KOBIT |7>

ESKİŞEHİR TEKNİK ÜNİVERSİTESİ
ESKİŞEHİR TECHNICAL UNIVERSITY

QUANTUM OPTICS & INFORMATION MEETING

KOBIT |7>

INVITED SPEAKERS:

- **ALİ ALHUN**
  Harvard University
- **ALİ BOZBEY**
  TOBB University of Economics and Technology
- **AVIJIT MISRA**
  The Weizmann Institute of Science
- **BULAT RAMEEV**
  Gebze Technical University
- **DENİZ AYBAŞ**
  University of California Berkeley
- **GIACAMO GUARNIERI**
  Freie Universitat Berlin
- **HALİDUN FİLDİŞ**
  Aselsan
- **MAURO PATERNOSTRO**
  Queen's University Belfast
- **OĞUZ GÜLSEREN**
  Bilkent University
- **SHANE P. KELLY**
  Johannes Gutenberg University Mainz

KoçDigital

QUBITRIUM

SCIENTIFIC BOARD:

- ABDULLAH VERÇİN
- ALPAN BEK
- AZİZ KOLKIRAN
- A. LEVENT SUBAŞI
- CEYHUN BULUTAY
- HÜMEYRA ÇAĞLAYAN
- KADİR DURAK
- M. ALİ CAN
- M. EMRE TAŞGIN
- M. ÖZGÜR OKTEL
- M.ZAFER GEDİK
- NADİR GHAZANFARİ
- ÖZGÜR ÇAKIR
- ÖZGÜR E. MÜSTECAPLIOĞLU
- R. ONUR UMUCALILAR
- SADİ TURGUT
- SERKAN ATEŞ
- SEVİLAY SEVİNÇLİ

ORGANIZATION BOARD:

- CEM YÜCE
- FERİDUN AY
- NİHAN KOSKU PERKGÖZ
- NESLİHAN ŞAHİN
- ÖZGE BAĞLAYAN
- SEÇİL ŞENTORUN

www.kobit.org.tr

ORAL PRESENTATION

Quantum neuromorphic approach for efficient sensing of gravity-induced entanglement

Mauro Paternostro
Queen's University Belfast, Northern Ireland
m.paternostro@qub.ac.uk

The detection of entanglement provides a definitive proof of quantumness. Its ascertainment might be challenging for hot or macroscopic objects, where entanglement is typically weak, but nevertheless present. I will discuss a platform for measuring entanglement by connecting the objects of interest to an uncontrolled quantum network, whose emission (readout) is trained to learn and sense the entanglement of the former. First, I will demonstrate the platform and its features with generic quantum systems. As the network effectively learns to recognise quantum states, it is possible to sense the amount of entanglement after training with only non-entangled states. Furthermore, by taking into account measurement errors, I demonstrate entanglement sensing with precision that scales beyond the standard quantum limit and outperforms measurements performed directly on the objects. Finally, I will utilise such platform for sensing gravity-induced entanglement between two masses and predict an improvement of two orders of magnitude in the precision of entanglement estimation compared to existing techniques.

Why optical properties of 2D materials are interesting?

Mahsa Seyedmohammadzadeh(1), Cem Sevik(2,3) and **Oğuz Gülseren**(1,4)

[1]Department of Physics, Bilkent University, Ankara 06800, Turkey,
[2]Department of Mechanical Engineering, Faculty of Engineering, Eskisehir Technical University, Eskisehir, TR 26555, Turkey,
[3]Department of Physics & NANOlab Center of Excellence, University of Antwerp, Groenenborgerlaan 171, B-2020 Antwerp, Belgium,
[4]TUBITAK Research Institute for Fundamental Sciences, 41470 Gebze, Turkey.

gulseren@fen.bilkent.edu.tr

Experimental fabrication of two dimensional carbon allotrope named as graphene has started a new era in materials science as well as nanotechnology. Two dimensional (2D) materials acquire exceptional properties distinctive from their bulk phases which make them promising candidates in vast range of device applications depending on their electronic, optical, mechanical and magnetic properties. Usually, identifying the application of these unexplored materials starts with investigating properties of new classes of 2D materials by theoretical prediction, which eventually lead to experimental fabrication.

Theoretical investigations of optical properties of 2D materials are one of the most challenging study, because accurate predictions are only possible by using methods beyond the standard density functional theory (DFT) and it is necessary to consider the electron-hole coupling and excitonic effects. Previous reports on optical properties of the materials considered here, are limited and mostly based on standard DFT calculations. Here we investigate the electronic structure, optical properties and exciton spectrum of selected 2D Group II-VI monochalcogenides materials, by considering many-body effects explicitly, through G_0W_0 approximation and by solving Bethe–Salpeter equation. Furthermore, due to the enriched functionalities resulting from combining different properties of separate monolayers, van der Walls heterostructures (vdWHs) are considered a revolutionary class among the plethora of currently fabricated or predicted two-dimensional materials. Motivated by the flourishing properties of lateral heterostructures, we systematically investigated four different heterostructures assembled by binary hexagonal monolayers of ZnO and MgO. It is demonstrated that strong excitonic effects reduce the optical band gap to the visible light spectrum range.

Superconducting Electronics for Qubit Control and Read-out

Ali Bozbey[1], Sasan Razmkhah[2], Pascal Febvre[3]
[1] Electrical and Electronics Engineering, TOBB University of Economics and Technology, Ankara, Turkey
[2] University of Southern California, Ming Hsieh Department of Electrical and Computer Engineering, Los Angeles, USA.
[3] IMEP-LAHC, University Savoie Mont-Blanc, 73376 Le Bourget du Lac, France

With the recent advances of superconducting qubits, it is now possible to develop quantum computers with hundreds of qubits. However, one of the main limiting factors in scaling the quantum computers to million qubits, is read-out and control electronics. One promising solution would be to integrate energy-efficient superconductor circuits close to the quantum chip to perform pre-processing tasks with orders of magnitude lower power consumption. This results in lower noise, to reach ultimate performance at cryogenic temperatures as well as decrease the complexity of wiring. In this talk, current state of the qubit control based on superconducting electronics will be summarized and our proposal that utilizes single flux quantum (SFQ) and adiabatic quantum flux parametron (AQFP) circuits to implement cryogenic qubit readout and control circuits will be presented. We have designed a superconductor-based function generator that can modulate the generated signal at tens of GHz, based on the input waveform applied to the mixer stage. Proposed device works at 4.2K and the signal is transmitted by a matching circuit to the ~mK stage.

Thermodynamics of Precision in quantum thermal machines: theory and experiment

Giacomo Guarnieri
Dahlem Center for Complex Quantum Systems, Freie Universität Berlin
giacomo.guarnieri@fu-berlin.de

Understanding and controlling microscopic quantum devices represents a major milestone. Their precision is related to the fluctuations of their measurable output, an aspect that becomes preponderant at the nano-scale. Achieving a regime where the machine operates at a given reliability/precision inevitably comes at a cost in terms of thermodynamic resources, such as dissipated heat or excess work, thus massively impacting the machines' performances. Thermodynamic Uncertainty Relations (TURs) have represented a landmark first step in understanding this balance, as they express a trade-off between precision, defined as the noise-to-signal ratio of a generic current, and the amount of associated entropy production. These results have deep consequences for quantum thermal machines, imposing an upper bound for their efficiency in terms of the power yield and its fluctuations. Such engines can be divided into two classes: steady-state heat engines and periodically driven heat engines. In this talk I will present and discuss the derivation of genuinely quantum corrections to TURs in both cases, which were obtained by combining techniques from quantum information theory and thermodynamics of geometry. Finally, I will report on an experimental measurement of such quantum correction in a trapped-ion experiment .

Strongly Coupled MW-Magnon Systems for Potential Applications in Quantum Frequency Conversion

Bulat Rameev[1,2,3*]
[1]Physics Department, Gebze Technical University, Gebze, Kocaeli, Turkey
[5]Kazan State Power Engineering University, Kazan/Tatarstan, Russian Federation
[4]Zavoisky Physical-Technical Institute – Subdivision of the FRC "Kazan Scientific Center of Russian Academy of Sciences", Kazan/Tatarstan, Russian Federation
rameev@gtu.edu.tr

Strong and ultra-strong coupling between microwave (MW) photons and magnons has attracted much research attention as a phenomenon interesting from the point of view of basic physics as well as due to its potential applications for quantum frequency converters (transducers) and quantum memories. Initially, most of the studies on the photon-magnon interaction have been done in the system formed by Yttrium Iron Garnet (YIG) material and a 3D MW resonator. It has been shown that various coupling regimes (strong or ultra-strong) between the YIG and microwave resonator can be realized and strong coupling between MW photons and magnons may be treated as a formation of the Cavity-Magnon-Polariton (CMP) [1]. Recently, the focus of researchers has shifted from volume (3D) resonators to planar (2D) ones. Novel physics observed is believed to provide a platform for the realization of many non-trivial applications in quantum information and sensing [2].

In this talk, the state of the art of strongly coupled MW-magnon systems will be briefly reviewed. I will also introduce approaches to model these systems and demonstrate their applicability to the various configurations. I will also show that Finite Element Method (FEM) simulations of the hybrid MW-magnon system consisting of planar MW resonators and YIG crystals are possible, providing a powerful tool for analysis of the experimental configuration with sizes much larger than the exchange length. Examples of experimental realization of the ultra-strong coupling regime between the planar resonator and magnetostatic resonance modes of YIG crystals of various shapes will be also given.

[1] B. Bhoi, S.-K. Kim, Roadmap for photon-magnon coupling and its applications, Solid State Physics vol.71 (Ed: R.L. Stamps), 39-71 (2020).
[2] C. Bonizzoni, M. Maksutoglu, A. Ghirri, J. van Tol, B. Rameev & M. Affronte. Coupling Sub-nanoliter BDPA Organic Radical Spin Ensembles with YBCO Inverse Anapole Resonators. Appl. Magn. Reson. **54**, 143–164 (2023).

Quantum sensors for precision magnetometry

Deniz Aybaş
Department of Physics, University of California, Berkeley
aybas@bu.edu

Magnetometers are used for measuring magnetic properties of materials and fundamental particle searches with particle physics experiments, as well as for broader applications in chemistry, geophysics, and biomedicine. Quantum sensors operating under principles such as quantum interference effects and optical pumping are used in precision magnetometers with competitive sensitivities at radio frequencies.

In this talk, I will present our work with two types of precision magnetometers, one based on nuclear magnetic resonance (NMR) with hyperpolarized atoms in liquid or solid-state samples and quantum sensors based on Josephson junctions in cryogenic temperatures [1,2], and one based on optical pumping of noble gas atoms and measuring polarization of a probe light beam without requiring cryogenic cooling [3]. I will explain how we used these magnetometers to search for a new particle called axion as a candidate for the dark matter, and how their use can be expanded to searches for the electric dipole moment, fifth force, or magnetic monopoles, as well as for applications in novel NMR and magnetic resonance imaging devices.

[1] A. Garcon, et al., Quantum Sci. Technol. **3**, 014008 (2018).
[2] D. Aybas, et al., PRL **126**, 141802 (2021).
[3] S. Afach, et al., Nature Physics **17**, 1396-1401 (2021).

Coherent state picture of charge carrier-lattice vibration dynamics

Alhun Aydin
Department of Physics, Harvard University, USA
Department of Physics, Koç University, Turkey
alhunaydin@fas.harvard.edu

We develop the coherent state description of lattice vibrations to model their interactions with charge carriers. In direct analogy to quantum optics, the coherent state picture leads from quantized lattice vibrations (phonons) naturally to a quasi-classical field limit, i.e., the deformation potential. To an carrier, the deformation field is a sea of hills and valleys, as "real'' as any external field, morphing and propagating at the sound speed, and growing in magnitude with temperature. In this disordered potential landscape, the carrier dynamics is treated nonperturbatively, preserving their coherence beyond single collision events. We solve the dynamics of a carrier under the deformation potential by using wave packet propagation methods. We show the coherent state picture agrees exactly with the conventional Fock state picture in perturbation theory. Furthermore, it goes beyond by revealing new aspects that the conventional theory could not explain: transient localization even at high temperatures by charge carrier coherence effects. The coherent state paradigm of lattice vibrations supplies new tools for probing important questions in condensed matter physics as in quantum optics.

Scrambling Transition in a Radiative Random Unitary Circuit

Shane Kelly
Johannes Gutenberg University Mainz
shakelly@uni-mainz.de

We study quantum information scrambling in a random unitary circuit that exchanges qubits with an environment at a rate p. As a result, initially localized quantum information not only spreads within the system, but also spills into the environment. Using the out-of-time-order correlator (OTOC) to characterize scrambling, we find a nonequilibrium phase transition in the directed percolation universality class at a critical swap rate pc: for p<pc the ensemble-averaged OTOC exhibits ballistic growth with a tunable light cone velocity, while for p>pc the OTOC fails to percolate within the system and vanishes uniformly after a finite time, indicating that all local operators are rapidly swapped into the environment. The transition additionally manifests in the ability to decode the system's initial quantum information from the swapped-out qubits: we present a simple decoding scheme which recovers the system's initial information with perfect fidelity in the nonpercolating phase and with continuously decreasing fidelity with decreasing swap rate in the percolating phase. Depending on the initial state of the swapped-in qubits, we observe a corresponding entanglement transition in the coherent information into the environment.

Work extraction from thermal noise by measurements and nonlinear interactions in quantum optical setups

Avijit Misra
The Weizmann Institute of Science
avijit.misra@weizmann.ac.il

In this talk, I will try to elucidate the rapport of work and information in the context of a minimal quantum mechanical setup. Specifically, I will talk about a converter of heat to work wherein the input consists of a single oscillator mode prepared in a hot thermal state along with few colder oscillator modes. I will compare the efficiencies of work extraction and the limitations of power in reversible manipulations and different, generic, measurement strategies in our minimal setup. I will demonstrate that extraction of work by observation and feedforward (WOF) that only measures a small fraction of the input, is clearly advantageous to the conceivable alternatives, by generalizing a method based on optimized homodyning. However, the main drawback of work extraction by measurement is it inevitably requires feedforward and outcome dependent control steps. To circumvent this, I will briefly discuss autonomous, coherent work extraction exploiting non-linear cross-Kerr interaction. Our results may become a basis of a practical strategy of converting thermal noise to useful work in optical setups, such as coherent amplifiers of thermal light, as well as in their optomechanical and photovoltaic counterparts.

[1]Phys. Rev. Lett. 127 (4), 040602 (2021).
[2] Phys. Rev. E 106 (5), 054131 (2022).
[3] Science Advances 9 (1), eadf1070 (2023).

Quantum Technologies In ASELSAN Research Center

Halidun Fildiş
Aselsan

Quantum technologies have been moving from laboratory to practical applications with potentially disruptive advantages over classical sensors, computers and communication protocols. In this talk, Research and Development activities in ASELSAN Research Center will be given with emphasis on quantum technologies. Current research areas in ASELSAN quantum technologies research laboratory (KUANTAL) will be summarized.

Security and Software Perspectives in Quantum Digital Transformation

Özgür Müstecaplıoğlu

Koç University

omustecap@ku.edu.tr

As the hardware of quantum technologies are getting closer to industrial scales of interest, there are still significant challenges against quantum sensors and quantum communication devices in real environments as well as against error-free quantum computation systems. On the other hand, there is immediate window of opportunity in utilizing existing intermediate, noisy, quantum hardware at their limits, which could be still advantageous relative to their classical counterparts. Such an opportunity could be partly exploited by developing efficient quantum software or software interfaces between quantum and classical computers or devices. At the same time, if in near or some future, quantum computers could reach to capacity to pose a real threat to current cryptology systems,,then one can search for improved, so-called post-quantum cryptology algorithms, which are entirely classical. Again, it is argued that it is a good time to start such a preparation right now. In this talk, we will overview the technological and industrial landscape of quantum security and software technologies, including some predictions about the future potential of and challenges against them.

Experimental Demonstration of Red-detuned Excitation of a Quantum Emitter

Yusuf Karlı [1], Florian Kappe [1], Vikash Remesh [1], Thomas Bracht[2], Julian Münzberg [1], S. Covre da Silva [3], Tim Siedelmann [4], Vollrath Martin Axt [4], Armando Rastelli [3], Doris Reiter[2], Gregor Weihs [1]

[1] Institut für Experimentalphysik, Universität Innsbruck, Innsbruck 6020, Austria
[2] Condensed Matter Theory, Department of Physics, TU Dortmund, Germany
[3] Institute of Semiconductor and Solid State Physics, Johannes Kepler University, Austria
[4] Theoretische Physik III, Universität Bayreuth, Bayreuth 95440, Germany

yusuf.karli@uibk.ac.at

In this work, we use two red-detuned pulses in the recently proposed [1] swing-up of quantum emitter population (SUPER) scheme to excite a quantum dot. It is rather surprising that this is possible at all, because neither of the two pulses alone will yield a significant exciton occupation. The SUPER scheme uses the coherent coupling of two laser fields to a quantum emitter to swing-up the system to full inversion. The decisive advantage over the dichromatic scheme is that both pulses are red-detuned and therefore, no higher-lying states of the quantum dot will be directly addressed. Because it operates below the band gap but yet coherently. We experimentally demonstrate that, under optimized detuning and intensity, a red-detuned, phase-locked pulse pair can populate the exciton state in a quantum dot relying on the Swing UP mechanism.[2] We also perform photon quality measurements and contrast the results with that of resonant excitation. Our results contribute towards an effortless method for generating high purity single photons, with the proof-of-concept performance on par with the resonant excitation scheme, yet most importantly, removing the need for stringent polarization filtering.

[1] Bracht et al, PRX Quantum 2, 040354 - DOI: 10.1103/PRXQuantum.2.040354
[2] Karli et al, Nano Letters 2022 22 (16), 6567-6572 - DOI: 10.1021/acs.nanolett.2c01783

Witnessing superpositions of causal orders by weak measurements at a given time

Onur Pusuluk [1], Zafer Gedik [2], Vlatko Vedral [3]
[1] Department of Physics, Koç University, İstanbul, Türkiye
[2] Faculty of Engineering and Natural Sciences, Sabancı University, İstanbul, Türkiye
[3] Department of Physics, University of Oxford, Oxford, UK

onur.pusuluk@gmail.com

The questions we will raise in this talk are as follows: What is the most general representation of a quantum state at a single time? Can we adapt the current representations to scenarios [1] where the order of quantum operations is coherently or incoherently superposed? If so, what is the relation between the state at a given time and the uncertainty in the order of events before and after it? By establishing the relationship of two-state vector formalism [2] with pseudo-density operators [3], we will introduce the notion of single-time pseudo-state which can be constructed by either ideal or weak [4] measurements. We will show that the eigenspectrum in the latter case enables us to discriminate between the coherent and incoherent superpositions of causal orders in which the pre- and post-selection measurements are interchanged with a non-zero probability [5]. Finally, we will discuss some of the possible experimental realizations in existing photonic setups.

[1] O. Oreshkov, F. Costa, Č. Brukner, Nat. Commun. 3, 1092 (2012); G. Chiribella et al., Phys. Rev. A 88, 022318 (2013).
[2] Y. Aharonov and L. Vaidman, J. Phys. A: Math. Gen. 24, 2315-2328 (1991); R. Reznik and Y. Aharonov, Phys. Rev. A 52, 2538 (1995).
[3] J.J. Fitzsimons, J. Jones, V. Vedral, Sci. Rep. 5, 18281 (2016); Z. Zhao et al., Phys. Rev. A 98, 052312 (2018).
[4] Y. Aharonov, D.Z. Albert, L. Vaidman, Phys. Rev. Lett. 60, 1351 (1988); Y. Aharonov and L. Vaidman, Phys. Rev. A 41, 11 (1990).
[5] O. Pusuluk, Z. Gedik, V. Vedral, arXiv:2209.09172 [quant-ph] (2022).

Can the human eye detect multipartite entangled state?

Lea Gassab

Koç University

lgassab20@ku.edu.tr

We propose a detection scheme for bipartite and tripartite entangled optical states based on a recent study (1). It was observed that the quantum noise can be too significant to obtain conclusive results for higher-order entanglement. This scenario can be remedied with the help of an amplitude squeezing operation instead of coherence generation before detecting the photons by the eye. For this purpose, firstly we use a two-photon interferometry setup (1) and a two-photon entanglement witness (2) to find out whether humans can perceive bipartite entanglement. Then, we generalize the interferometer for measuring three-photon W-state entanglement witness (3) in order to look at whether human subjects can detect such a multipartite entanglement. To perform a simulation with the associated psychophysical experimental conditions, the human subjects are modeled so as they will be probed as biological photodetectors. In the photodetection method, a revised version of the distribution of the "probability of seeing" is employed. It comes from physiological data originally proposed by Hecht et al except that effects of internal noise and experimental uncertainties are added. Finally, it can be deduced from our results that the tripartite entangled quantum light detection is dependent on the noise level and on the visual threshold.

[1] 10.1364/OPTICA.3.000473
[3] 10.1103/PhysRevA.101.062319
[3] 10.1103/PhysRevLett.92.087902

Using quantum states of light to probe the retinal network

Ali Pedram

Koç University

apedram19@ku.edu.tr

The minimum number of photons necessary for activating the sense of vision has been a topic of research for over a century. The ability of rod cells to sense a few photons has implications for understanding the fundamental capabilities of the human visual and nervous system and creating new vision technologies based on photonics. We investigate the fundamental metrological capabilities of different quantum states of light to probe the retina, which is modeled using a simple neural network. Stimulating the rod cells by Fock, coherent and thermal states of light, and calculating the Cramer-Rao lower bound (CRLB) and Fisher information matrix for the signal produced by the ganglion cells in various conditions, we determine the volume of minimum error ellipsoid. Comparing the resulting ellipsoid volumes, we determine the metrological performance of different states of light for probing the retinal network. The results indicate that the thermal state yields the largest error ellipsoid volume and hence the worst metrological performance, and the Fock state yields the best performance for all parameters. This advantage persists even if another layer is added to the network or optical losses are considered in the calculations.

Enantiomer detection via Quantum Otto cycle

Mohsen Izadyari
Koç University
mizadyari18@ku.edu.tr

Enantiomers are chiral molecules that exist in right-handed and left-handed conformations. Optical techniques of enantiomers detection are widely employed to discriminate between left- and right-handed molecules. However, identical spectra of enantiomers make enantiomer detection a very challenging task. Here, we investigate the possibility of exploiting thermodynamic processes for enantiomer detection. In particular, we employ a quantum Otto cycle, in which a chiral molecule described by a three-level system with cyclic optical transitions is considered a working medium. Each energy transition of the three-level system is coupled with an external laser drive. We find that the left-handed molecule works as a heat engine, while the right-handed molecule works as a thermal accelerator where the overall phase of the drives is considered as the cycle's control parameter. In addition, both left- and right-handed molecules work as heat engines by considering laser drives' detuning as the control parameter. However , the molecules can still be distinguished because both cases' extracted work and efficiency are quantitatively very different.Accordingly, left and right-handed molecules can be distinguished by evaluating the work distribution in the Otto cycle.

Low-temperature quantum thermometry boosted by coherence generation

Asghar Ullah, M. Tahir Naseem, and Özgür E. Müstecaplıoğlu

Department of Physics, Koç¸University, 34450 Sarıyer, Istanbul, Türkiye
TÜBITAK Research Institute for Fundamental Sciences, 41470 Gebze, Türkiye

aullah21@ku.edu.tr

Precise estimation of low temperature is a question of both fundamental and technological significance. We address this question by presenting a low-temperature measurement scheme with enhanced thermal sensitivity due to quantum coherence generation in a thermometer probe. Probes are expected to thermalize with the sample to be measured in typical temperature measurements. In our scheme, we consider a two-level quantum system (qubit) as our probe and forbid direct probe access to the sample by using a set of ancilla qubits as an interface. By deriving a global master equation to describe the open system dynamics of the probe, we show that while the whole ancilla-probe system thermalizes with the sample, the probe per se evolves under nonlocal dissipation channels into a non-thermal steady state whose populations and coherences depend on the sample temperature. We characterize the thermometric performance of the low-temperature measurement using quantum Fisher information, and we find that multiple and higher peaks at different low temperatures can emerge in the quantum Fisher information with increasing quantum coherence and the number of ancilla qubits. Our analysis reveals that using non-thermal quantum probes, specifically quantum coherence generation in a qubit thermometer by a multiple qubit interface between a thermal sample and the probe qubit, can enhance the sensitivity of temperature estimation and broaden the measurable low temperatures range.

[1] Ullah, Asghar, Naseem, M. Tahir and Müstecaplıoğlu, Özgür E. arXiv:2211.05461 (2022).

POSTER PRESENTATION

Quantum Frequency Conversion

Isa Ahmadalidokht, Alexander Ling

Centre for Quantum Technologies, National University of Singapore, 117543, Singapore
cqtisaa@nus.edu.sg

Distribution of entangled photons will enable the future quantum internet that can deliver improved security or sensing precision compared to using conventional technology. Building on existing investment in infrastructure, a natural choice for the quantum channel are optical fibres. However, intrinsic losses within fibres prevent very long-range networks; one way to enable global scale networks is via quantum communication satellites equipped with free space links. Furthermore, networks with moving nodes such as aircraft or drones will also require free space links. To date, most proof-of-concept free-space quantum communication experiments have used visible (VIS) or near-infrared (NIR) wavelengths. These demonstrations were most often carried out in the night where the noise due to solar radiation is avoided. Moreover, one needs to take care of urban background light as well. Therefore, it is imperative to look for solutions to supress the background solar or urban background light to enable daytime operation of the quantum network [1–4]. This can be achieved via careful mode engineering, or selection of appropriate wavelengths, such as the light in the O- or C-bands regularly used in fibre-based communication. A major advantage of using telecom wavelengths is the large number of commercial-off-the-shelf (COTS) components that could be used in building optical communication systems. Given the advantages of operating in the telecom bands, it may seem curious why these wavelengths are not already widely adopted in free-space entanglement distribution projects. The main reason why quantum engineers have avoided using telecom wavelengths is the fact that COTS single photon detectors in the telecom regime are not very effective. In this study we develop quantum receiver using frequency up-conversion to extend the Si based detector to telecom band while keep the noise level in Dark count rate and increase the detection efficiency and detection count rate.

Developing Digital Signatures Using Complex Numbers

Cumali Yaşar[1] ,Osman Semi Ceylan[1], **Elif Özceylan[2]**

[1]Çanakkale Onsekiz Mart Üniversitesi

[2]Arel Üniversitesi

cumali.yasar@gmail.com

An electronic signature, as defined generally[1], is a method of verifying the identity of the person signing a transaction. This is achieved through the use of a secure electronic signature creation tool that is at the disposal of the signer. Additionally, the signature must be able to be linked to the signer through a qualified electronic certificate. Furthermore, it must be possible to detect any changes made to the signed electronic data after the signature is applied. This is what is referred to as an electronic signature. In terms of historical process, this concept was first published by Diffie-Hellman and Martin Hellman in their article "New Direction in Cryptography"[2], the first public key cryptography and digital signature schemes. Rivest, Shamir and Adleman published the first digital signature scheme in the article “A method for obtaining digital signatures and public-key cryptosystems”. The digital scheme called "RSA" is the most widely used algorithm today.

Electronic signature and Digital certificate generation are produced with key pairs (Public and Private keys) based on mathematical one-way functions. In the use of a digital signature, each user has a binary number system, one private and one public key. It is based on modular mathematics. This is because it is a one-way function. The most distinctive feature of one-way functions is based on the difficulty of knowing the input value from the output value.

In general, key generation starts with the selection of two prime numbers as per the RSA algorithm and its implementation; Choose two very large prime numbers, P and Q. The product of these two prime numbers N = P.Q and their one missing φ(N)=(P-1) (Q-1) is calculated. A prime integer E is chosen between φ(N) greater than 1 and less than φ(N). The selected integer E is inverted in mod φ(N), the result is an integer like D. Integers E and N form the public key, and integers D and N form the private key[3].

[1] “E-imza ile İlgili Sıkça Sorulan Sorular - Bilgi Teknolojileri ve İletişim Kurumu”. https://www.btk.gov.tr/, 15 Aralık 2017.
[2] W. Diffie ve M. Hellman, “New directions in cryptography”, IEEE Trans. Inf. Theory, c. 22, sy 6, ss. 644-654, Kas. 1976, doi: 10.1109/TIT.1976.1055638.
[3] K. Verma, “RSA Algorithm mathematical explanation”, Medium, 07 Haziran 2019. https://54m4ri74n.medium.com/rsa-algorithm-mathematical-explanation-93f34ecef02a.

Steady-state entanglement of distant nitrogen vacancy centers in a coherent thermal magnon bath.

Kamran Ullah[1] , Emre Köse[2], Rawana Yagan[3], Mehmet C Onbaşlı4, Özgür E Müstecaplıoğlu[1]

[1]Department of Physics, Koç University, Türkiye

[2]Institut für Theoretische Physik, Eberhard Karls Universität Tübingen, Germany

[3]Department of Electrical and Electronics Engineering, Koç University, Türkiye

[4]Surface Science and Technology Center (KUYTAM), Koç University Türkiye

kullah19@ku.edu.tr

We study steady-state entanglement between two nitrogen-vacancy (NV) centers placed on an ultrathin Yttrium Iron Garnet (YIG) strip. We ignore the magnon's dephasing effect, and transform the bath into a multimode displaced thermal state by using external magnetic fields. An additional electric field is considered to manipulate the magnon dispersion relation and to control the Markovianity of the system. Furthermore, we analyze parameter regimes where displaced magnon bath can exhibits a notable steady-state entanglement against the local dephasing and decoherence of NV centers to their nuclear spin environments. Furthermore, we investigate the steady-state coherence, and explain its physical mechanism. We establish a non-monotonic relation between bath coherence and steady-state entanglement and determine the crucial coherence for maximum entanglement.

[1] H. P. Breuer and F. Petruccione, The Theory of Open Quantum Systems, Vol. 9780199213900 (Oxford University Press, Oxford, 2007), pp. 1–656.

[2] S. F. Huelga, A. Rivas, and M. B. Plenio, Non-Markovianity-Assisted Steady State Entanglement, Phys. Rev. Lett. 108, 160402 (2012).

[3] V. Eisler and Z. Zimborás, Entanglement negativity in the harmonic chain out of equilibrium, New J. Phys. 16, 123020 (2014).

Exceptional point induced optomechanical squeezing under synthetic gauge field control

Beyza Sütlüoğlu Ege and Ceyhun Bulutay
Physics Department, Bilkent University, Ankara, 06800
beyza.sutluoglu@bilkent.edu.tr

We theoretically study mechanical squeezing in a ternary system composed of an optical cavity and two parity-time (PT)-symmetric mechanical resonators having balanced gain and loss. The couplings among the cavity and mechanical resonators form a closed-contour interaction accompanied by a global phase. As the so-called exceptional point singularity introduced by the PT -symmetric scheme is approached in the parameter space, we observe an enhancement of optomechanical squeezing. This can be controlled by the closed-loop phase that acts as a synthetic gauge field. To further boost the amount of squeezing, an amplitude modulation is imposed over the cavity pumping laser. We use Floquet formalism to investigate the system's behavior remaining in the low modulation-depth regime. Due to potential instability to be caused by gain and modulation, we investigate the system's stability and the mechanical sector's root loci under a realistic range of parameters.

Neural-network quantum states for a two-leg Bose-Hubbard ladder under magnetic flux

Kadir Çeven[1], M. Özgür Oktel[1], and Ahmet Keleş[2]

[1] Department of Physics, Bilkent University, Ankara, 06800, Turkey
[2] Department of Physics, Middle East Technical University, Ankara, 06800, Turkey
kadir.ceven@bilkent.edu.tr

Quantum gas systems are ideal analog quantum simulation platforms for tackling some of the most challenging problems in strongly correlated quantum matter. However, they also expose the urgent need for new theoretical frameworks. Simple models in one dimension, well studie d with conventional methods, have received considerable recent attention as test cases for ne w approaches. Ladder models provide the logical next step, where established numerical met hods are still reliable, but complications of higher dimensional effects like gauge fields can b e introduced. In this paper, we investigate the application of the recently developed neural-net work quantum states in the two-leg Bose-Hubbard ladder under strong synthetic magnetic fiel ds. Based on the restricted Boltzmann machine and feedforward neural network, we show tha t variational neural networks can reliably predict the superfluid-Mott insulator phase diagram in the strong coupling limit comparable with the accuracy of the density-matrix renormalizati on group. In the weak coupling limit, neural networks also diagnose other many-body pheno mena such as the vortex, chiral, and biased-ladder phases. Our work demonstrates that the tw o-leg Bose-Hubbard model with magnetic flux is an ideal test ground for future developments of neural-network quantum states.

[1] G. Carleo and M. Troyer, Science **355**, 602 (2017).
[2] H. Saito, J. Phys. Soc. Jpn. **86**, 093001 (2017).
[3] A. Keleş and M. Ö. Oktel, Phys. Rev. A **91**, 013629 (2015).
[4] R. Wei and E. J. Mueller, Phys. Rev. A **89**, 063617 (2014).
[5] K. Çeven, M. Ö. Oktel, and A. Keleş, Phys. Rev. A **106**, 063320 (2022).

Electron delocalization in aromaticity as a superposition phenomenon

Mahir Hüseyin Yeşiller, Onur Pusuluk

Department of Physics, Koç University, 34450 Sarıyer, İstanbul, Turkey

mhrysllr@gmail.com

The concept of aromaticity, which was first introduced to explain the structural symmetry, energetic stability, and chemical reactivity of benzene and its derivatives, has yet to have a comprehensive and conventional definition. On the contrary, new types of aromaticity continue to be discovered, which in turn requires reconsidering the phenomenon within the framework of quantum mechanics. As the phenomenon of aromaticity originates from the delocalization of electrons in non-orthogonal atomic orbitals, the notion of orbital correlations [1,2] is insufficient for its identification. Here, we depart from the previous studies and examine the ground state of several archetypical aromatic molecules from the perspective of the resource theory of quantum superposition [3]. Additionally, we utilize the framework of biorthogonality [4] to take into account the overlap of atomic orbitals. Our findings indicate that quantum superposition shared between biorthogonal orbitals can capture the aromaticity order of the molecules, as effectively as the most successful measures of aromaticity used in the literature.

[1] Ding, L., Knecht, S., Zimborás, Z., Schilling, C. (2022). Quantum correlations in molecules: from quantum resourcing to chemical bonding. Quantum Science and Technology, 8(1), 015015.
[2] Pusuluk, O., Yeşiller, M. H., Torun, G., Müstecaplıoğlu, Ö. E., Yurtsever, E., Vedral, V. (2022). Classical and quantum orbital correlations in molecular electronic states. New Journal of Physics, 24(10), 102001.
[3] Theurer, T., Killoran, N., Egloff, D., Plenio, M. B. (2017). Resource theory of superposition. Physical Review Letters, 119(23), 230401.
[4] Pusuluk, O. (2022). Unified view of quantum superposition and quantum indistinguishability, arXiv:2210.02398.

The Characterization of photonic quantum wave-particle duality fluctuation phenomenon by Bayesian inference

Ahmet Orun

De Montfort University, School of Computer Sciences and Informatics, Leicester - UK

The magnitudes of atomic exchange [1] activities between the chemical substances (in an interaction at interferometer's test chamber) can be observed by quantization of interferometric (Mach-Zehnder) quantum eraser pattern's motions caused by the photonic wave-particle duality fluctuations [2][3]. In our further experiments, such fluctuations have also been characterized by use of Bayesian inference technique (AI) which was capable of revealing the hidden information/links in the wave-particle duality fluctuation phenomenon, as normally not visible to human observer in a complex time-domain sequence of measurements. Within this work, the constructive role of AI techniques (Bayesian Networks in particular) has been emphasized which would lead to more effective analysis of a quantum phenomenon.

[1] R. M. Handler et al., "Atom exchange between aqueous Fe(11) and goethite: an Fe isotope tracer study, "Environ. Sci. Technol. 43, 1102–1107 (2009).
[2] Qureshi, T. and M. A. Siddiqui, "Wave–particle duality in N-path interference," Ann. Phys. 385(2017), 598–604 (2017).
[3] Orun, A. and G. Smith,(2020).Investigation on a quantum communication phenomenon between subatomic properties of substances by quantum eraser pattern quantification, Optical Engineering, 59(3).

Quantum Superposition States for Spin Glasses

Aslı Tuncer
Koç University
asozdemir@ku.edu.tr

Spin glasses are disordered magnetic materials that exhibit peculiar behavior with exceptional ly slow relaxation toward equilibrium [1, 2]. There are many such states, each of which repre sents a local minimum and is inaccessible to the others. Phase coexistence and order co respo nd to the presence of more than one equilibrium state, and the order parameters are a measure of the extent to which different equilibrium states differ from each other [3]. For the Edward-Anderson model [4] , we can determine the states that contribute to the spin-glass behavior in all system sizes. We have obtaine d the quantum superposition states to identify the spin-glas s order. Moreover, we classified these superposi tions in terms of their contribution to the oth er phases such as paramagnetic, ferromagnetic, and antiferrom agnetic order. To determine th e contributions of these superposition states, we used magnetization and Edward-Anderson sp in-glass order parameters [2].

[1] Mezard, M and Parisi, G and Virasoro, M., Spin Glass Theory and Beyond, WORLD SCI ENTIFIC 2nd Edition (1986).
[2] Edwards, S. F. and Anderson, P. W., Journal of Physics F: Metal Physics 5, 5 (1975).
[3] van Enter, A.C.D. and Griffiths, R.B., Communications in Mathematical Physics 90, 3 (19 83).
[4] P.W., Anderson, Science 235, 4793 (1987).

Topological and Entanglement Properties of Two-Coin Quantum Walk on a Two Dimensional Lattice

Harun Gökalp
İYTE
harungokalp@iyte.edu.tr

We consider a quantum walk in a two-dimensional lattice governed by two coins, each of which dictates motion in different cartesian directions. Coin operations are composed of local coin operations followed by a collective two-coin operation. Local coin operations are characterized by some rotation angle in the two state coin space and non-local coin operation is a rotation in each coin space dependent on the state of the other coin. Followed by the coin operation, a displacement is made in two cartesian directions depending on the state of the corresponding coin. The effective Hamiltonian of the system corresponds to a four band system for which we have calculated the Chern numbers numerically. Topological and entanglement properties of the system are investigated for various coin operations.