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

Sol Marina Palace Hotel, Nessebar, Bulgaria, June 23 – June 28, 2024

CAMEL XIX

Nineteenth International Workshop

BOOK OF ABSTRACTS

Edited by

Ivo Mihov and Nikolay Vitanov

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Programme

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09:40-10:20 **Christian Ospelkaus**, *Arbitrary quantum circuits on a fully integrated two-qubit computation register for a trapped-ion quantum processor*

10:20-10:50 **Coffee break**

Noon Session chaired by **Christian Ospelkaus**

10:50-11:30 **Matthias Keller**, *Ion-photon interfaces for quantum networks*

11:30-12:10 **Lukáš Slodička**, *Coherence and statistics of light from large trapped-ion crystals*

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

Evening Session chaired by **Matthias Keller**

17:00-17:30 **Kaloyan Zlatanov**, *Rotational and temporal robustness of the Mølmer–Sørensen gate*

17:30-17:50 **Modesto Orozco Ruiz**, *A way around the exponential scaling in optimal quantum control*

17:50-18:10 **Yannick Strocka**, *Optimal control aspects for cluster state generation with Group-IV color centers in diamond*

18:10-18:30 **Ivo Mihov**, *Extreme spectral line effects with special pulse shapes*

18:30-18:50 **Hristo Tonchev**, *Fast high-fidelity composite gates in superconducting qubits*

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09:40-10:20 **Germano Montemezzani**, *Robust approaches in classical optics*

10:20-10:50 **Coffee break**

Noon Session chaired by **Boyan Torosov**

10:50-11:30 **Stéphane Guérin**, *Optimal robust quantum control*

11:30-12:10 **Andreas Ruschhaupt**, *Quantum control via enhanced shortcuts to adiabaticity*

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

Evening Session chaired by **Winfried Hensinger**

17:00-17:30 **Roberto Grimaudo**, *Integrable quantum Rabi model for two interacting qubits*

17:30-17:50 **Tom Rieckmann**, *Gate sequence optimization for parametrized quantum circuits*

17:50-19:20 **W. Hensinger, C. Ospelkaus, T. Walther, S. Paraoanu, S. Guérin**, *Quo Vadis Quantum?*

Wednesday, June 26

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09:00-09:40 **Sorin Paraoanu**, *Critical parametric quantum sensing with a Josephson amplifier*

09:40-10:20 **Boyan Torosov**, *Single flux quantum control of superconducting qubits*

10:20-10:50 **Coffee break**

Noon Session chaired by **Thomas Walther**

10:50-11:30 **Radim Filip**, *Rise of quantum coherences*

11:30-12:10 **Barry Garraway**, *Topology and control of ultra-cold atoms with radio-frequency fields*

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17:00-17:30 **Niels Joseph**, *Spatial confinement of atomic excitation by composite pulses in Pr:YSO*

17:30-17:50 **Jan Ole Ernst**, *Scheme for fast and deterministic generation of entangled photonic resource states with atom-cavity sources*

17:50-18:10 **Stancho Stanchev**, *Multipass quantum process tomography*

18:10-18:30 **Nayden Nedev**, *Robust dynamical decoupling on IBM Quantum*

18:30-18:50 **Meri Harutyunyan**, *Optimal quantum sensing*

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09:00-09:40 **Gediminas Juzeliūnas**, *Light induced spin squeezing for ultracold atoms in optical lattices*

09:40-10:20 **Andrea Alberti**, *Neutral-atom quantum computing with strontium optical qubits*

10:20-10:50 **Coffee break**

Noon Session chaired by **Andreas Ruschhaupt**

10:50-11:30 **Genko Genov**, *Optimization of dynamical decoupling for quantum technologies*

11:30-12:10 **Jukka Kiukas**, *Single-particle metrology based on time-of-arrival statistics from a uniform particle beam in free space*

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

Evening Session chaired by **Andrea Alberti**

17:00-17:30 **Rodolfo Muñoz-Rodriguez**, *Novel laser-free universal entangling gates and experimental cryogenic apparatus for RF-controlled trapped-ion quantum computers*

17:30-17:50 **Branislav Ilich**, *Ramsey interferometry with qudits*

17:50-18:10 **Christina Andreeva**, *Machine learning with insufficient data for applications in biophotonics*

18:10-18:30 **Hristina Hristova**, *New polarisation devices*

18:30-18:50 **Georgii Semin**, *Framework for canonical quantum plasmonics for finite structure in three dimensions*

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Closing Session

09:00-12:00 **Quo Vadis Quantum: Informal Discussion**

List of Abstracts

NEUTRAL-ATOM QUANTUM COMPUTING WITH STRONTIUM OPTICAL QUBITS

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Neutral atoms trapped in optical arrays are at the forefront of scalable quantum computing devices. Group 2 atoms like ^{88}Sr, known for their ultra-narrow optical transitions, not only are the basis of today's most accurate optical clocks but also provide an ideal two-level system for encoding qubits. In this talk, I will present the Munich Quantum Valley's ongoing effort to develop a quantum computer demonstrator using ^{88}Sr atoms, focusing on our recent realization of one- and two-qubit high-fidelity operations. Ultra-narrow optical transitions have the advantage of long coherence times, but also pose unique challenges for quantum computing applications. We will explore these challenges and the novel solutions we have devised to achieve fast, high-fidelity quantum gates with optical qubits.

MACHINE LEARNING WITH INSUFFICIENT DATA FOR APPLICATIONS IN BIOPHOTONICS

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In recent years, the algorithms of artificial intelligence (AI) are being developed extensively and they attract increasing attention of scientists since they open doors to efficient solutions of many problems that otherwise require a lot of time, effort, expenses and often inspiration. A main challenge to their wider application in biophotonics is the lack of ample amount of diverse and representative data for training. Therefore, we present here the application of Neural Network (NN) algorithms trained with insufficient data for solving two biophotonics tasks. The first one is classification of Laser-Induced Fluorescence (LIF) and reflection spectra of human skin (i.e. optical biopsy) for the purpose of early and non-invasive diagnosis of skin diseases. The second one is related to verification of food quality, and more specifically the identification of mixtures of sunflower and extra virgin olive oils with different concentrations, which can be treated both as a classification and as a fitting task. We present and compare the output of different approaches for treating the insufficient data problem.

SCHEME FOR FAST AND DETERMINISTIC GENERATION OF ENTANGLED PHOTONIC RESOURCE STATES WITH ATOM-CAVITY SOURCES

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Measurement based quantum computing is an appealing alternative quantum computing paradigm, where quantum operations are implemented as sequences of adaptive single qubit measurements on an entangled resource. The high rate and high fidelity preparation of large entangled resources remains a challenge and is central to measurement based quantum computing. Probabilistic photon sources exhibit severe scaling limitations for preparing larger resources. But deterministic schemes using quantum dots or single atoms have shown promise for preparing larger resources with high expected coincidences. We describe an improved scheme to be implemented on a cavity-QED platform and make crucial changes with respect to the state of the art, namely: improved Raman pulses, as well as a change in photonic basis. This allows us to simulate the generation of large linear cluster states, as well as GHZ states with a single Rb 87 atom in an optical cavity with several orders of magnitude higher expected coincidences compared to the state of the art. We also highlight the potential for state of the art machine learning techniques to aid in the determination of optimal pulses in a complex and lossy multilevel system subject to experimental imperfections.

RISE OF QUANTUM COHERENCES

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The talk will contribute to this understanding by widely demonstrating the counter-intuitive emergence of single-qubit coherence in different regimes at a low temperature. A typical setup to generate coherence in a qubit, a two-level system, or their ensembles requires a solid and coherent external input to drive the system, often leading to a linearization of the dynamics. Here, we use merely a low-temperature limit of an oscillator coupled to the qubit to generate qubit coherences with any external drive. Diverse models can be implemented in various experimental platforms, such as trapped ions, superconducting circuits, or solid-state qubits, for their qubit transients and steady states. We demonstrate how engineered nonlinear dynamics can produce significant coherence in the qubit from small incoherent thermal energy across a wide range of parameter values [1-5].

[1] G. Guarnieri, M. Kolář, and R. Filip, Phys. Rev. Lett. 121, 070401 (2018)
[2] A. Purkayastha, G. Guarnieri, M.T. Mitchison, R. Filip and J. Goold, npj Quantum Information 6, 27 (2020)
[3] A. Slobodeniuk, T. Novotný, and R. Filip, Quantum 6, 689 (2022).
[4] M. Kolář, R. Filip, arXiv:2211.08851, accepted in Quantum Science and Technology
[5] P. Laha, D.W. Moore, and R. Filip, Phys. Rev. Lett. 132, 210201 (2024)

TOPOLOGY AND CONTROL OF ULTRA-COLD ATOMS WITH RADIO-FREQUENCY FIELDS

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We develop techniques for the analysis of wave packet dynamics in 2D and 3D. We use a Gaussian approximation to a wave-packet in a ring potential and show how the orientation of the wave-packet changes as it propagates around the ring. Further to this, a method to obtain corrections to the Gaussian wave-packet is obtained by transforming the Hamiltonian of the system to a local co-moving and rotating harmonic basis. The same methodology is also used to examine the creation of angular momentum of a wave packet by means of rotating an anisotropic potential, which is a technique being used to impart angular momentum to Bose-Einstein condensates. Finally, the different method of representing a wave- function by a swarm of Gaussian wave-packets is used to analyse the dynamics of expanding matter-wave rings and shell states.

The motivation of the work is the analysis of systems that may be used to make Sagnac interferometers [1,2,3] for rotation meansurements, and the analysis of idealised shell states of a Bose-Einstein condensate. For the latter, experiments on the Cold Atom laboratory, or CAL [4,5]) have stimulated wide interest in the creation and physics of bubbles of quantum gas [6]. This includes the collapse and expansion of bubbles, vortices on closed surfaces, and vibration of the shell.

[1] See e.g. Matter-wave analog of a fiber-optic gyroscope, K.A. Krzyzanowska, J. Ferreras, C. Ryu, E.C. Samson, and M.G. Boshier, Phys. Rev. A 108, 043305 (2023).
[2] L. Amico, M. Boshier, G. Birkl, et al., AVS Quantum Sci. 3, 039201 (2021).
[3] Atomtronic circuits: From many-body physics to quantum technologies, L. Amico, D. Anderson, M. Boshier, J.-P. Brantut, L.-C. Kwek, A. Minguzzi, and W. von Klitzing, Rev. Mod. Phys. 94, 041001 (2022).
[4] Observation of Bose–Einstein condensates in an Earth-orbiting research lab, D.C. Aveline, J.R. Williams, E.R. Elliott et al., Nature 582, 193 (2020).
[5] Observation of ultracold atomic bubbles in orbital microgravity, R.A. Carollo, D.C. Aveline, B. Rhyno et al., Nature 606, 281 (2022).
[6] Perspective on Quantum Bubbles in Microgravity, N. Lundblad, D.C. Aveline, A. Balaz et al., Quantum Sci. Technol. 8, 024003 (2023).

OPTIMIZATION OF DYNAMICAL DECOUPLING FOR QUANTUM TECHNOLOGIES

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Decoherence and imperfect control are crucial challenges for quantum technologies. Common protection strategies rely on noise temporal autocorrelation, using pulsed or continuous fields for dynamical decoupling. Hereby we show that the decoupling can be improved by using cross-correlations of two noise sources, achieving a tenfold improvement in coherence time [1]. Modeling of magnetic and amplitude noise as an Ornstein-Uhlenbeck process also allows for the tailoring of dynamical decoupling of a germanium vacancy (GeV) center in diamond. GeV centers have great potential as quantum network nodes due to their efficient spin-photon interface. Using our optimized dynamical decoupling protocol, we improve the coherence time of a single GeV center by several orders of magnitude to a world-record of 20 ms at millikelvin temperatures [2].

[1] Alon Salhov, Qingyun Cao, Jianming Cai, Alex Retzker, Fedor Jelezko, and Genko Genov, Phys. Rev. Lett. 132, 223601 (2024).
[2] Katharina Senkalla, Genko Genov, Mathias H. Metsch, Petr Siyushev, and Fedor Jelezko Phys. Rev. Lett. 132, 026901 (2024).

INTEGRABLE QUANTUM RABI MODEL FOR TWO INTERACTING QUBITS

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A quantum Rabi model with a longitudinal qubit-mode coupling is investigated in the case of two interacting qubits. Independently of the coupling regime, this model results to be both integrable and exactly solvable. The existence of critical points stemming from level crossings and characterized by discontinuous two-spin magnetization, mean photon number, and concurrence, is brought to light. Further, the tripartite system undergoes a second order quantum phase transition under a specific condition which can be identified as a new thermodynamic-like limit for finite-size systems.

OPTIMAL ROBUST QUANTUM CONTROL

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Quantum computation requires ultrahigh-fidelity quantum gate via fast, ideally optimal [1], processes. Imperfections from physical implementation needs in addition robust control. We develop a geometrical procedure, referred to as robust inverse optimization (RIO) [2-4], which allows a time- or energy- optimal control, featuring robustness quantified by flattening the transfer profile around the target as a function of the ideal control deviation at chosen perturbation orders. At the lowest order, robustness with respect to pulse inhomogeneities is achieved with a constant pulse and a Jacobi elliptic cosine detuning [3]. The procedure is demonstrated on IBM's quantum computers via a digital version of RIO based [5]. The procedure can be extended for (high-order) ultra-robust processes [6]. We also design optimal and robust stimulated Raman exact passage (STIREP) [4], taking into account the lossy upper state [7]. RIO technique finds application to optimal quantum sensing.

[1] Q. Ansel et al., J. Phys. B 57, 133001 (2024).
[2] G. Dridi, K. Liu, S. Guérin, Phys. Rev. Lett. 125, 250403 (2020).
[3] X. Laforgue, G. Dridi, S. Guérin, Phys. Rev. A 106, 052608 (2022).
[4] X. Laforgue, G. Dridi and S. Guérin, Phys. Rev. A 105, 032807 (2022).
[5] M. Harutyunyan, F. Holweck, D. Sugny, and S. Guérin, Phys. Rev. Lett. 131, 200801 (2023).
[6] G. Dridi, X. Laforgue, M. Mejatty, S. Guérin, Phys. Rev. A (2024).
[7] K. Liu, D. Sugny, X. Chen, and S. Guérin, Entropy 25, 790 (2023).

OPTIMAL QUANTUM SENSING

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The presentation will introduce narrowband optimal control as a protocol for achieving optimal quantum sensing. This procedure maximizes the quantum Fisher information to reach the classical Fisher information for minimal resources through inverse optimization and the single-shot shaped pulse method. In addition, an experimental demonstration on the IBM's quantum computers wil be discussed.

ULTRASENSITIVE SINGLE-ION ELECTROMETRY IN A MAGNETIC FIELD GRADIENT

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Hyperfine energy levels in trapped ions offer long lived spin states. In addition, the motion of these charged particles couples strongly to external electric field perturbations. These characteristics make trapped ions an attractive platforms for the quantum sensing of electric fields. However, the spin states do not exhibit a strong intrinsic coupling to electric fields. This limits the achievable sensitivities. Here, we amplify the coupling between electric field perturbations and the spin states by using a static magnetic field gradient. Displacements of the trapped ion resulting from the forces experienced by an applied external electric field perturbation are thereby mapped to an instantaneous change in the energy level splitting of the internal spin states. This gradient mediated coupling of the electric field to the spin enables the use of a range of well-established magnetometry protocols for electrometry. This technique therefore enables the realisation of one of the most sensitive electric field sensors for the measurement of both DC signals and AC signals across a frequency range of sub-Hz to $\sim$ 500 kHz. I will also describe a set of hardware modifications that are capable of achieving a further improvement in sensitivity by up to 6 orders of magnitude.

NEW POLARISATION DEVICES

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The importance of manipulation of polarization in contemporary problems in optics related to precise measurements, signal transmission and others, leads to a race in the research of new type of polarization devices. We propose and theoretically consider two possible constructions. In the first, we present a composition of half-wave and quarter-wave plates operating as a polarization retarder with tunable retardance. We select a construction for adjustable retarder, and equiped with composite pulses technique, we identified optimal rotation angles for the wave plates to obtain spectrally narrowband or broadband device working regime. The proposed device can be constructed with the commercial wave plates, displaying utility for experimental application. The second proposed polarization device can operate as tunable retarder or rotator or tunable combination of both. It is composed of two half-wave plates and two quarter-wave plates, where the retardance and the rotation can be modified by rotating the half-wave plates. The results from the simulations and from analysed experimental data presented possibility for an arbitrary input to achieve an arbitrary output by using the device either in direct or in the inverse direction.

RAMSEY INTERFEROMETRY WITH QUDITS

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We present a simple modification to the Ramsey Interferometry protocol. Standard protocol procedure calls for two $\pi/2$ pulses with length T on a qubit, separated by a free evolution period t, resulting in Ramsey fringes. We hypothesize that using a qudit, a d-level system, instead of a qubit, increases the number of oscillations during the free evolution period t. Extension to higher orders of $d > 2$ is done using the Wigner-Majorana(WM) parametrisation. Simulations confirm our hypothesis, nearly doubling the resolution of the oscillations when using a qutrit ($d = 3$), with no loss in contrast. Going beyond $d > 3$ improves the resolution even further, though losses start to accumulate in the contrast. Analysis of the results shows that odd-state level systems are more efficient than even-state level systems when using the WM parametrisation.

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

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We experimentally demonstrate spatial confinement of atomic excitation by narrowband composite pulse sequences in 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 than the diameter of the driving Gaussian-shaped laser pulses. Our experimental data agree 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 carefully choosing experimental parameters. Our experiments prove that narrowband composite pulses are a versatile tool to localize atomic excitation, potentially also below the diffraction limit. This could also be of relevance to quantum computation, as further generalized composite sequences enable arbitrary quantum gate operations in precisely confined spatial regions.

LIGHT INDUCED SPIN SQUEEZING FOR ULTRACOLD ATOMS IN OPTICAL LATTICES

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In the initial part of the talk there will be an overview on individual and collective spins, the states of the collective spin and squeezing of these states. We will also talk on different spin squeezing mechanism including one axis twisting (OAT) and two axis countertwisting (TACT) spin squeezing models [1]. Subsequently we discuss possibilities to produce spin squeezing for spinful atomic fermions in optical lattices. It is shown that by applying laser radiation one can simulate not only OAT but also TACT spin squeezing models, the latter TACT model providing better squeezing [2, 3]. The spin squeezing generated in this way is mediated by spin waves playing a role of the intermediate states facilitating the squeezing process. Finally we will mention an ongoing research on producing non-classical spin states for an ensemble of atoms characterised by a larger spin, such as spin 9/2 for ^{87}Sr atoms [4]. The spin squeezing can be used for increasing sensitivity of atomic clocks.

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[2] T. Hernández Yanes, M. Płodzień, M. Mackoit Sinkevičienė, G. Žlabys, G. Juzeliūnas, E. Witkowska, One- and Two-Axis Squeezing via Laser Coupling in an Atomic Fermi-Hubbard Model, Phys. Rev. Lett. 129, 090403 (2022).
[3] T. Hernández Yanes, G. Žlabys, M. Płodzień, D. Burba, M. Mackoit Sinkevičienė, E. Witkowska, G. Juzeliūnas, Spin squeezing in open Heisenberg spin chains, Phys. Rev. B 108, 104301 (2023).
[4] D. Burba, H. Dunikowski, M. Robert-de-Saint-Vincent, E. Witkowska, G. Juzeliūnas, Effective light-induced Hamiltonian for atoms with large nuclear spin, arXiv:2404.12429 (2024).

ION-PHOTON INTERFACES FOR QUANTUM NETWORKS

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Combining trapped atomic ions with photons is currently the most promising system for building distributed quantum computers and large-scale quantum networks. Ions currently have the heist performing single and two-qubit quantum gate fidelity with highly efficient state initialisation and read-out. Photons are the most successful system to transmit quantum information over longer distances. Combining the two systems by coupling the ions to optical cavities takes advantage of both systems and allows the generation of remote entanglement, a precursor for quantum networking and distributed quantum computing.

To implement such an ion-photon interface needs to overcome three major challenges. First, the efficiency of the ion-photon interaction needs to be high to allow high rates with high entanglement fidelity. To this end, we are developing a quantum networking node with an integrated ion-cavity system in the strong coupling. In addition, we have developed a novel method to create ultra-low-loss optical cavity mirrors.

The second challenge is to ensure high-fidelity operation of such an ion-photon interface. We have developed a novel scheme to suppress the adverse effect of atomic spontaneous decay. The last challenge is to encode the quantum information in a way amenable to faithful transmission through a dynamic fibre network.

SINGLE-PARTICLE METROLOGY BASED ON TIME-OF-ARRIVAL STATISTICS FROM A UNIFORM PARTICLE BEAM IN FREE SPACE

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We study how an absorbing arrival time measurement process can be used to extract statistical information on single-particle properties from a spatially uniform "plane wave" beam of infinitely many Bosonic particles. We describe the beam rigorously as a limit of Fock space states, using both coherent superposition and incoherent mixtures of N-particle states, and modelling the detection process by a phenomenological Fock space master equation describing particle annihilation at a single point in the physical position space. We find explicitly the resulting arrival time distributions involving multiple detections, and compute numerically the Fisher Information characterising the optimal statistical estimation of the single-particle momentum parameter of the plane wave from this distribution.

EXTREME SPECTRAL LINE EFFECTS WITH SPECIAL PULSE SHAPES

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The shape of excitation pulses significantly affects the transition line of qubits. Certain pulse shapes, such as those described by the Rabi model, exhibit power broadening, while others, like those following the Rosen-Zener model, are neutral to the Rabi frequency, exhibiting constant transition linewidth. Remarkably, we have identified a family of pulse shapes that reverse power broadening and instead exhibit the opposite effect – power narrowing – effectively reverting the century-old phenomenon of power broadening. These effects have been both theoretically predicted and experimentally validated using IBM Quantum hardware.

In this study, we also focus on pulse shapes that induce extreme power broadening patterns. These pulses typically have a convex shape with sharp discontinuities at the beginning and end, akin to rectangular pulses. Specifically, we employed two pulse shapes: $\Omega_1(t) = \Omega_0\, t^{2N}$, where N is a non-negative integer, and $\Omega_2(t) = \Omega_0\,(1 + \beta t^2)$, with β being any real number,

including negatives. Our experiments, conducted on the IBM Quantum system ibmq_manila, demonstrated that our custom pulse shape increased the 9π pulse area excitation peak by a factor of approximately 5 compared to a simple rectangular pulse.

ROBUST APPROACHES IN CLASSICAL OPTICS

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The equations describing the evolution dynamics of coupled few levels quantum system bear direct analogy with those describing several processes in classical wave optics, including the cases of evanescently coupled waveguides, polarization transformation optics, and nonlinear optical frequency conversion. This allows to exploit the same kind of robust approaches used in the quantum field to reach a specific target state. This talk will summarize some of our recent works in this context conducted in collaboration with the Department of Physics of Sofia University. The examples will involve adiabatic approaches for light transfer, mode conversion or broadband polarization selective beam splitting in waveguide optics [1-3], a simple and robust composite optical rotator for polarization optics as well as corresponding non-reciprocal elements [4, 5], and composite approaches for broadband nonlinear optical frequency conversion based on segmented crystals [6]. The possible useful role of dissipation in non-Hermitian systems will also be discussed with examples in guided and nonlinear optics [7, 8].

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NOVEL LASER-FREE UNIVERSAL ENTANGLING GATES AND EXPERIMENTAL CRYOGENIC APPARATUS FOR RF-CONTROLLED TRAPPED-ION QUANTUM COMPUTERS

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Trapped ions are one of the most promising technologies for developing large-scale quantum computers [1-6]. In particular, RF- controlled ions are suitable candidates for achieving scalability because, unlike their laser-controlled counterparts, they avoid challenges associated with the upscaling of coherent control of the qubits [7-11]. Furthermore, with RF-controlled ions high fidelity for single- and two-qubit gate fidelities and low crosstalk between the addressed qubits have been demonstrated [12-19].

We present novel laser-free two-qubit entangling gates that have been proposed theoretically and investigated experimentally in a room-temperature macroscopic linear Paul trap [16, 20]. The results obtained have shown that, for a two-qubit entangling gate, it is possible to achieve gate speeds up to one order of magnitude higher than previous RF gates in static magnetic fields.

Scaling up ion traps to control large numbers of ions typically requires an excellent vacuum (XHV) and low heating rates of the ions' motion, both of which are achieved in a cryogenic environment. At the same time, electronics that generate electromagnetic fields for ion control should be placed on or near micro-structured traps. We currently build a new experimental apparatus for investigating cryogenic (4 K) planar ion traps with electrodes controlled by cryogenic digital-to-analog converters (DACs). Our trap chip architecture includes elements for generating a static magnetic field gradient which allows the use of RF fields for coherent control of the qubits. The integrated DACs allow for flexibly shaping the trapping potential for the targeted control and optimization of the interaction between ions for specific gate operations, and for transporting ions between different trapping zones. The current progress towards the building of this new experimental setup will be discussed.

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ROBUST DYNAMICAL DECOUPLING ON IBM QUANTUM

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Dynamical decoupling (DD) is one of the simplest and least resource-intensive methods for suppression of decoherence and has proven to be an essential tool on today's noisy intermediate-scale quantum (NISQ) devices. In this work we derive general formulas for two new classes of DD sequences which are constructed to be robust against detuning. We present numerical simulations showing increasing detuning frequency bandwidth with minimal error compared to CMPG. The robustness of the sequences to pulse area errors is also studied. Experimental results are presented from the 127-qubit open-access IBM Quantum processors, showing substantial increase in qubit fidelity compared to periods of free evolution.

A WAY AROUND THE EXPONENTIAL SCALING IN OPTIMAL QUANTUM CONTROL

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Just like the exponential scaling of quantum mechanics is the basis for the efficiency of quantum computing, it is also prohibitive for the description of quantum dynamics with classical computers. Among the tasks that suffer from our limitations to classically simulate quantum dynamics, optimal quantum control plays a pivotal role in the communities goal to develop quantum technological applications.

The work we present describes a fundamentally new approach to optimal quantum control, that avoids reference to quantum states or propagators that suffer from exponential scaling. We show that qubit registers with suitable interaction geometries admit a description of their quantum dynamics completely in terms of eigenvalue relations of quantum invariants that can be specified with polynomial effort. We illustrate this with the example of a spin chain, and the quadratically scaling effort allows us to design both state control and gate control

for up to 50 qubits (corresponding to a 10^{15}-dimensional Hilbert space).

ARBITRARY QUANTUM CIRCUITS ON A FULLY INTEGRATED TWO-QUBIT COMPUTATION REGISTER FOR A TRAPPED-ION QUANTUM PROCESSOR

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We report on the implementation of arbitrary circuits on a universal two-qubit register that can act as the computational module in a trapped-ion quantum computer based on the quantum charge-coupled device architecture. A universal set of quantum gates is implemented on a two-ion Coulomb crystal of $^9Be^+$ ions using only chip-integrated microwave addressing. Individual-ion addressing is implemented using microwave micromotion sideband transitions; we obtain upper limits on addressing cross-talk in the register. Arbitrary two-qubit operations are characterized using the cycle benchmarking protocol.

CRITICAL PARAMETRIC QUANTUM SENSING WITH A JOSEPHSON AMPLIFIER

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Josephson parametric amplifiers are nowadays widespread devices in nanoelectronics research. When pumped at a frequency close to double the natural resonance frequency, the device enters in various stability regimes, including an oscillatory state that can be observed experimentally, We map the phase diagram, identifying the first and second order transitions and the critical point. We show that the transition into the oscillatory state can be used for single-photon detection in the microwave frequency range. This allows us to map the Poissonian distribution of an incoming coherent probe field. I will conclude with a perspective on sensing using superconducting circuitry.

GATE SEQUENCE OPTIMIZATION FOR PARAMETRIZED QUANTUM CIRCUITS

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Currently, even the best-performing quantum computers are subject to significant amounts of noise, deriving especially from their two-qubit entangling operations. In order to achieve useful results on these systems, it is necessary to optimize the quantum circuits, taking into

account the experimental architecture and noise profile. We propose a novel algorithm to generate more efficient parametrized circuits for the elementary task of state preparation. Our algorithm, based on reinforcement learning to optimize the gate sequence, is adaptable to any quantum circuit- based architecture and gate set. Additionally, it can be tuned to find a balance between the circuit approximation degree and the resulting magnitude of noise, thus maximizing the experimentally observed fidelity to the target state.

In addition to our algorithm, this talk will introduce the previous approach of layered parametrized quantum circuits and compare their results for five-qubit systems with circuits containing CNOT gates and single-qubit rotations. Analysis regarding the effects of noise is performed using the publicly available IBM quantum computers.

QUANTUM CONTROL VIA ENHANCED SHORTCUTS TO ADIABATICITY

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Shortcuts to Adiabaticity (STA) 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" (eSTA) [1], which provides an easy to calculate analytical correction to existing STA protocols. After giving some introductory overview about STA, I start with a presentation of the formalism of eSTA. I present then some applications of eSTA [2, 3], for example, also spin squeezing in internal bosonic Josephson junctions [4, 7]. Finally, I will also give an outlook towards Shortcut-Enhanced Quantum Thermodynamics.

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FRAMEWORK FOR CANONICAL QUANTUM PLASMONICS FOR FINITE STRUCTURE IN THREE DIMENSIONS

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We provide the framework and tools for canonical quantization of plasmon polaritons from metallic or dielectric finite nanostructures. These tools allow one to diagonalize the Hamiltonian and to determine exactly the quantized electromagnetic field and an imaginary Green's tensor identity satisfying the Sommerfeld radiation boundary conditions.

COHERENCE AND STATISTICS OF LIGHT FROM LARGE TRAPPED-ION CRYSTALS

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We present experimental realizations of free-space optical emission of light from ion Coulomb crystals in Paul traps, which result in the generation of diverse paradigmatic photon statistics, including pure single-photon emission, or the largest discrete photonic nonclassical states. We observe experimental evidence of single-modeness and coherence for light scattered from many ions, which correspond to necessary conditions for the efficient photonic generation of multi-ion entanglement, or for the directional control of light from large ion crystals. We employ the achieved excitation and detection regimes to observe the emergence of super-Poissonian quantum statistics from a finite number of indistinguishable single-photon emitters and the realization of enhancement of collection efficiency of nonclassical light scattered from linear ion strings.

MULTIPASS QUANTUM PROCESS TOMOGRAPHY

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We introduce a method to enhance the precision and accuracy of Quantum Process Tomography (QPT) by mitigating the errors caused by state preparation and measurement (SPAM), readout and shot noise. Instead of performing QPT solely on a single gate, we propose performing QPT on a sequence of multiple applications of the same gate. The method involves the measurement of the Pauli transfer matrix (PTM) by standard QPT of the multipass process, and then deduce the single-process PTM by two alternative approaches: an iterative approach which in theory delivers the exact result for small errors, and a linearized approach based on solving the Sylvester equation. We examine the efficiency of these two approaches through simulations on IBM Quantum using qasm_simulator. Compared to the Randomized Benchmarking type of methods, the proposed method delivers the entire PTM rather than a single number (fidelity). Compared to standard QPT, our method delivers PTM with much higher accuracy and precision because it greatly reduces the SPAM, readout and shot noise errors. We use the proposed method to experimentally determine the PTM and the fidelity of the CNOT gate on the quantum processor ibmq_manila.

OPTIMAL CONTROL ASPECTS FOR CLUSTER STATE GENERATION WITH GROUP-IV COLOR CENTERS IN DIAMOND

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The control of the spin of negatively charged Group-IV color centers in diamond plays an important role in various applications such as quantum repeaters and measurement-based quantum computing. The latter relies on single qubit measurements of large multipartite entangled states, so-called cluster states. An emission based cluster state generation protocol requires fast high fidelity control of the spin qubit, which is formed by the two lowest lying energy eigenstates of the system. Here we theoretically analyze a Raman control scheme, involving two laser pulses with two destinct central frequencies. The Raman pulses implement a spin gate. Optical pulses allow the control over a larger range of ground state splittings compared to microwave control. In a closed system perfect gates are in theory possible. Phononic decay of the involved levels, however, greatly impacts the gate fidelity. In this work we use global optimization strategies to reduce the phononic impact on fidelities.

FAST HIGH-FIDELITY COMPOSITE GATES IN SUPERCONDUCTING QUBITS

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We present a method for quantum control in superconducting qubits. We show that for short-time operations it achieves better results than standard industry approaches. The technique utilizes composite pulses, that allow for the correction of various types of errors, which naturally arise in a system. We use our approach to produce complete and partial population transfers between the qubit states, as well as two basic single-qubit quantum gates. Our simulations show a substantial reduction of the typical errors and a gate speed-up by orders of magnitude. Three different independent verifications are made to justify our claims.

SINGLE FLUX QUANTUM CONTROL OF SUPERCONDUCTING QUBITS

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Superconducting qubits are traditionally controlled using microwave pulses. This approach, however, suffers from scalability difficulties. We examine alternative methods, based on single-flux-quantum (SFQ) pulses to construct robust and high-fidelity quantum gates. The single-qubit gates are produced by exploiting an analogy to the derivative-removal by adia-

batic gates (DRAG) technique, while the two-qubit control is performed by direct optimization of the SFQ train.

TOWARDS A PRACTICAL CITY-SCALE QUANTUM KEY DISTRIBUTION NETWORK

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We report on the recent progress on our scalable quantum key distribution network. In the recent months we focussed in demonstrating the flexibility of our set-up by improving the pulse nesting and reduced the number of necessary detectors by applying detector time multiplexing. In addition, we implemented the full software stack from initialisation and authorisation to error correction and privacy amplification. Our progress towards a distributed network will be discussed.

ROTATIONAL AND TEMPORAL ROBUSTNESS OF THE MOLMER-SORENSEN GATE

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We present a comprehensive analysis of the Mølmer-Sørensen gate, focusing on the enhancement of its operational robustness and fidelity through the implementation of amplitude modulation and composite pulses techniques. The Mølmer-Sørensen gate, is often susceptible to motional and rotational errors due to operational imperfections. To address these challenges, we introduce a refined approach utilizing amplitude modulation to dynamically adjust the interactions time profile during gate operation, effectively mitigating error rates due to impercise timing of the gate. Furthermore, we integrate composite pulse sequences, to correct for rotational errors and enhance the gate's resistance to external disturbances.

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CAMEL XIX Programme

Time	June 24	June 25	June 26	June 27	June 28
09:00-09:40	Hensinger	Walther	Paraoanu	Juzeliūnas	**QVQ**
09:40-10:20	Ospelkaus	Montemezzani	Torosov	Alberti	
10:20-10:50	coffee	coffee	coffee	coffee	
10:50-11:30	Keller	Guérin	Filip	Genov	
11:30-12:10	Slodička	Ruschhaupt	Garraway	Kiukas	
16:30-17:00	coffee	coffee	coffee	coffee	
17:00-17:30	Zlatanov	Grimaudo	Joseph	Rodriguez	
17:30-17:50	Orozco Ruiz	Rieckmann	Ernst	Ilich	
17:50-18:10	Stroka	**QVQ**	Stanchev	Andreeva	
18:10-18:30	Mihov		Nedev	Hristova	
18:30-18:50	Tonchev		Harutyunyan	Semin	
20:00			**DINNER**		

* Registration is available on June 23 between 18:00 - 19:00 and on June 24 between 08:00 - 09:00 in the conference room