Posters Presented at Horizons Workshop

Fabio Scardigli

A Quantum Effect in the Classical Limit: Non-equilibrium Tunneling in the Duffing Oscillator

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The Duffing model is an oscillator with weak near-resonant driving, damping, and nonlinearity. For certain parameters, the stationary amplitude and phase bifurcate depending on initial conditions, and vary widely from one stable branch to the other. Due to this sensitivity, the system can be used for constructing detection devices.

In recent years, an implementation using superconducting devices—the so-called Josephson bifurcation amplifier (JBA)—has been successfully used experimentally for superconducting qubit readout. In the experimental literature, the JBA is often taken as classical. However, for e.g. understanding how the stability of the stationary states is modified by tunneling, a proper quantum analysis is necessary. Such tunneling transitions would be an error process from the point of view of detector applications.

One thus has to study dissipative tunneling not between two potential wells, but between the limit cycles of a nonlinear dynamical system. Our data, supported by semi-analytical asymptotic work, point at some intriguing aspects particular to the nonequilibrium setting, including noncommuting classical and low-temperature limits.
All Electrical Control and Slowing of Microwaves Using Circuit Nano-electromechanics

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Microwave superconducting coplanar waveguide resonators are crucial elements in sensitive astrophysical detectors and circuit quantum electrodynamics. Coupled to artificial atoms in the form of superconducting qubits, they now provide a technologically promising and scalable platform for quantum information processing tasks. Coupling of these circuits, in situ, to other quantum systems, such as molecules, spin ensembles, quantum dots or mechanical oscillators has been explored to realize hybrid systems with extended functionality. In our work, using a low-mass (∼15 pg), high-Q (>100,000) nanomechanical oscillator coupled to a Nb superconducting quarter wave cavity, we realize a circuit nano-electromechanical system coupling microwaves to mechanical motion oscillating at 1.45 MHz. By exciting the system on the lower motional sideband with a strong drive tone, a transparency window for a probe field is created originating from the effect of optomechanically induced transparency. This phenomenon, analogous to electromagnetically induced transparency in Atomic Physics, arises from the interference of different excitation pathways for an intra-cavity probe field. Here we demonstrate a novel class of control phenomena over microwave field. Exploiting the electromechanical coupling to a nanomechanical oscillator, we demonstrate tunable sub- and superluminal microwave pulse propagation, mediated by the nanomechanical oscillators response. We utilize the transparency window to demonstrate slow microwave propagation. A tunable delay more than 3 ms is demonstrated experimentally for a microwave pulse on resonance with the cavity. Moreover, we explore the circuit nano-electromechanical behavior to a time-dependent controlled, which is required for a series of advanced protocols including quantum state transfer and storage, sideband cooling, as well as switching, modulation and routing of classical and quantum microwave signals.

Anti-de Sitter Space as Topological Insulator and Holography

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We argue that the Anti-de Sitter (AdS) space can be thought as a topological insulator with the asymptotic AdS boundary as a co-dimensional one defect. Combining the bulk/edge correspondence for the topological insulators and the AdS/CFT correspondence, the fermionic topological phases for the dual conformal field theories (CFTs) can then be classified in the same way as classifying the topological phases of the massive free fermions in the co-dimensional one higher Minkowski
spaces. The latter can then be obtained in Kitaev’s framework of the K-theory analysis in classifying the topological insulators/superconductors. Our framework provides a way of classifying the symmetry-protected topologically ordered phases for the strongly interacting gapless systems, of which the classification is intractable in the context of strongly correlated condensed matters devised mainly for gapped systems.

Band-Structure of Graphene Above the Vacuum Level

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We study the two-dimensional band-structure of the stand-alone graphene in the context of the bound states immersed in the three-dimensional continuum. Depending on the symmetry of the in-plane \( k \) vector, the bound states above the vacuum level either survive in the continuum or disappear. By use of a nearly exactly solvable model we demonstrate that those bound states which do not survive acquire a finite life-time, in other words they turn into resonances.

Beamlike Polarization Entangled Photon Pair Study

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In this study, we have entangled polarization of the beamlike photon pairs. The beamlike photon pairs were generated by pumping a type-II BBO nonlinear crystal. We have developed two schemes to entangle polarization of the beamlike photon pairs. In the first scheme, photon pairs were generated by pumping the crystal twice. The photon pair generated in the first pump of the crystal passed through quart-wave plates twice to rotate its polarization by 90°. The rotated photon pair was reflected back into the crystal to be overlapped with the photon pair generated in the second pump of the crystal. The photon pairs were observed confirming that they have polarization entanglement. In the second scheme, we have used a 2 x 2 fiber generating beamlike polarization entangled photon pairs much easier than the first scheme. Fidelity and Bell’s inequality measurement showed that the photon pairs have high quality entanglement.

Bifermionic Superfluidity in Toroidal Optical Lattices

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We consider a gas of neutral fermions trapped in a specific optical trap that provides a tight confinement of a Fermi gas in a torus with a potential periodic along the azimuthal direction. The effective model is interacting fermions moving in a periodic potential along the ring. We show that the model demonstrates a novel type of superfluidity different from the BCS mechanism. This pure 1D quantum gas in a ring can also form crystalline structures with both ferro- and antiferro-magnetic type orders. Possibilities of realization of quantum crystals and their application for quantum computing are discussed.

**BPS States On M5-Brane in Large C-Field Background**

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We extensively study BPS solutions of the low energy effective theory of M5-brane in large C-field background. This provides us an opportunity to explore the interactions turned on by C-field background through the Nambu–Poisson structure. The BPS states considered in the JHEP 1208, 076 (2012) include the M-waves, the self-dual string (M2 ending on M5), tilted M5-brane, holomorphic embedding of M5-brane and the intersection of two M5-branes along a 3-brane.

**Conifold Geometry**

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In the Calabi-Yau manifolds we have points where the moduli spaces meet correspond to conifolds, i.e. singular spaces that are smooth apart from a number of isolated canonical singularities and that have vanishing first Chern class. However this singularities can be removed or smoothed in two ways.

**Curvature, Torsion and Geometry of Serret–Frenet Formulae in Geometric Quantum Mechanics**

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This exercise proposes formulation of curvature and torsion in Quantum Mechanics. Curvature in the quantum evolution formulated earlier by Brody and Houghton in terms of Hamiltonian is verified. Thus, the formulation of curvature in quantum evo-
lution is reassuring in more than one ways. Whereas, the present exercise is first ever attempt to formulate torsion in quantum evolution. Also, Torsion in quantum evolution for symmetric states is proposed in the present paper. The Geometry of Seret–Frenet formulae are recast in the context of Geometric Quantum Mechanics. The geometry of quantum neighborhood also leads to the formulation of curvature and torsion during quantum evolution. Estimator problem when subjected to neighborhood test brings about many significant results. Fourth order term in the quantum neighborhood test carries information of curvature whereas the sixth order term conveys information regarding torsion.

Detecting the Steering Effect Using the Maximal Certain States

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How can Alice convince remote Bob that she can steer his qubit? Here we consider the following scenario. Alice is to steer Bob's qubit into some specific state. To confirm her steering ability, Bob measures his qubit using either of two mutually unbiased basis. If the steered state is the maximal state, Bob's action can reach the upper bound of the uncertainty relations proposed by Maassen and Uffink. By double use of the relations, we propose two uncertainty relations. The operational criteria can be stated as follows. If Alice is capable of steering Bob's qubit, these two relations can be held simultaneously. In addition, these relations can be also exploited for state collapse criteria in the experiment with a single photon passing through a series of polarizers.

Directed Percolation Effects in Quantum Communication Networks

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Classical communication, assisted by entanglement, in networks consisting of quantum channels is studied. We provide an example of network, where effect of superadditivity of classical capacity on the level of single cell leads to percolation effect for high capacity information transfer on the level of the whole network. In that network, both directed bond percolations and randomly oriented bond percolations are analyzed.

Dynamics of Cascaded Harmonic Oscillators Governed by Negative-Binomial Probability Distributions

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Negative-binomial probability distributions are interpreted as models for cascaded harmonic oscillators. To this goal, both probability flow and classical mass-damper-spring systems are investigated. As a result, the unique features of the Bose–Einstein probability are clarified as regards log-concavity, memoryless property, and probability flow. In addition, the roles of both neutral stability and metastability are clarified.

**Dynamics of Quantum Discord for Two-Qubit X-States**

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Quantum discord, a kind of quantum correlation as the difference between quantum mutual information and classical correlation in a bipartite system. For two-qubit states, Symmetric geometric measure and dynamics of quantum discord obtained by Mingjun Shi, Fengjian Jiang and Jiangfeng [arXiv:1107.2958v(14 Jul 2011)] they simplify considerably the optimization procedure so that numerical evaluation can be performed efficiently. Analytical expressions of quantum correlation are attained for some special states and make an effort evaluate analytically the quantum discord for a family of two-qubit states. We further investigate is about the dynamics of quantum correlation of the system qubits in the presence of independent dissipative environment. In this paper, we make a comparative study of the relationships between time and the diagram for minimizing the quantum conditional entropy and find that the quantum discord directly for two instances that solved in paper that brought above, also illustrate that it can decrease even if the system state be transferred into quantum channel.

**Explicit Relations Between All Lower Bounds Techniques for Quantum Query Complexity**

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Quantum query complexity is a potent tool to characterize the power of quantum algorithms: given a function \( f \) and an oracle which, on input \( i \), reveals the \( i \)-th bit \( x_i \) of the input string \( x \), the qqc \( Q \in (f) \) is defined as the minimum number of calls to the oracle necessary to compute \( f(x) \). An important challenge is to design strong methods to prove lower bounds on qqc, as this allows to prove the optimality of given quantum algorithms, or certify the hardness of computational tasks even for quantum attacks, which is important in cryptographic applications. Thus far, two families of lower bound techniques have been developed: the polynomial method and the adversary methods. These were so far considered as unrelated techniques, and it seemed that
each approach was better suited for different applications. Here we show that all these techniques are special cases of a common method, the multiplicative adversary method, which therefore combines the advantages of all known lower bound techniques for qqc.

Extended Gap Bloch State and Multimode Emission of Polariton Condensates in a Periodic Potential

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The nonlinear band structures and corresponding Bloch states of the polariton condensates in a 1-D periodic potential are investigated under various pump power and potential depth. Below a critical pump power, extended gap Bloch states are formed in the forbidden zones of the nonlinear spectrum which serve as a mediator for the population exchange between Pi-state and zero-state. When the pump power is above the critical power, however, we observe that the Pi-state emission from the second Bloch band is suppressed by the zero-state from the first Bloch band with eliminated side lobes. The emission evolution and mode competition with pump power coming from the nonlinear interaction of Bloch wave-function in a periodic potential are discussed, while the window for extended gap Bloch state with respect to pump power and potential depth is also included.

Generation and Stabilization of W State in Circuit QED System via Quantum Feedback Control

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Circuit quantum electrodynamics (QED) has been demonstrated to be a promising solid-state quantum computing architecture. Due to the great controllability of the qubits and microwaves in the circuit system, it also has excellent potential as a platform for quantum control-especially quantum feedback control-experiments. Here we present a simple and promising quantum feedback control scheme for deterministic generation and stabilization of a three-qubits W state in the superconducting circuit QED system. The control scheme is mainly based on continuous joint Zeno measurement of multiple qubits in a dispersive regime, which enables us not only to infer the state of the qubits for further information processing but also to create and stabilize the target W state through adaptive quantum feedback control. We simulate the dynamics of the proposed quantum feedback control scheme using the quantum trajectory approach and demonstrate that in the presence of moderate environmental decoherence, the average state fidelity
higher than 0.9 can be achieved and maintained for a considerably long time (much longer than the qubits decoherence time). This control scheme is also shown to be robust against measurement inefficiency and individual qubit decay rate differences.

Incompatible Local Hidden-Variable Models of Quantum Correlations

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There exist correlations between quantum systems which cannot be explained by any local hidden-variable (LHV) theory. The simplest scenario that demonstrates this phenomenon involves bipartite entangled quantum states measured with one of two local observables. This original approach of Bell was later extended to correlations between more parties and to correlations between different numbers of subsystems. A natural question arises if there is a correlation Bell inequality that can be violated although all inequalities involving correlations between fixed number of observers are satisfied? Our main finding is that there exist multiparty states with explicit local hidden-variable models for correlations between any fixed number of subsystems (in a Bell scenario with two settings per party). Nevertheless these models can be disqualified. It turns out that they are incompatible with each other and cannot be extended to model correlations between various numbers of subsystems. We present a Bell-like inequality that involves correlations between different numbers of subsystems which is satisfied by all LHV models and violated by quantum correlations.

Isotopic Separation of the 34S, by the Way of Selective Multiphoton Dissociation of the SF6 Molecule, by the Powerful CO2 Laser

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We devoted our study to the separation of 34S Isotope by the way of selective multi photon dissociation of the SF6 molecule, and by single frequency method, and use of produced CO2 Laser, in this paper. In this way, the result of the change of the enrichment of the molecule without the trying for chemical separation of products from the particulars had investigated. Spectrum chart for variable pulse has been reached after several investigations. The details of the experiment that had done have presented.
Non-Markovian Dynamics of a Solid-State Charge Qubit Measured by a Quantum Point Contact

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We study a system of a charge qubit consisting of an electron in two coupled quantum dots (CQDs) detected by a quantum point contact (QPC). We derive perturbatively the non-Markovian quantum master equation for the CQDs system and calculate the transport current through the QPC (considered as a reservoir) to second-order in the system-reservoir interaction. The non-Markovianity of the whole system comes from the energy-dependent tunneling amplitudes and energy-dependent densities of states of the QPC, which are modeled as a spectral density with a Lorentzian shape. In the non-Markovian case, the decay coefficients in the derived master equation and transport current are time-dependent and involve the real and imaginary parts of the contributions from the QPC reservoir correlation functions. In the wide-band limit (WBL), the various Markovian master equations in different parameter regimes are recovered, and the contributions of the imaginary parts are found to vanish. However, in the non-Markovian regime, the contributions of the imaginary parts significantly influence the dynamics of the charge qubit and thus the transport current. Especially, the non-Markovian transient currents through QPC differ significantly from the WBL Markovian counterparts and thus may serve as a witness for the non-Markovian behavior in the QPC-qubit system.

Non-Markovian Finite-Temperature Two-Time Correlations of System Operators of a Quantum Brownian Motion

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We evaluate the non-Markovian two-time correlations (CFs) of system operators of a quantum Brownian motion model in two different ways, one by the exactly solvable Heisenberg equation of motion through fluctuation–dissipation theorem and the other by the projection operator technique through the perturbative time-convolutionless non-Markovian effective master equation. In Markovian case, a famous procedure to compute two-time CFs of system operators in open quantum systems is the quantum regression theorem (QRT). However, the QRT is not valid or needs corrections in the non-Markovian domain even in the weak system-bath coupling regime. The calculated non-Markovian two-time CFs up to fourth order in system–environment coupling strength agree well with those obtained from exact evaluation in the weak and mediate coupling regime, which demonstrates the validity of our derived non-Markovian evolution equations. But, the exact analytical two-time CFs for an Ohmic
bath presented in the literature are only for the initial time $t$ being in the steady state, i.e. at equilibrium. Our evolution equations of the non-Markovian two-time CFs are, however, valid for any initial time $t$. For a finite initial time $t$, considerable difference in the non-Markovian CFs between the fourth-order system-bath coupling case and its second order counterparts can be observed. These results obtained using our derived non-Markovian evolution equations differ significantly from the Markovian case obtained using the QRT and from the non-Markovian case obtained directly using the QRT.

On Horizons and Negative Energy Flux

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In the moving mirror model, removal of horizons gives rise to negative energy flux. The total emitted energy is positive and finite. Exact solutions to the moving mirror model have been found.

Open Quantum Walks From Unitary Quantum Walks: Construction and Examples on the 1-Dimensional Lattice Space

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The Open Quantum Random Walk (OQRW) is a new model of the Quantum Walk (QW)-the quantum counterpart of the classical random walk. The walk arose in an effort to understand the role quantum transport plays in biological systems. In order to investigate the role quantum transport plays in biological systems, it is necessary to find a framework for quantum walks in an open environment. The OQRW is based on the non-unitary dynamics induced by the environment. The walk deals with density matrices rather than pure states. In this poster we show how to construct OQRW from the unitary QW and show their behavior graphically. We consider the following examples:

(i) The Hadamard OQRW;
(ii) The Grover OQRW;
(iii) The Homogeneous OQRW;
(iv) The Time-Dependent OQRW.

Related Work: Ampadu, C., Open Quantum Random Walks in Two Dimensions, Canadian Journal of Physics, Submitted, (2012).
Optimal Control of Quantum Gates for Josephson Charge Qubits in Non-Markovian Environments

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Quantum optimal control theory (QOCT) is a powerful tool that provides a variational framework for calculating optimal control pulses to maximize a desired physical objective (or minimize a physical cost function) within certain constraints. QOCT thus enables us to design and realize, even in the presence of decoherence, high-fidelity quantum gates by selecting optimal pulse shapes (arbitrarily shaped pulses and duration; or continuous dynamical modulation) for the external control within experimental capabilities. Here, we employ a recently developed QOCT approach based on the Krotov method and an extended Liouville space quantum dissipation formulation to find the control sequences for a high-fidelity controlled-NOT (CNOT) gate of two Josephson charge qubits in the presence of 1/f noise and non-Markovian environments (baths). We take the experimentally measured noise spectral densities into account in our model and find that CNOT gates with errors less than $10^{-4}$ can be achieved for realistic qubit and bath parameters. The control–dissipation correlation and the time scales of the gate operations, bath correlation functions (memory effect of the bath) and qubit decay are important factors in the control process of achieving the high-fidelity quantum gates.

Optimal Control of Quantum Gates in an Exactly Solvable Non-Markovian Open Quantum Bit System

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An efficient quantum optimal control theory (QOCT) based on Krotov method is applied to find control sequences of quantum gate operations for an exactly solvable open system model of a qubit embedded in a non-Markovian environment (bath). This damped Jaynes–Cummings model that we investigate describes physically the coupling of a qubit (two-level atom) to a single cavity mode which in turn is coupled to a zero-temperature reservoir. We find that even in the presence of decoherence, high-fidelity Z-gates and identity gates with error less that $10^{-6}$ can be achieved over a wide range of qubit and bath parameters. To our knowledge, this is the first optimal control investigation for quantum gate operation in an exactly solvable open system model, and our QOCT approach can deal with any arbitrary bath spectral densities or bath correlation functions. Our results would have immediate implications for the quantum control experiments on superconducting circuit cavity QED systems.
Orbital-Effects in Strongly Interacting Fermi–Fermi Mixtures in Optical Lattices

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Ground-state properties of Fermi–Fermi mixtures in the presence of optical lattices are investigated. We show that in a strongly attractive regime interaction-induced inter-orbital tunneling becomes important. New term describing such a process must be added to the Hubbard model which leads to significant changes in a ground-state phase diagram in comparison to results based on the standard Hubbard Hamiltonian. We describe different states arising from this effect.

Quantum Information Processing with Relativistic Motion of Qubits

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In the field of Relativistic Quantum Information, general relativistic effects such as ultra-relativistic accelerations or intense gravitational fields have been often considered in the past as a source of noise, decoherence and entanglement degradation. We will see how general relativistic effects can actually be taken advantage of in order to process quantum information by means of particle detectors. We will show that the motion of such detectors through space–time could be used to build quantum gates and outperform equivalent settings that do not make use of quantum effects induced by relativity.

Randomizing Method for Quantum States in Shatten Norms

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We will formulate a method for randomizing quantum states with respect to the Shatten $p$-norms in trace class. Although many studies on this topic are already presented, but considering the importance of the problem, we look back to the randomizing scheme for quantum states again under a unified argument. That is, this work includes the operator norm and the trace norm simultaneously in a single statement.
The Planck Scale as a Duality of the Cosmological Constant

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We introduce the Planck scale ($l_{pl}$) as an ultraviolet (UV) cut-off and the Hubble scale ($r_{\Lambda} = \frac{1}{\sqrt{\Lambda}}$) as an infrared (IR) one inside the q-Bargmann-Fock formalism. As a consequence, it is possible to demonstrate that a generalized uncertainty principle given by $\Delta X \Delta P \geq \frac{\hbar}{2} + \frac{l_{pl}^2}{2r_{\Lambda}}(\Delta P)^2 + \frac{\hbar}{2r_{\Lambda}}(\Delta X)^2$, can reproduce appropriately the thermodynamic (with UV cut-off) for both, the Schwarzschild Anti de-Sitter (S-AdS) and the Schwarzschild de-Sitter (S-dS) space without making any analytical extension for the coefficient (parameter) related to the minimum uncertainty in momentum (as has been already suggested in the literature). This is possible if the physics in the dS space is described with respect to the Static observer as has been suggested by Bousso and Hawking.

Towards Long-Distance Ghost Imaging with Cosmic Ray Muons

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Ghost imaging is a remote optical imaging technique that exploits the spatio-temporal correlations exhibited by both entangled photon pairs, chaotic light sources, and pairs of light beams classically correlated in momentum.

Towards the Maximal Efficiency and Sensitivity of a Quantum Point Contact Detector

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We investigate the sensitivity and the efficiency of the charge detection with a quantum point contact in which a superposed input state is being used. We show that the coherence of the input state provides an improvement in charge sensitivity. This improvement is related to the fundamental property of the scattering matrix. Further, a quantum-limited detection is achievable by constructing an appropriate interference between the two output beams. We argue that our scheme provides the ultimate sensitivity and efficiency of charge detection with injection of single electrons into a quantum point contact.
Trade-Off Between Information Gain and Reversibility in Quantum Measurement

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We derive an inequality showing a balance between the degree of information obtained by measurement and the possibility of reversing measurement in arbitrary dimensional systems, which are respectively quantified with the estimation fidelity and the reversal probability. For a qubit system, it becomes a monotonic equation, which manifests a tight trade-off relation between information-gain and reversibility in quantum measurement. In this formulation, it is clearly shown that the same amount of information extracted from a weak measurement is erased through the reversing process. It may broaden the information-theoretic perspective on quantum measurement as well as provide useful applications in quantum information processing.

Variational Quantum Tomography

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We present a new method to reconstruct unknown quantum states and processes out of incomplete and noisy information. It’s a linear convex optimization problem, efficiently solved with Semidefinite Programs. It converges like compressed sensing methods, demanding just a fraction of the effort corresponding to an informationally complete measurement. It has been successfully tested in real experiments in optics and NMR.

Wave–Particle Duality in an Environment with Arbitrary White Noise

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The development of quantum technologies depends on investigating of the behavior of quantum systems in noisy environments, since complete isolation from its environment is impossible to achieve. In this paper we show that a wave–particle duality experiment performed in a system with an arbitrarily white noise level cannot be explained in classical terms, using hidden-variables models. In the light of our results, we analyze recent optical and NMR experiments and show that a loophole on non-locality is not fundamental.