fluctuations can support the build-up of an intracavity field, which in turn amplifies quantum fluctuations. In this parameter regime the atoms form clusters which are phase locked, thereby maximizing the intracavity photon number. I will argue that this system constitutes a novel setting where quantum fluctuations give rise to effects usually associated with disorder.

Randomness evaluation and certification in a steering scenario

Elsa Passaro [(1)], Paul Skrzypczyk [(1)], Daniel Cavalcanti [(1)], and Antonio Acín [(1,2)]

[(1)] ICFO-Institut de Ciencies Fotoniques, Mediterranean Technology Park, E-08860 Castelldefels (Barcelona), Spain

[(2)] ICREA-Institucio Catalana de Recerca i Estudis Avançats, Lluis Companys 23, E-08010 Barcelona, Spain

elsa.passaro@icfo.es

Abstract

In this work we study the conditions under which randomness can be extracted in the so-called *steering* scenario [1], i.e. a bipartite scenario where the measurement apparatus of one party is trusted but not the other's. The untrusted party, let us say Alice, does not make any assumptions on her devices which are treated as a "black box", while the other party Bob can perform complete quantum state tomography on his state. In this framework one has to observe a violation of a steering inequality in order to certificate that the state shared by the parties is entangled, but this is not enough to certify randomness [2]. One natural and important application is in the context of *quantum key distribution* (QKD) [3,4] where on the one hand a device-independent implementation is too demanding due to the high detection efficiencies required to close the *detection loophole* [5], and on the other hand the assumptions on which the device-dependent schemes relies are never exactly fulfilled in practice.

Since no assumption is made on Alice's devices, they may be correlated to some systems held by an eavesdropper Eve. Hence, by measuring her system Eve can obtain information about Alice's outcome. The eavesdropper can then exploit the inefficiencies of Alice's detectors to fake a violation of the steering inequality while having perfect knowledge of Alice's outcome. In order to close the detection loophole the efficiency of Alice's detectors must be higher than a certain threshold. We evaluate Eve's *guessing probability* P_{guess} [6], namely the probability for Eve to correctly guess Alice's outcome to quantify how random Alice's output is. This is a useful quantity in QKD since it is related to a lower bound on the asymptotic secret key rate [7] in cryptographic protocols.

The aim of this work is to find a lower bound on the detection efficiency needed to have that Eve's guessing probability P_{guess} is strictly less than 1. Hence, the critical detection efficiency η_c is such that for every $\eta > \eta_c$ Eve cannot perfectly predict Alice's outcome.

This problem can be cast as a see-saw iteration of two semidefinite programmes (SDP) [8]. The first one maximizes the guessing probability over all possible strategies available to Eve, given the set of states observed by the trusted party Bob. The dual problem of this first SDP also gives the optimal steering inequality depending on the detection efficiency η. The second SDP minimizes the value of the optimal steering inequality over Alice's measurements.

The result obtained is that the critical detection efficiency η_c for having randomness in Alice's outcomes is 1/2 for every 2-qubit entangled state with 2 measurements on Alice's side. Moreover, we present an attack that allows Eve's outcomes to be perfectly correlated with Alice's ones, therefore leading to a guessing probability $P_{guess} = 1$. We prove analytically that this attack is valid for every dimension of the shared state and for any number of projective measurements of Alice if and only if $\eta = 1/2$.

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Interference in a Bose-Einstein condensate is typical

P. Facchi[1], *H. Nakazato*[2], *S. Pascazio*[1], ***Francesco V. Pepe***[1], *K. Yuasa*[2]
Affiliation 1: Dipartimento di Fisica, Università di Bari and INFN – Sezione di Bari,
Via Amendola 173, 70126 Bari, Italy
Affiliation 2: Department of Physics, Waseda University, Tokyo 169-8555, Japan
francesco.pepe@ba.infn.it

Abstract

When a Bose-Einstein condensate is divided into two parts that are subsequently released and overlap, interference fringes are observed. This phenomenon occurs even for states in which the relative phase between particles in the two modes is indetermined.

We show here that this interference is typical, in the sense that most wave functions of a two-mode Bose system, randomly sampled out of a suitable ensemble, display interference. No hypothesis of decoherence between the two parts of the condensate is made.

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Characterizing topological orders in quantum matter

Frank Pollmann
Max Planck Institute for the Physics of Complex Systems, Dresden, Germany
frankp@pks.mpg.de

Abstract

Matter occurs in various phases that are usually characterized in terms of symmetry breaking. A major discovery in the 1980s were the quantum Hall effects which exhibit a new kind of "topological" order. This order represents a class of exotic phases which cannot be described by spontaneous symmetry breaking. The lack of symmetry breaking order parameters makes it difficult to characterize these phases. In this talk, I will show that numerical investigations of a many-body wavefunction can yield a remarkably complete characterization of different types of topological orders. A central tool is the ground state entanglement which encodes many of the essential features.

First, I will consider symmetry protected topological phases in one-dimensional systems [1,2,3]. We derive non-local order parameters for time-reversal symmetry, inversion symmetry, and a generalized string- order for local symmetries for which the regular string-order parameter cannot be applied. With these tools, we provide a framework that allows for a complete characterization of one-dimensional SPT phases (e.g, the spin-1 Haldane phase in Fig. 1) and their detection in numerical simulations.

Second, I will show how characteristic properties of the topological excitations in fractional quantum Hall states can be extracted directly from the ground state [4,5]. We demonstrate how to numerically calculate several characterizing quantities. To find the set of topologically degenerate ground states, we employ the infinite density matrix renormalization group method based on the matrix-product state representation of FQH states on an infinite cylinder. We then show that the wave function obtained on the infinite cylinder geometry can be adapted to a torus of arbitrary modular parameter as shown in Fig. 1, which allows us to explicitly calculate the non-Abelian Berry connection associated with the modular T-transformation shown in Fig. 2.

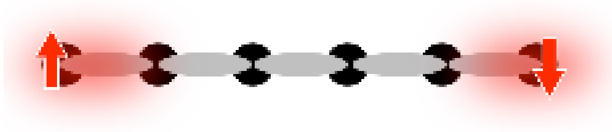

Fig. 1. The occurrence of spin-½ edge spins in the spin-1 Heisenberg chain are a characteristic feature of the Haldane phase.

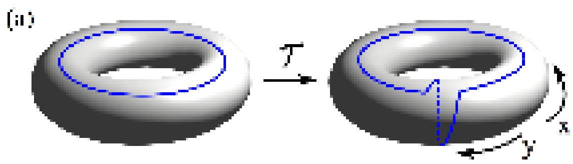

Fig. 2. A torus with dimensions $L_x \times L_y$. Taking the modular parameter $\tau \rightarrow \tau + 1$ corresponds to a Dehn twist of the torus and generates the modular T-transformation on the set of ground states.

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Optimal persistent currents for interacting bosons on a 1D ring with a gauge field

M. Cominotti[1], D. Rossini[2], **M. Rizzi**[3], F. Hekking[1], A. Minguzzi[1]

[1] Université Grenoble 1/CNRS, Laboratoire de Physique et de Modélisation des Milieux Condensés (UMR 5493), B.P. 166, 38042 Grenoble, France

[2] NEST, Scuola Normale Superiore and Istituto Nanoscienze-CNR, I-56126 Pisa, Italy

[3] Institut für Physik, Johannes-Gutenberg-Universität Mainz, Staudingerweg 7, D-55099 Mainz, Germany

matteo.rizzi@uni-mainz.de

anna.minguzzi@lpmmc.cnrs.fr

I. Abstract

We study persistent currents for interacting one-dimensional (1D) bosons on a tight ring trap, subjected to a rotating barrier potential, which induces an artificial U(1) gauge field (Fig.1). By combining analytical as well as numerical techniques suited for the different regimes of the 1D problem, we show that the current amplitude is a non monotonous function of the interaction strength and displays a pronounced maximum in all regimes of barrier height (Fig.2).

The presence of an optimal regime illustrates the highly non-trivial combination of correlations, quantum fluctuations and barrier effects. Our results demonstrate that, in a large range of interaction strengths, unwanted impurities or imperfections on the ring affect only weakly the system properties. For the application to quantum state manipulation, the regimes of choice should be either very weak or very strong interactions, where the response to a localized external probe is stronger.

Our predictions are readily amenable to experimental testing with quasi-1D ultracold atomic gases confined in mesoscopic uniform and lattice rings.

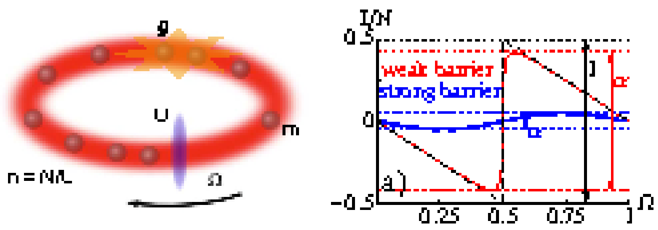

Fig. 1. (left) A pictorial representation of the system, i.e. a ring-formed trap of length L with tight transverse confinement, where N bosonic particles are confined to move and subjected to a two-body contact interaction parametrized by g; a repulsive barrier/defect U in the local chemical potential is rotated with an angular speed Ω. (right) The current curve $I(\Omega) = -1/2\pi\hbar\, \partial E(\Omega)/\partial\Omega$ (in units of $I_0 = 2\pi\hbar/mL^2$) in some paradigmatic cases and the definition of its amplitude α, whose behavior is then plotted in Fig. 2.

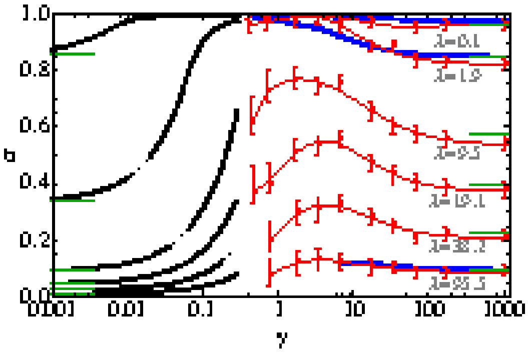

Fig. 2. Persistent current amplitude α, as a function of the dimensionless interaction strength $\gamma = m g / \hbar^2 n$ at varying dimensionless barrier strength $\lambda = m U L / \pi \hbar^2$, as obtained from the different approaches: Gross-Pitaevskii equation (black dotted lines), Luttinger liquid approach (blue solid lines), numerical matrix-product-states (MPS) calculations (red squares, red thin lines are guides to the eye), as well as ideal-gas and Tonks-Girardeau exact solutions (green dashes).

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(Presenting author)

Matteo Rizzi,

Institut für Physik, Johannes-Gutenberg-Universität Mainz,

Staudingerweg 7, D-55099 Mainz, Germany

matteo.rizzi@uni-mainz.de

Simulating Lattice Gauge field theories with Tensor Networks

Pietro Silvi[1], Enrique Rico[1,2], Tommaso Calarco[1,3], Simone Montangero[1,3]

NEST, Scuola Normale Superiore and Istituto di Nanoscienze-CNR, Pisa, Italy

e-mail addresses

Abstract

We consider a qubit prepared in an arbitrary initial state and relaxing to a steady state due to the action of a Markovian dissipative channel. We study how optimal control can be used for speeding up or slowing down the relaxation towards the fixed point of the dynamics. We analytically derive the optimal relaxation times for different quantum channels in the ideal ansatz of unconstrained quantum control (a magnetic field of infinite strength). We also analyze the situation in which the control Hamiltonian is bounded by a finite threshold. If the qubit is initially in a thermal state hotter than the environmental bath, quantum control cannot speed up its natural cooling rate. Instead, if the qubit is initially in a thermal state colder than the bath, it can reach the fixed point of the dynamics in finite time if a strong control field is applied, Finally, in the presence of unconstrained quantum control it is possible to keep the evolved state indefinitely and arbitrarily close to special initial states which are far away from the fixed points of the dynamics.

(Presenting author)

Efficient experimental validation of photonic Boson Sampling

Nicolò Spagnolo[1], Chiara Vitelli[1,2], Marco Bentivegna[1], Daniel J. Brod[3], Andrea Crespi[4,5], Fulvio Flamini[1], Sandro Giacomini[1], Giorgio Milani[1], Roberta Ramponi[4,5], Paolo Mataloni[1], Roberto Osellame[4,5], Ernesto F. Galvão[3], and Fabio Sciarrino[1]

[1]Dipartimento di Fisica, Sapienza Università di Roma, Piazzale Aldo Moro 5, I-00185 Roma, Italy
[2]Center of Life NanoScience @ La Sapienza, Istituto Italiano di Tecnologia, Viale Regina Elena, 255, I-00185 Roma, Italy
[3]Instituto de Física, Universidade Federal Fluminense, Av. Gal. Milton Tavares de Souza s/n, Niterói, RJ, 24210-340, Brazil
[4]Istituto di Fotonica e Nanotecnologie, Consiglio Nazionale delle Ricerche (IFN-CNR), Piazza Leonardo da Vinci, 32, I-20133 Milano, Italy
[5]Dipartimento di Fisica, Politecnico di Milano, Piazza Leonardo da Vinci, 32, I-20133 Milano, Italy

I. Abstract

Quantum computer of large size promises the capability of solving problems which are hard-to-calculate with classical computers, such as factoring, but its realization is currently far with the present technology. It is then necessary to identify suitable intermediate steps showing the computational capabilities of quantum mechanics in smaller-size systems. For instance, sampling (even approximately) the output distribution of bosons evolving under the action of an arbitrary linear unitary transformation is believed to be hard-to-compute with a classical approach. This is the so-called boson sampling problem [1–5], and is naturally solved by photons in a multi-port linear interferometer. We report boson-sampling experiments [2, 6, 7] up to three-photons evolving in laser-written integrated interferometers with up to 13 modes. We report three-photon interference experiments which confirm the quantum mechanical predictions given by the permanent formula.

In the hard-to-simulate regime, it is not trivial to certify the correct operation of the device [8–10]. We discuss the validation [7] of small sets of experimental data against the hypotesis that they are sampled from a uniform distribution, by using a recently proposed scalable statistical test recently proposed [9] which exploits the available input information of Boson Sampling. We also discuss how to discriminate data which are obtained from indistinguishable or distinguishable photons.

Larger versions of the presented multi-photon, multiport interference experiments may represent a promising evidence of a hard-to-simulate scenario, even in the presence of noise, and can find application in other contexts such as quantum simulation, quantum communication, quantum cryptography and quantum metrology.

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(Presenting author)		

Kitaev chains with long-range pairing

Davide Vodola[1,2]

[1] *IPCMS (UMR 7504) and ISIS (UMR 7006), Universitè de Strasbourg and CNRS, Strasbourg, France.*

[2] *Dipartimento di Fisica, Universita` di Bologna and INFN, Via Irnerio 46, 40126 Bologna, Italy.*

Abstract

We propose and analyze a generalization of the Kitaev chain for fermions with long-range p-wave pairing, which decays with distance as a power-law with exponent α. Using the integrability of the model, we demonstrate the existence of two types of gapped regimes, where correlation functions decay exponentially at short range and algebraically at long range ($\alpha > 1$) or purely algebraically ($\alpha < 1$). Most interestingly, along the critical lines, long-range pairing is found to break conformal symmetry for sufficiently small α. This is accompanied by a violation of the area law for the entanglement entropy in large parts of the phase diagram in the presence of a gap, and can be detected via the dynamics of entanglement following a quench. Some of these features may be relevant for current experiments with cold atomic ions.

Elements of Quantum Simulations with Trapped Ions using MAGIC

Christof Wunderlich
Universität Siegen, Naturwissenschaftlich-Technische Fakultät, Department Physik, 57068 Siegen, Germany
christof.wunderlich@uni-siegen.de

I. Abstract

Atomic ions confined in an electrodynamic trap are well suited for simulating static and dynamic properties of other quantum systems [e.g., 1,2,3]. Using a collection of trapped ions, individual quantum system can be accessed and their interaction can be controlled by the experimenter to a high degree. Here, we report on recent experimental and theoretical progress using trapped ion spin ``molecules'' that exhibit adjustable spin-spin interactions due to Magnetic Gradient Induced Coupling (MAGIC) [4,5].

We investigate adiabatic quantum simulations in a linear Paul trap taking advantage of various types of spin-spin Hamiltonians [6]. These Hamiltonians with non-commuting interaction terms (e.g., $\sigma_z\sigma_z$ and $\sigma_x\sigma_x$) are generated by creating suitable $\sigma_z\sigma_z$ coupling patterns and through Trotterization using resonant driving of qubit transitions. These Hamiltonians can be varied adiabatically thereby realizing the preparation of the ground states of interesting quantum spin-Hamiltonians.

Of particular interest in these investigations is the quantum simulation of spin models that exhibit long-distance entanglement (LDE) in the ground state. LDE is a global nonclassical effect that can be monitored by the analysis of only two spins, namely the end spins of the chain. It is therefore a sufficiently simple, yet rich phenomenon that could be demonstrated using an ion trap quantum simulator [6].

We have characterized experimentally magnetic gradient induced coupling (MAGIC) between spins in strings of two and three ions and have used this spin-spin coupling to implement a CNOT gate between non-neighbouring ions It was shown that the spin-spin coupling strength can be adjusted by variation of the secular axial trap frequency [7]. Tailoring of these coupling constants is particularly versatile in ion traps with segmented electrodes. Here, it is shown how static potentials applied to individual electrodes of a micro-structured trap allow for the creation of coupling patterns suitable for creating spin Hamiltonians exhibiting LDE [6]. A Trotter expansion serves for generating the relevant spin-spin interactions in all needed directions and components and shall be implemented by using sequences of RF pulses. These sequences can be made robust against instrumental errors [8].

In addition, we present addressing of individual spins qubits within a quantum byte (eight qubits) and measure a cross-talk associated with the application of single-qubit gates on the order of 10^{-5}, breaching an important threshold for fault-tolerant quantum computing [9]. This is a key prerequisite for scalable quantum computing.

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(Presenting author)

The Casimir effect: present status, theoretical puzzles and future perspectives.

G. Bimonte

Dipartimento di Scienze Fisiche, Università degli Studi di Napoli Federico II,Complesso Universitario di Monte Sant'Angelo, Via Cintia, 80126, Napoli, Italy

e-mail addresses

Abstract

In this talk I shall present an informal overview of the Casimir effect. One of the rare manifestations of the quantum at the macroscopic scale, this phenomenon was predicted in 1948 by the dutch physicist H. Casimir. The Casimir effect has become the subject of intense experimental and theoretical work in the last 15 years, as a result of important advancements in experimental techniques which allowed to measure the tiny Casimir force with unprecedented precision, paving the way to exciting applications in nano-technology.

(Presenting author)

Robustness of collective properties to disorder: the case of Superradiance. Applications to light harvesting systems

G.L. Celardo[1]

[1] *Dipartimento di Matematica e Fisica and Interdisciplinary Laboratories for Advanced Materials Physics, Università Cattolica, via Musei 41, 25121 Brescia, Italy and Istituto Nazionale di Fisica Nucleare, Sezione di Pavia, via Bassi 6, I-27100, Pavia, Italy*

Open quantum systems are at the center of many research fields in condensed matter physics. We will introduce the non Hermitian Hamiltonian approach to open quantum systems, showing that this approach, in its simplest form, can be viewed as an extension of the Fermi Golden Rule. This approach allows to take into account the effect of the opening beyond the perturbation limit, where novel collective effects can arise. As an example of quantum collective property we consider here single excitation Superradiance. Among the many fascinating aspects of these properties, one important open question regards their robustness[1, 2] to the effects induced by the presence of an environment. This robustness might enable to exploit coherent quantum effects to build quantum devices for information technologies and basic energy science. Indeed, evidence of quantum coherent effets has been recently found in photosynthetic light-harvesting systems [3], and in other biological systems, even at room temperature. These findings raise many questions: how Nature can preserve quantum coherence in macromolecules in a wet and hot environment? what is the functional purpose of quantum coherence in Natural systems? We will investigate these questions using some realistic models of photosynthetic complexes.

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Universal Optimal Quantum Correlator

Francesco Buscemi[1], Michele Dall'Arno[1,2], Masanao Ozawa[1], Vlatko Vedral[2,3]
[1] Graduate School of Information Science, Nagoya University, Chikusa-ku, Nagoya, 464-8601, Japan
[2] Center for Quantum Technologies, National University of Singapore, Republic of Singapore
[3] Atomic and Laser Physics, Clarendon Laboratory, University of Oxford, Parks Road, Oxford OX13PU, United Kingdom
michele.dallarno@gmail.com

In the description of stochastic physical processes, it is important to determine how dynamical variables are correlated with each other. Correlation functions are computed as products of two (or more) dynamical variables (or their powers), averaged over time, or over many sites, or in both ways. In the simplest case of the average of the product of two dynamical variables, one usually speaks of two-point correlation functions.

In classical physics, dynamical variables are real-valued functions of the state of the system. In fact, the state of the system can be fully specified, in principle, by giving the values of all its dynamical variables (or its generating set of variables), at any instant in time. In classical statistical mechanics, therefore, there is no difficulty in defining and computing correlation functions, however complicated, between dynamical variables; as dynamical variables are all experimentally accessible, so are all correlation functions.

In quantum mechanics, on the contrary, the relation between states and dynamical variables is much more subtle. In particular, the notion of dynamical variables is replaced by that of observables, namely, self-adjoint operators that can or cannot commute; this is the formal reason for the existence of "incompatible" variables that cannot simultaneously assume definite values in any state. This feature arguably lies at the origin of all "quantum spooks," including a prevailing view that correlation functions are typically ill-defined for a quantum mechanical system — if two observables do not both have a definite value simultaneously, how could one compute the average of their product then?

Interpretational problems notwithstanding, one still can formally define two-point quantum correlation functions as $\mathrm{Tr}[A\ \rho\ B]$, where ρ describes the state of the system and A, B are any two observables (or, possibly, the same observable at different times, in which case we more precisely speak of auto-correlation functions). In fact, such functions are extensively used in a wide variety of fields, such as quantum statistical mechanics, quantum thermodynamics, and quantum field theory. The question then naturally arises, whether quantum correlation functions can be given a clear operational interpretation.

In our presentation (see Ref. [1] for technical details) we construct a "black-box"–like approach to quantum correlation functions, working for (but being independent of) any state ρ and any pair of observables A and B.

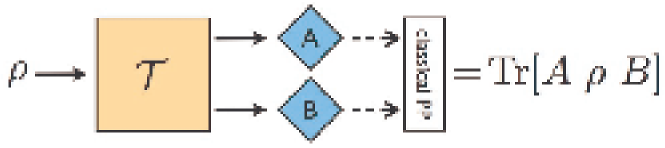

Fig. 1. The ideal two-point correlator described as a black-box, labeled by T. The quantum system, in state ρ, is fed into the black-box. The output consists of two quantum systems, on which independent measurements of observables A and B are performed. The data collected are then recombined by a purely classical post-processing, resulting in the value Tr[A ρ B]. Notice that both the black-box T and the final classical post-processing are independent of ρ, A and B. In this sense, the black-box T and the post-processing are universal.

First, the quantum system of interest is fed through a black-box, what we call the "ideal two-point correlator." The black-box in turns produces two output systems, on which the two observables A and B can be independently measured, even if they were incompatible. The recorded values are finally post-processed according to a fixed post-processing function such that, if the system was initially prepared in state ρ, the average result equals $\mathrm{Tr}[A\ \rho\ B]$.

Since both the quantum black-box and the classical post-processing are independent of ρ, A, and B, our scheme shows that quantum two-point correlation functions are no less operational than any other expectation value, challenging the common understanding explained above and suggesting, at the same time, new experimental procedures to directly measure them. We will also prove that our strategy is optimal, for any state ρ and any observables A and B, in the sense that it always minimizes the error propagation due to the final post-processing of data. We will finally present a very simple probabilistic implementation of our proposal on qubits encoded in the polarization of photons, feasible with current linear quantum optical technology.

Further technical details can be found in [1].

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From quantum data locking to the quantum enigma machine

Cosmo Lupo, Massachusetts Institute of Technology

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One major contemporary application of quantum mechanics is within cryptography. In quantum key distribution, the goal is to distribute secret keys among two legitimate parties. Once a secret key is shared, it is used to encrypt a message on a public channel, where a third party has negligible probability of successful decryption. A drawback, however, is that the key and the message must have equal length. This yields a major challenge for quantum key distribution, i.e., the distribution of secret keys at bit rates comparable to standard communication technology.

To explore alternative scenarios, we consider the phenomenon of quantum data locking. According to this unique quantum phenomenon, a small secret key can be used to "lock" an exponentially longer message, if this message is suitably encoded into a quantum system. This resembles the XX century enigma machine, a cipher that used a short secret key to encrypt a much longer message. Unlike the classical enigma machine, our "quantum enigma machine" is provably secure. The reason for that is that quantum data locking violates the famous theorem of Shannon's, according to which the secure encryption of a message of n classical bits requires a secret key of at least n bits.

We answer several questions about the possibility of applying quantum data locking for cryptography. One of them concerns the locking of information through noisy channels. We put the problem of quantum data locking of quantum channels on a solid theoretical ground. We formally define the locking capacities of a quantum channel, and prove bounds and results concerning these quantities.

The power of quantum data locking originates from a large gap existing between two security criteria for quantum cryptography quantified by two entropic quantities: the Holevo and the accessible information. We show that the latter becomes a sensible security criterion if an upper bound on the coherence time of the eavesdropper's quantum memory is known. Under this condition we introduce protocols for key distribution through a memoryless qudit channel. For channels with enough symmetry, such as the d-dimensional erasure and depolarizing channels, these protocols allow secret key distribution at an asymptotic rate as high as the classical capacity (that is, the rate of classical communication without any privacy requirement) minus one bit.

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Transitionless quantum driving in open quantum systems

Massimo Palma
Università di Palermo
massimo.palma@unipa.it

Abstract

We extend the concept of superadiabatic dynamics, or transitionless quantum driving, to quantum open systems whose evolution is governed by a master equation in the Lindblad form. We provide the general framework needed to determine the control strategy required to achieve superadiabaticity. We apply our formalism to two examples consisting of a two-level system coupled to environments with time-dependent bath operators.

(Presenting author)

Photonic States Manipulation In Atomic Ensembles

Valentina Parigi
Laboratoire Kastler Brossel, Université Pierre et Marie Curie,
Centre Nationale de la Recherche Scientifique, and Ecole Normale Supérieure,
Case 74, 4 place Jussieu, 75252 Paris Cedex 05, France
parigi@lkb.upmc.fr

I. Abstract

Quantum information processing requires efficient encoding, manipulation and storage of quantum states.
Photons are excellent carriers of quantum information, since they travel fast without being affected by external disturbances. On the other hand, cold atomic ensembles are a very versatile tool to store, manipulate and retrieve quantum states of light. In the past decade, they have been extensively used to store and retrieve photonic states by using either the so called Electromagnetically Induced Transparency (EIT) protocol, or the DLCZ protocol.

In the case of a free-space setup it is possible to make use of the multimode nature of the storage medium, and it has been demonstrated that the system can be used as a quantum memory (in the EIT protocol) for q-bits encoded in the orbital angular momentum (OAM) of single photons [1]. The use of this potentially high-dimensional encoding has been theoretically proposed in several quantum information processing protocols [2, 3]. More recently it has been shown that hybrid states encoded in orbital angular momentum and polarization degree of freedom provide alignment- free quantum key-distribution or ultrasensitive measurements [4, 5].

In the case of the DLCZ protocol the detection of a Raman photon triggers the creation of a collective atomic excitation in a lambda-medium. The shared excitation can be reconverted later into a single photon leaving the ensemble. The process has been extensively investigated in the photon counting regime showing the non-classical character of the emerging photonic state [6]. Only very recently the photonic states leaving the atomic ensemble have been characterized by quantum homodyne tomography. The state is hence completely described in the continuous variables picture by the reconstructed Wigner function giving complete information on a well-defined spatial-temporal mode [7].

Atomic ensembles can be also used for manipulating photonic stats by atomic interactions and they are promising candidates to reach strong-nonlinearities at the single-photon level. Photonic states can be converted into strongly interacting particles, like collective excitations involving Rydberg atoms. Interactions between Rydbergs in fact lead to a "blockade" phenomenon, where each Rydberg atom blocks the excitation of its neighbors, which can result in strong nonlinearities [8].

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(Presenting author)

A quantum information approach to the black-hole information paradox

Stefano Pirandola
Department of Computer Science, University of York, York YO10 5GH, United Kingdom
Stefano.pirandola@york.ac.uk

Abstract

Classically, black holes are compact objects with perfect semi-permeable horizons: Anything may enter, nothing may leave. Quantum black holes are also subject to evaporation, via a mechanism which leads to a loss of information [1]. However, the recent discover of the black-hole firewall paradox [2,3] has undermined the basic mechanism of this radiation process (pair creation into vacuum). For this reason, here we consider an axiomatic approach [4] that applies to any black hole type that can unitarily evaporate away completely by any mechanism. Using tools from quantum information theory, we show that a quantum black hole must either have a leaky horizon allowing quantum information out (e.g., via quantum tunnelling [5,6]), or it must look very different from its classical counterpart, having an external neighbourhood consisting of exotic matter with super-ordinary entropic content (such as an 'atmosphere' of microscopic black holes). Work in collaboration with Samuel L. Braunstein [4].

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A quantum gate between a flying optical photon and a single trapped atom

Stephan Ritter
Max-Planck-Institute of Quantum Optics, Hans-Kopfermann-Str. 1, 85748 Garching, Germany
Stephan.Ritter@mpq.mpg.de

Abstract

A hybrid system of light and matter qubits might allow to scale quantum communication to large distances using quantum repeaters and to increase the number of qubits in quantum computation. To this end, the development of a robust two-qubit gate that allows to link distant computational nodes is a pressing challenge.

We have realized such a quantum gate between the spin state of a single trapped ^{87}Rb atom and the polarization state of an optical photon contained in a faint laser pulse [1]. The gate mechanism is deterministic, robust and expected to be applicable to almost any matter qubit. It is based on reflecting the photonic qubit from a cavity that provides strong light-matter coupling. We demonstrate the versatility of the gate mechanism by creating atom-photon, atom-photon-photon, and photon-photon entangled states from separable input states.

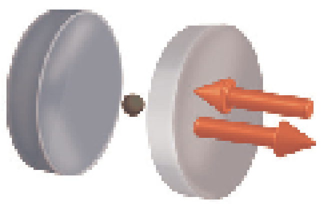

Fig. 1. A quantum gate between the spin of a single atom and the polarization of a single photon is achieved via reflection of the light (red) from an optical resonator (blue) containing a single atom (green) in the strong coupling regime.

One of the applications enabled by this gate mechanism is the nondestructive detection of optical photons [2]. Instead of being absorbed, impinging light is reflected off the cavity containing a single atom in a superposition of two states. Upon reflection of a single photon, the phase of the superposition state is flipped, which allows us to nondestructively detect the photon.

This experimental achievement has two major consequences: First, it facilitates repeated measurements of one and the same photon, which boosts the photon detection efficiency. Second, nondestructive detection can serve as a herald that signals the presence of a photon without affecting its unmeasured degrees of freedom, like its temporal shape or its polarization. This is in stark contrast to absorbing detectors, where the photon and its quantum state are irreversibly lost. Both implications are of great importance for the rapidly evolving research fields of quantum measurement, quantum computation, quantum communication, and quantum networks.

We also expect our experiment to break ground for further applications, including the generation of atomic and photonic cluster states and deterministic photonic Bell-state measurements.

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Extending the Quantum Communications toward the Space exploiting Satellite Links

Giuseppe Vallone, Davide Bacco, Daniele Dequal, Simone Gaiarin, Vincenza Luceri*, Giuseppe Bianco§ and Paolo Villoresi

Dipartimento di Ingegneria dell'Informazione, Università degli Studi di Padova, Padova, Italy

e-GEOS spa, Matera, Italy

§*Matera Laser Ranging Observatory, Agenzia Spaziale Italiana, Matera, Italy*

paolo.villoresi@dei.unipd.it

Quantum Communications on planetary scale require complementary channels including ground and satellite links [1-5].

The former have progressed up to commercial stage using fiber-cables, while for satellite links, the absence of terminals in orbit has impaired theirs development.

Nowadays, the demonstration of the feasibility of such links is crucial for designing space payloads and to eventually enable the realization of protocols such as quantum-key-distribution (QKD) and quantum teleportation along satellite-to-ground or intersatellite links [4].

In the work that shell be presented, the faithful transmission of qubits from space to ground by exploiting satellite corner cube retroreflectors acting as transmitter in orbit, as alredy exploited in the fisrt single photon exchange [6] obtaining a low error rate suitable for QKD is detailed. The scheme of the experiment is illustrated in the Figure on the right [7].

Finally, on the base of the findings, we envisage a two-way QKD protocol exploiting modulated retroreflectors that necessitates a minimal payload on satellite, thus facilitating the expansion of Space Quantum Communications [7].

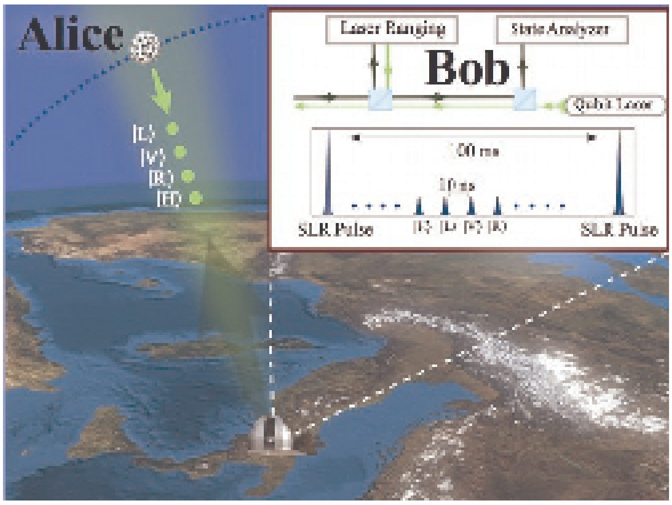

Figure: Scheme of the Satellite QKD demonstration. Qubit pulses are sent at 100 Mhz repetition rate and are reflected back at the single photon level from the satellite, thus mimicking a QKD source on Space. Synchronization is performed by using the bright SLR pulses at repetition rate of 10 Hz.

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Paolo Villoresi
University of Padua
Department of Information Engineering
via Gradenigo 6, 35131 Padova - Italia
paolo.villoresi@unipd.it

http://quantumfuture.dei.unipd.it/

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The shift in the communication paradigm

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