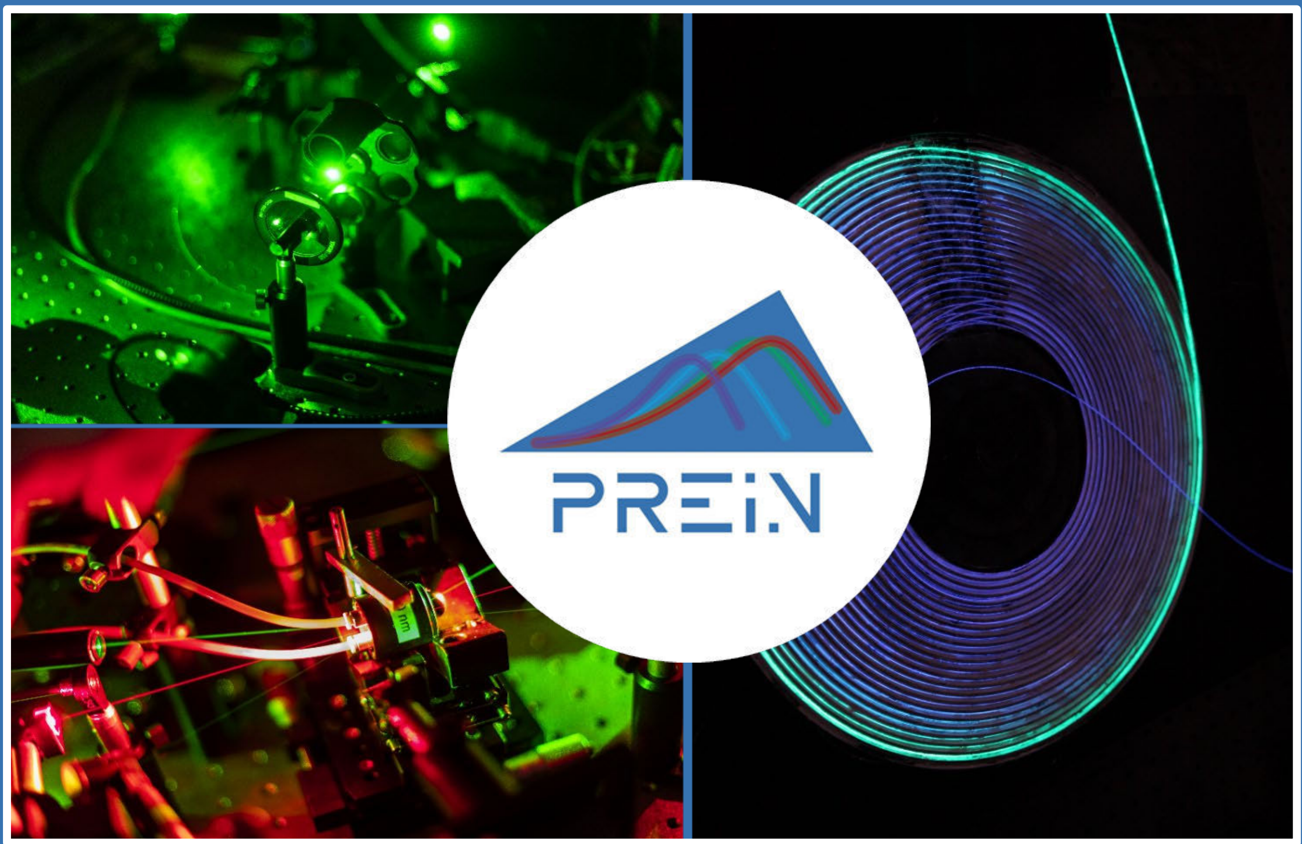
PREIN Workshop on Quantum Research and Technologies



NOVEMBER 12-14, 2024

Paasitorni Congress, Helsinki, Finland

George Thomas, Robert Fickler, Andreas Norrman, and Zhipei Sun (eds.)

FLAGSHIP PROGRAMME
Tampere University
UNIVERSITY OF EASTERN FINLAND
Aalto University
VTT

PREIN Workshop on Quantum Research and Technologies

Book of Abstracts

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PREIN Workshop on Quantum Research & Technologies

The workshop organized in Helsinki aims at bringing together all partners involved in the PREIN work package "Quantum Technologies" as well as researchers from the newly established Finnish Quantum Flagship (FQF).

Photonics Research and Innovation (PREIN) is a flagship Program funded by the Research Council of Finland and was launched in 2019.

The workshop will be a perfect platform to present latest results, exchange ideas, and discuss possible future collaborations within PREIN and between the flagships. The general topics of the workshop include the development of components and schemes to generate, detect, and manipulate quantum states of light as well as the study of quantum optical foundations. In addition, we welcome all colleagues that are working on research and technologies in the fields of quantum science that are related to quantum photonics activities of PREIN or can benefit from it.

Venue

The workshop takes place from Tuesday 12 November (09:30) until Thursday 14 November (12:00) at Paasitorni (Paasivuorenkatu 5 A). A workshop dinner will be held on Wednesday evening at 19:00 in restaurant MeriPaviljonki (Säästöpankinranta 3). In addition, there will be a social event on Tuesday evening in Allas Sea Pool (Katajanokan laituri 2 A) for all participants at 19:00.

12 to 14 November 2024

Helsinki, Finland

Workshop organizers

FLAGSHIP PROGRAMME

Tampere University

UNIVERSITY OF EASTERN FINLAND

Aalto University

VTT

Organizing Committee

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Program

TUESDAY, 12 NOVEMBER

09:00 – 09:30	Registration
09:30 – 09:45	Opening words
09:45 – 10:15	Diamond-Based Quantum Sensing and an Introduction to the Diamond Needles *Bo Xu*, UEF, Finland
10.15 – 10.45	Development of GaSb-based Quantum Dots for Telecom Wavelength Deterministic Quantum Light Sources *Teemu Hakkarainen*, TAU, Finland
10:45 – 11:15	Coffee Break
11:15 – 11:45	Tailoring Carbene-Metal-Amides for Thermally Activated Delayed Fluorescence: A Computationally Guided Study on the Effect of Amide Ligan *Thao Nguyen Le Phuoc*, UEF, Finland
11:45 – 12.15	Quantum Theory of Light Scattering from Electromagnetic Time Interfaces *Mohammad Sajjad Mirmoosa*, UEF, Finland
12:15 – 13.30	Lunch Break
13:30 – 14:00	Finnish Quantum Flagship overview *Pekka Pursula*, VTT, Finland
14.00 – 14:30	Scalable Solid-State Refrigeration for Quantum Technology *Mika Prunnila*, VTT, Finland
14.30 – 15:00	Transfer Matrix of Thick Silicon-on-Silica Photonic Integrated Components *Vladimir Kornienko*, Aalto
15:00 – 15:30	Coffee Break
15:30 – 17:00	Poster session
18:00 onwards	Social Event at Allas Sea Pool (Katajanokanlaituri 2)

PLENARY TALK
PREIN TALK
FQF TALK

WEDNESDAY, 13 NOVEMBER

09:30 – 10:15	Recognition of light Orbital-Angular-Momentum Superpositions for Quantum Communication *Antonio Zelaquett Khuory*, Universidade Federal Fluminense, Brazil
10:15 – 10:45	Spin-orbit quantum frequency conversion *Rafael Barros*, TAU, Finland
10:45 – 11:15	Coffee break
11:15 – 11:45	Non-Hermitian Topological Modes from Local Loss Engineering in Photonic Arrays *Elizabeth Pereira*, Aalto, Finland
11:45 – 12:15	Electric Field Control of Moiré Skyrmion Phases in Twisted Multiferroic NiI2 Bilayers *Tiago Antão*, Aalto, Finland
12:15 – 13.30	Lunch Break
13:30 – 14:00	TBD *Alexandru Paler*, Aalto, Finland
14:.00 – 14:30	Optical Integration of Cryogenic Quantum Technologies *Antti Kemppinen*, VTT, Finland
14:30 – 15:00	Photonics for Quantum *Sara Pourjamal*, VTT, Finland
15:00 – 15:30	Coffee Break
15:30 – 16:00	Fabrication of vdW Microdisk Cavities for Photonics & Optoelectronics *Andreas Liapis*, Aalto, Finland
16:00 – 16:30	Van der Waals Bottom-Contacted Field Effect Transistors for 2D Electronics *Fida Ali*, Aalto, Finland
16:30 – 17:00	Metrology & Hypothesis Testing with Spatial Demultiplexing *Łukasz Rudnicki*, UEF, Finland & University of Gdansk, Poland
19:00 -	Dinner at MeriPaviljonki (Säästöpankinranta 3)

THURSDAY, 14 NOVEMBER

09:30 – 10:15	Photonic Quantum Technologies: From Integrated Quantum Devices to Designing Large Complex System *Christine Silberhorn*, University Paderborn, Germany
10:15 – 10:45	Double-Slit Interference with Multimode NOON States *Elvis Pillinen*, UEF, Finland
10:45 – 11:15	Coffee break
11:15 – 12:45	Discussion session
12:15 – 13.30	Lunch break

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ORAL PRESENTATIONS

POSTER PRESENTATIONS

Oral Presentations

Diamond-based Quantum Sensing and an Introduction to the Diamond Needles

Bo Xu, Sergei Malykhin, and Polina Kuzhir

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The nitrogen-vacancy color center （NV） in diamond is an atomic-sized fluorescent defect that is predominantly used in diamond-based quantum sensing. The NV's electronic spin boasts the longest coherence time among all solid-state defects and is coupled to various physical variables such as EM field, temperature and stress. Sensing with NV promises a combination of nanoscale resolution, room-temperature operation and ultra sensitivity and multi-functionality. Chemical stability and non-toxicity of the diamond host also makes NV-nanodiamond an attractive fluorescent marker.

At UEF, we use chemical vapor deposition (PECVD) and selective oxidation to fabricate the so-called diamond needles, which are single-crystalline diamond structures. Incorporation of NV centers into such structures takes place during the CVD growth with no post-processing which promises superior quality of NV centers. The CVD system at the same time allows precise control of structure geometry and color center distribution.

Development of GaSb-based Quantum Dots for Telecom Wavelength Deterministic Quantum Light Sources

Teemu Hakkarainen

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The presentation covers the recent developments concerning emerging GaSb-based quantum dot materials and devices for on-demand single and entangled photon sources operating at telecom S and C bands.

Tailoring Carbene-Metal-Amides for Thermally Activated Delayed Fluorescence: A Computationally Guided Study on the Effect of Amide Ligand

Nguyen Le Phuoc[1], Alexander Romanov[2], and Mikko Linnolahti[1]

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Carbene-metal-amides (CMAs) enabling thermally activated delayed fluorescence (TADF) have emerged as a promising class for emitter materials in OLED devices. To uncover the comprehensive understanding of structure-property relationships governing the photoluminescence characteristics of CMAs, we conducted a systematic computational investigation of the influence of amide structure on photoluminescence properties. Various structural motifs, including modified carbazoles, expanded ring systems, indole and carboline derivatives, and guanidine-based amides, were designed and calculated by employing the well-known density functional theory. Our findings reveal that precise control over emission color could be achieved through the strategic modification of amide ligand, with S1 energy varying from 2.38 eV to 3.91 eV, encompassing the visible spectrum and therefore offering pathways to efficient red, green, and blue emitters. Moreover, such complexes exhibit efficient TADF behavior when a compromise is attained between key parameters, including HOMO-LUMO overlap integral, energy gap between S1 and T1 states, and oscillator strength coefficient.

Quantum Theory of Light Scattering from Electromagnetic Time Interfaces

Mohammad Sajjad Mirmoosa, Tero Setälä, and Andreas Norrman

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Recently, time interfaces have garnered significant attention in optics due to their diverse applications, including frequency conversion, amplification, polarization rotation, light freezing, etc. This presentation elucidates such interfaces through the framework of quantum optics. We begin by reviewing the basic principles of time interfaces from a classical electrodynamics perspective. We then transition to the quantum optics framework, demonstrating the transformation of mode operators at a time interface between two nondispersive dielectric media. We consider temporal evolution of quantum states, such as Fock states and coherent states, and analyze their corresponding probability distributions. A thorough examination of the photon statistics associated with the scattered modes is provided. Moreover, we highlight phenomena such as photon-pair production, vacuum state generation, and state discrimination, emphasizing their relevance in quantum optics. We hope that our work deepens the understanding of time interfaces at the quantum level and shows their potential implications in advancing quantum technologies.

Finnish Quantum Flagship Overview

Pekka Pursula

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The presentation will give an overview for Finnish Quantum Flagship, covering its goals, objectives and main research directions and actions.

Scalable Solid-State Refrigeration for Quantum Technology

Joel Hätinen, Renan Loreto, Emma Mykkänen, Tuure Rantanen, Klaara Viisanen, Joel Geisor, Antti Kemppinen, Alberto Ronzani, and Mika Prunnila

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Numerous applications, from industrial non-destructive imaging through ultra-sensitive photon counting to various implementations of solid-state quantum computers require low temperatures for their sensor and processor chips. Replacing the bulky cryo-liquid based cooling stages of cryo-enabled instruments by chip scale refrigeration is envisioned to disruptively reduce the system size similarly as microprocessors did for computers. Chip scale cooling has been demonstrated with electronic refrigerators based on tunnel junctions in the sub-1 K temperature range, and just recently also above 2 K. In this communication we discuss physics and recent approaches of chip scale refrigeration.

Transfer Matrix of Thick Silicon-on-Silica Photonic Integrated Components

Vladimir Kornienko[1], George Thomas[2], and Ilkka Tittonen[1]

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Light is an attractive platform for quantum computing due to the low interaction with environment and room-temperature operation. Integrated photonics offers interferometric stability and unprecedented control for tailoring individual optical elements.

Here we present our results on reconstructing the transfer matrix for a linear optical multiport device implemented in a thick silicon-on-silica platform. We optimize numerically the single photon source for the infrared range. We use coherent light and heralded single photons to reconstruct the transfer matrix of our device.

Our results are an important step in developing the silicon photonics applications in quantum computing and sensing."

Recognition of Light Orbital-Angular-Momentum Superpositions for Quantum Communication

Antonio Zelaquett Khoury[1], Marcos Gil de Oliveira[1], Andre L. S. Santos Junior[1], Patrick M. R. Lima[2], Altilano C. Barbosa[1], Braian Pinheiro da Silva[1], and Sebastião Pádua[2]

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We study the tomography of spatial qudits encoded on structured light photons in the space of fixed order transverse modes. While direct position measurements with cameras do not provide an informationally complete Positive Operator Valued Measure (POVM), this property is achieved with the use of astigmatic transformation, allowing full characterization of the spatial quantum state from simple intensity measurements in both the intense and in the low photocount regimes. These methods are useful for classical and quantum communication with structured light and will be tested in a quantum network being set up in the Rio de Janeiro metropolitan area.

Spin-Orbit Quantum Frequency Conversion

Rafael Barros[1], André Junior[2], Antonio Zelaquett Khoury[2], and Robert Fickler[1]

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Quantum frequency conversion (QFC) is the process of coherently changing the color of an optical signal while preserving its quantum state. Applications of QFC are many, including single-photon detection and the interfacing of photons with quantum memories, both extremely important for current quantum technologies. In this work, we present a spin-orbit quantum frequency converter, a device that carries quantum information from the polarization of a Telecom photon to the spatial profile of a visible photon. We show that spin-orbit QFC is possible by driving the process with a classical field that is non-separable in the polarization and spatial degrees of freedom, a feature that is necessary for the coherence of the QFC process. We do so by converting one out of a pair of polarization-entangled photons, showing that the preservation of the entanglement (non-local) in the final two-photon state is conditioned upon the classical non-separability (local) of the driving field.

Non-Hermitian Topological Modes from Local Loss Engineering in Photonic Arrays

Elizabeth Pereira[1], Jose L. Lado[1], Hongwei Li[2], and Andrea Blanco Redondo[3]

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[2]*Nokia Bell Labs, Cambridge, UK.*

[3]*CREOL, The College of Optics and Photonics, University of Central Florida, Orlando, USA*

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Non-Hermitian systems have risen as a powerful strategy to engineer new topological excitations. Photonic devices allow the creation of a whole variety of new artificial lattices challenging to emulate in conventional materials, opening up possibilities to realize new forms of topological matter. Beyond conventional photonic topological states in closed quantum systems, photonic devices provide a flexible platform to harvest non-Hermitian topology, particularly robust topological modes by exploiting engineered gains and losses. Here (Pereira et al., 2024) we present a family of photonic models relying on the real-space modulation of photonic losses giving rise to non-Hermitian topological excitations. We demonstrate that the non-Hermitian topological modes survive spatial fluctuations in the system's loss and couplings. We also discuss the localization transition associated with this model in the quasicrystalline in analogy to the Hermitian model. Our results provide a realistic strategy to create topological modes in photonic systems from real-space loss engineering.

References

Pereira, E. L., Li, H., Blanco-Redondo, A., & Lado, J. L. (2024). Non-Hermitian topology and criticality in photonic arrays with engineered losses. Physical Review Research, 6(2), 023004.

Electric Field Control of Moiré Skyrmion Phases in Twisted Multiferroic NiI2 Bilayers

Tiago V. C. Antão, Jose L. Lado, and Adolfo O. Fumega

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Twisting magnetic van der Waals materials creates a versatile platform for unconventional magnetism, enabling the emergence of topological magnetic phases. Recently, multiferroic monolayer materials have emerged as a novel fundamental building block in van der Waals heterostructure engineering, offering unprecedented opportunities for light-matter control of magnetic order. In this study, we demonstrate the appearance of tunable topological moiré multiferroic orders in twisted bilayers of spin-spiral multiferroic NiI_2. A rich phase diagram is revealed, featuring kπ-skyrmion lattices among a variety of nematic magnetic textures ordered at the moiré scale. These phases emerge due to modulated spin frustration from local stacking in the moiré pattern. The strong magnetoelectric coupling inherent to the multiferroic nature of NiI_2 allows for electric-field control of kπ-skyrmion lattices, with abrupt field changes triggering transitions between skyrmion states. This establishes a tunable platform for skyrmionics in twisted van der Waals multiferroics, paving the way for topologically protected spintronic devices.

Optical Integration of Cryogenic Quantum Technologies

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Cryogenic quantum technologies typically operate at microwave frequencies, utilizing many techniques originally developed for optics, but at lower frequencies. However, the Wiedemann-Franz law states that in metals, thermal and electrical conductivities are proportional to each other and thus microwave cables bring a major passive heat load into cryogenic systems. Hence, as an example, superconducting quantum computers require ~100 W/qubit of electrical power to maintain the millikelvin range operating temperature, which is unsustainable for large-scale, error-corrected quantum computers. I will discuss, how optical techniques are expected to mitigate this issue, yielding a strong motivation for the optical integration of cryogenic quantum technologies.

Photonics for Quantum

Sara Pourjamal

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This presentation provides an overview of VTT's activities in the field of photonics for quantum technologies, with a particular focus on quantum communication and quantum sensing. Key developments include receivers Rx for continuous variable (CV) and discrete variable (DV) Quantum Key Distribution (QKD). For these technologies VTT is developing balanced Ge PIN detectors and superconducting nanowire single-photon detectors (SNSPDs) for hybrid and monolithic integration on VTT's ultra-low loss and polarization-independent SOI platform. Cryo and UHV compatible fiber-to-chip packaging solutions are also under development to characterize theses sensors for a broad range of applications from quantum communication networks to advanced quantum computing systems.

Fabrication of vdW Microdisk Cavities for Photonics & Optoelectronics

Andreas C. Liapis[1], Xiaoqi Cui[1], Zhi-Yan Wang[2], Yun-Feng Xiao[2], and Zhipei Sun[1]

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2D materials have emerged as a highly promising alternative to traditional photonic materials for on-chip applications, offering unique properties and potential for miniaturization. In this work, we demonstrate a versatile and universal method for patterning van der Waals multilayer flakes using focused ion beam lithography. Utilizing this approach, we successfully fabricate van der Waals microdisk resonators, which serve as a robust platform for exploring both linear and nonlinear photonic phenomena. This technique opens new avenues for the integration of 2D materials into next-generation photonic devices.

Van der Waals Bottom-Contacted Field Effect Transistors for 2D Electronics

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Two-dimensional (2D) semiconductors (MoS2, WSe2, InS2, BP) could be excellent channel materials for designing high-quality ultrathin field-effect transistors (FETs). However, stable electrical and optical performance of 2D FETs remains elusive due to the large influence of trap charges, crystal defects arising from direct metallization on the underlying 2D channel, and generation of metal-induced gap states (MIGS) at the electrodes and 2D channel interface. Therefore, in the present work, we have suggested a pre-pattern van der Waals contacted FET structure in which the 2D channel is protected from crystal defects created by direct metallization and MIGS. As a result, this approach provides a pristine 2D channel with stable device performance and a damage-free platform for designing high-quality 2D FETs. Further, the pristine 2D channel with stable and consistent electrical characteristics down to cryogenic temperature allows us to investigate quantum phase transition and metal-insulator transition (MIT in 2D layered materials-based devices.

Metrology and hypothesis testing with crosstalk-affected spatial demultiplexing

Łukasz Rudnicki[1,2]

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While quantum-optimal discrimination of two closely separated light sources can be achieved by ideal spatial-mode demultiplexing, we show that any imperfections of the demultiplexer make simple statistical tests practically useless. As a handy alternative, we propose a simple semi-separation-independent test with asymptotically vanishing probability of making an error.

Photonic Quantum Technologies: From Integrated Quantum Devices to Designing Large Complex System

Christine Silberhorn

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Quantum technologies promise a change of paradigm for many fields of application, for example in communication systems, in high-performance computing and simulation of quantum systems, as well as in sensor technology. Current efforts in photonic quantum science target the implementation of practical devices and scalable systems, where the realization of quantum devices for real-word deployment and controlled quantum network structures is key for many applications.

Here we present our work on three different fields in this area: non-linear integrated quantum optics, pulsed temporal modes and photonic quantum computation.

Double-Slit Interference with Multimode NOON States

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The geometric phase is a universal physical concept that stems from the curvature of the underlying parameter space. In optics, the geometric phase may arise from the change in the polarization state, with numerous applications in advanced light manipulation. The continuously changing polarization state and associated geometric phase were recently considered for coherent classical light and single-photon quantum light in double-slit interference. So-called NOON states, however, can offer N times higher phase sensitivity in interferometry compared to classical light and single-photon states, with benefits in quantum metrology, imaging, and sensing. Here, we explore theoretically the polarization properties and geometric phase of multimode NOON states in double-slit interference. Based on Nth-order coherence functions and Stokes parameters, we especially show that multimode NOON states exhibit N times faster polarization modulation and geometric phase accumulation than coherent and single-photon states. The findings also reveal a link between higher-order wave-particle duality and geometric phase.

Poster Presentations

Building Fault-Tolerance with Unreliable Quantum Circuits

Huyen Do, and Alexandru Paler

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Achieving computational fault-tolerance requires controlling the propagation of errors. To this end, fault-tolerance has been proposed using quantum circuits with regular structures. However, real quantum hardware often has missing qubits, low qubit connectivity, and non-uniform qubit error rates, making practical fault tolerance challenging to achieve. We build on recent methods for achieving fault tolerance despite irregular hardware characteristics and present a semi-automatic co-design method for implementing quantum error-correcting codes from circuits that, independently, would not be fully considered fault-tolerant. We provide numerical evidence demonstrating the practicality and scalability of our approach.

Generalized Angle-Orbital-Angular-Momentum Talbot Effect and Modulo Mode Sorting

Matias Eriksson[1], Jianqi Hu[2], Sylvain Gigan[2], and Robert Fickler[1]

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Control of periodic structures in different degrees of freedom (DoF) of waves will enable novel research and technological prospects. One useful tool for such control is the Talbot effect – a self-imaging effect that occurs when a wave is periodic in one DoF, and a quadratic phase is applied in its corresponding Fourier domain. By a recent extension known as the generalized Talbot effect, a combination of the self-imaging effects in both Fourier-connected DoFs, arbitrary control of field periodicities can be realized.

We experimentally demonstrate the generalized Talbot effect in the azimuthal angle- and orbital angular momentum DoFs for versatile control of light in both domains. Utilizing ring-core fibers and phase plates, we showcase the scheme by performing conversions between fields consisting of different numbers of equidistant angular petals, or equivalently, the corresponding OAM spectral combs. Further, we explore a novel application of the effect as a modulo OAM sorter with theoretically zero crosstalk – a useful addition to the optical toolbox to control light in all its DoFs.

Polarization of Quantized Light under Lorentz Transformations

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The fundamental laws of electrodynamics – Maxwell's equations – are invariant under Lorentz transformations. However, since the electromagnetic field components change in such relativistic transformations, observers moving relative to each other at a constant velocity will generally perceive different states of polarization. Moreover, any polarization state involves unavoidable quantum fluctuations due to the noncommutative Stokes operators, i.e., the quantum counterparts of the classical Stokes parameters. Here we explore the polarization properties of quantized light fields under Lorentz transformations. We especially derive analytical expressions for the Lorentz-transformed Stokes operators and their associated uncertainty relations for three specific field types: plane wave, spherical wave, and dipole radiation. It is further demonstrated how the transformed quantum polarization fluctuations depend on the velocity when the field in the rest frame is in a coherent state and a number state. Besides providing fundamental insights into relativistic quantum polarization effects, our work could find use in high-precision astropolarimetry.

Infrastructure for Quantum Communication and Testing and Experimentation for Quantum Technologies in Finland

Kalle Hanhijärvi, Kari Seppänen, Antti Manninen, Pekka Koskela, Sami Lehtonen, Anssi Lintulampi, and Sara Nikula

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VTT participates actively in EU-funded endeavors in developing and deploying infrastructure for quantum communication and open testing and experimentation in quantum technologies. Recent activities in National Quantum Communication (NaQCI.fi) and open testing and experimentation (Qu-Test) projects are presented with an emphasis on progress in practical quantum key distribution (QKD) links and devices as they are currently deployed at VTT's testing facilities.

In addition to deploying and developing practical infrastructure, the quantum communication and quantum technology testing projects aim to facilitate quick growth in national and European competence in these fields.

Quantum Uncertainty of Optical Coherence

Martti Hanhisalo[1], Mohammad Sajjad Mirmoosa[1], Tero Setälä[1], Łukasz Rudnicki[1,2], and Andreas Norrman[1]

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Light is known to show quantum uncertainty via its several fundamental properties, such as amplitude, phase, spectrum, and polarization. Here, we discover and formulate an unexplored manifestation of light's quantum uncertainty in the form of optical coherence. We especially focus on the first-order coherence of the arguably simplest possible light field, a purely monochromatic plane wave, being classically fully coherent. Starting from a scalar treatment, we show that the field exhibits coherence uncertainty due to the underlying photon number fluctuations. Hence, the coherence uncertainty vanishes only for a number state. We then proceed to derive coherence uncertainty relations for vectorial light. In particular, we show that for any state such light always possesses unavoidable quantum coherence fluctuations, which depend both on the polarization properties and on the space-time points. Our work hence reveals uncharted quantum aspects of light in terms of optical coherence uncertainty.

Study of Quantum Szilard Engine for Non-Interacting Bosons in Fractional Power-Law Potentials

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In this article, we have realized the quantum Szilard engine (QZE) for non-interacting bosons. We have adopted the Bose–Einstein statistics for this purpose. We have considered fractional power law potential for this purpose and have used the artifact of the quantization of energy. We have calculated the work and the efficiency for non-interacting bosons in fractional power potential. We have shown the dependence of the number of particles for the work and the efficiency. We also have realized the QZE for a single-particle in a Morse potential revealing how the depth of the potential impacts both work and efficiency. Furthermore, we have examined the influence of temperature and the anharmonicity parameter on the work. Finally, we have conducted a comparative analysis, considering both non-interacting bosons in a fractional power law potential and a single-particle in a Morse potential under harmonic approximation conditions.

High-Dimensional Interface for Multi-Mode Waveguides

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Optical waveguides are used in a wide range of applications, e.g. optical fiber communications and integrated photonic circuits, which are crucial for high-speed data processing and telecommunications. Here, multi-mode waveguides are of particular interest as they allow for enhanced data rates through mode multiplexing. On the other hand, transverse spatial modes like Laguerre-Gauss and Hermite-Gauss are widely considered as promising candidates when multi-mode light needs to be transmitted through free space. Therefore, developing a multi-modal device that efficiently interfaces free space modes with waveguide modes would significantly benefit optical telecommunications.

Tailoring Carbene-Metal-Amides for Thermally Activated Delayed Fluorescence: A Computationally Guided Study on the Effect of Amide Ligand

Nguyen Le Phuoc[1], Alexander Romanov[2], and Mikko Linnolahti[1]

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Carbene-metal-amides (CMAs) enabling thermally activated delayed fluorescence (TADF) have emerged as a promising class for emitter materials in OLED devices. To uncover the comprehensive understanding of structure-property relationships governing the photoluminescence characteristics of CMAs, we conducted a systematic computational investigation of the influence of amide structure on photoluminescence properties. Various structural motifs, including modified carbazoles, expanded ring systems, indole and carboline derivatives, and guanidine-based amides, were designed and calculated by employing the well-known density functional theory. Our findings reveal that precise control over emission color could be achieved through the strategic modification of amide ligand, with S1 energy varying from 2.38 eV to 3.91 eV, encompassing the visible spectrum and therefore offering pathways to efficient red, green, and blue emitters. Moreover, such complexes exhibit efficient TADF behavior when a compromise is attained between key parameters, including HOMO-LUMO overlap integral, energy gap between S1 and T1 states, and oscillator strength coefficient.

Linear Optical Properties of Organic Microcavity Polaritons with Non-Markovian Quantum State Diffusion

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Strong light-matter interactions in organic microcavities result in hybrid light-matter states called polaritons. To improve our understanding of polariton dynamics, we introduce a new method for computing the linear optical properties of organic microcavity polaritons. We calculate the electric susceptibility of the system using non-Markovian quantum state diffusion. The transfer matrix method can then be used to calculate the absorption, reflectivity, and transmission spectra. We fit the absorption spectrum of the bare molecules to experimental data to extract parameters for the molecules. Then we use these parameters for the whole cavity system and fit the calculated reflectivity spectrum to experimental data. The height and the location of the polariton peaks in the computed reflectivity spectrum match with those in the experimental data within the estimated error for small angles of the incoming light. For high angles, the positions of the polariton peaks remain within the error.

Machine Learning Message-Passing for the Scalable Decoding of QLDPC Codes

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We present Astra, a novel and scalable decoder using graph neural networks. Our decoder works similarly to solving a Sudoku puzzle of constraints represented by the Tanner graph. In general, Quantum Low Density Parity Check (QLDPC) decoding is based on Belief Propagation (BP, a variant of message-passing) and requires time intensive post-processing methods such as Ordered Statistics Decoding (OSD). Without using any post-processing, Astra achieves higher thresholds and better logical error rates when compared to BP+OSD, both for surface codes trained up to distance 11 and Bivariate Bicycle (BB) codes trained up to distance 18. Moreover, we can successfully extrapolate the decoding functionality: we decode high distances (surface code up to distance 25 and BB code up to distance 34) by using decoders trained on lower distances. Astra+OSD is faster than BP+OSD. We show that with decreasing physical error rates, Astra+OSD makes progressively fewer calls to OSD when compared to BP+OSD, even in the context of extrapolated decoding. Astra(+OSD) achieves orders of magnitude lower logical error rates for BB codes compared to BP(+OSD).

Towards Structured Beams of Low-Energy Electrons and Ions

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Creating and manipulating coherent electron and ion beams is a crucial challenge in quantum applications such as microscopy, interferometry, and metrology. Metallic nanotips with a counter electrode generate strong electric fields, leading to electron emission through field emission. The field strength at the tip depends on its geometry, with higher voltages producing faster electrons. However, our goal is to work with low-energy electrons (~5 keV). Unlike typical microscopes, our approach focuses on both low-energy electrons and ions using a field emission/gas field ion source. Microchannel plates (MCP) and field ion microscopy (FIM) will study the source properties, while a cryogenic system will cool the nanotips below 10 K to enhance beam brightness and coherence. To shape the matter wave, electrostatic or magnetic elements will impart structured features, such as orbital angular momentum, which will be recorded using a high-resolution spatial detector. This setup will benefit coherence and wavefront property investigations, with applications in fundamental science and sensor technology.

Propagation of Optical Vortex Constellation

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Optical vortex beams with different topological orders are crucial for addressing fundamental optical physics questions and have diverse applications, such as in microscopy, lithography, and quantum information. However, generating ideal high-order vortex beams is impossible due to device limitations, resulting in constellations of unit charge vortices concentrated at the beam's center. Therefore, to study high-order optical vortices, understanding their behavior and propagation is essential. This work experimentally explores the free-space propagation of such optical vortex constellations, presenting mathematical formalism and initial results as a foundation for deeper understanding and possible future applications.

On the Constant Depth Implementation of Pauli Exponentials

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We decompose for the first time, under the very restrictive linear nearest-neighbour connectivity, ZZ...Z exponentials of arbitrary length into circuits of constant depth using O(n) ancillae and two-body XX and ZZ interactions. Consequently, a similar method works for arbitrary Pauli exponentials. We prove the correctness of our approach, after introducing novel rewrite rules for circuits which benefit from qubit recycling. The decomposition has a wide variety of applications ranging from the efficient implementation of fault-tolerant lattice surgery computations, to expressing arbitrary stabilizer circuits via two-body interactions only, and to reducing the depth of NISQ computations, such as VQE.

Faking Entanglement with Undetectable Errors

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Quantum technologies rely on two key principles: entanglement, which confers properties to states without classical counterparts, and the exponential scaling of information capacity with system dimensionality. Consequently, realizing systems capable of handling high-dimensional entangled states (HDES) with high fidelity is crucial for fully exploiting quantum mechanics. However, experimental noise and errors degrade entanglement witnesses, with this effect being more pronounced in high-dimensional states, making entanglement verification for HDES more challenging. In this work, we propose a protocol to show that entanglement can be faked by introducing artificial errors within the range of experimental noise, rendering perturbations in the measurement scheme difficult for users to detect. The scheme is experimentally implemented using a prepare-and-measure approach with spatial modes of light. Furthermore, we show that smaller errors are sufficient as the system's dimensionality increases, showing that it is more feasible to manipulate high dimensional systems.

Real-Time Spatial Field Measurement in Multimode Fibers

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Here, we perform for the first time single-shot spatial full-field measurements of self-cleaning dynamics in graded-index (GRIN) MMFs using a real-time off-axis holography. Our results shows that self-cleaning arises from the spectral broadening induced by self-phase modulation.

Electronic Transport of the Topological Insulator Edge States in the Proximity of the Quantum Spin Spiral

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Topological insulators (TIs) have been drawing significant interest due to the unique properties of the edge or surface states such as time-reversal symmetry protection and spin-momentum locking which have a great potential for topological quantum computing and spintronics. However, it is still challenging to control electronic transport provided by the topological states and to unambiguously observe the contribution of the topological states to the total conductance in experiments. Here, we study the transport properties of the system consisting of a 2DTI nanoribbon with non-magnetic random disorder and two quantum spin spirals (QSSs) on its edges. We present a formula for the effective transport band gap arising in a band structure of the edge states as a function of the disorder and QSSs magnetization strengths and a characteristic wavevector of the QSSs. Our findings show that a proximity effect from the QSSs provides an efficient way to control the electronic transport of topological edge states.

Ghost Imaging in the Mid-Infrared Range

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In the concept of ghost imaging, the image of a sample is formed by detecting two correlated optical beams: the test beam passing through the sample is detected by a single-pixel detector, while the reference beam is detected by a camera with a high spatial resolution. The image appears in the correlation function of the two recorded data sets and relies on strong spatial correlations between the test and reference beams.

Ghost imaging technique attract much attention due to their inherent insensitivity to the distortion that may occur between the object and the single-pixel detector, allowing one to form high-resolution images in a strongly scattering medium, i.e. in optical coherence tomography or ultra-high frequency signal transmission.

Ghost imaging based on photon pairs admits dual-color imaging with a reference beam at a visible range and the infrared test beam. Reference beam can be observed with high quantum efficiency and resolution silicon detectors.

Joint qubit observables induced by indirect measurements in cavity QED

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A fundamental feature of quantum mechanics is that there are observables which can be measured jointly only when some noise is added to them. Their sharp versions are said to be incompatible. We investigate time-continuous joint qubit observables induced by a indirect time-continuous measurements. In particular we study a paradigmatic situation where a qubit is interacting with a mode of light in a cavity and the light escaping the cavity is continuously monitored. We find that the properties of the qubit observables can be tuned by changing the type of the monitoring scheme or by tuning the initial state of the cavity. We observe that homodyning two orthogonal quadratures produces an optimal pair of biased jointly measurable qubit observables.

Simulating the dynamics of quantum dots using hierarchy of pure states

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This poster presents findings from my master's thesis, which focused on the implementation of the hierarchy of pure states (HOPS) method to simulate the dynamics of quantum dots. Quantum dots are tiny semiconductor structures with unique optical properties, enabling applications such as single-photon sources and potential qubits in quantum computing. The HOPS method effectively simulates the linear absorption and resonance fluorescence spectra and demonstrates its utility even in challenging parameter regimes.

Open Quantum System Modeling of Optically Trapped Nanoparticles

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We developed an open quantum system model for a levitating nanoparticle trapped in an optical cavity by external optical tweezers. The model consists of two interacting harmonic oscillators, the particle and the cavity, which interact with each other. By studying the quantum properties of a relatively large particle in a highly controlled environment we aim to bridge the gap between quantum and classical physics.

We first derived the Gorini-Kossakowski-Sudarshan-Lindblad (GKSL) master equation for the density matrix our system, and the corresponding quantum state diffusion (QSD) equation for pure states. From these equations, we solved the parameters of an ansatz state, and calculated the time dependent norm of the state and the expectation values for creation, annihilation, and number operators of both oscillators as functions of the parameters.

Keywords: Open Quantum System, Quantum Optics, Optomechanics, Optical Trapping, Levitodynamics"

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