Control of Quantum Dynamics of Atoms, Molecules and Ensembles by Light

Hotel Sol Marina Palace, Nessebar, Bulgaria, Aug 29 – Sept 02, 2022

CAMEL XVII

Seventeenth International Workshop

BOOK OF ABSTRACTS

Edited by

Svetoslav Ivanov and Nikolay Vitanov

Supported by

COST Action CA17113 - Trapped Ions: Progress in classical and quantum applications (TIPIQCA)

Local Organizing Committee

Nikolay Vitanov (chairman), Ivaylo Ivanov,
Svetoslav Ivanov, Boyan Torosov,
Kaloyan Zlatanov, Stancho Stanchev,
Andon Rangelov, Ivo Mihov

Quantum Optics and Quantum Information Group
Theoretical Physics Division
Department of Physics
Sofia University "St. Kliment Ohridski"
5 James Bourchier Blvd, 1164 Sofia, Bulgaria
http://camel17.quantum-bg.org

Contents

List of Participants

Yavor Boradjiev (Sofia)
Timko Dubielzig (Hannover)
Barry Garraway (Sussex)
Markus Hennrich (Stockholm)
Winfried Hensinger (Sussex)
Hristina Hristova (Sofia)
Mark IJspeert (Oxford)
Ivaylo Ivanov (Sofia)
Svetoslav Ivanov (Sofia)
Niels Joseph (Darmstadt)
Teodora Kirova (Riga)
Lora Konstantinova (Sofia)
Axel Kuhn (Oxford)
Xavier Laforgue (Dijon)
Sabrina Maniscalco (Helsinki)
Antonino Messina (Palermo)
Ivo Mihov (Sofia)
Darren Moore (Olomouc)
Sorin Paraoanu (Aalto)
Asen Pashov (Sofia)
Andon Rangelov (Sofia)
Andreas Ruschhaupt (Cork)
Alessandro Sergi (Messina)
Markus Stabel (Darmstadt)
Stancho Stanchev (Sofia)
Graham Stutter (Sussex)
Boyan Torosov (Sofia)
Genko Vasilev (Sofia)
Nikolay Vitanov (Sofia)
Thomas Walther (Darmstadt)
Kaloyan Zlatanov (Sofia)
Yonka Zlatanova (Sofia)

Bulgaria	14	Czech Republic	1	Finland	2
France	1	Germany	4	Ireland	1
Italy	2	Latvia	1	Sweden	1
United Kingdom	5				

Programme

Monday, August 29

Evening Session chaired by **Nikolay Vitanov**

17:00-18:30 **Round-table discussion**, *Quo Vadis Quantum?*

Tuesday, August 30

Morning Session chaired by **Sabrina Maniscalco**

10:30-12:30 **Round-table discussion**, *Quo Vadis Quantum?*

Lunch

16:30-17:00 **Coffee break**

Evening Session chaired by **Andon Rangelov**

17:00-17:45 **Thomas Walther**, *The Darmstadt scalable time-bin entanglement quantum key distribution network*

17:45-18:15 **Kaloyan Zlatanov**, *Extending the Morris-Shore transformation to nondegenerate systems and arbitrary time-dependent driving fields*

18:15-18:35 **Ivo Mihov**, *Exact qubit resonance calibration and power narrowing using IBM Quantum*

Wednesday, August 31

Morning Session chaired by **Andreas Ruschhaupt**

09:00-09:45 **Sabrina Maniscalco**, *Adaptive POVM implementations and measurement error mitigation strategies for near-term quantum devices*

09:45-10:30 **Sorin Paraoanu**, *Coherent interaction-free measurements*

10:30-11:00 **Coffee break**

Noon Session chaired by **Sorin Paraoanu**

11:00-11:45 **Andreas Ruschhaupt**, *Enhanced shortcuts to adiabaticity*

11:45-12:30 **Asen Pashov**, *Absolute numbering of asymptotic vibrational levels of diatomic molecules from cold-physics experiments*

Lunch

16:30-17:00 **Coffee break**

Evening Session chaired by **Thomas Walther**

17:00-17:45 **Axel Kuhn**, *How to administer an antidote to Schrödinger's cat*

17:45-18:15 **Mark IJspeert**, *Deterministic filling of long-lifetime, single-atom traps in the collisional blockade regime*

18:15-18:35 **Teodora Kirova**, *Azimuthal modulation of electromagnetically induced grating using structured light*

20:00 **Conference dinner**

Thursday, September 1

TIPICQA workshop of WG3: Quantum Control

Morning Session chaired by **Markus Hennrich**

09:00-09:45 **Winfried Hensinger**, *A high-fidelity quantum matter-link between ion-trap microchip modules*

09:45-10:30 **Timko Dubielzig**, *Development of the quantum valley lower saxony (QVLS) quantum computer*

10:30-11:00 **Coffee break**

Noon session chaired by **Winfried Hensinger**

11:00-11:45 **Markus Hennrich**, *Trapped Rydberg ions*

11:45-12:30 **Graham Stutter**, *Ion-photon interfaces for quantum networking*

Lunch

Evening session chaired by **Timko Dubielzig**

17:00-17:45 **Darren Moore**, *Thermally induced quantum phenomena*

17:45-18:15 **Svetoslav Ivanov**, *Quantum control by polychromatic pulse trains*

Friday, September 2

Morning Session chaired by **Antonino Mesinna**

09:00-09:45 **Barry Garraway**, *Quantum bubbles and rings with ultra-cold atoms*

09:45-10:30 **Alessandro Sergi**, *Theory and simulation of probability non-conserving quantum systems in classical environments*

10:30-11:00 **Coffee break**

Noon session chaired by **Barry Garraway**

11:00-11:45 **Boyan Torosov**, *Experimental demonstration of composite pulses on IBM's quantum computer*

11:45-12:30 **Andon Rangelov**, *Non-reciprocal wave retarder based on optical rotators combination*

Lunch

16:30-17:00 **Coffee break**

Evening session chaired by **Boyan Torosov**

17:00-17:20 **Markus Stabel**, *Confining atomic populations in space via stimulated Raman adiabatic passage in a doped solid*

17:20-17:40 **Niels Joseph**, *Spatial confinement of atomic excitation by composite pulses in Pr:YSO*

17:40-18:10 **Xavier Laforgue**, *Optimal robust stimulated Raman exact passage by inverse optimization*

18:10-18:30 **Stancho Stanchev**, *Characterization of high-fidelity Raman qubits*

List of Abstracts

DEVELOPMENT OF THE QUANTUM VALLEY LOWER SAXONY (QVLS) QUANTUM COMPUTER

T. Dubielzig

Leibniz University Hannover Callinstr. 36 30167 Hannover

email: dubielzig@iqo.uni-hannover.de

In January 2021, the local government of Lower Saxony in Germany, provided 25 Million Euros to establish a hub for quantum technologies: The Quantum Valley Lower Saxony (QVLS). The hub is open to partners from industry and science, as a concentrated effort to combine and funnel resources/efforts. The central focus of the QVLS-project is an ion trap based, 50 qubit quantum computer, which is currently under development. The overall funding has risen to more than 100 Million Euros as various projects, funding agencies and partners have joined. At the beginning of this talk, I will give an overview of the activities that are centered around the QVLS quantum computer. I will then briefly introduce various technologies that are being developed which enable us to build, operate, scale and standardize the quantum computer. Those include trap design, trap production, socket technologies, laser and detector development, cryogenic technology, electronics and a user interface to operate the quantum computer. I will also present recent results from our efforts to engineer microwave pulse shapes for more efficient two-qubit entangling gates as well as cycle benchmarking of those gates.

QUANTUM BUBBLES AND RINGS WITH ULTRA-COLD ATOMS

B. Garraway

Dept of Physics and Astronomy, University of Sussex, Falmer, Brighton, United Kingdom

email: b.m.garraway@sussex.ac.uk

The technique of radio-frequency dressing [1] allows the possibility to generate new types of traps for ultra-cold atoms. This can include different dimensionalities and different topologies such as rings, shells and toroidal surfaces. We will discuss the production and properties of these types of traps using the RF dressing technique. Full exploration of a large shell, to produce a bubble of matter-waves, or BEC, has to be performed in free-fall, i.e. in space or a drop-tower. We will show how NASA's BEC experiment in orbit (the Cold Atom laboratory [2,3]) can be enhanced [4]. Diagnostic information is analysed using a method inspired by the work of Janszky. We examine the free-expansion of shells and we also discuss applications to expanding ring structures [5].

On a different topic, a brief overview of a proposal for ancilla-based quantum gates in a cavity QED context will be presented [6].

[1] B.M. Garraway and H. Perrin, J. Phys. B 49, 172001 (2016).

[2] D.C. Aveline et al. Nature 582, 193 (2020).

[3] R.A. Carollo et al. Nature 606, 281 (2022).

[4] G.A. Sinuco-Leon, N. Lundblad and B.M. Garraway, in preparation.

[5] A.E. Elbourn and B.M. Garraway, in preparation.

[6] M.M. Alqahtani, M.S. Everitt, and B.M. Garraway, J. Phys. B 55, 184004 (2022).

TRAPPED RYDBERG IONS

M. Hennrich

Department of Physics, Stockholm University, Stockholm, Sweden

email: markus.hennrich@fysik.su.se

Trapped Rydberg ions are a novel quantum platform [1,2]. This idea joins the advanced quantum control of trapped ions with the strong dipolar interaction between Rydberg atoms. For trapped ions, this method promises to speed up entangling interactions and to enable such operations in larger ion crystals. In this presentation, I will introduce the novel experimental platform of trapped Rydberg ions [2]. I will describe the specific physics involved when exciting ions into Rydberg states, the effects on the trapping potential due to the strong polarizability of Rydberg ions, and the controllable strong interaction between ion and motion. Moreover, I will summarize methods and results in speeding up trapped ion entanglement operations via strong dipolar Rydberg interaction [3].

[1] M. Müller, L. Liang, I. Lesanovsky, and P. Zoller, Trapped Rydberg Ions: From Spin Chains to Fast Quantum Gates, New J. Phys. 10, 093009 (2008).

[2] A. Mokhberi, M. Hennrich, and F. Schmidt-Kaler, Trapped Rydberg Ions: A New Platform for Quantum Information Processing, in Advances In Atomic, Molecular, and Optical Physics, Vol. 69 (Elsevier, 2020), pp. 233–306.

[3] C. Zhang, F. Pokorny, W. Li, G. Higgins, A. Pöschl, I. Lesanovsky, and M. Hennrich, Submicrosecond Entangling Gate between Trapped Ions via Rydberg Interaction, Nature 580, 345 (2020).

A HIGH-FIDELITY QUANTUM MATTER-LINK BETWEEN ION-TRAP MICROCHIP MODULES

W. Hensinger

Sussex Centre for Quantum Technologies, University of Sussex, Brighton, BN19QH

email: w.k.hensinger@sussex.ac.uk

System scalability is fundamental for large-scale quantum computers and is being pursued over a variety of hardware platforms. For quantum computers based on trapped ions, architectures such as the quantum charge-coupled device (QCCD) are used to scale the number of qubits on a single device. However, the number of ions that can be hosted on a single quantum computing module is limited by the size of the chip being used. Therefore, a modular approach is of critical importance and requires quantum connections between individual modules. Here, I discuss the demonstration of a quantum matter-link in which ion qubits are transferred between adjacent quantum computing modules. Ion transport between adjacent modules is realised at a rate of 2424 s^{-1} and with an ion-transport success fidelity in excess of 99.999993%. Furthermore, I show that the link does not measurably impact the phase coherence of the qubit. The realisation of the quantum matter-link demonstrates a novel mechanism for interconnecting QCCD devices. This achieves a key milestone for the implementation of modular quantum computers capable of hosting millions of trapped-ion qubits.

DETERMINISTIC FILLING OF LONG-LIFETIME, SINGLE-ATOM TRAPS IN THE COLLISIONAL BLOCKADE REGIME

M. IJspeert

University of Oxford, Parks Rd, Oxford OX1 3PU, United Kingdom

email: mark.ijspeert@physics.ox.ac.uk

Efficient single-atom single-photon interfaces are essential to many applications in quantum information processing. The potential of such hybrid systems for the delivery of single photons and distributed entanglement has been demonstrated using Rb-87 atoms stochastically loaded into a high-finesse optical cavity to achieve strong coupling. Whilst this source constitutes an excellent testbed, probabilistic loading limits the scalability of its design and gives rise to time-dependent coupling strengths. The solution is to trap and hold a single atom in a tightly focused dipole trap, a technique that relies on the collisional blockade effect. However, the time-averaged probability of single atom occupation in the collisional blockade regime is limited to 0.5. In this work, we demonstrate that increasing the depth of a static, optical dipole trap enables the transition from fast loading (at a rate of 0.32s^{-1}) to long-lifetime trapping (average lifetime of 8.2s) with a success rate of 98%. This translates to an achievable filling ratio of 0.72. We present simulations of atomic trajectories in this dipole trap as a result of stochastic photon scattering events. Such a deterministic means of holding a single atom in place is an important step towards the deterministic cavity loading scheme required for a scalable atom-photon quantum interface.

QUANTUM CONTROL BY POLYCHROMATIC PULSE TRAINS

S. Ivanov

Department of Physics, Sofia University, 5 James Bourchier Blvd, 1164 Sofia, Bulgaria

email: sivanov@phys.uni-sofia.bg

We introduce a quantum control technique using polychromatic pulse trains (PPTs), consisting of pulses with different carrier frequencies, i.e. different detunings with respect to the qubit transition frequency. We derive numerous PPTs, which generate broadband, narrowband, and passband excitation profiles for different target transition probabilities. This makes it possible to create high-fidelity excitation profiles which are either (i) robust to deviations in the experimental parameters, which is attractive for quantum computing, or (ii) more sensitive to such variations, which is attractive for cross talk elimination and quantum sensing. The method is demonstrated experimentally using one of IBM's superconducting quantum processors, in a very good agreement between theory and experiment. These results demonstrate both the excellent coherence properties of the IBM qubits and the accuracy, robustness and flexibility of the proposed quantum control technique. They also show that the detuning is as efficient control parameter as the pulse phase that is commonly used in composite pulses. Hence the method opens a variety of perspectives for quantum control in areas where phase manipulation is difficult or inaccurate.

SPATIAL CONFINEMENT OF ATOMIC EXCITATION BY COMPOSITE PULSES IN PR:YSO

N. Joseph

Institut für angewandte Physik AG Halfmann Hochschulstraße 6, 64289 Darmstadt

email: niels.joseph@physik.tu-darmstadt.de

We experimentally demonstrate spatial confinement of atomic excitation by narrowband composite pulse sequences in a rare-earth ion-doped crystal (Pr:YSO). In particular, we implement a variety of previously proposed sequences and compare their performance. We achieve population transfer that is spatially confined to an area significantly smaller (by a factor of 3) than the diameter of the driving Gaussian-shaped laser pulses. Our experimental data agree very well with a numerical simulation and confirm that the confinement improves with the number of pulses in the sequence. However, we find that inhomogeneous broadening in Pr:YSO reduces the performance, i.e., leading to the formation of additional rings around the localized centre. A theoretical treatment, confirmed by experiments, shows that the perturbing effect can be reduced by larger driving Rabi frequency (provided power broadening remains small compared to the level splitting). Our experiments prove that narrowband composite pulses are a versatile tool to localize atomic excitation. While we still operate in our measurements at rather large diameters of the excitation region to demonstrate a first proof-of-concept, the technique will be also applicable to proceed below the diffraction limit.

AZIMUTHAL MODULATION OF ELECTROMAGNETICALLY INDUCED GRATING USING STRUCTURED LIGHT

T. Kirova

Institute of Atomic Physics and Spectroscopy, University of Latvia, Jelgavas street 3, Riga, LV-1004, Latvia

email: teo@lu.lv

We propose theoretical schemes for creating a two-dimensional Electromagnetically Induced Grating (EIG) [1] in a three-level Lambda-type [2] and a four-level N-type [3] atomic systems interacting with a weak probe field and two simultaneous position-dependent coupling fields: a two dimensional standing wave and an optical vortex beam. Our numerical calculations show that due to the azimuthal modulation of the Laguerre-Gaussian field, a two-dimensional asymmetric [2] or symmetric [3] gratings are observed, giving an increase of the zeroth and high orders of diffraction, thus transferring the probe energy to the high orders of direction. A detailed analysis of the probe field energy transfer to different orders of diffraction proves the possibility of direct control over the performance of the grating by changing the winding number of the vortex beam. Our findings are relevant for designing new quantum devices e.g. all-optical quantum switches and logic gates, as well as improving the performance of other EIT [4]-based devices. This may find applications in all-optical information processing and atom-manipulation technologies.

[1]Y. Ling, Y.-Q. Li, and M. Xiao, Phys. Rev. A 57, 1338 (1998).

[2] S. H. Asadpour, T. Kirova, J. Qian, H. R. Hamedi, G. Juzeliūnas, and E. Paspalakis, Sci. Rep. 11, 20721 (2021).

[3] S. H. Asadpour, H. R. Hamedi, T. Kirova, and E. Paspalakis, Phys. Rev. A 105 (4), 043709 (2022).
[4] S. E. Harris, Phys. Today 50(7), 36 (1997).

HOW TO ADMINISTER AN ANTIDOTE TO SCHRÖDINGER'S CAT

A. Kuhn

University of Oxford

email: axel.kuhn@physics.ox.ac.uk

In his most famous Gedankenexperiment, Erwin Schrödinger imagined a box with a cat and a poisonous substance that is released based on the 50% probable decay of a radioactive atom. As such, the life of the cat and the state of the poison become entangled, and the fate of the cat is determined upon opening the box. We present an experimental technique that keeps the cat alive on any account. Our approach relies on the time-resolved Hong–Ou–Mandel effect: two long, identical photons impinging on a beam splitter always bunch in either of the outputs. Interpreting the first photon detection as the state of the poison, the second photon is identified as the state of the cat. Once the first photon's state has been determined, the second normally follows suite. However, we here demonstrate that a sudden phase change between the inputs, administered conditionally on the outcome of the first detection, allows us to steer the second photon to a pre-defined output and thus ensures that the cat is always observed alive.

OPTIMAL ROBUST STIMULATED RAMAN EXACT PASSAGE BY INVERSE OPTIMIZATION

X. Laforgue

Laboratoire Interdisciplinaire Carnot de Bourgogne, UMR CNRS 6303, Université de Bourgogne Franche-Comté, BP 47870, F-21078 Dijon, France

email: xavierjimmys@gmail.com

We apply the inverse geometric optimization technique to generate an optimal and robust stimulated Raman exact passage (STIREP) considering the loss of the upper state as a characterization parameter. Control fields temporal shapes that are optimal with respect to pulse area, energy, and duration, are found to form a simple sequence with a combination of intuitively (near the beginning and the end) and counter-intuitively ordered pulse pairs. Robustness up to third order with respect to pulse amplitude inhomogeneities is demonstrated, accounting for a 13-fold increase on the fidelity profile waist at fidelity $= 10^{-4}$ regarding the unconstrained optimal. The resulting population dynamics produces a loss, through spontaneous emission, of $0.1291\Gamma T$ where T is the interaction time and Γ the dissipation rate; this represents a 34% reduction from the non-robust optimal case. We find a family of optimal robust solutions featuring even lower losses that the optimal one, but with larger pulse areas. The resulting dynamics produces a loss which is about a third of that of the non-robust optimal STIREP. Alternative optimal solutions featuring lower losses, larger pulse areas, and fully counter-intuitive pulse sequences are derived.

ADAPTIVE POVM IMPLEMENTATIONS AND MEASUREMENT ERROR MITIGATION STRATEGIES FOR NEAR-TERM QUANTUM DEVICES

S. Maniscalco

Algorithmiq Oy, Kanavakatu 3C Helsinki

email: sabrina@algorithmiq.fi

We present adaptive measurement techniques tailored for variational quantum algorithms on near-term small and noisy devices. In particular, we generalise earlier "learning to measure" strategies in two ways. First, by considering a class of adaptive positive operator valued measures (POVMs) that can be simulated with simple projective measurements without ancillary qubits, we decrease the amount of required qubits and two-qubit gates. Second, by introducing a method based on Quantum Detector Tomography to mitigate the effect of noise, we are able to optimise the POVMs as well as to infer expectation values reliably in the currently available noisy quantum devices. Our numerical simulations clearly indicate that the presented strategies can significantly reduce the number of needed shots to achieve chemical accuracy in variational quantum eigensolvers, thus helping to solve one of the bottlenecks of near-term quantum computing

EXACT QUBIT RESONANCE CALIBRATION AND POWER NARROWING USING IBM QUANTUM

I. Mihov

Department of Physics, Sofia University, James Bourchier 5 Blvd, 1164 Sofia, Bulgaria

email: imihov@phys.uni-sofia.bg

In resonant quantum computing, pulse shapes have no effect on the population transfer; nevertheless, they affect the resonance response curves of the qubit. In this work, the experimental response curves of various pulse shapes were validated against the theoretical predictions. Furthermore, the effects of symmetrical cropping of the Lorentzian function at different heights were examined, using one of the open-access back-end IBM quantum processors. We also observed a solid power narrowing pattern in Lorentzian pulses.

THERMALLY INDUCED QUANTUM PHENOMENA

D. Moore

Department of Optics, Palacky University Olomouc, 17. Listopadu 12, 77146 Olomouc, Czech Republic

email: darren.moore@upol.cz

Nonlinear dynamics possesses the capacity to convert thermal energy into coherent behaviour. Here we provide three examples, mainly motivated by trapped ion systems, in which nonclassicality, entanglement and quantum coherence are generated via nonlinear interactions, in proportion to the thermal energy. We study systems where two degrees of freedom of atomic motion are entangled via their simultaneous weak coupling to a ground state two-level system (TLS), where qubit quantum co-

herence is generated by strong coupling of the TLS to a thermal oscillator and where trilinear interactions among the atomic motion generate strong nonclassicality and non-Gaussian entanglement. Each quantity increases with an increase in the thermal energy.

COHERENT INTERACTION-FREE MEASUREMENTS

S. Paraoanu

Department of Applied Physics, Aalto University, FI-00076 Aalto, Finland

email: sorin.paraoanu@aalto.fi

Interaction-free measurements illustrate in a dramatic way the consequences of particle-wave duality, showing that one can assess the presence of a sensitive object placed in one of the arms of a Mach-Zehnder interferometer without photon absorption. The single-interferometer detection is probabilistic, with success rate of 25%, but when repeated many times it can lead to a success rate of nearly 100%, due to the quantum Zeno effect. I will present a protocol whereby these repetitions are realized in a coherent manner. This also results in a success rate of 100%. I will outline an experimental implementation and discuss also some of the theoretical underpinnings of this surprising effect.

ABSOLUTE NUMBERING OF ASYMPTOTIC VIBRATIONAL LEVELS OF DIATOMIC MOLECULES FROM COLD-PHYSICS EXPERIMENTS

A. Pashov

Sofia University, Faculty of Physics, 5 J. Bourchier Blvd, Sofia, Bulgaria

email: pashov@phys.uni-sofia.bg

We present a simple method for determination of absolute vibrational numbering of isolated near dissociation levels in diatomic molecules, usually observed in cold-physics experiments. The method is based on the isotope shift and works even when energies of only two levels from one isotopologue and one level from another isotopologue have been measured. It is demonstrated with data from recently reported precise measurements of binding energies of levels lying close to the dissociation limits in ultracold Yb2, CsYb, RbSr, and RbYb molecules. Its predictions agree with those of much more elaborate multi-isotope potential curve fitting.

NON-RECIPROCAL WAVE RETARDER BASED ON OPTICAL ROTATORS COMBINATION

A. Rangelov

Department of Physics, Sofia University James Bourchier 5 blvd, 1164 Sofia, Bulgaria

email: rangelov@phys.uni-sofia.bg

We propose and demonstrate a method to realize an easily tunable non-reciprocal wave retarder whose phase retardation depends on the light propagation direction. The system is based on a combination of a reciprocal polarization rotator, a non-reciprocal magneto-optical rotator, and two quarter-wave plates. Experimental tests demonstrate various non-reciprocal functionalities in complete agreement with the underlying theoretical concept.

ENHANCED SHORTCUTS TO ADIABATICITY

A. Ruschhaupt

Department of Physics, University College Cork, Cork, Ireland

email: aruschhaupt@ucc.ie

The preparation and control of quantum states in a fast and robust way is of the utmost importance for current and future quantum technologies. One class of quantum control schemes are "Shortcuts to Adiabaticity" (STA). They are quantum control protocols motivated by adiabatic processes and mainly derived using analytical techniques. However, there are still quantum systems where these STA methods cannot be applied. Therefore, I will then present a new technique for such scenarios, called "Enhanced Shortcuts to Adiabaticity". These new method works for previously intractable Hamiltonians by providing an analytical correction to existing STA protocols. This correction can be easily calculated and the resulting protocols are outside the class of STA schemes. Finally, I will also give an outlook towards Shortcut-Enhanced Quantum Thermodynamics.

THEORY AND SIMULATION OF PROBABILITY NON-CONSERVING QUANTUM SYSTEMS IN CLASSICAL ENVIRONMENTS

A. Sergi

Dipartimento di Scienze Matematiche e Informatiche, Scienze Fisiche e Scienze della Terra, Università degli Studi di Messina, Contrada Papardo 98166 Messina, Italy

email: asergi@gmail.com

There are physical systems where quantum transport takes place in presence of sinks or sources. Since the time evolution of the system does not conserve probability, non-Hermitian Hamiltonians can be used to model this scenario. Moreover, the quantum system can be embedded in a classical environment, acting as a thermal bath. A detailed model, incorporating explicitly a minimal but sufficient number of coordinates for a fine-grained description of the process, without invoking either the rotating wave or the Markovian approximation, is not amenable to an analytical solution. However, numerical approaches and digital computers can often be used to solve the model non-perturbatively. A brute force applications of numerical simulation techniques cannot be expected to provide the direct solution of the complex problem without designing a formalism fit to be implemented on the computer. Not only the detailed description of a mixed quantum-classical system is non-unique, but the simulation of classical non-Markovian thermal baths cannot be implemented by means of an infinite number of coordinates, as required in the thermodynamic limit, because there is no computer apt to the task.

In this talk, we illustrate a theory based on the operator-valued Wigner formulation of quantum mechanics (wherein the density matrix depends on the points of the Wigner phase space associated to the system) that describes quantum-classical systems by means of a quasi-Lie bracket [1]. The adoption of non-Hermitian terms in the quantum-classical Hamiltonian requires to further generalize the bracket but leads to a formalism suitable to simulating probability non-conserving quantum systems embedded in classical baths. Thermodynamic constraints on bath dynamics can be efficiently represented in terms of quasi-Hamiltonian dynamics, implementing thermostats by means of just a few fictitious degrees of freedom. Applications of the theory will be shown through a tunnelling system in a fluctuating quartic potential [3] and a non-Hermitian quantum single-molecule junction at constant temperature [4].

[1] A. Sergi, G. Hanna, R. Grimaudo, and A. Messina, "Quasi-Lie Brackets and the Breaking of Time-Translation Symmetry for Quantum Systems Embedded in Classical Baths", Symmetry 10, 518 (28pp) (2018).

[2] A. Sergi, "Embedding quantum systems with a non-conserved probability in classical environments", Theoretical Chemistry Accounts 134, 79 (9pp) (2015).

[3] A. Sergi and R. Kapral, "Quantum-Classical Dynamics of Nonadiabatic Chemical Reactions", Journal of Chemical Physics 118, 8566-8575 (2003) doi: 10.1063/1.1566731.

[4] A. Grimaldi, A. Sergi, and A. Messina, "Evolution of a Non-Hermitian Quantum Single-Molecule Junction at Constant Temperature", Entropy 23, 147(1-22) (2021).

CONFINING ATOMIC POPULATIONS IN SPACE VIA STIMULATED RAMAN ADIABATIC PASSAGE IN A DOPED SOLID

M. Stabel

Technical University of Darmstadt, Institute of Applied Physics, AG Halfmann, Hochschulstraße 6, 64289 Darmstadt, Germany

email: markus.stabel@physik.tu-darmstadt.de

We experimentally demonstrate spatial confinement of atomic excitation by adiabatic passage processes in a rare-earth ion-doped Pr:YSO crystal. In particular, we apply stimulated Raman adiabatic passage (STIRAP) and compare its performance with electromagnetically induced transparency (EIT). Using a Stokes beam with Gaussian and a pump beam with donut shape we localize the atomic population in the zero-intensity center of the latter. Our data confirm that adiabatic passage confines excitation far below the diameter of the driving laser beams, and that this localization rapidly increases with laser intensity. We find, that STIRAP significantly outperforms EIT, as it was predicted by previous theory proposals, i.e., STIRAP reaches small excitation volumes with much lower laser intensity. The experimental data agree very well with numerical simulations. The findings serve as a step towards new applications for STIRAP, to prepare excitation regions or population patterns in space with large resolution.

[1] Markus Stabel et al, 2022 J. Phys. B: At. Mol. Opt. Phys. 55 154003

CHARACTERIZATION OF HIGH-FIDELITY RAMAN QUBITS

S. Stanchev

Faculty of Physics, Sofia University, 5 James Bourchier Blvd, 1164 Sofia, Bulgaria

email: stanchov@phys.uni-sofia.bg

In quantum information and computation, very high fidelity of gate operations is required. Measuring tiny gate errors with high accuracy is a difficult task, which is traditionally done by randomized benchmarking. In this work we present a new method which allows to determine the gate errors of Raman qubits, in which the qubit states are coupled in a Raman transition via another state, thereby forming a three-state chainwise-connected system. The method is based on the repetition of the same gate sufficiently many times and thereby amplifying the tiny error to easily measurable sufficiently large values. In order to deduce the gate error from the amplified error, analytic connections between the single-gate and multi-gate propagators are derived for three-state Raman systems with two types of symmetries: Majorana and Morris-Shore. We extend these connections to arbitrary dimensions which paves the path toward tomography of qudits.

ION-PHOTON INTERFACES FOR QUANTUM NETWORKING

G. Stutter

Department of Physics and Astronomy, University of Sussex, Brighton BN1 9QH, United Kingdom

email: g.stutter@sussex.ac.uk

A system that combines the complementary strengths of trapped ions and photons as carriers of quantum information is an appealing prospect. Ions contribute long coherence times, high levels of quantum control and high-fidelity state readout, while photons are a natural choice for transmitting information over anything but very short distances. To interface these two platforms we use calcium ions, trapped close to the mode centre of a high-finesse optical cavity. The resulting ion-cavity coupling allows us to produce single photons via a Raman transition.

To study the properties of single photons produced via this method we use a linear Paul trap with macroscopic mirrors installed in its endcaps. With this weakly-coupled system we are able to study the photons that we produce using various schemes. Alongside this work, we utilise a specialised endcap trap with an integrated fibre Fabry–Pérot cavity. After optimisation of the position and localisation of the ion inside the cavity we have obtained a cavity coupling rate of 16.7 MHz, which is greater than both the rate of photon loss from the cavity, and the decay rate of the excited state of the ion.

As a next step we have designed and are constructing a next-generation, flexible, multi-zone trap system with strongly coupled ion-photon interface. This will act as a node of a distributed quantum computer, and allow for higher rates of remote ion-ion entanglement than can be achieved in free space systems.

EXPERIMENTAL DEMONSTRATION OF COMPOSITE PULSES ON IBM'S QUANTUM COMPUTER

B. Torosov

72 Tsarigradsko chaussee, 1784 Sofia, Bulgaria

email: torosov@gmail.com

We perform comprehensive experimental tests of various composite pulse sequences using one of open-access IBM's quantum processors, based on superconducting transmon qubits. We implement explicit pulse control of the qubit by making use of the opportunity of low-level access to the backend, provided by IBM Quantum. We obtain the excitation profiles for a huge variety of broadband, narrowband, and passband composite pulses, producing any pre-chosen target probabilities, ranging from zero to one. We also test universal composite pulses which compensate errors in any experimental parameter. In all experiments, we find excellent agreement between theoretical and experimental excitation profiles. This proves both the composite pulses as a very efficient and flexible quantum control tool and the high quality of the IBM quantum processor. As an extreme example, we test and observe a pronounced narrowband excitation profile for a composite sequence of as many as 1001 pulses.

THE DARMSTADT SCALABLE TIME-BIN ENTANGLEMENT QUANTUM KEY DISTRIBUTION NETWORK

T. Walther

Schlossgartenstr. 7, Inst. for Applied Physics, TU Darmstadt, 64289 Darmstadt, Germany

email: thomas.walther@physik.tu-darmstadt.de

In this talk, we report on our scalable network for quantum key distribution [1]. The central component is an all fiber spontaneous parametric downconversion (SPDC) source in a type-0 PPLN crystal. The photons are distributed via an arrayed waveguide grating or by a wavelength selective switch to the respective parties. The actual key distribution is based on time-bin entanglement requiring identically imbalanced Franson interferometers at each party as well as the source. The quantum bit error rates (QBER) are sufficiently low to use them to precisely adjust the temperatures of the interferometers and maintain phase stability. We have performed simultaneous quantum key exchange over various distances by placing fiber spools up to a length of 100 km between the source and the four parties including one field deployed fiber in the telecom network of Deutsche Telekom.

[1] E. Fitzke, L. Bialowons, M. Tippmann, O. Nikiforov, F. Wissel, M. Gunkel, Th. Walther, PRX Quantum **3** (2022) 020341.

EXTENDING THE MORRIS-SHORE TRANSFORMATION TO NON-DEGENERATE SYSTEMS AND ARBITRARY TIME-DEPENDENT DRIVING FIELDS

K. Zlatanov

Department of Physics, Sofia University, James Bourchier 5 Blvd, 1164 Sofia, Bulgaria

email: k.zlatanoff@gmail.com

The Morris-Shore (MS) transformation is a powerful tool for decomposition of the dynamics of multistate quantum systems to a set of two-state systems and uncoupled single states. It assumes two sets of states wherein any state in the first set can be coupled to any state in the second set but the states within each set are not coupled between themselves. Another important condition is the degeneracy of the states in each set, although all couplings between the states from different sets can be detuned from resonance by the same detuning. The degeneracy condition limits the application of the MS transformation in various physically interesting situations, e.g. in the presence of electric and/or magnetic fields or light shifts, which lift the degeneracy in each set of states, e.g. when these sets comprise the magnetic sublevels of levels with nonzero angular momentum. This paper extends the MS transformation to such situations, in which the states in each of the two sets are nondegenerate. To this end, we develop an alternative way for the derivation of Morris-Shore transformation, which can be applied to non-degenerate sets of states. We present an approximated eigenvalue approach, by which, in the limit of small detunings from degeneracy, we are able to generate an effective Hamiltonian that is dynamically equivalent to the non-degenerate Hamiltonian. The treatment of time-dependent dynamics of quantum systems involving multiple states poses considerable technical challenges. One of the most efficient approaches in treating such systems is the Morris-Shore transformation. The standard MS transformation imposes restrictions on the time dependence of the external fields addressing the states, as it requires that all Rabi frequencies have the same time profile. In this work we treat the case of the time-dependent MS transformation, which opens prospects for a variety of physically interesting processes wherein the fields may have different time dependencies. We explore the adiabatic and the double-adiabatic limit, in which we demonstrate population transfer between the MS states that results in population transfer from one set of states onto another. We demonstrate the generation of superposition states between the MS states by the techniques of half adiabatic passage and fractional stimulated Raman adiabatic passage, which translate to superpositions of all the states of the involved levels.

Index

CAMEL XVII Programme

Time	Mon, Aug 29	Tue, Aug 30	Wed, Aug 31	Thu, Sep 01	Fri, Sep 02
09:00-09:45			Maniscalco	Hensinger	Garraway
09:45-10:30			Paraoanu	Dubielzig	Sergi
10:30-11:00		QVQ2	coffee	coffee	coffee
11:00-11:45			Ruschhaupt	Hennrich	Torosov
11:45-12:30			Pashov	Stutter	Rangelov
		coffee	coffee	coffee	coffee
17:00-17:45	QVQ1	Walther	Kuhn	Moore	Stabel Joseph Laforgue Stanchev
17:45-18:15		Zlatanov	IJspeert	S Ivanov	
18:15-18:35		Mihov			
20:00			DINNER		

The TIPICQA workshop of WG3: Quantum Control is embedded in the programme on September 1.