48 Symposium on Mathematical Physics

Gorini-Kossakowski-Lindblad-Sudarshan Master Equation - 40 Years After

Toruń, Poland, June 10-12, 2016

Book of abstracts

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48 SMP is devoted to celebrate the 40th anniversary of the publication of

"On the generators of quantum dynamical semigroups" by G. Lindblad
and
"Completely positive dynamical semigroups of N-level systems"
by V. Gorini, A. Kossakowski and G. Sudarshan

Guests of Honour: Vittorio Gorini, Andrzej Kossakowski and George Sudarshan

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Speakers:

The first 40 years of GKSL generators

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Should entanglement measures be monogamous or faithful?

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"Is entanglement monogamous?" asks the title of a popular article [B. Terhal, IBM J. Res. Dev. 48, 71 (2004)], celebrating C. H. Bennett's legacy on quantum information theory. While the answer is certainly affirmative in the qualitative sense, the situation is far less clear if monogamy is intended as a quantitative limitation on the distribution of bipartite entanglement in a multipartite system, given some particular measure of entanglement. Here, we clarify the most general form of a universal quantitative monogamy relation for a bipartite measure of entanglement. We then go on to show that an important class of entanglement measures fail to be monogamous in this most general sense of the term, with monogamy violations becoming generic with increasing dimension. In particular, we show that entanglement measures cannot satisfy monogamy while at the same time faithfully capturing the entanglement of the fully antisymmetric state in arbitrary dimension. Nevertheless, monogamy can be recovered if one allows for dimension-dependent relations, as we show explicitly with relevant examples.

Geometry and response of Lindbladians

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Markovian reservoir engineering, in which time evolution of a quantum system is governed by a Lindblad master equation, is a powerful technique in studies of quantum phases of matter and quantum information. It can be used to drive a quantum system to a desired (unique) steady state, which can be an exotic phase of matter difficult to stabilize in nature. It can also be used to drive a system to a unitarily-evolving subspace, which can be used to store, protect, and process quantum information. In this paper, we derive a formula for the map corresponding to asymptotic (infinite-time) Lindbladian evolution and use it to study several important features of the unique state and subspace cases. We quantify how subspaces retain information about initial states and show how to use Lindbladians to simulate any quantum channels. We show that the quantum information in all subspaces can be successfully manipulated by small Hamiltonian perturbations, jump operator perturbations, or adiabatic deformations. We provide a Lindblad-induced notion of distance between adiabatically connected subspaces. We derive a Kubo formula governing linear response of subspaces to time-dependent Hamiltonian perturbations and determine cases in which this formula reduces to a Hamiltonian-based Kubo formula. As an application, we show that (for gapped systems) the zero-frequency Hall conductivity is unaffected by many types of Markovian dissipation. Finally, we show that the energy scale governing leakage out of the subspaces, resulting from either Hamiltonian/jump-operator perturbations or corrections to adiabatic evolution, is different from the conventional Lindbladian dissipative gap and, in certain cases, is equivalent to the excitation gap of a related Hamiltonian.

From GKLS equations to theory of solar cells

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Twirling Semigroups and Variations on the Theme

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The special class of semigroups of operators that we nowadays call "twirling semigroups" were first considered by Kossakowski in the early 1970s. In that pioneering times for the theory of open quantum systems — the celebrated Gorini-Kossakowski-Lindblad-Sudarshan classification of the generators of quantum dynamical semigroups had not been established yet — they were probably rather exotic objects. Today, the twirling semigroups have found remarkable applications, e.g., in quantum information science, and the general form of the associated infinitesimal generators has been explicitly described. We will focus, in particular, on the group-theoretical framework underlying this class of semigroups of operators and their realization in terms of 'phase-space functions'. Suitable generalizations will be also outlined.

Physics of complete positivity

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That dissipative dynamical maps must be completely positive is often criticised as a mathematical request that is too much physically constraining while, at the same time, lacks a sound physical motivation. The standard argument in favour of complete positivity is indeed based on coupling the open quantum system of interest with an arbitrary, inert ancilla. We briefly review these criticisms and propose a different, more physical perspective from which it becomes apparent that complete positivity cannot easily be dispensed with.

SIC-POVMS – where do the numbers come from?

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Non-Markovian quantum dynamics of open systems

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Dynamical Decoupling of Quantum Noise

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I provide a system-bath model which is exactly solvable and for which the bath trace provides a GKLS generator without approximation. Using this example, I show how dynamical decoupling - a sequence of rapid operations on the system - can remove the Hamiltonian coupling to the bath and thereby maintain coherence. On the other hand, applying decoupling on the level of the GKLS generator has, perhaps surprisingly, no effect. I generalize these observations and suggest to use them to distinguish collapse models (intrinsic modifications of Schroedinger dynamics) from ordinary decoherence.

A brief history of GKSL master equation

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Contractivity properties of a quantum diffusion semigroup

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We consider a quantum diffusion equation, which can be viewed as the quantum generalisation of the classical heat equation. The quantum dynamical semigroup (QDS),corresponding to this diffusion equation, has unbounded generators and does not have an invariant state. We prove contractivity properties of this QDS. Our results include a log Sobolev inequality and a Nash inequality for Gaussian states. The latter in turn is used to establish that the QDS is ultracontractive. Ultracontractivity leads to a bound on the purity of the state evolving under this QDS and hence tells us how the state decoheres. Our proof is analogous to that used by Toscani to prove sharp Nash- and log-Sobolev inequalities for the classical heat semigroup, and employs a concavity property of the entropy power with respect to time. This is joint work with Cambyse Rouzé (Cambridge) and Yan Pautrat (Orsay).

Quantum Theory is an Information Theory

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The experience in Quantum Information has led the theoretical community to look at foundations of Quantum Theory under a completely new angle, regarding it as a “theory of information”, for an information of a new kind. This has lead to a new axiomatization of the theory based on six axioms of informational nature: 1) Causality, 2) Local Discriminability, 3) Perfect Discriminability, 4) Ideal Compressibility, 5) Atomicity of composition, 6) Purification. Axioms 1-5 are shared by classical theory. Axiom 6 is distinctive of quantum theory. In my talk I will briefly illustrate the informational framework and the axioms. Differently from the von Neumann axiomatization, the information-theoretic axiomatization has a direct operational interpretation, and allows to prove the theorems of the theory without using Hilbert spaces. Examples of relevant theorems proved by using the axioms only will be provided, including open system dilations, no signaling, nonlocality, entanglement, tomography, teleportation.

References:

G. Chiribella, G. D’Ariano, P. Perinotti, *PRA Phys. Rev. A*, **84**, 012311 (2011)
G. D’Ariano, G. Chiribella, P. Perinotti, Quantum Theory from First Principles, Cambridge University Press (in press)

Pauli-LKGS hybrid master equations

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Revisiting Markovianity

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The Gorini-Kossakowski-Lindblad-Sudarshan theorem is one of the cornerstones of mathematical physics. It provides the most general generators of quantum dynamical semi-groups under reasonable conditions, and hence captures dissipative Markovian quantum evolution. The importance of this structural clarification of Markovian dynamics can hardly be overestimated.

And yet, there are many important types of processes that are not memoryless in this sense and hence deviate from Markovian dynamics. In this talk, we will revisit questions of non-Markovianity, presenting both old and new results, based on Gorini-Kossakowski-Lindblad-Sudarshan's work. We look at the quantum embedding problem, judging whether a completely positive map can arise from a dynamical semi-group [1] and assess the computational complexity thereof [2]. In a second part, we investigate an optomechanical setting in which it has been a-priori very much unclear whether the dynamics is Markovian [3]. If time allows, I will briefly hint at novel developments of Markovian quantum many-body systems [4-7], with respect to protecting topological quantum memories [6] and symmetry breaking [7].

References:

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Universal quantum computing from local dissipation

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Structure of norm-continuous quantum Markov (dynamical) semigroups

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Starting from the celebrated papers of Gorini, Kossakowski, Sudarshan and Lindblad in 1976, the structure of uniformly continuous quantum Markov semigroups (QMSs) and their generators has been studied by several authors because it is quite general and several special classes deserve further investigation. In most of these researches, concern has been focused on the structure of the generator and the relationships between its algebraic properties and structural properties of the underlying open quantum system. In recent years, there has been a growing interest in the use of QMSs to model open quantum systems having subsystems which are not affected by decoherence.

In this talk we describe the structure of generators of norm-continuous quantum Markov semigroups with atomic decoherence-free subalgebra providing a natural decomposition of a Markovian quantum open system into its irreducible components and noiseless components.

We also discuss new characterisations of the structure of invariant states and decoherence-free subsystems.

Reference:

J. Deschamps, F. Fagnola, E. Sasso and V. Umanita, *Rev. Math. Phys.*, **28** (2016), 1650003.

From nonlocal correlations to uncertainty principle

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The G-K-L-S master equation at high energies

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Quantum metrology in open quantum systems

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Information gain and storage in General Probabilistic Theories

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Master equation for the ensemble averaged dynamics of disordered quantum systems

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In this talk, we present our approach [1] to the ensemble averaged dynamics of disordered quantum systems using the framework of quantum master equations. The latter allows for a full characterization of the coherent and incoherent contents of the ensemble averaged dynamics on transient and asymptotic time scales. In the cases of spectral disorder (induced e.g. by slow intensity variations of experimental control fields) and of isotropically disordered eigenvector distributions (e.g. random unitary ensembles), we derive exact master equations which are valid for all times. Furthermore, for the short-time limit, we provide an explicit form valid for any disorder distribution. Finally, with the help of standard perturbation theory, we succeed to derive perturbative disorder master equations for systems with on-site disorder and a weak, disorder-independent, coupling potential. This approach is applicable to a variety of situations, such as finite-size Anderson models, Bose-Hubbard Hamiltonians or biology-inspired networks.

Reference:

[1] C. Kropf, C. Gneiting and A. Buchleitner, arXiv:1511.08764 (2015)

Remarks on Contractions of Lie-Jordan Algebras

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A new approach to the quantum entanglement for identical particles

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Efficient detection of quantum channel capacities

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Three new ideas about reservoir engineering (and their applications to practically everything)

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The coherent control of quantum system is the central ingredient to all new sub-branches of quantum physics, from quantum thermodynamics to quantum technologies, from quantum biology to relativistic quantum dynamics.
It is nowadays an established fact that the persistence of quantum coherences is not incompatible with the presence of a surrounding environment. Environment induced decoherence was indeed initially accused to be the major enemy of quantum technologies. Subsequently, however, it became clear that loss of quantumness does depend crucially on the properties of the environment. Certain types of environment allow now only for the preservation of quantum properties but also for their creation. Within this framework, reservoir engineering techniques where conceived. Contrarily to what one may believe at first sight, indeed, in most physical scenarios it is possible to have access to a limited number of control parameters regulating the properties of the environment. In this way, one can in turn control and enhance the persistence of quantum properties, e.g., to extend the life time of quantum devices.
In my talk I will present three new ideas on reservoir engineering for quantum control. All of them are based on the exploitation of memory effects characterising the open quantum system dynamics. The first idea is the reservoir-induced control of the uncertainty associated to lack of knowledge of possible measurement outcomes, quantified by entropic uncertainty relations [1]. The second idea is the exploration of the interplay between memory effects and the action of dynamical decoupling pulses to enhance quantum coherence [2]. The third idea is the use of dynamical decoupling as a tool for inducing memory effects and, in particular, for improving the phenomenon of time-invariant discord, i.e. the freezing of quantum correlations in presence of noise [3].

References:

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[2] C Addis, F Ciccarello, M Cascio, GM Palma, S Maniscalco, *New Journal of Physics 17* (12), 123004 (2015).
[3] C Addis, G Karpat, S Maniscalco, *Physical Review A* 92 (6), 062109 (2015).

The Kossakowski-Lindblad Vector Field on the Space of States

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In the geometrical formulation of quantum mechanics ,on the stratified manifold of states, it is possible to introduce Hamiltonian vector fields, "gradient vector fields" and Kraus-Sudarshan vector fields. The last two vector fields are non-linear.By selecting a particular combination of them ,it is possible to cancel the non-linearities to obtain the Kossakowski-Lindblad vector field. Once the equations of motion are described by a vector field it is possible to consider the equations of motion also on tensor fields associated with algebraic structures, this allows to interpret the evolution as a contraction procedure of the Lie-Jordan algebra on the space of observables.

Full and efficient characterisation of non-Markovian quantum processes

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In science, we often want to characterise processes undergone by a system; this allows us to both identify the underlying physics and to predict the future of the system. If the state of the system at any time depends only on the state of the system at the previous time-step and some predetermined rule then these dynamics are characterised with relative ease. For instance, the dynamics of quantum mechanical systems in isolation is described in this way. But, when a quantum system repeatedly interact with an environment, the environment often 'remembers' information about the system's past. This leads to non-Markovian processes, which depend nontrivially on the state of the system at all times during its evolution and they are not, in general, be easily characterised using conventional techniques. Since the early days of quantum mechanics it has been a challenge to describe non-Markovian processes. Here we will show that using operational tools from quantum information theory we can fully characterise any non-Markovian process. In general the full characterisation is not efficient, as it requires exponentially large number of experiments. To overcome this obstacle we map the full process to a many-body state. We show that this can be achieved by using linear (in the number of time steps) amount of bipartite entanglement. Next, the state can be measured to any desired precision, thus the process can be characterised to any desired precision. Finally, we define a natural measure for the degree of non-Markovianity.

Collision model of non markovian dynamics

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Dynamical Observables in Dissipative Quantum Systems

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From Open Quantum Walks to Open Quantum Brownian motion

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Open quantum walks were introduced as quantum walks exclusively driven by the interaction with the external environment and defined in terms of discrete completely positive maps on graphs [S. Attal, F. Petruccione, C. Sabot and I. Sinayskiy, J. Stat. Phys. 147 (2012) 832]. Recently, a new type of quantum Brownian motion for Brownian particles with internal quantum degrees of freedom was introduced as a scaling limit of Open Quantum Walks [M. Bauer, D. Bernard, A. Tilloy, Phys. Rev. A 88 (2013) 062340]. The microscopic derivation of open quantum Brownian motion relates the dynamical properties of open Quantum Brownian motion and the thermodynamical properties of the environment. In particular, this allows the possibility of control of the external degrees of freedom of the "walker" (position) by manipulating the internal one, e.g. spin, polarization, occupation numbers.

Beyond GKSL master equation: randomness, quantifying, applying

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Sufficient separability criteria: From some linear maps and for some symmetric states

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Thermodynamics of Quantum Coherences

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Quantum decoherence is seen as an undesired source of irreversibility that destroys quantum resources. Quantum coherences seem to be a property that vanishes at thermodynamic equilibrium. Away from equilibrium, quantum coherences challenge the classical notions of a thermodynamic bath in a Carnot engines, affect the efficiency of quantum transport, lead to violations of Fourier's law, and can be used to dynamically control the temperature of a state. However, the role of quantum coherence in thermodynamics is not fully understood. Here we show that the relative entropy of a state with quantum coherence with respect to its decohered state captures its deviation from thermodynamic equilibrium. As a result, changes in quantum coherence can lead to a heat flow with no associated temperature, and affect the entropy production rate. From this, we derive a quantum version of the Onsager reciprocal relations that shows that there is a reciprocal relation between thermodynamic forces from coherence and quantum transport. Quantum decoherence can be useful and offers new possibilities of thermodynamic control for quantum transport.

Open Quantum System Dynamics from a Total State Point of View

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Non-Markovian quantum evolutions

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On Complexity for Quantum Open Systems

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Unbounded generators of dynamical semigroups

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Following work of Holevo and many others I will define an unbounded version of the generator form we are celebrating: A generator (of a strongly continuous semigroup of cp maps on the trace class) is called "standard" if it is a minimal positive perturbation of a "no-event" generator. Here no-event semigroups are defined as those taking pure states to pure states. This is formulated so as to make sense also in the discrete classical case. In this case it is clear how to construct also some non-standard generators by an escape to infinity in finite time, followed by the rebound to a finite state. Quantum analogues of such examples suggest the existence of non-standard generators. I will discuss the current status of such constructions.

Spectral properties of quantum channels – a glimpse from algebraic point of view

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Spectral properties of quantum channels are important e.g. in investigating the asymptotic behaviour of iterated quantum maps. The most important is the peripheral spectrum, i.e. the eigenvalues of modulus 1. We present the tools of analysing the algebra generated by the Kraus operators of the given channel which gan give the information about the structure of the peripheral spectrum. We show in details how we can use Amitsur-Levitzki and Shemesh criterion for qutrit, ququart and ququint maps.

On the equivalence between completely-positive-divisibility and information flow

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We prove the equivalence between two approaches to the characterisation of quantum Markovianity, divisibility and lack of information backflow. We show that a bijective dynamical map is completely-positive-divisible if and only if a monotonic non-increase of distinguishability is observed for two equiprobable states of the evolving system and an ancilla. Moreover our proof is constructive: given any such map that is not completely-positive-divisible, we give an explicit construction of two states that exhibit information backflow. Finally, while an ancilla is necessary for the equivalence to hold in general, we show that it is always possible to witness the non-Markovianity of maps without using any entanglement between system and ancilla.

On the geometric formulation of markovian dynamics

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We present a geometric description of the space of states of a finite-dimensional quantum system and the Markovian evolution associated with the Kossakowski-Lindblad operator. By using a tensorial formulation for the quantum description, we are able to encode, in a natural way, the Markovian dynamical evolution as a vector field on the space of tensor fields. The corresponding dynamics on the set of linear operators is obtained as a contraction of the different algebraic structures the space is endowed with (associative and Lie-Jordan). The tensorial nature allows also to consider dynamical effects on physical magnitudes which are not linear with respect to the physical state, such as von Neumann entropy.

Dynamic Quantum Tomography Model for Systems with Pure Decoherence

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According to one of the most fundamental assumptions of quantum theory, the density matrix carries the achievable information about the quantum state of a physical system. In recent years the determination of the trajectory of the state based on the results of measurements has gained new relevance because the ability to create, control and manipulate quantum states has found applications in other areas of science, such as: quantum information theory, quantum communication and computing.

I propose a dynamic quantum tomography model for open quantum systems with evolution given by phase-damping channels (pure decoherence evolution). Mathematically, these channels correspond to completely positive trace-preserving maps defined by the Hadamard product of the initial density matrix with a time-dependent matrix which carries the knowledge about the evolution. Physically, there is a strong motivation for considering this kind of evolution because such channels appear naturally in the theory of open quantum systems. Algebraic analysis of phase-damping channels allows one to determine optimal criteria for quantum tomography of systems in question. General theorems and observations will be accompanied by a specifc example, which shows step by step how the theory works. The results outlined in this presentation can potentially be applied in experiments where there is a tendency a look at quantum tomography from the point of view of economy of measurements, because each distinct kind of measurement requires, in general, preparing a separate setup.

Quantum filtering for systems driven by fields in non-classical states

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An example of quantum trajectories for a system driven by non-classical states of light is presented. Using Gardiner and Collet's input-output theory and the concept of cascade systems we derive stochastic master equation for amplitude quadrature measurements. The system and electromagnetic field are described by making use of quantum stochastic unitary evolution. As the non-classical state of field we consider a superposition of vacuum and single photon states. In this case the master equation is given by a finite set of coupled equations which reflects the non-Markovian character of the problem. The output field carries information and it can be used to monitor the state of the system. To find the stochastic evolution of the system we use the conditional characteristic function method and we extend the compound system by an ancilla which is driven by the vacuum (quantum white noise) and it generates the non-classical state of light.

Probing the eigenstates thermalization hypothesis with many-particle quantum walks on lattice.

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Quantum thermalization remains an elusive concept. Understanding how it arises in many-particles systems has been at the core of numerous studies. We present a computational proof of the eigenstate thermalization hypothesis in both bosons and fermions systems on lattices. While we simulate quantum walks we record the time evolution of the entropy and the temperature of a specific eigenstate during the entire dynamics and observe how it thermalizes on two different lattices. We make simulations using two different numbers of particles walking on two grid graphs with 25 vertices. In each case we start with the same initial conditions for many-particle quantum walks.

Semi-stochastic unitary matrices

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A matrix of complex numbers is said to be *semi-stochastic* if for every column the sum of elements equals one. With the use of unitary semi-stochastic matrices a multi-instant quantum pure states are introduced. For two instants, say 0 and 1, a pure state at instant 0 represented by a unit vector $\Psi^{(0)} = \left[\psi_1^{(0)}, \psi_2^{(0)}, \dots, \psi_d^{(0)}\right]$ and the unitary semi-stochastic matrix $\mathrm{U}^{(1|0)} = \left[u_{j,k}^{(1|0)}; (j,k) \in \{1,2,\dots,d\}^2\right]$, the two-instant state is defined as the (unit) d ^{2}-dimensional vector

$$\Psi^{(1,0)} = \left[\psi_{j,k}^{(1,0)} \coloneqq u_{j,k}^{(1,0)} \cdot \psi_k^{(0)}; (j,k) \in \{1,2,\dots,d\}^2\right].$$

Let us note, that the state at instant 1 is given by

$$\Psi^{(1)} = \left[\psi^{(1)} \coloneqq \sum_k \psi_{j,k}^{(1,0)}; j = 1,2,\dots,d\right],$$

whereas, due to semi-stochastic property, $\psi_k^{(0)} = \sum_j \psi_{j,k}^{(1,0)}, k = 1,2,\dots,d$.

The *reverse* two-instant state is defined by

$$\Psi^{(0,1)} = \left[\psi_{k,j}^{(0,1)} \coloneqq u_{k,j}^{(0|1)} \cdot \psi_j^{(1)}; (k,j) \in \{1,2,\dots,d\}^2\right],$$

where $u_{k,j}^{(0|1)} = \overline{u_{j,k}^{(1|0)}}$ form the inverse unitary matrix. The main goal is to present a partial solution of the problem of reversibility defined as follows:

Does there exist a complex number α of modulus 1, that $\psi_{k,j}^{(0,1)} = \alpha\psi_{j,k}^{(1,0)}$ all pairs (j,k)?

An Amplification Process in Quantum Algorithm described by the GKSL Master Equation

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Ohya and Masuda considered a quantum algorithm which can solve the satisfiability (SAT) problem and showed that the SAT problem can be solved in polynomial time by the algorithm. The probability of obtaining correct result by the algorithm is sometimes very small. To amplify the probability, Ohya and Volovich proposed Chaos amplifier and showed that the probability can be amplified in polynomial time. In this study, we consider an amplification process which is generalization of the Chaos amplifier and show that it can be described by the GKSL master equation.

Exactly solvable model of two coupled spin-1 systems

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We propose and investigate the properties of a generalized Heisenberg model describing two coupled spin 1. Exploiting peculiar symmetry properties it possesses by construction, we disclose the existence of underlying and decoupled subynamics of two spin 1/2 and a spin 2 in the quantum dynamics of the two qutrits .The route we follow to get such a result demands no approximation and moreover it is applicable also when some parameters appearing in the Hamiltonian model are time dependent. Some consequent intriguing features emerging in the quantum evolution of the system are successfully brought to light and carefully examined.

Energy Backflow Measure in non-Markovian Open Quantum Systems

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We characterize the time behavior of the energy exchange between an open quantum system and its environment in a non-Markovian dynamical regime using the full counting statistics formalism. In particular we focus on the occurrence of energy backflow from environment to system, to which we introduce a suitable condition and measure. We study in detail this quantifier in two paradigmatic open quantum systems, namely the spin-boson model and the quantum brownian motion, drawing a connection with recently introduced notions of non-Markovianity. Results show that, while Born-Markov semi-group limiting case and, more in general, Markovian regime prevent the occurrence of energy backflow, non-Markovianity allows for its observation and quantification.

Markovian dynamics of quantum correlations in two-mode Gaussian open systems

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In the framework of the theory of open systems based on completely positive quantum dynamical semigroups, we make a comparison of the behaviour of continuous variable quantum correlations (quantum entanglement, quantum discord, quantum steering) for a system consisting of : 1) two noninteracting; 2) two interacting bosonic modes embedded in a thermal environment. We solve the Gorini-Kossakowski-Lindblad-Sudarshan Markovian master equation for the time evolution of the considered system and describe the quantum entanglement, discord and steering in terms of the covariance matrix for Gaussian input states. Depending on the values of the parameters characterizing the initial state of the system (squeezing parameter, average photon numbers), the coefficients describing the interaction of the system with the reservoir (temperature, dissipation constant), and of the strength of interaction between the two modes, one may notice such phenomena like generation of quantum correlations, their suppression (sudden death), or an asymptotic decay in time of quantum correlations. We describe also the time evolution of the classical correlations and quantum mutual information, which measures the total correlations of the quantum system.

Effective Method for the Solutions of Functionally Commutative

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In this presentation, we will study a certain type of open quantum systems, so called the functionally commutative systems, and an effective method for solving these quantum systems will be shown.

Criterions for quantum gates universality

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The conditions for a set of quantum k-mode unitary and orthogonal gates to be universal are presented. It is shown that if the spectra of considered gates do not belong to a finite list of exceptional spectra, the problem of deciding universality boils down to solving a set of linear equations. We also present how the exceptional spectra are determined and prove that their number grows exponentially with the number of modes. Finally, for 2- and 3-mode gates it turns out that the exceptional spectra correspond to either finite subgroups of SU(2), (SO(3)) or give universality. This way we classify all universal pairs of one qubit gates. These are the results of the joint work in progress with Adam Sawicki.

Bose Polaron as an Instance of Quantum Brownian Motion

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Quantum Brownian motion represents a paradigmatic model of open quantum system. It describes the dynamics of a particle coupled to a huge environment. In our work we employ such a model to investigate the physical behaviour of an impurity embedded in an ultra colds gas (Polaron Problem). This approach allows to calculate measurable observables and predict new effects, such as squeezing and cooling.

Non-linear dynamics induced by successive rank-r selective measurements

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Selective measurements are known to lead to nonlinear transformations of quantum states. We consider measurements which are performed not on the system itself but on the probe (coupled to the system), which is in contrast to Zeno and anti-Zeno effects. The total "system + probe" density operator ρ is transformed as follows:

$$\rho \longrightarrow \frac{E_i \rho E_i}{tr[E_i \rho E_i]},$$

where E_i is a projector, which acts as an identity transformation in the system Hilbert space $\mathcal{H}_1$ and as a rank-r projector in the probe Hilbert space $\mathcal{H}_2$. Stroboscopic measurements of the probe with a time interval τ between successive shots result in a new interesting type of quantum dynamics, which explains the emergence of effective Hamiltonians in some physical problems. For instance, let $\sum_i \gamma A_i \otimes B_i$ be the ``system + probe" Hamiltonian, where $A_i \in \mathcal{H}_1$ and $B_i \in \mathcal{H}_2$. If rank r=1 and $\tau \longrightarrow 0$, $\gamma \longrightarrow \infty$, with $\gamma^2 \tau = \Omega$, then the system evolution is described by the effective Hamiltonian $H_{eff} = \sum_i \gamma A_i \langle B_i \rangle - \sum_{i,j} \frac{i}{2} \Omega A_i A_j (\langle B_i B_j \rangle - \langle B_i \rangle \langle B_j \rangle) + O(\sqrt{\tau})$, where $\langle \cdot \rangle$ denotes averaging over the state, which is supported by the probe measurements. We also generalize this approach to higher ranks r. In the limit above, analytical solutions are shown to converge to the exact dynamics. Possible applications of the developed theory include measurements of weak populations via amplification induced by such a non-linear dynamics.

Three-dimensional visualisation of a qutrit

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We present a surprisingly simple three-dimensional Bloch sphere representation of a qutrit, i.e., a single three-level quantum system. We start with a symmetric state of a two-qubit system and relate it to the spin-1 representation. Using this representation we associate each qutrit state with a three-dimensional vector $\boldsymbol{a}$ and a metric tensor $\hat{\boldsymbol{\Gamma}}$ which satisfy $\boldsymbol{a} \cdot \hat{\boldsymbol{\Gamma}} \cdot \boldsymbol{a} \leq \mathbf{1}$. This resembles the well known condition for qubit Bloch vectors in which case $\hat{\boldsymbol{\Gamma}} = \mathbf{1}$. In our case the vector $\boldsymbol{a}$ corresponds to spin-1 polarization, whereas the tensor $\hat{\boldsymbol{\Gamma}}$ is a function of polarization uncertainties. Alternatively, $\boldsymbol{a}$ is a local Bloch vector of a symmetric two-qubit state and $\hat{\boldsymbol{\Gamma}}$ is a function of the corresponding correlation tensor.

Entanglement of an open quantum system with its Markovian environment

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To investigate entanglement of an open quantum system with its environment the description using reduced density operator is not sufficient. By a linear coupling to the bath of harmonic oscillators the partial P-representation allows to efficiently determine the total state of system and environment. We investigate the dissipation of a qubit and of a harmonic oscillator. With the Peres-Horodecki separability criterion we show that the system - environment entanglement is also possible for Markovian environments.

Time-dependent exactly solvable models of two coupled spin-1/2

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A system of two spin 1/2, coupled to each other by a spin-spin interaction and placed under external time-dependent magnetic fields, is modeled by a general Hamiltonian endowed with a symmetry that enables us to reduce the total dynamics into two independent 2 dimensional sub- dynamics. Each of the sub-dynamics is shown to be brought into an exactly solvable form by appropriately engineering the magnetic fields and thus we obtain an exact time evolution of the system of coupled two spin 1/2. Several physically relevant and interesting quantities are evaluated exactly to disclose intriguing phenomena in such a system.

Gaussian Quantum Steering of Two Bosonic Modes in a Thermal Environment

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Einstein-Podolsky-Rosen steerability of quantum states is a property that is different from entanglement and Bell nonlocality. We describe the time evolution of a recently introduced measure that quantifies steerability for arbitrary bipartite Gaussian states [1] in a system consisting of two bosonic modes embedded in a common thermal environment.

We work in the framework of the theory of open systems. If the initial state of the subsystem is taken of Gaussian form, then the evolution under completely positive quantum dynamical semigroups assures the preservation in time of the Gaussian form of the state [2]. We study the Gaussian quantum steering in terms of the covariance matrix under the influence of noise and dissipation and find that the thermal noise introduced by the environment destroys the steerability between the two parts [3]. We make a comparison with other quantum correlations for the same system, and show that, unlike Gaussian quantum discord, which is decreasing asymptotically in time, the Gaussian quantum steerability suffers a "sudden death" behaviour, like quantum entanglement.

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Monitoring of the process of system information broadcasting in time

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One of the fundamental problems of modern physics is how from the quantum reality with reversible evolution emerges the classical world, the 2nd Law of Thermodynamics and the whole irreversibility. This relates to the problem of measurement transforming quantum, non-copyable, data, towards intersubjective, copyable classical knowledge. We use the quantum state discrimination to show in a central system model how it's evolution leads to the broadcasting of the classical information. We analyze the process of orthogonalization and decoherence, their time scales and dependence on the environment. In a given moment of time we bound the distance of the system-environment state to the state with the ideal spectrum broadcasting structure.

The activation of the violation of Svetlichny inequality in the GHZ states

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The fact that several copies of the local quantum state when proceed together can generate the nonlocal correlation i.e. the activation of the of quantum nonlocality has been recently the object of many research. The majority of recent papers describe the activation in the bipartite scenario (or bipartite division of multipartite systems) whereas our work is related to the activation of the Svetlichny inequality i.e. the tripartite scenario. We observe that a several copies of GHZ state can violate the Svetlichny inequality even if the single copy does not violate it. The amount of violation increases with the an entanglement of single copy of the state. However it is an open question whether the activation of the Svetlichny inequality is equal to the activation of the genuine tripartite nonlocality.

Quantum Simulation of two interacting Schrödinger particles

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In this paper, we examine whether a quantum computer can efficiently simulate time evolution of two Schrödinger particles. We consider particles interacting each other and with an external potential. In order to solve Schrödinger equation in quantum register we use algorithm based on Quantum Fourier Transform.

Asymptotic distances of random quantum states and random quantum channels

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Properties of random mixed states of dimension N distributed uniformly with respect to the Hilbert-Schmidt measure are investigated. We show that for large N, due to the concentration of measure, the trace distance between two random states tends to a fixed number $\widetilde{D}=\frac{1}{4}+\frac{1}{\pi}$, which yields the Helstrom bound on their distinguishability. To arrive at this result we apply free random calculus and derive the symmetrized Marchenko--Pastur distribution, which is shown to describe numerical data for the model of coupled quantum kicked tops. Asymptotic value for the root fidelity between two random states, $\sqrt{F}=\frac{3}{4}$ can serve as a universal reference value for further theoretical and experimental studies. Analogous results for quantum relative entropy and Chernoff quantity provide other bounds on the distinguishablity of both states in a multiple measurement setup due to the quantum Sanov theorem. We study also mean entropy of coherence of random pure and mixed states and entanglement of a generic mixed state of a bi--partite system. For quantum channels, we show that their level density is also described by the Marchenko-Pastur distribution. This allows us to deduce some properties of the diamond norm of large dimensional quantum channels.

An Operational Framework for Non-Markovian Quantum Processes

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In all but the most trivial open quantum process, some amount information about a system's state will be `remembered' by its environment, influencing the system's future evolution. However, in practice, the assumption of environmental `forgetfulness' or Markovianity is almost always made. This is partly for practical reasons - until now there has been no unified framework to describe the most general non-Markovian quantum dynamics - but also remarkably, because the Markovian assumption appears to be valid in many cases. I will present a new scheme for operationally characterising non-Markovian quantum processes, which both gives a theoretical understanding of such processes and provides a recipe for reconstructing them experimentally. Moreover, this scheme yields a natural measure on the space of of all processes, which can be used to define a notion of typical Markovianity.

Lively quantum walks on cycles

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We introduce a family of quantum walks on cycles parametrized by their liveliness, defined by the ability to execute a long-range move. We investigate the probability distribution and time-averaged probability distribution. We show that the liveliness parameter, controlling the magnitude of the additional long-range move, has a direct impact on the periodicity of the limiting distribution. We also discuss possibilities for improving the efficiency of the network exploration.

Spontaneous collapse as a solution of the measurement problem and a source of the decay of neutral mesons.

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Quantum mechanics, in its standard formulation, allows superpositions of macroscopic objects, which contradict our everyday experience known as the so-called measurement problem. Dynamical reduction or spontaneous collapse models have introduced a solution by considering the wave function collapse as an ontologically objective process. In this work we show that flavor oscillating neutral mesons copiously produced at accelerator facilities are suitable systems for testing of collapse models. We consider the two most promising collapse models, the QMUPL (Quantum Mechanics with Universal Position Localization) model and the mass-proportional CSL (Continuous Spontaneous Localization) model. Collapse models propose a random noise field which induces the collapse typically modelled by Wiener processes. In the time evolution of neutral meson systems we find two interesting effects. Firstly, the spontaneous collapse in space causes a damping of the interference term in the flavour space, and secondly,collapse models can generate the two distinct decay constants in the mesonic system. These decay constants are input variables in the Standard Model. Indeed, a broken time symmetry in the Wiener process scenario causes decay. Last but not least, we present a Gorini-Kossakowski-Lindblad-Sudarshan master equation with Gaussian noise that covers the same dynamics, but does not offer the dynamical generation of the two distinct decay constants.

Markovianity of the generalized Pauli channels

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The author shows how to generalize the Pauli channel to prime dimensions using maximal sets of mutually unbiased bases. Each MUB corresponds to a set of mutually commuting Weyl operators, which are used to construct such channels, as well as the generators of their evolution. The author presents certain conditions for the evolution of the generalized Pauli channel to be Markovian.

The role of phase covariant dynamics in quantum metrology

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Quantum metrology protocols allow to surpass precision limits typical to classical statistics [1]. However, in recent years, no-go theorems have been formulated [2,3], which state that the typical forms of uncorrelated noise constrain the quantum enhancement to a constant factor, bounding the error to the standard asymptotic scaling. This is the case for the time-homogeneous dephasing [4] and, more generally, for all the completely positive semigroup dynamics [5] that include phase covariant terms, which commute with the system Hamiltonian. In this poster, it is discussed how the standard scaling with the number of sensing particles can be truly overcome when the dynamics is no longer ruled by a semigroup and becomes time-inhomogeneous. Contrary to possible expectations, non-Markovianity does not play any specific role, but the relevant noise feature dictating the asymptotic precision is whether the semigroup property is violated at short timescales. In particular, if the system's dynamics exhibits the natural Zeno regime [6], the asymptotic scaling is intermediate between the standard classical one and the quantum noiseless one, for any phase covariant dynamics [7].

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Quantum coherence of two-mode systems in a thermal environment

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In the framework of the theory of open systems based on completely positive quantum dynamical semigroups, we address the quantification of coherence for Gaussian states of continuous variable systems from a geometric perspective. We give a description of the quantum coherence for a system consisting of two non-interacting non-resonant bosonic modes embedded in a thermal environment.

Approximate quantum programming

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We present an analysis on the approximate programming of quantum observables and channels via quantum multimeters. For this purpose, we introduce upper bounds to the delity of programming states in terms of the programmed quantum devices. Our observations clarify the programmability of quantum circuits, e.g. quantum computer, and allows us in particular to negatively answer an open question "whether a post-processing assisted universal programmable quantum multimeter exists or not?". We also suggest some possible applications in open quantum scenarios, such as a novel quantum thermometer not requiring any a priori knowledge of the system-environment interaction.

Information transfer in Quantum Brownian Motion

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We analyze one of the fundamental models of decoherence and quantum-to-classical transition-Quantum Brownian Motion, and study the information content of partially reduced system-environmental state. We show that this state admits so called spectrum broadcast structure (SBS). As recently shown, this is a specific structure of multi-partite quantum states responsible for appearance of classical objective features in quantum mechanics. We derive timescales of SBS's formation and characterize asymptotic properties of this process using an analytical approach.

Optimal Currents of Indistinguishable Fermions

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We study currents of indistinguishable particles, in disordered systems far from equilibrium. Our goal is to identify fundamental bounds to the particle flow, and design principles to saturate these bounds. In the fermionic case, for weak coupling between system and reservoirs, we introduce a symmetry-based mechanism to enhance the flow. This mechanism is broadly applicable provided the inter-particle interactions are small with respect to quantum statistical effects.

Markovian semigroup from non-Markovian evolutions

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It is shown that a convex combination of two non-Markovian evolutions may lead to Markovian semigroup. This shows that convex combination of quantum evolutions displaying nontrivial memory effects may result in a perfectly memoryless evolution.

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