Quantum Information and Quantum Computing

This session has been organised in collaboration with the SFB BeyondC.

Thursday, 21.08.2025, Room HS 7

Time	ID	Quantum Information and Quantum Computing I: Quantum Thermodynamics *Chair: Joshua Morris, Universität Wien*
14:00	801	**Precision is not limited by the second law of thermodynamics** *Florian Meier [1], Yuri Minoguchi [1,2], Simon Sundelin [3], Tony J. G. Apollaro [4], Paul Erker [1,2], Simone Gasparinetti [4], Marcus Huber [1,2]* *[1] Atominstitut, Technitsche Universität Wien, Austria,* *[2] Institute for Quantum Optics and Quantum Information - IQOQI Vienna, Austrian Academy of Sciences, Wien, Austria,* *[3] Department of Microtechnology and Nanoscience, Chalmers University of Technology, Gothenburg, Sweden,* *[4] Department of Physics, University of Malta, Msida, Malta* Physical devices operating out-of-equilibrium are affected by thermal fluctuations, limiting their operational precision. This issue is particularly pronounced at quantum scales, where its mitigation requires additional entropy dissipation. Clocks, for example, need a thermodynamic flux towards equilibrium to measure time, resulting in a minimum entropy dissipation per clock tick. Although classical and quantum models often show a linear relationship between precision and dissipation, the ultimate bounds on this relationship remain unclear. We present an autonomous quantum model achieving clock precision scaling exponentially with entropy dissipation. This is enabled by coherent transport in a spin chain with tailored couplings. The result demonstrates that coherent quantum dynamics can surpass traditional thermodynamic precision limits, potentially guiding development of future high-precision, low-dissipation quantum devices.
14:15	802	**Quantum Master Equations in the Presence of Continuous Measurement and Feedback: Theory and Applications** *Pharnam Bakhshinezhad, TU Wien, Austria* We study quantum systems under continuous measurement and feedback using the recently developed Quantum Fokker-Planck Master Equation (QFPME). This framework enables analytical modeling of weakly monitored quantum dynamics with real-time feedback. We apply the QFPME to diverse scenarios: (i) quantum thermometry via Bayesian estimation in bosonic and fermionic environments; (ii) feedback-based ground-state cooling of a harmonic oscillator; (iii) generation of steady-state entanglement in quantum thermal machines; and (iv) information-to-work conversion in a monitored double quantum dot across the quantum-classical transition. These results showcase the QFPME as a powerful tool in quantum thermodynamics and feedback control.
	~~803~~	*cancelled*
	~~804~~	*cancelled*
14:30	805	**Information Thermodynamics of Agents** *Lukas J. Fiderer, Paul Barth, Isaac Smith, Hans Briegel, University of Innsbruck, Austria* We study the energetic limits of information processing in percept-action loops—agent–environment interactions where both agent and environment are modeled as channels with memory. Using tools from information theory and stochastic thermodynamics, we define the work capacity of an environment as the maximum rate at which an agent can extract work from it. This generalizes previous results from passive tape models to non-stationary settings with genuine feedback. We show that established principles such as maximizing predictive power and forgetting actions are no longer optimal.Instead, a trade-off emerges: work-efficient agents must balance prediction and forgetting. This highlights a fundamental departure from the thermodynamics of passive observation, suggesting that prediction and energy efficiency may be at odds in active learning systems.

14:45	**806**	**On the second law of thermodynamics in isolated quantum systems** *Tom Rivlin, Florian Meier, Tiago Debarba, Jake Xuereb, Marcus Huber, Maximilian P. E. Lock* *Atominstitut, TU Wien, Austria* The second law of thermodynamics makes entropy increase over time. But for isolated quantum systems, the most widely-used definition of entropy, the von Neumann entropy, is always constant. So in what sense does the entropy of an isolated quantum system actually satisfy the second law? In this talk I will present a perspective we propose in a recent paper based on the entropy of observables. We recover a version of the second law: relative to a given observable, the entropy of an isolated quantum system tends towards an equilibrium value (with post-equilibration fluctuations). Analytically-derived bounds on entropy equilibration will be presented, alongside numerical illustrations of these arguments using a one-dimensional quantum Ising chain.
15:00	**807**	**Stabilizer-based entanglement and secure key distillation** *Christopher Popp, University of Vienna, Austria* Uncontrolled interactions with the environment introduce errors that remain a significant challenge to the reliability of quantum technologies using entangled states. An essential method to overcome or mitigate these errors is entanglement distillation. A construction based on stabilizer codes offers an effective method for designing such protocols, which can also be leveraged for the distillation of secure key states. We establish a standard form for the output states of stabilizer-based protocols. This links the properties of input states, stabilizers, and encodings to the properties of the protocol, allowing to optimize required operations for the desired output. The performance of such protocols highlights the capability of stabilizer-based methods to address the effects of environmental noise, advancing the robustness of quantum technologies.
15:15		
15:30		***Coffee Break***
		QUANTUM INFORMATION AND QUANTUM COMPUTING II: **QUANTUM INFORMATION THEORY** *Chair: Christian Siegele, Institute of Science and Technology Austria*
16:00	**811**	**High-dimensional entanglement witnessed by correlations in arbitrary bases** *Nicky Kai Hong Li [1,2], Marcus Huber [1,2], Nicolai Friis [1,2]* *[1] Atominstitut, TU Wien, Austria, [2] IQOQI Vienna, Austria* Certifying entanglement is an important step in the development of many quantum technologies, especially for higher-dimensional systems, where entanglement promises increased capabilities for quantum communication and computation. A key feature distinguishing entanglement from classical correlations is the occurrence of correlations for complementary measurement bases. In particular, mutually unbiased bases (MUBs) are paradigmatic examples that are routinely employed for entanglement certification. However, implementing unbiased measurements exactly is experimentally infeasible. Here, we extend the entanglement-certification framework from correlations in MUBs to arbitrary bases. This practical simplification enables efficient characterisations of high-dimensional entanglement in many physical systems. Furthermore, we introduce a simple three-MUBs construction for all dimensions without using the Wootters–Fields construction, simplifying experimental requirements for implementing MUBs in high-dimensional settings.

16:15	**812**	**A Framework for the Security Analysis of Practical High-Dimensional QKD Setups** *Florian Kanitschar, Marcus Huber, Technische Universität Wien, Austria* High-dimensional quantum key distribution (HD-QKD) offers improved key rates and noise resilience, but security analyses often rely on impractical measurements or heavy computation. We present a physics-guided framework grounded in entanglement theory, enabling secure key rate certification using only native, experimentally accessible measurements. By combining entanglement-witness observables with matrix completion, we bound adversarial knowledge efficiently and reformulate the problem as a dual semidefinite program involving tractable eigenvalue computations. Our method improves noise tolerance, scales to high dimensions, and supports composable finite-size security. We further introduce a variable-length key rate model to address fluctuating channels. Demonstrated on time-bin entanglement, the framework is platform-independent and bridges the gap between theoretical analysis and practical HD-QKD implementations.
16:30	**813**	**Bypassing Losses in Quantum Optics: A Robust Measurement Design** *Mohammad Mehboudi [1], Fatemeh Rezaeinia [3], Saleh Rahimi-Keshari [2]* *[1] TU Wien, Austria, [2] IPM, Tehran, Iran, [3] University of Tehran, Iran* Photon loss represents a primary decoherence mechanism in quantum optics, posing a significant challenge for quantum information protocols relying on measurement incompatibility, such as quantum steering and communication. We study the impact of pure loss channels on continuous-variable incompatibility. We show any n measurements become compatible under transmissivity $\tau \leq 1/n$. However, we construct a feasible set of n+1 displaced on-off measurements that remains incompatible for $\tau \geq 1/n$. Fundamentally, we prove no loss ($\tau > 0$) universally destroys incompatibility; some measurements always remain incompatible. This confirms quantum steering is possible despite arbitrary amounts of pure loss, offering routes to mitigate loss in quantum communication.
16:45	**814**	**Estimating entanglement monotones of non-pure spin-squeezed states** *Julia Mathe [1], Ayaka Usui [2], Otfried Gühne [3], Giuseppe Vitagliano [1]* *[1] Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien, Austria,* *[2] Departament de Física, Universitat Autònoma de Barcelona (UAB), Spain,* *[3] Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Germany* We investigate how to estimate entanglement monotones of general mixed many-body quantum states via lower and upper bounds from entanglement witnesses and separable ansatz states. This enables analysis of spin systems on fully-connected graphs at nonzero temperature. We derive lower bounds to distance-like measures using spin-squeezing inequalities and apply our methods to equilibrium states of spin models with an external field. The lower bound becomes tight for zero temperature as well as for the temperature where entanglement disappears, both of which are thus precisely captured by the spin-squeezing inequalities. We further observe that entanglement arises at nonzero temperature close to a quantum phase transition, even when the ground state is separable. This "entanglement signature" may also be visible in experiments.
17:00	**815**	**The Impact of Architecture and Cost Function on Dissipative Quantum Neural Networks** *Tobias Christoph Sutter, Christopher Popp, Beatrix Hiesmayr, University of Vienna, Austria* A prominent approach to leveraging machine learning techniques on quantum devices is the so-called dissipative quantum neural network (DQNN) model. In our work, we develop an extended architecture for DQNNs where each building block can implement any quantum channel, thus introducing a clear notion of universality suitable for the quantum framework. We reformulate DQNNs using isometries instead of the conventionally used unitaries, thereby reducing the number of parameters in these models, and derive a versatile one-to-one parametrization of isometries to efficiently implement the proposed structure. Focusing on the impact of different cost functions on the optimization process, we numerically investigate the trainability of extended DQNNs, thus unveiling significant training differences among the cost functions considered.

17:15 | **816**

Generalized Parity Measurements and Efficient Large Multi-component Cat State Preparation with Quantum Signal Processing

Sina Zeytinoglu, TU Wien, Austria

General measurements with binary outcomes are crucial for quantum information processing applications. Here, we present a method for designing wide range of such measurements using the toolbox of Quantum Signal Processing, and apply it to design generalized parity measurements. Most strikingly, the proposed generalized parity measurements can be implemented in constant time, set by the interaction rate. We evaluate the effectiveness of our measurement protocol in preparing high-fidelity multi-component cat states in the setting of current superconducting cavity quantum electrodynamics experiments. Through detailed numerical simulations, we show that a 20-component cat state with 400 photons can be prepared with > 2 % success probability and $\approx$ 90 % fidelity, limited by the cavity decay and nonlinear qubit-cavity coupling rates.

17:30 | **817**

Quantum entanglement in Wigner functions

Shuheng Liu [1,2], Jiajie Guo [2], Qiongyi He [2], Matteo Fadel [3]
[1] Atominstitut, TU Wien, Austria, [2] School of Physics, Peking University, Beijing, China,
[3] Department of Physics, ETH Zürich, Switzerland

While commonly used entanglement criteria for continuous variable systems are based on quadrature measurements, we study entanglement detection from measurements of the Wigner function. These are routinely performed in platforms such as trapped ions and circuit QED, where homodyne measurements are difficult to be implemented. We provide complementary criteria which we show to be tight for a variety of experimentally relevant Gaussian and non-Gaussian states. Our results show novel approaches to detect entanglement in continuous variable systems and shed light on interesting connections between known criteria and the Wigner function. Furthermore, we generalize our criteria to multipartite systems for the detection of genuine multipartite entanglement, and these criteria can be readily implemented in experiments.

17:45 | **818**

Exact Steering Bound for Two-Qubit Werner States

Martin J. Renner, ICFO - The Institute of Photonic Sciences, Castelldefels, Spain

Many quantum technologies rely on nonlocality—correlations between distant particles that defy classical explanation. To harness this, it's essential to know which quantum states can or cannot display nonlocal behavior. A seminal 1989 result by Werner showed that some entangled states can be fully explained by local models, but only under the restricted class of projective measurements. We extend this result for two-qubit Werner states to the most general class of measurements, known as positive operator-valued measures (POVMs). Our model identifies exactly which of these states can demonstrate quantum steering—the effect Einstein famously called "spooky action at a distance." Surprisingly, we find that POVMs offer no advantage over simpler projective measurements, resolving a long-standing open question in quantum foundations.

18:00		***END***
		Transfer to Dinner
19:00		***Conference Dinner***

Friday, 22.08.2025, Room HS 7

Time	ID	QUANTUM INFORMATION AND QUANTUM COMPUTING III: QUANTUM FOUNDATIONS AND INFORMATION *Chair: Iris Agresti, Universität Wien*
11:00	821	**How to implement a causal measurement scheme for quantum fields?** *Jan Mandrysch, Miguel Navascués,* *Institute for Quantum Optics and Quantum Information, Vienna, Austria* While measurement processes in standard quantum mechanics are well understood, the extension of these ideas to quantum field theory (QFT) remains a key challenge. In particular, ensuring that measurements respect fundamental principles such as relativistic causality is crucial. A persistent issue concerning measurements in QFT is, though, that microcausality alone is insufficient to prevent superluminal signaling. In this talk, I will present a concrete scheme for measuring real linear scalar fields which allows to model projective and Gaussian measurements and more. The approach fully respects the principles of relativistic covariance, locality, and causality, offering a robust solution to the challenges of measurement in QFT.
11:15	822	**On the Planckian time of thermalization** *Paolo Abiuso [1], Pavel Sekatski [2], Alberto Rolandi [3], John Calsamiglia [4], Martí Perarnau-Llobet [4]* *[1] IQOQI - Vienna, Austria, [2] University of Geneva, Switzerland,* *[3] Technical University Vienna Austria, [4] Universitat Autònoma de Barcelona, Spain* We present the first mathematical proof that quantum mechanics entails a minimum time for any system to thermalize, namely, half of the Planckian dissipation time $\tau_{\mathrm{Pl}} = \frac{\hbar}{k_{\mathrm{B}} T}$ in general. Our bounds, rooted in Hamiltonian estimation, are valid for arbitrarily engineered baths/machines that only have to comply with the Schrödinger equation and are required to output a state close to its thermal ensemble for a nontrivial set of Hamiltonians.
11:30	823	**Events and their Localisation are Relative to a Lab** *Lin-Qing Chen, IQOQI-Vienna, Austria, & University of Vienna, Austria* The notions of events and their localisation are fundamentally different between quantum theory and general relativity, the reconciliation becomes more important and challenging in quantum gravity. We propose an operational approach, to define events and their localisation relative to a Lab, which includes a choice ofreference providing a generalised notion of “location” with certain operational properties.Applying this proposal to analyse the quantum switch (QS),we uncover its differences between classical and quantum spacetime realisations. Our analysis also clarifies a longstanding debate on the interpretation of QS experiments, demonstrating how different conclusions stem from distinct assumptions on the Labs. This provides a foundation for a more unified view of events, localisation, and causality across quantum and relativistic domains.
	~~824~~	*→ moved to 807*
11:45	825	**Optimising quantum tomography with classical post-processing** *Andrea Caprotti, University of Vienna, Austria* In quantum information theory, the accurate estimation of observables is pivotal for quantum information processing, playing a crucial role in compute and communication protocols. We introduce a novel technique for estimating such objects, levereging an underutilised resource in the inversion map of classical shadows that greatly refines the estimation cost of target observables without incurring any additional overhead. Specifically, considering the additional degrees of freedom in the homogeneous space of dual basis in overcomplete measurement schemes opens the possibility of extracting information more efficiently from limited resources. Starting from the classical shadow measurement scheme, this opens to improvements in more general quantum estimation procedures.
12:00		

12:30		*Poster Awards and Closing Ceremony*
12:45		*Lunch*

QUANTUM INFORMATION AND QUANTUM COMPUTING IV: EXPERIMENT

Chair: Patrik Sund, Universität Wien

14:00 831

High finesse microcavities for quantum science and technology

Philipp Koller [1,2,3], Jannek J. Hansen [1,2,3], David Walcher [1,2], Stefan Putz [1,2], Thomas Astner [1,2], Daniel Wirtitsch [1,2], Rhys Povey [1,2], Michael Trupke [1,2]
[1] Institute for Quantum Optics and Quantum Information (IQOQI), Vienna, Austria,
[2] Vienna Center for Quantum Science and Technology, Austria,
[3] University of Vienna, Faculty of Physics & Vienna Doctoral School in Physics, Austria

Lithographically produced optical microcavities with open access, high finesse and small mode volume can drastically improve performance of quantum devices, by optical confinement and enhanced light matter interaction. The development of micromirrors on thin silicon membranes is a crucial step for MEMS tuneability and efficient fiber coupling, which is a prerequisite for scalable spin-based quantum memories. Small lightweight mirrors have further advantages in levitation experiments, when supported by a superconducting structure. This would greatly improve the position readout precision of magnetically levitated superconductors, making it a promising approach for the creation of non-classical states of macroscopic objects which are sufficiently massive for the observation of gravitational interactions.

14:15 832

Experimental certification of high-dimensional entanglement with randomized measurements

Giuseppe Vitagliano [1], Ohad Lib [2], Shuheng Liu [3], Ronen Shenkel [2], Qiongyi He [3], Marcus Huber [1], Yaron Bromberg [2]
[1] TU Wien, Austria, [2] University of Jerusalem, Israel, [3] Peking University, China

High-dimensional entangled states offer higher information capacity and stronger resilience to noise compared with two-dimensional systems. However, the large number of modes and sensitivity to random rotations complicate experimental entanglement certification. Here, we experimentally certify three-dimensional entanglement in a five-dimensional two-photon state using 800 Haar-random measurements implemented via a 10-plane programmable light converter. We further demonstrate the robustness of this approach against random rotations, certifying high-dimensional entanglement despite arbitrary phase randomization of the optical modes. This method, which requires no common reference frame between parties, opens the door for high-dimensional entanglement distribution through long-range random links.

14:30 833

Entropic costs of the quantum-to-classical transition in a microscopic clock

Paul Erker [1], Vivek Wadhia [2], Florian Meier [1], Natalia Ares [2]
1 Atominstitut, TU Wien, Austria, 2 University of Oxford, UK

We experimentally realize a quantum clock by using a charge sensor to count charges tunneling through a double quantum dot (DQD). Individual tunneling events are used as the clock's ticks. We quantify the clock's precision while measuring the power dissipated by the DQD. This allows us to probe the thermodynamic cost of creating ticks microscopically and recording them macroscopically. Our experiment is the first to explore the interplay between the entropy produced by a microscopic clockwork and its macroscopic measurement apparatus. Our results suggest that the entropy produced by the amplification and measurement of a clock's ticks, which has often been ignored in the literature, is the most important and fundamental thermodynamic cost of timekeeping at the quantum scale.

14:45	**834**	**Robust generation of multiphoton states from quantum dots** *Vikas Remesh, Yusuf Karli, Iker Avila Arenas, Gregor Weihs, University of Innsbruck, Austria* High-purity multi-photon states are essential for photonic quantum computing. Among existing platforms, semiconductor quantum dots offer a promising route to scalable and deterministic multi-photon state generation. To fully realize their potential we require a suitable optical excitation method. Current approaches rely on active polarization-switching elements to spatio-temporally demultiplex the emitted single photons. Here, the achievable multi-photon rate is fundamentally limited by the switching speed of the EOM. Here, we introduce a fully passive demultiplexing technique that leverages a stimulated two-photon excitation process to achieve switching rates that are only limited by the quantum dot lifetime. Our approach significantly reduces the cost of demultiplexing, shifting it to the excitation stage, and effectively doubling the achievable multi-photon generation rate.
15:00	**835**	**Quantum network node based on trapped ions coupled to a cavity** *Sudhan Bhadade, Mehdi Rizvandi, Moming Jia, Roberts Berkis, Dmitry Bykov, Miao Cai, Shivam Sawarn, Bo Wang, Liyang Zhang, Tracy Northup* *Institute for Experimental Physics, University of Innsbruck, Austria* Quantum networks require nodes capable of generating high fidelity entanglement athigh rates. Trapped calcium ions coupled to a high-finesse optical cavity provide a promising platform for this. We are developing a new node designed to operate over metropolitan-scale distances of up to 50 km using polarization-state encoded single photons. In this talk, I will outline the advantages of trapped-ion based quantum networks, discuss the challenges of achieving faster entanglement generation, and present the strategies we are implementing. The focus will be on the key features of our next-generation node currently under construction.
15:15	**836**	**Experimentally probing Landauer's principle in the quantum many-body regime** *Stefan Aimet [1], Mohammadamin Tajik [2], Gabrielle Tournaire [1,3], Philipp Schüttelkopf [2], João Sabino [2], Spyros Sotiriadis [4], Giacomo Guarnieri [5], Jörg Schmiedmayer [2], Jens Eisert [1]* *[1] FU Berlin, Germany, [2] TU Wien, Austria, [3] University of British Columbia, Vancouver, Canada, [4] University of Crete, Heraklion, Greece, [5] Università di Pavia, Italy* Landauer's principle bridges information theory and thermodynamics by linking the entropy change of a system during a process to the average energy dissipated to its environment. Although typically discussed in the context of erasing a single bit of information, Landauer's principle can be generalised to characterise irreversibility in out-of-equilibrium processes, such as those involving complex quantum many-body systems. Here we experimentally probe Landauer's principle in the quantum many-body regime using a quantum field simulator of ultracold Bose gases. Our work demonstrates the ability of ultracold atom-based quantum field simulators to experimentally investigate quantum thermodynamics.
15:30	**837**	**High-Dimensional Time-Bin Entanglement for Quantum Key Distribution** *Dorian Schiffer [1,2], Robert Kindler [1], Florian Kanitschar [2,3], Alexandra Bergmayr-Mann [2], Amin Babazadeh [1], Paul Erker [1,2], Marcus Huber [1,2], Anton Zeilinger [1]* *[1] Institute for Quantum Optics and Quantum Information (IQOQI), Austrian Academy of Sciences, Vienna, Austria,* *[2] Atominstitut, Technische Universität Wien, Austria,* *[3] AIT Austrian Institute of Technology, Center for Digital Safety and Security, Vienna, Austria* Researchers have long looked to high-dimensional entanglement to enable quantum key distribution (QKD) in high loss and noise scenarios. Whether and when using the full entanglement dimensionality leads to a practical increase in key rates remains, however, the central open question. Here, we experimentally demonstrate that sought-after advantage by implementing a QKD protocol based on discretisations of temporally entangled photonic states. Our protocol allows for a novel entangled-photon source, which achieves extreme brightness and high heralding ratios while maintaining low complexity. We locally distill key rates, with maxima appearing in higher dimensions. Varying the discretisations in post-processing, we scan a large parameter space, within which our results indicate ‚Goldilocks zones', where higher entanglement dimensionality translates into higher key rates.

15:45	**838**	**Experimental data re-uploading with provable enhanced learning capabilities** *Martin Mauser [1], Solene Four [1], Lena Marie Predl [1], Francesco Ceccarelli [2], Roberto Osellame [2], Philipp Petersen [1], Borivoje Dakic [1,3], Iris Agresti [1], Philip Walther [1]* *[1] University of Vienna, Austria, [2] IFN-CNR, Milano, Italy, [3] IQOQI, Vienna, Austria* The last decades have seen the development of quantum machine learning, stemming from the intersection of quantum computing and machine learning. In this context, we present the implementation of a data re-uploading scheme on a photonic integrated processor, applied to several image classification tasks, where it grants high accuracies. We thoroughly investigate the capabilities of this apparently simple model, which relies on the evolution of one-qubit states, by providing an analytical proof that our implementation is a universal classifier and an effective learner, capable of generalizing to unknown data. Hence, our results shed new theoretical insight into this algorithm, its trainability, and generalizability properties.
16:00		***END***

ID	Quantum Information and Quantum Computing Poster
841	**Subjective nature of path information in quantum mechanics** *Xinhe Jiang [1,2], Armin Hochrainer [1,2], Jaroslav Kysela [1,2], Manuel Erhard [1,2], Xuemei Gu [1,3], Ya Yu [1,4], Anton Zeilinger [1,2]* *[1] Institute for Quantum Optics and Quantum Information, Austrian Academy of Sciences, Boltzmanngasse 3, AT-1090 Vienna,* *[2] Vienna Center for Quantum Science and Technology, Faculty of Physics, University of Vienna, Boltzmanngasse 5, AT-1090 Vienna ,* *[3] Max Plank Institute for the Science of Light, Staudtstraße 2, Erlangen DE-91058,* *[4] Shanghai Jiao Tong University, Dongchuan Road 800, Shanghai 200240, China* Common sense suggests that a particle must have a definite origin if its full path information is available. In quantum mechanics, the knowledge of path information is captured by the complementarity principle through the well-established duality relation $D^2 + V^2 \leq 1$, which describes the trade-off between path distinguishability D and interference visibility V. If visibility is zero, a high path distinguishability is obtained, which enables one with high predictive power to know where the particle comes from. Here we show that this perception of path information is problematic. We demonstrate that it is impossible to ascribe a definite physical origin to the photon pair even if the emission probability of one individual source is zero and full path information is available.
842	**The Cumulant Expansion Approach: the Good, the Bad and the Ugly** *Johannes Kerber, Helmut Ritsch, Laurin Ostermann* *Institute for Theoretical Physics, University of Innsbruck, Austria* The configuration space of compound quantum systems grows exponentially with the number of its subsystems. The full-quantum treatment, in general, is hardly possible analytically and can be determined numerically for small systems only. To obtain interesting physics, approximations might very well suffice, e.g. the Cumulant Expansion Method (CEM). Although the CEM is widely used, a general criterion for its applicability remains to be found. We discuss two problems in quantum electrodynamics (the dipole-dipole interacting chain of atoms) and quantum information (the factorization of bi-primes by annealing in an adiabatic quantum computer). On the one hand, we find smooth behavior, where the approximation becomes increasingly better with higher orders, while, on the other hand, we are puzzled by completely uncontrolled solutions.

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Random Numbers from Cosmic Microwave Background for Bell test

Amin Babazadeh [1,2], Ricardo T. Genova-Santos [3,4], Alessandro Fasano [3,4], Jose Alberto Rubino Martin [3,4], Roger J. Hoyland [3,4], Rafael Rebolo Lopez [3], Anton Zeilinger [1,5]
[1] Institute for Quantum Optics and Quantum Information, Austrian Academy of Sciences, Vienna, Austria,
[2] Quantum Optics, Quantum Nanophysics and Quantum Information, University of Vienna, Austria,
[3] Instituto de Astrofisica de Canarias (IAC), Tenerife, Spain,
[4] Universidad de La Laguna, Dpto. Astrofisica, Tenerife, Spain,
[5] Vienna Center for Quantum Science and Technology (VCQ), Faculty of Physics, Austria

We propose using Cosmic Microwave Background (CMB) radiation as a natural random number generator. Randomness is derived from CMB photons, emitted 378,000 years after the Big Bang. Links measurement choices to ancient, causally independent events nearly 13.8 billion years ago. This significantly strengthens Bell test experiments by extending causal separation and addressing the freedom-of-choice loophole, surpassing previous efforts by 7 billion years. With optimized detector bandwidths and strategic station placement, both locality and setting-independence loopholes can be closed for parameters significantly beyond current experiments. We also discuss technical challenges in isolating CMB signals from noise. Beyond foundational tests, this cosmological randomness offers a good source for quantum cryptography, randomness expansion, and secure communication.

844

Uncertainty relations and entanglement with finite Fourier transformed variables.

Dimpi Thakuria, TU Wien, Austria

We explore uncertainty relations for discrete phase-space observables in finite-dimension, focusing on canonical position/momentum observables linked by finite Fourier transforms. Our approach is complementary to the typical way of usingfinite-dimensional Heisenberg-Weylframework (especially, finite discrete-displacement operators) for studying such systems. Utilizing recent finite-dimensional phase-space formalisms, including analogs of Gaussian functions and Fourier matrix eigenstates, we analyze states saturating the Robertson-Schrödinger uncertainty relation. We extend our approach by embedding the problem in continuous-variable space, redefining displacement and squeezing operators beyond traditional Heisenberg-Weyl frameworks. We also examine uncertainty relations involving multiple observables, comparing minimum-uncertainty states, and discuss the continuous limit as dimension increases. We discuss applications that include entanglement detection in finite-dimensional systems, akin to covariance matrix criteria in continuous-variable systems.

845

Approaching the mechanical ground state in an inductively coupled electromechanical system

Bhargava Thyagarajan [1], Lukas Felix Deeg [1], Raamamurthy Sathyanarayanan [2], Christian Dejaco [2], Gerhard Kirchmair [1]
[1] IQOQI, ÖAW, Innsbruck, Austria, [2] Institute for Experimental Physics, University of Innsbruck, Austria

A flux tunable microwave resonator coupled inductively to a magnetic cantilever has been shown to achieve optomechanical couplings > 10 kHz (Zoepfl, et al. PRL 2020), larger than state-of-the-art optomechanical devices. Backaction cooling of such a device to the mechanical ground state remains an outstanding challenge since it operates in the unresolved sideband regime. We circumvent this limitation by capacitively coupling the microwave mode to an auxiliary high-Q mode. Both the resulting hybridized modes inherit the optomechanical coupling and one of them should reside in the resolved sideband regime, allowing us to cool to the ground state. Alternatively, we use a flux transformer to mediate the optomechanical coupling. This mitigates the detrimental effect of the magnetized cantilever on the superconducting resonators.

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Towards a Quantum Network Node: Trapped Calcium Ions Coupled to a High-Finesse Optical Cavity

Mehdi Rizvandi, Sudhan Bhadade, Moming Jia, Roberts Berkis, Dmitry Bykov, Miao Cai, Shivam Sawarn, Bo Wang, Liyang Zhang, Tracy Northup
University of Innsbruck, Austria

Trapped calcium ions optically coupled to cavities can serve as nodes in future quantum networks. They allow for the production of photons that are entangled with long-lived atomic qubits, making them ideal for quantum information transmission. We are working on a quantum node that can connect to another nodes over metropolitan distances of up to 50 kilometers using a polarization-state encoding of single photons. In this poster, I present our advances on constructing a novel system incorporating a linear Paul trap, a high-finesse optical cavity, and ablation loading of trapped ions. I will also present future envisioned improvements such as a Raman transition scheme for high-purity photon states and mechanisms to enhance stability and control of the ion-cavity system.

847

Adding and removing systems in quantum reference frames

Bruna Sahdo, Esteban Castro Ruiz, IQOQI Vienna, Wien, Austria

We analyse the problem of adding and ignoring systems from the perspective of a quantum reference frame. We use examples with translation invariance to illustrate that an apparent modification of the rules of Quantum Theory for adding can indicate the 'quantumness' of an observer's frame. This is true when the symmetry invariance is demanded at the level of operators. However, we also show that there is a unitary way to go to a classicalized perspective of a frame, where the rules apply again, after internalizing the initial describer. This generates discussion about how this formalism can recover other QRF formulations, as well as an analogy between QRFs that are manifestly quantum and reference frames that are non-inertial in classical mechanics.

848

A new view on Quantum Computers

Christoph Grüner [1], Daniel Aziz [1], Joachim Bosina [1], Tobias Jenke [2], Hartmut Abele [1]
[1] Atominstitut, TU Wien, Austria, [2] Institut Laue-Langevin, Grenoble, France

We describe a concept for a quantum computer based on an abundant number of energy eigenstates. These states form Q-bits or, ad libitum, higher dimensional Q-Nits with $N > 2$, allowing gate operations according to the quantum computing requirements of DiVincenzo. This system with higher dimensional Q-Nits offers potential advantages over traditional qubit-based quantum computing. It provides a larger state space for storing and processing information, which can reduce circuit complexity, simplify experimental setups, and enhance algorithm efficiency.

849

Detecting genuine multipartite entanglement in multi-qubit devices with restricted measurements

Nicky Kai Hong Li [1,2], Xi Dai [3,4], Manuel H. Muñoz-Arias [5], Kevin Reuer [3,4], Marcus Huber [1,2], Nicolai Friis [1,2]
[1] Atominstitut, TU Wien, Austria, [2] IQOQI Vienna, Austria,
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Detecting genuine multipartite entanglement (GME) can serve as a benchmark of coherence and control in quantum systems. However, many GME tests require joint measurements on all or most of the involved quantum systems, posing experimental challenges for platforms with restricted qubit connectivity, such as typical setups for time-bin encoded qubits. Here we construct a family of versatile GME criteria that require measurements of only a small subset—$O(n^2)$ out of 2^n—of (at most) m-body stabilizers of n-qubit target graph states, with m bounded from above by twice the graph's maximum degree. We present analytical results for white-noise-added graph states and numerical simulations for graph states produced in microwave photonic qubits that demonstrate the effectiveness of our GME criteria under realistic conditions.

850	**Security Analysis and Implementation of Finite-Size Multi-User CV-QKD with Discrete Modulation**

850 Security Analysis and Implementation of Finite-Size Multi-User CV-QKD with Discrete Modulation

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We present the first security analysis and experimental implementation of multi-user continuous-variable QKD with discrete modulation. Our protocol enables a central node to establish secret keys with multiple users over a passive optical network using standard telecom components. We analyze realistic trust scenarios and provide asymptotic and composable finite-size security proofs, employing efficient analytical and numerical methods that scale independently of the number of users. Demonstrated with a three-user 10 km fiber setup, our implementation achieves 0.866 Mbit/s under experimentally feasible conditions. The results confirm that scalable, fiber-based quantum networks with discrete-modulated CV-QKD are practical, bridging theory and deployment in real-world networked quantum communication.

851 Robust quantum memory in a trapped-ion quantum network node with an optical cavity

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A key threshold for quantum networks is to store remotely entangled states for longer than the time required to generate them. Achieving that with trapped-ion network nodes requires quantum memories robust to photon generation attempts on co-trapped ions. In this work, a quantum memory is implemented in $^{40}Ca^{+}$ ions using dynamical decoupling that survive 8000 photon generation attempts on a co-trapped ion, lasting 1.7 s. The demonstrated storage time approaches the anticipated generation time of remote ion-ion entanglement over 100 km of ~ 10 s, achievable by modestly optimizing and duplicating our current experimental platform.

852 Josephson Gravimeter - Gravity Sensing by Quantum Tunneling in Superconducting Circuit

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Recent studies suggest gravity might influence quantum tunneling in superconducting Josephson junctions (JJs). The idea is that gravity changes the potential across the junction, affecting how electrons (Cooper pairs) tunnel. This can create an electromagnetic signal – the AC Josephson effect. If the JJ is aligned with gravity, the signal's frequency could increase due to higher gravitational potential energy. We propose using this to detect gravity with high precision. With the right circuitry and a proper setup calibration, such signals can be measurable. This opens a new way to study gravity at the atomic scale and may find uses in nanotechology, material science, geophysics, and navigation systems.