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

Sol Marina Palace Hotel, Nessebar, Bulgaria,
June 22 – June 26, 2026

CAMEL XXI

Twenty-First International Workshop

BOOK OF ABSTRACTS

Edited by
Ivo Mihov and Nikolay Vitanov

LOCAL ORGANIZING COMMITTEE

Nikolay Vitanov (chairman), Ivo Mihov,
Stancho Stanchev, Simona Grigorova,
Hristo Tonchev, Kaloyan Zlatanov,
Andon Rangelov, Lidya Slavova,
Branislav Ilich, Vasil Vasilev,
Nayden Nedev, Kremena Parashkevova,
Julian Dimitrov, Nadezhda Markova,
Aida Shiroyan, Georgi Aleksandrov,
Tihomir Tenev, Martin Dimov,
Pavel Pisanov, Aleksandra Antonova,
Kristina Borisova

Center for Quantum Technologies
Department of Physics
Sofia University “St. Kliment Ohridski”
5 Yakubitsa str., 1164 Sofia, Bulgaria
https://camel21.com

Supported by:
Bulgarian national plan for recovery and resilience,
Contract No. BG-RRP-2.004-0008-C01 (SUMMIT),
Project No. 3.1.4

Contents

List of Participants

Georgi Aleksandrov (Sofia)
Rares Barcan (Sussex)
Thomas Clarke (Sussex)
Virginie Coda (Metz)
Julian Dimitrov (Sofia)
Michael Drewsen (Aarhus)
Radim Filip (Olomouc)
Genko Genov (Ulm)
Simona Grigorova (Sofia)
Roberto Grimaudo (Catania)
Markus Hennrich (Stockholm)
Winfried Hensinger (Sussex)
Patrick Huber (Siegen)
Branislav Ilikj (Sofia)
Gediminas Juzeliūnas (Vilnius)
Matthias Keller (Sussex)
Nadezhda Markova (Sofia)
Antonino Messina (Palermo)
Ivo Mihov (Sofia)
Nayden Nedev (Sofia)
Finnlay O'Dwyer (Sussex)
Christian Ospelkaus (Hannover)
Sorin Paraoanu (Aalto)
Kremena Parashkevova (Sofia)
Jyrki Piilo (Turku)
Ana Predojevic (Stockholm)
Andreas Ruschhaupt (Cork)
Aida Shiroyan (Sofia)
Lukas Slodicka (Olomouc)
Stancho Stanchev (Sofia)
Tihomir Tenev (Sofia)
Hristo Tonchev (Sofia)
Boyan Torosov (1QBit)
Thomas Walther (Darmstadt)
Thomas Zanon (Sorbonne)
Kaloyan Zlatanov (Sofia)

Bulgaria	13	Canada	1	Czech Republic	2
Denmark	1	Finland	2	France	2
Germany	4	Ireland	1	Italy	2
Lithuania	1	Sweden	2	United Kingdom	5

Programme

Monday, June 22

Morning Session chaired by **Nikolay Vitanov**

09:00-09:40 **Thomas Walther**, *Alice, Bob, . . . and Friends: What's next for the Darmstadt Quantum Key Distribution Network*

09:40-10:20 **Ana Predojevic**, *Advancing quantum dot sources of entangled photon pairs*

10:20-11:00 **Coffee break**

Noon Session chaired by **Thomas Walther**

11:00-11:40 **Antonino Messina**, *Engineering the Hilbert space: Inverse Hamiltonian design for passive structural error avoidance*

11:40-12:20 **Radim Filip**

Lunch

Evening Session chaired by **Patrick Huber**

16:30-17:10 **Genko Genov**, *Efficient Quantum Sensing and High-Fidelity Electron Spin Gates for Diamond Quantum Registers*

17:10-17:40 **Kaloyan Zlatanov**, *Fast two-qubit gates in ion traps*

17:40-18:10 **Coffee break**

Late Session chaired by **Ana Predojevic**

18:10-18:40 **Nayden Nedev**, *Twinned Dynamical Decoupling with All-Order Pulse-Area Cancellation and Arbitrary-Order Detuning Suppression*

18:40-19:00 **Thomas Clarke**, *Robust Phase Estimation for a Trapped Ion Qubit*

19:00-19:20 **Finnlay O'Dwyer**, *Characterising Single Qubit Operations with Interleaved Transport and State Mapping in a Switchable Magnetic Gradient*

Tuesday, June 23

Morning Session chaired by **Markus Hennrich**

09:00-09:40 **Winfried Hensinger**, *Developing modular microwave trapped-ion quantum computers for operation with millions of qubits*

09:40-10:20 **Patrick Huber**, *Towards a scalable, laser-free, quantum processor*

10:20-11:00 **Coffee break**

Noon Session chaired by **Michael Drewsen**

11:00-11:40 **Christian Ospelkaus**, *Scalable trapped-ion quantum computing based on NFQC*

11:40-12:20 **Thomas Zanon-Willette**, *Fault-tolerant dynamically-decoupled hyper-Ramsey spectroscopy with a superconducting qubit*

Lunch

15:00-18:00 **Boat trip**

Wednesday, June 24

Morning Session chaired by **Christian Ospelkaus**

09:00-09:40 **Michael Drewsen**

09:40-10:20 **Markus Hennrich**, *Trapped Rydberg ions: A novel platform for quantum simulation*

10:20-11:00 **Coffee break**

Noon Session chaired by **Winfried Hensinger**

11:00-11:40 **Matthias Keller**, *Generation of Two-Photon Entanglement Using a Single Ion–Cavity System*

11:40-12:20 **Lukas Slodicka**, *Observation of Cooperative Light Scattering in Trapped-Ion Crystals*

Lunch

Evening Session chaired by **Kaloyan Zlatanov**

16:30-17:10 **Roberto Grimaudo**, *Two-Qutrit Quantum Rabi model: criticalities and counter-intuitive effects*

17:10-17:40 **Ivo Mihov**, *Extending the DRAG Method to Landau–Zener Control via Iso-probability Twin Models*

17:40-18:10 **Coffee break**

Late Session chaired by **Gediminas Juzeliūnas**

18:10-18:40 **Tihomir Tenev**, *Improvement of performance of Grover's algorithm on three generations of Heron family IBM QPUs without and with topological dynamical decoupling*

18:40-19:00 **Rares Barcan**, *Linking noise spectra to gate errors in trapped-ion processors*

19:00-19:20 **Nadezhda Markova**, *A Trapped-Ion RF-Driven Entangling Gate using URDD: an Exploration in Stability*

20:00 **Conference dinner**

Thursday, June 25

Morning Session chaired by **Sorin Paraoanu**

09:00-09:40 **Jyrki Piilo**, *Quantum jump unravelings of open system dynamics from Markovian to non-Markovian regime*

09:40-10:20 **Andreas Ruschhaupt**, *Quantum Control of a Thermodynamic Piston*

10:20-11:00 **Coffee break**

Noon Session chaired by **Jyrki Piilo**

11:00-11:40 **Gediminas Juzeliūnas**, *Synthetic magnetic field for ultracold atoms using optical vortices*

11:40-12:20 **Sorin Paraoanu**, *Superconducting qutrits: quantum control and applications in sensing*

Lunch

Evening Session chaired by **Ivo Mihov**

16:30-17:10 **Virginie Coda**, *Broadband Nonlinear Frequency Conversion using Quantum Analogies*

17:10-17:40 **Boyan Torosov**, *Single Flux Quantum Control in Superconducting Qubits*

17:40-18:10 **Coffee break**

Late Session chaired by **Andreas Ruschhaupt**

18:10-18:40 **Stancho Stanchev**, *Non-Clifford Benchmarking by Ensemble Feature Selection*

18:40-19:00 **Simona Grigorova**, *Phase-Altered Interleaved Randomized Benchmarking for Compiled Quantum Gates*

Friday, June 26

Morning Session chaired by **Boyan Torosov**

09:00-09:20 **Branislav Ilikj**, *Engineering the Ramsey fringe: from error suppression to entanglement-enhanced resolution*

09:20-09:40 **Hristo Tonchev**, *Composite quantum gates simultaneously compensated for multiple errors*

09:40-10:00 **Georgi Aleksandrov**, *Simulating Chiral Separation on Quantum Hardware*

10:20-11:00 **Coffee break**

Noon Session chaired by **Stancho Stanchev**

11:00-11:20 **Kremena Parashkevova**, *Universal Composite Pulses for Ultrastrong-Field Control and Light-Shift Compensation in Trapped Ions*

11:20-11:40 **Aida Shiroyan**, *Nonadiabatic Transitions in the Demkov–Kunike Model via the Dykhne–Davis–Pechukas Method*

11:40-12:00 **Julian Dimitrov**, *High-fidelity multistate Stimulated Raman adiabatic passage via parallel eigenenergies*

List of Abstracts

SIMULATING CHIRAL SEPARATION ON QUANTUM HARDWARE

G. Aleksandrov
Center for Quantum Technologies, Department of Physics, Sofia University, 5 James Bourchier Blvd, 1164 Sofia, Bulgaria
email: goshko104@gmail.com

A chiral molecule is one that differs from its mirror image. In chemistry, chiral molecules are also called enantiomers. Differentiating between the two enantiomers can be a matter of life and death, as medications have different biological properties from their mirror image. One technique to identify enantiomers relies on microwave control of the rotational levels of the molecule. When we mirror a molecule, we mirror its electric dipole moment. This adds a minus sign to the dipole moment (and therefore the Rabi frequency) of some transitions between rotational states. By constructing a suitable pulse sequence, exploiting the sign difference, separate enantiomers can be driven to separate states. We construct simple interferometric schemes for three- and four-level system models of chiral molecules. Then, we map their states to qubit states of a quantum computer and we map the laser fields to quantum gates. In that way, we can simulate the schemes on IBM's quantum computer. We also demonstrate error correction of non-ideal pulses mapped to non-ideal gates using composite pulses.

LINKING NOISE SPECTRA TO GATE ERRORS IN TRAPPED-ION PROCESSORS

R. Barcan
1. University of Sussex, Brighton, UK 2. Universal Quantum Ltd, Gemini House, Mill Green Business Estate, Haywards Heath, UK
email: r.barcan@sussex.ac.uk

Trapped-ion quantum processors operating under laser-free microwave and RF control remain constrained by noise from control electronics and the trapping environment. Translating noise characterisation measurements into quantitative gate error predictions for a specific ion species and control scheme is non-trivial, motivating dedicated simulation tools.

Here we present IonLab, a modular QuTiP-based framework for noise-aware modelling of $^{171}\mathrm{Yb}^{+}$ qubit dynamics at the Hamiltonian level. IonLab supports both spin-only and spin-motion Hamiltonians, enabling simulation of single- and multi-ion gates including entangling operations. Its extensible design allows integration with external trap-modelling tools, connecting trap-specific parameters directly to observable dynamics.

We show simulations of coherence dynamics under quasi-static and white noise, visualising state evolution on the Bloch sphere and demonstrating how low-frequency noise dominates control infidelity. Building on this decoherence model, we perform Quantum State Tomography and single-qubit Randomised Benchmarking, validated against experimental data from our group. We additionally present a calibration and gate error model mapping infidelity across detuning and pulse area error space, consistent with error budgets in the literature.

Future work will extend the noise model toward 1/f spectra and two-qubit Randomised Benchmarking.

ROBUST PHASE ESTIMATION FOR A TRAPPED ION QUBIT

T. Clarke
University of Sussex, Brighton, UK
Universal Quantum Ltd, Gemini House, Mill Green Business Estate, Haywards Heath, UK
email: t.r.clarke@sussex.ac.uk

Roadmaps for next-generation trapped ion quantum computers are built on distributed architectures, where qubits are shuttled between different zones for loading, gates, and readout. When the ion is shuttled, changes in the magnetic field environment can lead to the spin on the ion accumulating a phase dependent on the transport path and duration. As the number of qubits on commercially available quantum processors increases, the total duration of circuit time occupied by shuttling increases. If the shuttling phase is not corrected, ion transport can become a significant source of error as transport becomes a larger overhead on wider quantum circuits. A method to characterise this transport phase is demonstrated that offers some robustness to calibration errors, whilst achieving phase resolution beyond the standard quantum limit. To mitigate the error, phase-compensation can be utilised in which applying a virtual Z-gate cancels the phase accumulated during transport without requiring pulsed dynamical decoupling. Finally, randomised benchmarking of the Clifford-1 group can characterise the error attributed to shuttling, where the phase is left uncorrected compared with phase compensation. Early theoretical and experimental results suggest the phase characterisation circuit can outperform randomised benchmarking by a quadratic scaling advantage in the number of phase passes required.

BROADBAND NONLINEAR FREQUENCY CONVERSION USING QUANTUM ANALOGIES

V. Coda
Université de Lorraine, France
email: coda5@univ-lorraine.fr

Nonlinear Frequency Conversion (NFC) is essential for generating tunable coherent light at wavelengths that are inaccessible via conventional gain media. Efficient conversion requires precise control of the phase relationships between interacting waves, typically achieved through phase-matching techniques such as birefringence, quasi-phase-matching (QPM), or modal phase-matching. However, traditional devices, such as periodically poled lithium niobate (PPLN) waveguides or bulk nonlinear crystals, are typically optimized for narrowband operation, limiting their applicability in modern photonics. Broadband or tunable light sources, which are increasingly demanded in applications like quantum computing, optical communications, and ultrafast spec-

troscopy, require novel approaches. One promising strategy is to exploit analogies between nonlinear optics and quantum dynamics. For example, Rapid Adiabatic Passage (RAP), a quantum control technique, has inspired designs that enhance NFC bandwidth. In RAP, a system is driven through an avoided crossing in its energy levels, with adiabatic evolution ensuring efficient population transfer between states while maintaining alignment with the instantaneous eigenstate of the Hamiltonian. By translating this concept to nonlinear optics, we can achieve broadband phase-matching, where the system dynamically adjusts to maintain optimal conversion efficiency across a wide spectral range. We will present several examples demonstrating the potential of such analogies for developing innovative photonic devices.

HIGH-FIDELITY MULTISTATE STIMULATED RAMAN ADIABATIC PASSAGE VIA PARALLEL EIGENENERGIES

J. Dimitrov
Center for Quantum Technologies, Department of Physics, Sofia University, 5 James Bourchier Blvd, 1164 Sofia, Bulgaria
email: yulian@uni-sofia.bg

We present a new approach to high-fidelity multistate Stimulated Raman adiabatic passage (STIRAP). Techniques that optimize multistate STIRAP have been proposed before and they require using additional (shortcut) fields. Here we propose an optimization which does not require additional fields but pulse shaping only. The optimization is based upon the concept of quasi-parallel eigenenergies, which are known to suppress nonadiabatic transitions between two states. It is shown analytically how the parallelization criterion imposes certain time-dependent pulse shapes of the driving fields. Similar to parallel three-level STIRAP, proposed earlier, the parallel multistate STIRAP is robust to errors in the driving fields and the detunings while leaving the intermediate states unpopulated in the adiabatic limit. Moreover, this improvement of fidelity does not require prohibitively large pulse areas. We manage to enhance the STIRAP fidelity by up to 5 orders of magnitude thereby making multistate STIRAP suitable for quantum information processing. We anticipate applications in atomic clocks and atom optics.

A 1,000-FOLD INCREASE IN THE COHERENCE OF A 138BA+ OPTICAL QUBIT VIA CONTINUOUS DYNAMICAL DECOUPLING

M. Drewsen
Aarhus University, Denmark
email: drewsen@phys.au.dk

A qubit coherence time much longer than the duration of individual gate operations is essential for scalable quantum computing. In trapped-ion systems, coherence is often limited by fluctuations in the addressing laser frequency and intensity, as well as in ambient magnetic fields. Continuous dynamical decoupling via frequency modulation (FM) generated double-dressed states highly suppress all these noise channels by nesting the qubit inside two protective energy gaps [1,2]. Here, we apply this protocol to

an optical-frequency qubit in 138Ba+, extending the Rabi coherence time from 100 μs to 100 ms , i.e., an increase of about three orders of magnitude, or extending coherent Rabi oscillations beyond 10,000. We further demonstrate motional sideband coupling in the double-dressed basis, where the phase modulation that creates the second dressing simultaneously generates sideband transitions between the double-dressed states and the motional mode, without requiring a separate laser detuned to the motional sideband. This sideband coupling is a prerequisite for implementing a recently proposed scheme [1] for robust two-qubit entangling gates, where geometric phase form state-dependent displacement loops produce entanglement while inheriting the noise resilience of the double-dressed basis.

References
[1] M. Nünnerich et al., Phys. Rev. X 15, 021079 (2025).
[2] I. Cohen et al., New J. Phys. 17, 043008 (2015).

NONLINEARITY AND NON-GAUSSIANITY

R. Filip
Palacky University, Czechia
email: filip@optics.upol.cz

The talk will report recent theoretical and experimental achievements that have opened the door to highly non-Gaussian quantum states at optical, microwave and mechanical platforms from a genuine quantum nonlinearity. This territory is challenging for investigation, both theoretically and experimentally. We will present recent approaches, particularly focusing on new nonlinear quantum processes to obtain quantum non-Gaussian states and their experimental verification.

EFFICIENT QUANTUM SENSING AND HIGH-FIDELITY ELECTRON SPIN GATES FOR DIAMOND QUANTUM REGISTERS

G. Genov
Institute for Quantum Optics, Ulm University, Albert-Einstein-Allee 11, 89081 Ulm, Germany
email: genko.genov@uni-ulm.de

Nuclear magnetic resonance spectroscopy with solid-state spin sensors is a promising pathway towards nuclear spins detection at the micro- and nanoscale. Although many experiments rely on single sensor spins for detection, utilizing spin ensembles can significantly enhance sensitivity. We demonstrate multipoint correlation spectroscopy with NV centers in diamond, leveraging the advantages of quantum heterodyne detection to spin ensembles [1]. In a second advance, we demonstrate a robust two-qubit gate between nitrogen-vacancy (NV) electron spins of in diamond, reaching a record gate fidelity of 96.0±2.5% under ambient conditions [2].

Finally, we apply two-dimensional correlation spectroscopy to identify single nuclear spins within a convoluted spin environment. We demonstrate high-fidelity single-shot readout of a GeV center and a neighboring carbon-13 nuclear spin - a key tool for feed-forward error correction. These advances position the GeV center as a compelling candidate for next-generation quantum network nodes.

[1] T. Spohn, N. Staudenmaier, P. J. Vetter, T. Joas, T. Unden, I. Schwartz, P. Neumann, G. Genov, and F. Jelezko, Phys. Rev. Lett. 135, 250801 (2025).
[2] T. Joas, F. Ferlemann, R. Sailer, P. J. Vetter, J. Zhang, R. S. Said, T. Teraji, S. Onoda, T. Calarco, G. Genov, M. M. Mueller, and F. Jelezko. Phys. Rev. X, 15:021069 (2025).
[3] P. Gundlapalli, P. J. Vetter, G. Genov, M. Olney-Fraser, P. Wang, M. M. Müller, K. Senkalla, and F. Jelezko, arXiv:2510.09164.

PHASE-ALTERED INTERLEAVED RANDOMIZED BENCHMARKING FOR COMPILED QUANTUM GATES

S. Grigorova
Center for Quantum Technologies, Department of Physics, Sofia University, 5 James Bourchier Blvd, 1164 Sofia, Bulgaria
email: simonakg@uni-sofia.bg

Interleaved randomized benchmarking (IRB) provides a scalable estimate of gate's error rate, but its standard guarantees rely on the interleaved gate being Clifford [1]. In superconducting quantum processors, many phase gates appearing in compiled circuits are implemented virtually as software-defined frame updates (e.g., virtual $R\_Z(\phi)$), rather than as additional control pulses [2]. This raises the question: does inserting/removing virtual non-Clifford phase gates in a compiled implementation measurably change IRB error estimates?

We introduce *phase-altered interleaved randomized benchmarking* (PA-IRB), a paired-IRB diagnostic protocol that compares two Clifford interleaving gates derived from the same compiled implementation: (i) a phase-stripped gate in which virtual non-Clifford phase gates are removed, and (ii) a phase-dressed gate in which virtual phase gates are explicitly added, while the overall interleaved action remains Clifford by construction in both cases. PA-IRB reports the difference $\Delta r = r\_d - r\_s$ combined uncertainty, thereby testing whether virtual phase gates affects the extracted IRB decay beyond statistical error.

As a case study, we apply PA-IRB to a Toffoli-gate compilation executed on IBM superconducting processors, where the constituent $T/T^\dagger$ gates are implemented as virtual Z-rotations [2]. Across the tested calibration runs, we find Δr consistent with zero within uncertainty, supporting the conclusion that — under the employed compilation and execution stack — explicit virtual phase addition/removal do not measurably alter the IRB-derived error estimate of the compiled interleaving gate. PA-IRB provides a lightweight, abstraction-aware check for benchmarking workflows that mix calibrated entangling gates with software-defined phase gate execution. [1] E. Magesan, J. M. Gambetta, and J. Emerson, Characterizing quantum gates via

randomized benchmarking, Phys. Rev. A **85**, 042311 (2012).
[2] D. C. McKay, C. J. Wood, S. Sheldon, J. M. Chow, and J. M. Gambetta, Efficient Z gates for quantum computing, Phys. Rev. A **96**, 022330 (2017).

TWO-QUTRIT QUANTUM RABI MODEL: CRITICALITIES AND COUNTER-INTUITIVE EFFECTS

R. Grimaudo
Università degli Studi di Catania
email: roberto.grimaudo@dfa.unict.it

A two-qutrit extension of the quantum Rabi model is considered. The ground-state phase diagram can be derived, and the analysis reveals critical phenomena linked to both level crossings and quantum phase transitions. Further, a counter-intuitive phenomenon is highlighted: a Jaynes-Cummings dynamics can emerge in strong coupling regime.

TRAPPED RYDBERG IONS: A NOVEL PLATFORM FOR QUANTUM SIMULATION

M. Hennrich
Stockholm University, Sweden
email: markus.hennrich@fysik.su.se

Quantum simulation offers a new way to understand complex quantum systems in nature by recreating their essential physics in a controlled laboratory environment. Rather than solving equations on a classical computer, a quantum simulator uses a well-controlled quantum system whose behavior directly mirrors that of the system being studied. This approach provides insight into quantum phenomena that would otherwise be inaccessible, such as the vibrational dynamics of molecules – problems that quickly exceed the capabilities of even the most advanced supercomputers. Trapped ions are among the most precise and versatile platforms for such simulations. They can be cooled, trapped, and precisely manipulated using lasers. A recent breakthrough involves exciting these ions to Rydberg states, in which an electron is excited to a very high-energy orbit [1,2]. This creates strong, long-range interactions between ions [3] and opens up entirely new possibilities for quantum simulation. I will show how trapped Rydberg ions can mimic both molecular dynamics and quantum magnetism. I will present recent results on the Rydberg excitation-induced transition from linear-to-zigzag configuration in an ion crystal – a process reminiscent of light-induced conformational changes in molecules, such as those underlying vision. I will also outline how arrays of Rydberg ions could emulate two-dimensional spin systems, enabling the exploration of collective magnetic behavior. These studies illustrate that trapped Rydberg ions provide a powerful new tool for investigating the dynamics of complex quantum systems.

[1] M. Müller, et al., New J. Phys. 10, 093009 (2008).
[2] A. Mokhberi, et al., in Adv. At. Mol. Opt. Phys. 69, 233 (2020).

[3] C. Zhang, et al., Nature 580, 345 (2020).
[4] M. Mallweger, et al., arXiv:2507.23631 (2025).
[5] W. S. Martins, et al., arXiv:2601.01626 (2026).

DEVELOPING MODULAR MICROWAVE TRAPPED-ION QUANTUM COMPUTERS FOR OPERATION WITH MILLIONS OF QUBITS

W. Hensinger
1 Sussex Centre for Quantum Technologies, University of Sussex, Brighton, UK 2 Universal Quantum Ltd, Brighton, UK
email: w.k.hensinger@sussex.ac.uk

Microwave technology poses a significant opportunity to scale trapped ion quantum computers to system sizes that support utility scale quantum computation within the fault-tolerant regime. We have successfully developed a new generation of ion microchips capable of generating large magnetic field gradients in excess of 100 T/m. I will show progress on realizing high-fidelity gates with these new chips. We have invented a new approach to generate magnetic field gradient enabling orders of magnitude lower noise, while reducing expected power dissipation for the operation within utility scale-quantum computers and I will report on the first demonstration of this new approach. I will discuss progress in the development of trapped-ion quantum microchips including the integration of atomic ovens into the microchips and materials studies enabling much deeper trap depths in such chips. As an application of our quantum computing research, I will discuss the realisation of a new electric field quantum sensor with unprecedented electric field sensitivities for the measurement of both DC signals and AC signals across a frequency range of sub-Hz to $\sim$ 500 kHz.

TOWARDS A SCALABLE, LASER-FREE, QUANTUM PROCESSOR.

P. Huber
Universität Siegen, Germany
email: p.huber@physik.uni-siegen.de

One of the key challenges in quantum information science is achieving scalable, fault-tolerant quantum computation. The quantum charge-coupled device (QCCD) architecture is a leading approach to overcoming this challenge [1]. This architecture physically separates the memory, interaction and detection zones, enabling parallel operations and modular scaling, both of which are essential for quantum processors. Here I will present our work towards developing scalable quantum processors based on rf driven trapped ion qubits. Generating qubit interactions based on MAGIC (magnetic gradient induced coupling) requires the presence of a magnetic field gradient [2]. We report on the progress of the design and development of ion trap chips with integrated permanent magnets, which enable multi-zone ion traps.

[1] Kielpinski, D., Monroe, C. & Wineland, D. Architecture for a large-scale ion-trap quantum computer. Nature 417, 709–711 (2002).
[2] F. Mintert and Ch. Wunderlich. PRL 87, 257904 – 1-4 (2001)

ENGINEERING THE RAMSEY FRINGE: FROM ERROR SUPPRESSION TO ENTANGLEMENT-ENHANCED RESOLUTION

B. Ilikj
Center for Quantum Technologies, Department of Physics, Sofia University, 5 James Bourchier Blvd, 1164 Sofia, Bulgaria
email: biilich@uni-sofia.bg

Ramsey interferometry underpins precision frequency metrology — from atomic clocks to the readout and control of qubits — yet its accuracy is degraded by probe-induced light shifts and its coherence by detuning noise. We present a family of tailored Eulerian hyper-Ramsey sequences that suppress both. By alternating the sign of the detuning between the two free-evolution arms (an Eulerian echo) and combining it with composite pulses, the protocol pins the interrogation point to zero frequency error independently of the residual light shift and of the Rabi frequency, while refocusing slowly varying detuning noise. Adding refocusing pulses, CPMG-style, pushes this robustness to higher-frequency noise — all at no cost in fringe contrast, which remains area-determined. We benchmark the gains with a full density-matrix simulation including non-Markovian (Ornstein–Uhlenbeck) detuning noise. Finally, we outline an implementation on superconducting qubits and show that preparing the interferometer in entangled Dicke states can sharpen the spectroscopic resolution, effectively magnifying the detuning between the two interfering components of the cat state.

SYNTHETIC MAGNETIC FIELD FOR ULTRACOLD ATOMS USING OPTICAL VORTICES

G. Juzeliūnas
Vilnius University, Lithuania
email: gediminas.juzeliunas@tfai.vu.lt

Ultracold atoms provide a versatile platform for simulating topological and many-body phenomena in condensed matter and high-energy physics [1-4]. The use of atomic dark states (long-lived superpositions of atomic internal ground states immune to atom-light coupling) offers new possibilities for such simulations. Making the dark states position-dependent allows for the generation of a synthetic magnetic field for ultracold atoms, as they adiabatically follow the dark states [5-7]. Here, we describe and analyse a method for generating a strong and non-staggered synthetic magnetic field for dark-state atoms. This can be done using vortex light beams containing an array of vortices and antivortices [7]. The method enables the formation of topological phases in dark-state atoms, offering new opportunities for simulating the Quantum and Fractional Hall effects in degenerate Fermi gases of ultracold atoms.

[1] M. Lewenstein et al, Adv. Phys. 56, 243 (2007).
[2] I. Bloch, J. Dalibard, and W. Zwerger, Rev. Mod. Phys. 80, 885 (2008).
[3] C. Gross and I. Bloch, Science 357, 995 (2017).
[4] N. Goldman, G. Juzeliūnas, P. Öhberg, and I. B. Spielman, Rep. Prog. Phys., 77, 126401 (2014).

[5] E. Gvozdiovas, I. B. Spielman, and G. Juzeliūnas, Phys. Rev. A, 107, 033328 (2023).
[6] S. Nascimbene and J. Dalibard, Phys. Rev. Lett. 135, 153402 (2025).
[7] D. Burba and G. Juzeliūnas, Phys. Rev. Research 7, 043090 (2025).

GENERATION OF TWO-PHOTON ENTANGLEMENT USING A SINGLE ION–CAVITY SYSTEM

M. Keller
University of Sussex, UK
email: m.k.keller@sussex.ac.uk

Control over the internal states of trapped ions makes them the ideal system to generate single and two-photon states. Coupling a single ion to an optical cavity enables efficient emission of single photons into a single spatial mode and grants control over their temporal shape, phase and frequency. Using the long coherence time of the ion's internal states and employing a scheme to protect the coherence of the ion-cavity interaction, we demonstrate the generation of a two-photon entangled state with full control over the phase. Initially, ion-photon entanglement is generated. A second photon is subsequently generated, mapping the ion's state onto the second photon. By adjusting the drive field the phase of the entangled state can be fully controlled. We implement this scheme in the most resource efficient way by utilizing a single 40Ca+ ion coupled to an optical cavity and demonstrate the generation of a two-photon entangled stated with full phase control with a fidelity of up to 82%.

A TRAPPED-ION RF-DRIVEN ENTANGLING GATE USING URDD : AN EXPLORATION IN STABILITY

N. Markova
Center for Quantum Technologies, Department of Physics, Sofia University, 5 James Bourchier Blvd, 1164 Sofia, Bulgaria
email: nymarkova@uni-sofia.bg

Robust entangling operations are a key requirement for scalable trapped-ion quantum computing. In this collaborative work between theory and experiment, from Sofia University and University of Siegen, respectively, a laser-free, RF-driven entangling gate for trapped ions is investigated. The gate employs the MAGIC mechanism and phase jumps based on a universal-rotation dynamical decoupling (URDD) scheme [1]. Experimental implementation is carried out at University of Siegen, while theoretical modelling and numerical simulations are used to characterize the gate dynamics and robustness. We explore the effects of different URDD orders, in particular their impact on gate performance and stability against experimental imperfections. The gate is further compared with an earlier continuously phase-modulated protocol [2], where both approaches employ dynamical decoupling but differ in how phase control is implemented. By combining simulations with experimental data, the work provides insight into the gate dynamics and highlights the advantages of the phase-jump approach for robust trapped-ion entanglement.

[1] Genov, G., Schraft, D., Vitanov, N., & Halfmann, T. (2017). Arbitrarily Accurate Pulse Sequences for Robust Dynamical Decoupling. Phys. Rev. Lett., 118, 133202
[2] Nunnerich, M., Cohen, D., Barthel, P., Huber, P., Niroomand, D., Retzker, A., & Wunderlich, C. (2025). Fast, Robust, and Laser-Free Universal Entangling Gates for Trapped-Ion Quantum Computing. Phys. Rev. X, 15, 021079.

ENGINEERING THE HILBERT SPACE: INVERSE HAMILTONIAN DESIGN FOR PASSIVE STRUCTURAL ERROR AVOIDANCE

A. Messina
Dipartimento di Matematica e Informatica, Università degli Studi di Palermo, Palermo, Italy
email: antonino.messina1949@gmail.com

We challenge the traditional forward-modeling approach in quantum dynamics by treating the Hamiltonian not as a physical given, but as an engineered response to specific dynamical requirements. In this work, we formalize this paradigm shift by introducing a framework for inverse Hamiltonian design. First, we prescribe three desired constants of motion necessary to ensure manifold invariance. Subsequently, we search and derive, step by step, the most general Hamiltonian operator that realizes these constraints within a finite-dimensional Hilbert space. For concreteness, we demonstrate our protocol for a system of three distinguishable qubits, denoted by s_i with $i = 1, 2, 3$. Our primary nontrivial objective is to identify a physical scenario that allows us to build a Hamiltonian with four invariant subspaces of the same dimension. To this end, we set three constants of motion that encode the desired symmetries into the Hamiltonian. The angular momenta of the three spin 1/2 can be coupled following the coupling scheme s_12, s_3, S, M_S, where s_12 and S are the quantum numbers associated with the square total angular momentum of the subsystem of spins 1 and 2 and that of the overall system, respectively, and M_S is the quantum number of its z-component. Through suitable conservation conditions imposed on spin operators, we carve out four invariant 2×2 subspaces in the Hilbert space of the system, which are clearly reflected in the structure of the Hamiltonian. Our construction ensures that the quantum information is confined to the prescribed symmetry, effectively preventing state leakage into the remainder of the 8-dimensional Hilbert space. A first key advantage of this method is its applicability to non-stationary and even open systems. In the latter case, however, the system-environment interaction terms added to the Hamiltonian must be compatible with the preservation of the three prescribed constants of motion. A second important aspect of the approach is the simplification of the dynamical problem, which is fragmented into four new dynamical (generally not-stationary) problems, each formulated in one of the four invariant subspaces. A third advantage the scalability of our method with respect to the number of constituent few-level systems, which are not required to be identical. For example, we might add a qutrit to the system under scrutiny, redefining the new complete Hamiltonian. It is also worth emphasizing the parametric invariance, that is, the robustness of coherence and transport properties exhibited by the physical system to fluctuations of the coupling parameters. The resulting Hamiltonian operator is not merely an abstract mathematical exercise; in fact, it provides a rigorous recipe for engineering synthetic quantum matter on platforms such as circuit QED and quantum dot clusters. In these setups, the interaction topology acts as a insurmountable dynamical constraint, meaning that stability is not actively corrected, but structurally ensured by the very design of the interaction geometry.

Joint work with Tatiana Mihaescu, Agostino Migliore, and Hiromichi Nakazato.

EXTENDING THE DRAG METHOD TO LANDAU-ZENER CONTROL VIA ISOPROBABILITY TWIN MODELS

I. Mihov
Center for Quantum Technologies, Department of Physics, Sofia University, 5 James Bourchier Blvd, 1164 Sofia, Bulgaria
email: imihov@phys.uni-sofia.bg

The Derivative Removal by Adiabatic Gate (DRAG) technique is the standard remedy for leakage to non-computational states in transmon-based quantum gates. However, a wide class of platforms — including fluxonium and composite-transmon qubits — cannot benefit from it, since their canonical gate implementations rely on Landau-Majorana-Stückelberg-Zener (LMSZ) protocols. Specifically, the constant Rabi envelope of the LMSZ model does not allow using the DRAG correction, which requires a non-zero first derivative. A complementary obstruction affects hardware that does not support time-dependent Rabi-frequency modulation: such platforms cannot benefit from the Allen-Eberly-Hioe (AEH) model either, an unpleasant fact given its analytical tractability. We resolve both limitations by introducing the concept of isoprobability twin models — distinct pairs of Rabi frequency $\Omega(t)$ and detuning $\Delta(t)$ that yield identical post-pulse transition probabilities through the Delos-Thorson transformation. We experimentally demonstrate the equivalence of multiple LMSZ and AEH twin models on IBM's ibm_kyiv processor. We then show that the framework unlocks the DRAG technique by trading the canonical, constant-Rabi LMSZ pulse for a smooth cosine-Rabi twin, and numerically demonstrate that the resulting DRAG-corrected pulse suppresses leakage to a transmon's $|2\rangle$ state by over five orders of magnitude while preserving the LMSZ transition-probability landscape.

TWINNED DYNAMICAL DECOUPLING WITH ALL-ORDER PULSE-AREA CANCELLATION AND ARBITRARY-ORDER DETUNING SUPPRESSION

N. Nedev
Center for Quantum Technologies, Department of Physics, Sofia University, 5 James Bourchier Blvd, 1164 Sofia, Bulgaria
email: naydenpn@uni-sofia.bg

Systematic pulse-area errors limit the fidelity of quantum control across many qubit platforms. We introduce twinned dynamical decoupling (TDD), an analytic family of sequences $T2n$ in which a pulse sequence is paired with its π-phase-shifted twin. This π-phase step cancels common-mode systematic pulse-area errors to all orders

on exact resonance. Then the phases of the pulses in each of the constituent twins are determined in such a manner that detuning errors are suppressed to the highest possible order as well. We have derived a simple analytic formula for these phases applicable to arbitrary sequence length. We demonstrate the sequences with superconducting transmon qubits on the IBM Quantum processor ibm_torino and the IQM Quantum processor Garnet. The measured population plateaus agree closely with theory and show enhanced robustness compared to the most frequently used dynamical decoupling protocols. Twinned dynamical decoupling therefore offers a simple, hardware-efficient method for suppressing systematic control errors in quantum computing, sensing, and memory applications.

CHARACTERISING SINGLE QUBIT OPERATIONS WITH INTERLEAVED TRANSPORT AND STATE MAPPING IN A SWITCHABLE MAGNETIC GRADIENT.

F. O'Dwyer
University of Sussex, Brighton, UK
email: finnlayodwyer@gmail.com

Scalable quantum computing architectures require the ability to individually address qubits, maintain long coherence times relative to gate times, and support arbitrary qubit connectivity. We are developing a quantum processor architecture based on modular ion traps and physical ion shuttling, this allows for maximum connectivity, as well as zones dedicated for loading, coherent operations and measurements (Lekitsch, B. et. al. 2017). Coherent operations are performed in a magnetic field gradient, to allow for spin-motion coupling and the use of global microwave fields. Before transporting ions, magnetic gradients are ramped down to preserve qubit coherence. In this work, we demonstrate the feasibility of this architecture by implementing randomised benchmarking of dressed state qubits in Yb171+, interleaved with gradient ramping, dressed state mapping and ion transport. Randomised single qubit gates are performed on a multi-level dressed state basis in the presence of a magnetic field gradient. The qubit is mapped into a clock state, using protocols described in (Randall J. et. al. 2018) with errors bellow 1×10^{-4}. We characterise the ramping of the magnetic field gradient using the ion as a magnetic field sensor. The gradient is ramped within a few microseconds using an external current source, incurring average errors below 1×10^{-2}. We also characterise the error from interleaved ion transport for a total distance of 240 μm in 140 μs and demonstrate average errors below 1×10^{-4}. Finally, we measure a total process error, demonstrating that with appropriate calibration we maintain the individual quantum state of single qubits to high fidelity throughout the interleaved ion reconfiguration. The results validate an important core element of the proposed operational protocol and confirm the practicality of this modular architecture.

Lekitsch, B. et al. (2017) 'Blueprint for a microwave trapped ion quantum computer', Science Advances, 3(2), p. e1601540. doi:10.1126/sciadv.1601540. Randall, J. et al. (2018) 'Generation of high-fidelity quantum control methods for multilevel systems', Physical Review A, 98(4), p. 043414. doi:10.1103/PhysRevA.98.043414.

SCALABLE TRAPPED-ION QUANTUM COMPUTING BASED ON NFQC

C. Ospelkaus
Institute for Quantum Optics, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover
Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig Germany
email: christian.ospelkaus@iqo.uni-hannover.de

This talk will present a route towards quantum computers with trapped ions based on chip-integrated Near-Field microwave Quantum Control (NFQC). We discuss chip designs that can serve as the unit cell of a scalable device, comprising dedicated registers for state preparation and readout, storage and gate operations. While the relative insensitivity is a key feature of the NFQC gate scheme, ultimately sympathetic cooling is required in order to ensure that the motion is cold enough. We present a framework that allows motional heating to be tracked for elementary transport operations and incorporated into a motional heating aware compiler infrastructure as a cost function. This allows to reduce the sympathetic cooling overhead, a major time factor in any scaled device, to the necessary minimum. In addition, we discuss optimized electrode shapes that can help cut down the resources for transport operations in a processor. NFQC as the first demonstrated chip-integrated gate mechanism significantly reduces the control overhead for quantum gates. We take this one step further and demonstrate the control of a trapped-ion qubit through a custom designed cryogenic BiCMOS DDS circuit which can be integrated with the ion trap. We present strategies and experimental results on the integration of photonic waveguide technology into surface-electrode ion traps, targeting specifically the ”blue” wavelengths suitable for detection and state preparation, and discuss the fabrication of these devices.

SUPERCONDUCTING QUTRITS: QUANTUM CONTROL AND APPLICATIONS IN SENSING

S. Paraoanu
Aalto University, Finland
email: sorin.paraoanu@aalto.fi

The transmon is an established superconducting device, serving as the building block of most superconducting quantum computers. I will outline some of our recent experiments that leverage phase modulation and various forms of optimization, including machine learning, to obtain pulses with reduced errors. Phase modulation [1] is a technique derived from the Landau-Zener-Stueckelberg-Majorana effect, and various expressions for the time-dependence and for the pulse envelope have been studied in experimental quantum physics [2]. We have demonstrated experimentally that this effect can be exploited to achieve better frequency robustness [2]. Moreover, higher order processes can be generated, employing two drive fields that couple the first three transmon levels [3]. Recently, we have used the framework of neural ordinary differential equations (Neural ODEs) to achieve single-qubit gates with fidelity greater than 99.9%. I will present recent results that use these pulses for detectors of dark matter.

References:
1. M.P. Silveri et al., Rep. Prog. Phys. 80, 056002 (2017)
2. J. J. McCord et al. EPJ Quantum Technol. 12, 121 (2025)
3. M. Kuzmanovic et al., Phys. Rev. Research 6, 013188 (2024)
4. I. Björkman et al., Phys. Rev. Lett. 134, 060602 (2025)
5. M. Kuzmanović et al., arXiv:2505.02054

UNIVERSAL COMPOSITE PULSES FOR ULTRASTRONG-FIELD CONTROL AND LIGHT-SHIFT COMPENSATION IN TRAPPED IONS

K. Parashkevova
Center for Quantum Technologies, Department of Physics, Sofia University, 5 James Bourchier Blvd, 1164 Sofia, Bulgaria
email: kremenagalinovap@gmail.com

We present universal composite pulse sequences for coherent quantum control of a qubit driven by an ultrastrong field, beyond the validity of the rotating-wave approximation. Building on our previous demonstration that universal composite pulses uniquely maintain high fidelity in this regime - where counter-rotating terms render resonant, adiabatic, and shortcut-to-adiabaticity techniques ineffective - we now introduce composite half-π pulses with universal robustness against simultaneous errors in the pulse parameters. We demonstrate that both half-π and π composite pulses provide highly accurate quantum control in the presence of the light shift inherent to trapped-ion systems, suppressing its detrimental effect across a wide range of field strengths. These results establish universal composite pulses as a versatile and practical tool for ultrastrong-field quantum control with direct applications to light-shift compensation in trapped-ion quantum computing and simulation.

QUANTUM JUMP UNRAVELINGS OF OPEN SYSTEM DYNAMICS FROM MARKOVIAN TO NON-MARKOVIAN REGIME

J. Piilo
University of Turku, Finland
email: jyrki.piilo@utu.fi

Stochastic unravelings provide a useful way to represent open quantum system dynamics in terms of pure state realizations. Their importance arises both from fundamental and from computational point of view. They were originally formulated for Markovian dynamics described by the Gorini-Kossakowski-Sudarshan-Lindblad master equation [1,2,3]. With these seminal works and due to the subsequent developments over the years, there exists nowadays a variety of stochastic jump methods extended also to treat non-Markovian open system dynamics. We give an overview of this progress including the latest results [4-9].

[1] V. Gorini, A. Kossakowski, and E. C. G. Sudarshan, Journal of Mathematical

Physics 17, 821 (1976).
[2] G. Lindblad, Communications in Mathematical Physics 48, 119 (1976).
[3] J. Dalibard, Y. Castin, and K. Molmer, Phys. Rev. Lett. 68, 580 (1992).
[4] J. Piilo, S. Maniscalco, K. Harkonen, and K.-A. Suominen, Phys. Rev. Lett. 100, 180402 (2008).
[5] A. Smirne, M. Caiaffa, and J. Piilo, Phys. Rev. Lett. 124, 190402 (2020).
[6] F. Settimo, K. Luoma, D. Chruscinski, B. Vacchini, A. Smirne, and J. Piilo, Phys. Rev. A 109, 062201 (2024).
[7] F. Settimo, K. Luoma, D. Chruscinski, A. Smirne, B. Vacchini, and J. Piilo, Phys. Rev. A 112, 042204 (2025).
[8] F. Settimo, K. Luoma, D. Chruscinski, B. Vacchini, A. Smirne, and J. Piilo, Phys. Rev. A 113, 042444 (2026).
[9] F. Settimo and J. Piilo, arXiv:2605.07797 (2026).

ADVANCING QUANTUM DOT SOURCES OF ENTANGLED PHOTON PAIRS

A. Predojevic
Department of Physics, Stockholm University, Sweden
email: ana.predojevic@fysik.su.se

Single quantum dots are established sources of single photons and entangled photon pairs. Under resonant excitation, they efficiently generate photon pairs with low multi-photon contributions, making them suitable for polarization- and time-bin–based entanglement schemes. However, achieving high degrees of entanglement and enabling deployment in quantum communication protocols require additional functionalities, particularly efficient photon collection. I will present photonic systems that enhance the efficiency of entangled photon-pair sources. Furthermore, we investigate the statistics of the emitted photons and develop approaches to facilitate the fabrication of photonic devices.

QUANTUM CONTROL OF A THERMODYNAMIC PISTON

A. Ruschhaupt
School of Physics, University College Cork, Cork, Ireland
email: aruschhaupt@ucc.ie

I present two different setups and strategies for the quantum control of a thermodynamic piston. In the first part, I develop a model and explore the dynamics of a hybrid classical-quantum system consisting of a classical piston and a self-interacting pseudospin 1/2 Bose–Einstein condensate with a time-dependent Rabi coupling [1]. I show how by optimised design of the time-dependent direction of the Rabi field to control both the position and velocity of the piston. In the second part, I propose a scheme for piston control in a two-ion quantum device with motion confined to orthogonal axes [2]. In this system, one ion plays the role of a “classical” piston driven by the Coulomb interaction with the other ion, whose quantum motion is controlled through modulation of its trapping potential. I will design inverse-engineering protocols to control the motion of the “classical” ion, i.e. the ”piston”. The proposed control scheme provides a useful route toward controlled piston dynamics in microscopic quantum devices.

[1] Jing Li, E Ya Sherman, and Andreas Ruschhaupt, ”Quantum control of classical motion: piston dynamics in a Rabi-coupled Bose–Einstein condensate”, New J. Phys. 26 (2024) 053031
[2] Jing Li, E. Ya. Sherman, and Andreas Ruschhaupt, ”Piston control in a two-ion quantum device”, in preparation

NONADIABATIC TRANSITIONS IN THE DEMKOV–KUNIKE MODEL VIA THE DYKHNE–DAVIS–PECHUKAS METHOD

A. Shiroyan
Center for Quantum Technologies, Department of Physics, Sofia University, 5 James Bourchier Blvd, 1164 Sofia, Bulgaria
email: shiroyan@uni-sofia.bg

We use the Dykhne–Davis–Pechukas (DDP) method to build physical intuition about nonadia- batic transitions in two-level quantum systems, using the Demkov–Kunike model 1 as a case study. We show that the Stokes-line geometry in the complex time plane directly encodes the transition physics, and that the method yields exact results in the symmetric limits — the Allen–Eberly and Rosen–Zener models. In the non-symmetric case ab = 0, the Stokes contour intersects poles of the quasi-energy, and the failure of the standard prescription itself reveals the deeper complexity of the transition dynamics.

OBSERVATION OF COOPERATIVE LIGHT SCATTERING IN TRAPPED-ION CRYSTALS

L. Slodicka
Palacký University, Olomouc, Czechia
email: slodicka@optics.upol.cz

Collective emission from quantum emitters is a hallmark of many-body quantum optics. While traditionally studied in large ensembles, accessing its microscopic origin in fully controlled systems remains an outstanding challenge. Here, we experimentally achieve coherent control over the statistical properties of resonance fluorescence and observe the onset of cooperative scattering signatures in linear chains of laser-cooled Ca+ ions.

By controlling the interference of resonance fluorescence, we demonstrate tunable photon statistics of the scattered light and observe a transition from sub-Poissonian to super-Poissonian behavior depending on the relative phase of photons scattered from different ions. To reveal subtle coherent phenomena arising from mutual dipole–dipole interactions, we maximize the coherent fraction of the scattered light using electromagnetically induced transparency cooling combined with optimized pulsed excitation of ion chains. The achieved interference visibility of $(97.4 \pm 0.9\%)$ for a four-ion string approaches the limit imposed by the motional ground-state position uncertainty.

Such highly coherent light–ion interaction enables access to a regime in which dipole–dipole interactions directly modify the emission dynamics. We measure clear signatures of collective coupling, including steady-state modulations of the photon scattering rate of up to $\sim 2\%$. We further investigate how these effects scale with increasing system size, tracing the emergence of collective behavior at the level of individual atoms.

These results provide direct experimental access to the microscopic mechanisms underlying cooperative light scattering in trapped-ion systems. They also have implications for the estimation and mitigation of photon-mediated errors in quantum memories and multi-qubit operations based on trapped-ion crystals.

NON-CLIFFORD BENCHMARKING BY ENSEMBLE FEATURE SELECTION

S. Stanchev
Center for Quantum Technologies, Department of Physics, Sofia University, 5 James Bourchier Blvd, 1164 Sofia, Bulgaria
email: stanchov@phys.uni-sofia.bg

Characterization of non-Clifford gates remains a major challenge in scalable quantum computation, often requiring complex and resource-intensive procedures. In this work, we propose Ensemble Feature Selection (EFS) as an alternative approach for addressing this problem.

The method selects informative circuits and measurements, referred to as features, from experimentally executable candidates through offline training on physically motivated ensembles of noisy gates. The selected features are then used for direct estimation of process infidelities.

Since no direct benchmarking reference exists for non-Clifford gates, we first demonstrate the method on the non-Clifford CCZ gate via realistic device simulation. The method is then assessed on embedded 3-qubit realizations of the Clifford gate CZ(0,2) on the IBM quantum processor ibm_kingston, where Interleaved Randomized Benchmarking (IRB) provides an independent reference for comparison, achieving sufficiently accurate and fast estimations in both cases.

IMPROVEMENT OF PERFORMANCE OF GROVER'S ALGORITHM ON THREE GENERATIONS OF HERON FAMILY IBM QPUS WITHOUT AND WITH TOPOLOGICAL DYNAMICAL DECOUPLING

T. Tenev
Georgi Nadjakov Institute of Solid State Physics, Bulgarian Academy of Sciences, 72 Tsarigradsko chaussée, 1784 Sofia, Bulgaria
email: tihomir.g.tenev@issp.bas.bg

We investigate the performance of Grover's algorithm on three different generations of IBM Heron QPUs. On Heron family of IBM QPUs the success probabilities for three, four and five qubits without dynamical decoupling are better than results reported for previous generations of QPUs. The success probability as function of number of iterations of Grover operator is considered. A study of the improvement of results of Grover's algorithm for five qubit case with the help of topological dynamical decoupling is considered. For a six qubit case on Heron r3 QPU a clear result for finding the sought-after bitstring is reported for theoretically suboptimal number of iterations of Grover operator with the help of dynamical decoupling.

COMPOSITE QUANTUM GATES SIMULTANEOUSLY COMPENSATED FOR MULTIPLE ERRORS

H. Tonchev
Center for Quantum Technologies, Department of Physics, Sofia University, 5 James Bourchier Blvd, 1164 Sofia, Bulgaria
email: hgtonchev@uni-sofia.bg

Systematic control errors remain a primary obstacle to realizing high-fidelity single-qubit gates. We introduce composite pulse sequences that implement X and Hadamard gates while simultaneously compensating amplitude (Rabi-frequency), detuning (frequency), and duration errors. Our construction uses two complementary strategies: (i) derivative-based cancellation of error terms in the full unitary (not just the transition probability), formulated via the Cayley-Klein parametrization, and (ii) direct minimization of the average gate infidelity over prescribed error ranges. We derive symmetric five-pulse solutions with closed-form phases that cancel all first-order terms (including the mixed derivative), and numerically optimize longer sequences – up to 15 pulses – to achieve higher-order suppression. We also show that standard "universal" five-pulse sequences (U5a/U5b) emerge as simple phase-shifted instances of our symmetric solutions, yielding broad robustness to both detuning and amplitude errors. Finally, we construct variable-area sequences for Rx(pi/2), which, up to virtual Z rotations, benchmark the Hadamard gate. Across all families we observe the expected trade-off between sequence length and robustness window, with substantial boosts in fidelity over large error domains.

SINGLE FLUX QUANTUM CONTROL IN SUPERCONDUCTING QUBITS

B. Torosov
1QB Information Technologies (1QBit), Vancouver, British Columbia, Canada
email: boyan.torosov@1qbit.com

Scaling superconducting quantum processors using traditional microwave electronics presents a significant bottleneck due to heat dissipation and footprint constraints. Single-flux quantum (SFQ) digital logic offers a promising, energy-efficient, and scalable alternative for on-chip qubit control. In this talk, we present recent advancements in SFQ-based quantum control across both transmon and fluxonium architectures. By optimizing discrete binary control sequences, we demonstrate compact pulse scheduling that achieves single-qubit gate fidelities exceeding 99.99% for both single transmons and highly coherent fluxonium qubits, while drastically reducing memory requirements and mitigating coherent leakage. Extending this methodology to two-qubit operations in tunable-coupler transmon architectures, we utilize gradient-based auto-differentiation to realize high-fidelity fSim, CZ, and CNOT gates (¿99.9%). Together, these results establish that optimized SFQ digital logic can achieve state-of-the-art performance across multiple superconducting platforms, paving the way for fully scalable, on-chip quantum control.

ALICE, BOB, ... AND FRIENDS: WHAT'S NEXT FOR THE DARMSTADT QUANTUM KEY DISTRIBUTION NETWORK

T. Walther
Institute of Applied Physics, Technical University of Darmstadt, Hochschulstraße 6, 64289 Darmstadt, Germany
email: thomas.walther@physik.tu-darmstadt.de

Quantum key distribution (QKD) is one of the possible solutions to maintain data privacy when quantum computers will render today's public-key cryptography insufficient. For a broad deployment of QKD, scalable and robust systems are necessary. Scalability can be achieved by using star-shaped networks in combination with entanglement-based QKD protocols. We implemented a city-wide QKD network comprised of four users employing a time-bin variant of the BBM92 protocol. Scaling up to 100 users is possible.

We briefly review our work on our distributed network with full implementation of post-quantum secure authentication schemes for the public channel as well as full error correction, privacy amplification and software based clock recovery.

In the second part of our talk we report on the progress towards implementing photonic chips in our network.

[1] E. Fitzke et al., PRX 3 (2022) 020341;
[2] T. Dolejsky et al. Europ. Phys. J. Spec. Top. 232 (2023) 3553;
[3] J. Kaltwasser et al., Physical Review A 109 (2024) 012618;

FAULT-TOLERANT DYNAMICALLY-DECOUPLED HYPER-RAMSEY SPECTROSCOPY WITH A SUPERCONDUCTING QUBIT

T. Zanon
Sorbonne Université & MONARIS LAB, France
email: thomas.zanon@sorbonne-universite.fr

Dynamically decoupled hyper-Ramsey spectroscopy synthesizes Hahn spin-echo interferometry with composite pulse protocols providing a very robust suppression of systematic perturbations including AC-Stark shifts coupled to laser intensity noise, decoherence and low probe-frequency spectral drifts. By employing sequences of rotary Hahn-echo pulses, which utilize sign-toggled frequency detunings into hyper-Ramsey spectroscopy, high-contrasted quantum interferences achieve complete immunity to the frequency shifts induced by the probing field itself and offer a very weak sensitivity to pulse control imperfections even in presence of external fields inhomogeneities. We experimentally validate the robustness of our dynamically-decoupled hyper-Ramsey interrogation scheme by implementing it at the pulse level on a superconducting quantum processing unit. Fault-tolerant dynamically-decoupled SU(2) hyper-clocks provide a new experimental platform for testing more advanced NMR-like multiple refocusing pulse sequences to benchmark quantum sensing fidelity and accuracy performances in harsh electromagnetic environments.

FAST TWO-QUBIT GATES IN ION TRAPS

K. Zlatanov
Center for Quantum Technologies, Department of Physics, Sofia University, 5 James Bourchier Blvd, 1164 Sofia, Bulgaria
email: kzlatanov@phys.uni-sofia.bg

In this talk we discuss our latest results towards faster two-qubit ion gates. We explore excitaion through Rydberg states, realizing C-Phase gates in alternative field configuration, namely decoupling the STIRAP process from the induced dipole-dipole excitation stage. Alternatively we provide a novel framework for gate dynamics that allows an extension beyond the linear bosonic algebra and incorporates second order bosonic operators. Our framework provides a generalization of the phase-space dynamics, by which we are able to derive the conditions by which the motional state remains unchanged afther the excitation and also a way to calculate the associated geometrical phase.

Index

CAMEL 2026 Programme

Time	**Monday June 22**	**Tuesday June 23**	**Wednesday June 24**	**Thursday June 25**	**Friday June 26**
09:00-09:40	Walther	Hensinger	Drewsen	Piilo	Ilikj Tonchev Aleksandrov
09:40-10:20	Predojevic	Huber	Hennrich	Ruschhaupt	
10:20-11:00	coffee	coffee	coffee	coffee	coffee
11:00-11:40	Messina	Ospelkaus	Keller	Juzeliūnas	Parashkevova Shiroyan Dimitrov
11:40-12:20	Filip	Zanon	Slodicka	Paraoanu	
Lunch					
16:30-17:10	Genov	*Boat trip (15:00-18:00)*	Grimaudo	Coda	**END**
17:10-17:40	Zlatanov		Mihov	Torosov	
17:40-18:10	coffee		coffee	coffee	
18:10-18:40	Nedev		Tenev	Stanchev	
18:40-19:00	Clarke		Barcan	Grigorova	
19:00-19:20	O'Dwyer		Markova		
20:00			**Conf. dinner**		

Registration is available on June 21 between 18:00 - 19:00 and on June 22 between 08:00 - 09:00 in the conference room.