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online

# 22-23 April 2021

**Quantum Optics & Quantum Information Meeting 2021**
**Conference Program All times are GMT+3**
**Available from Zoom or YouTube**

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# Önsöz

KOBİT$|0\rangle$ toplantısıyla 2016 yılında başladığımız serinin bu yıl altıncısı olan KOBİT $|5\rangle$ 'i düzenlemenin mutluluğu içindeyiz. Toplantı programımız, çevrimiçi yapılıyor olması sayesinde dünyanın dört bir yanından tanınmış konuşmacıyı bir araya getirmenin beraberinde, dağınık zaman farkından kaynaklanan koşullar göz önüne alınarak oluşturulmuştur.

Toplantı canlı, önkayıtlı ve poster sunum olmak üzere üç farklı katkı türünü barındırmaktadır. Son iki türdeki sunumlara etkileşimli soru/yanıt olanağı tanımak amacıyla 23 Nisan 2021 Cuma öğle arasında (GMT+3) Zoom ayrık odalar tahsis edilecektir (ayrıtılar, kobit web sayfası). Onay veren konuşmacıların videoları, etkinlik sonrasında YouTube kobit kanalında bu onaylarını geri çekmedikleri sürece izlenebilecektir.

Son olarak, ana konuşmacılarımız Marlan Scully ve Ataç İmamoğlu, ile birlikte çok tanınmış çağrılı ve katkıda bulunan diğer konuşmacı ve katılımcılara toplantıya verdikleri destek için şükranlarımızı iletiyoruz.

Yararlı bir bilimsel etkinlik olması dileklerimizle,

**Yerel Düzenleme Kurulu**
Ceyhun Bulutay
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## Foreword

It gives us a great pleasure to be holding KOBİT $|5\rangle$ , the sixth of the series of meetings which started with KOBİT $|0\rangle$ in 2016. Thanks to its online format, this year we enjoy geographically a wide spread of eminent speakers from around the world. In part, its toll is seen on the meeting program due to time zone constrains.

The conference hosts three types of contributions in the form of live, prerecorded, and poster presentations. The latter two formats will be provided an interactive Q&A session on Friday, 23 April 2021 lunch time (GMT+3) in the form of breakout rooms (details on the kobit webpage). For those speakers who give consent and do not withdraw this in the future, their live and prerecorded presentations will be accessible after the conference via the kobit YouTube channel.

Finally, we would like to thank our plenary speakers Marlan Scully and Ataç İmamoğlu, and the distinguished invited and contributed speakers as well as all participants for supporting this conference.

We look forward to an effective and exciting event.

**Organization Committee**
Ceyhun Bulutay
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# Quantum Optics & Quantum Information Meeting 2021
## Conference Program **All times are GMT+3**
## Available from Zoom or YouTube

| Thursday, 22 April 2021 | | |
|---|---|---|
| **GMT+3** | Chair: Kadir Durak | ***Speakers: connect 10 min. before the session for tests*** |
| **10:00-10:05** | Kadir **Durak** (Özyeğin) | Opening |
| **10:05-10:35** | Erhan **Sağlamyürek** (Alberta/Calgary) | Storing short pulses of single-photon-level light in Bose-Einstein condensates for high-performance quantum memory |
| **10:40-11:35** | Ataç **İmamoğlu** (ETH) | Atomically thin semiconductors: probing strongly correlated electrons using excitons |
| **11:40-12:10** | İnanç **Şahin** (Ankara) | Parallel Lives model and its implications on special theory of relativity |
| | | |
| **GMT+3** | Chair: A. Levent Subaşı | ***Speakers: connect 10 min. before the session for tests*** |
| **14:00-14:15** | Belkıs **Gökbulut** (Boğaziçi) | Enhanced spontaneous emission of fluorescent molecules coupled into quasi-optical modes in random media |
| **14:15-14:45** | Enderalp **Yakaboylu** (MPQ) | Molecular impurities as a realization of anyons on the two-sphere |
| **14:50-15:05** | Mahir **Yeşiller** (Koç) | Quantum information theory for fermions and its application in quantum biology |
| **15:05-15:20** | Gökhan **Torun** (Boğaziçi) | Resource theory of superposition: states transformation |
| | | |
| **GMT+3** | Chair: M. Emre Taşgın | ***Speakers: connect 10 min. before the session for tests*** |
| **15:50-16:20** | Turan **Birol** (UMN) | First principles calculations in correlated materials |
| **16:25-16:55** | Deniz **Yavuz** (UWM) | Atomic metamaterials: progress and challenges |
| **17:00-17:55** | Marlan **Scully** (TAMU) | Using quantum mechanics to detect COVID-19 disease |
| | | |
| **GMT+3** | Chair: Ö. E. Müstecaplıoğlu | ***EVENING TALK*** |
| **20:30-21:30** | Hakan **Türeci** (Princeton) | Machine learning with quantum dynamical systems |

*version: 20 April 2021*

# Quantum Optics & Quantum Information Meeting 2021
# Conference Program All times are GMT+3
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| Friday, 23 April 2021 | | |
|---|---|---|
| **GMT+3** | Chair: Hümeyra Çağlayan | ***Speakers: connect 10 min. before the session for tests*** |
| **10:15-10:30** | Debabrata **Goswami** (IIT Kanpur) | Quantum Information processing with femtosecond laser-induced control |
| **10:30-11:00** | Renbao **Liu** (Hong Kong) | Quantum sensing of correlations inaccessible to nonlinear spectroscopy |
| **11:05-11:35** | Ahmet **Avşar** (Newcastle) | Extrinsic magnetism in a two-dimensional noble metal dichalcogenide |
| **11:40-12:10** | Irene **D'Amico** (York) | Distributed quantum information processing with spin networks |
| | | |
| **GMT+3** | | |
| **13:00-13:40** | **Prerecorded Talk / Poster Q&A Session** (Zoom Breakout Rooms) | |
| | | |
| **GMT+3** | Chair: Devrim Tarhan | ***Speakers: connect 10 min. before the session for tests*** |
| **14:00-14:15** | Teodora **Kirova** (Latvia) | Ultrahigh-precision Rydberg atomic localization using standing waves and optical vortices |
| **14:15-14:45** | Şener **Özönder** (İstinye) | Physics and machine learning reunited |
| **14:50-15:05** | Farokh **Mivehvar** (Innsbruck) | Open quantum-system simulation of Faraday's induction law via dynamical instabilities |
| **15:05-15:20** | İskender **Yalçınkaya** (Czech TU) | Disorder-free localization in quantum walks |
| | | |
| **GMT+3** | Chair: M. Zafer Gedik | ***Speakers: connect 10 min. before the session for tests*** |
| **16:00-16:30** | Cihan **Okay** (Bilkent) | A hidden variable model for universal quantum computation with magic states on qubits |
| **16:35-17:05** | Ahmad **Salmanogli** (Çankaya) | Quantum radar |
| **17:05-17:20** | Fatih **Dinç** (Stanford) | Waveguide QED is inherently non-Markovian |
| **17:25-17:30** | M. Zafer **Gedik** (Sabancı) | Closing |

*version: 20 April 2021*

# *Konuşmalar / Talks*

**Storing short pulses of single-photon-level light in Bose-Einstein condensates for high-performance quantum memory**

Dr. Erhan Saglamyurek,

*Research Associate at University of Alberta & University of Calgary, Canada*

Photonic quantum memories are key ingredients for global quantum networks [1,2]. Despite over 20 years of active research and technical progress, a practical quantum memory remains elusive due to intrinsic limitations of matter platform and/or light-matter interaction techniques. Towards overcoming this obstacle, we propose and experimentally demonstrate a quantum-memory approach that combines the well-known Bose-Einstein Condensate (BEC) platform [3] and the recently proposed Autler-Townes-Splitting (ATS) light-storage technique [4-6]. The non-adiabatic character of the ATS technique (leading to broadband and low-noise operation) in conjunction with the intrinsically large atomic densities and ultra-low temperatures of the BEC platform (offering highly efficient and long-lived storage) opens up a new avenue towards high-performance quantum memories [7].

[1] H. J. Kimble, *Nature* **453**, 1023 (2008).
[2] M. Gundogan et al, *Preprint* at arXiv:2006.10636 (2020).
[3] C. Liu et al *Nature* **409**, 490 (2001).
[4] E. Saglamyurek et al, *Nature Photonics* **12**, 774 (2018).
[5] A. Rastogi et al, *Phys. Rev. A* **100**, 012314 (2019).
[6] E. Saglamyurek et al, *Phys. Rev. Research* **1**, 022004(R) (2019).
[7] E. Saglamyurek et al, *New J. Phys.* DOI: 10.1088/1367-2630/abf1d9 (2021).

**Atomically thin semiconductors : probing strongly correlated electrons using excitons**

Ataç Imamoglu

*Institute for Quantum Electronics, ETH Zürich, CH-8093 Zürich, Switzerland*

If the Coulomb repulsion between the electrons becomes significantly stronger than their kinetic energy, the itinerant electrons in the two-dimensional systems are expected to form a spatially-ordered state, termed a Wigner crystal [1]. According to former Quantum Monte Carlo calculations [2], the ratio $r_s$ of the two energy scales must exceed 30 for such a crystallization to occur in the absence of the magnetic field ($B = 0$). Owing to severe difficulties in satisfying this condition for conventional semiconductors (e.g., GaAs), prior experimental studies of the crystalline electronic states have mainly focused on the electrons confined to single Landau level under strong external magnetic field, which almost quenches the kinetic energy.

In this talk, I will describe recent experiments in atomically-thin transition metal dichalcogenides (TMDs) where it is possible to reach $r_s > 40$. Our measurements provide a direct evidence that the electrons at densities $< 3 \cdot 10^{11}$ cm$^{-2}$ in a pristine $MoSe_2$ monolayer form a Wigner crystal even at $B = 0$ [3]. This is revealed by our low-temperature ($T = 80$ mK) magneto-optical spectroscopy experiments that utilize a newly developed technique allowing to unequivocally detect charge order in an electronic Mott-insulator state [4]. This method relies on the modification of excitonic band structure arising due to the periodic potential experienced by the excitons interacting with a crystalline electronic lattice. Under such conditions, optically-inactive exciton states with finite momentum matching the reciprocal Wigner lattice vector $k = k_W$ get Bragg scattered back to the light cone, where they hybridize with the zero-momentum bright exciton states. This leads to emergence of a new, umklapp peak in the optical spectrum heralding the presence of periodically-ordered electronic lattice.

[1] E. Wigner, Phys. Rev. **46**, 1002 (1934).
[2] N. D. Drummond and R. J. Needs, Phys. Rev. Lett. 102, 126402 (2009).
[3] T. Smoleński, P. E. Dolgirev, C. Kuhlenkamp, A. Popert,1 Y. Shimazaki, P. Back, M. Kroner, K. Watanabe, T. Taniguchi, I. Esterlis, E. Demler, and A. Imamoglu, arXiv:2010.03078 (2020).
[4] Y. Shimazaki, C. Kuhlenkamp, I. Schwartz, T. Smolenski, K. Watanabe, T. Taniguchi, M. Kroner, R. Schmidt, M. Knap, A. Imamoglu, arXiv:2008.04156 (2020).

**Parallel Lives model and its implications on special theory of relativity**

İnanç Şahin

*AnkaraUniversity, Science Faculty, Physics Department, Ankara, Turkey*

Parallel lives (PL) is a model of quantum theory that is both local and realistic. According to PL all quantum fields consist of point beings called "lives" that carry a memory of their previous interactions and interact with each other locally. The lives move on continuous world-lines in space-time with a speed bounded by the speed of light and they can split into copies when they meet each other. This feature resembles many worlds interpretation. However in the PL model, the division of lives takes place locally. Since the model is local and lives propagate at speeds not exceeding the speed of light, it has been claimed to be compatible with the theory of relativity. We confront the PL model with Hardy's paradox and show that the PL model is inconsistent with the special theory of relativity. The inconsistency does not actually arise when we consider the first-person observations of Lorentz observers. The inconsistency arises when one Lorentz observer observes the observation results of another Lorentz observer. We discuss implications of this inconsistency on special theory of relativity, and speculate a solution that we believe, fits the spirit of the PL model.

# Enhanced spontaneous emission of fluorescent molecules coupled into quasi-optical modes in random media

Belkıs Gökbulut

*Department of Physics, Boğaziçi University, Bebek, 34342 Istanbul, Turkey*

In this work, quasi-optical modes are created inside an optical waveguide with a disordered polymeric medium with fluorescent molecules, which involves gold nanoparticles and air inclusions to be exploited as the scattering centers for the electromagnetic light waves. Quasi-optical modes are acquired by the interference of the electromagnetic waves through various light scatterings in the random polymer medium. Thus, photons at specific frequencies are confined within transient artificial photonic cavities provided that the length of localization is comparable to the wavelength scale. The optical waveguide ensures guidance of a single localized optical mode to allow coupling of the fluorescent molecules into the particular mode at certain frequency. The spontaneous emission rate of the quantum emitters coupled into the quasi-optical cavities is investigated by single photon counting technique. The resonant optical modes are observed like lasing peaks by the photoluminescence emission spectrum of the molecules under high-excitation power. Once a localization is detected for which the emission spectrum is confirmed to be unchanged during the pulses of the exciting laser beam, the high power laser beam is deactivated and the time-resolved fluorescence lifetime measurements are performed for the confined photons at this specific frequency. For realization of the time-resolved experiments, a pulsed laser with a high repetition rate is utilized to send periodic pulse signals for the excitation of the fluorescent emitters, then photon signals are directed to the Single Photon Avalanche Photodiode to realize the individual time measurements of the single photons over the periodic signals. For registration of a single photon, the time difference between the excitation pulse and the photon event is measured by recording the arrival time of an individual photon. The overall data is collected in time channels to construct a histogram memory. After the sufficient amount of data is collected in the histogram memory, the time-resolved fluorescence decay curve is obtained. The coupling of the quantum sources into the localized optical mode is determined to result in a significant change in the density of electromagnetic states to alter the spontaneous emission rate of the quantum sources. The emission dynamics of the light emitters, which are on resonance with the localized optical mode at a particular frequency, are explored through the fastest decay rate in total emission since the localization of the electromagnetic waves dramatically enhances the vacuum fluctuations. Consequently, the spontaneous emission rate of the quantum sources in disordered optical waveguide structure is determined to be significantly enhanced upon coupling into the quasi-optical modes. The experimental results are also confirmed with the numerical calculations by the investigations of the light localization emitting from a dipole in a scattering medium with air inclusions and gold nanoparticles in a guiding photonic structure. According to the numerical results, the small mode volume of the quasi-optical cavity induced by the scattering centers causes the enhanced decay rate in the optical waveguide. Thus, the photonic design of the structure offers new avenues to improve the light-matter interaction in a three dimensional random polymeric medium. Such a system can be advanced to engineer random lasers at desired emission wavelengths as well as numerous efficient host polymer media to produce single photon sources for quantum information processing.

**Molecular Impurities as a Realization of Anyons on the Two-Sphere**

Enderalp Yakaboylu

*Max Planck Institute of Quantum Optics, Garching, Germany*

Studies on experimental realization of two-dimensional anyons in terms of quasiparticles have been restricted, so far, to only anyons on the plane. It is known, however, that the geometry and topology of space can have significant effects on quantum statistics for particles moving on it. In this talk, I will show that the emerging fractional statistics for particles restricted to move on the sphere, instead of on the plane, arises naturally in the context of quantum impurity problems. In particular, I will demonstrate a setup in which the lowest-energy spectrum of two linear bosonic molecules immersed in a quantum many particle environment can coincide with the anyonic spectrum on the sphere. This paves the way towards experimental realization of anyons on the sphere using molecular impurities. Finally, I will present an approach to interacting quantum many-body systems based on the notion of quantum groups, also known as q-deformed Lie algebras. In particular, I will exemplify this approach by considering a quantum rotor interacting with a bath of bosons.

**Quantum information theory for fermions and its application in quantum biology**

Onur Pusuluk[1], Mahir Yeşiller[1], Gökhan Torun[1], Özgür E. Müstecaplıoğlu[1], Ersin Yurtsever[2], Vlatko Vedral[3,4]

[1]*Department of Physics, Koç University, Istanbul, Turkey*
[2]*Department of Chemistry, Koç University, Istanbul, Turkey*
[3]*Departmant of Physics, University of Oxford, Oxford, UK*
[4]*Centre for Quantum Technologies, National University of Singapore, Singapore*

One of the most foundational distinctions that separate the quantum world from the classical world is the indistinguishable particles. However, a consistent formulation of quantum information theory (QIT) for systems that consist of such particles, especially for fermionic systems, is still an active research area. The Jordan-Wigner transformation that maps fermions into qubit systems leads to some ambiguities in defining the subsystems. Besides, the superselection rules place additional constraints on the state space. Therefore, we need to redefine some basic operations, including partial trace or partial transpose for fermions.

In this talk, after giving a brief introduction to the fermionic QIT, we will utilize its tools to show that resourceful correlations can be generated in the electronic states of molecular systems calculated by post-Hartre-Fock quantum simulations. To this end, for the first tie in the literature, we will properly separate orbital-orbital correlations into classical and quantum parts. Finally, we will discuss the possible applications of fermionic QIT in quantum biology.

**Resource Theory of Superposition: States Transformation**

Gökhan Torun [1,2], Hüseyin Talha Şenyaşa[3], Ali Yildiz[3]

[1]*Department of Physics, Boğaziçi University, 34342 Bebek, İstanbul, Turkey*
[2]*Department of Physics, Koç University, 34450 Sarıyer, İstanbul, Turkey*
[3]*Department of Physics, İstanbul Technical University, 34469 Maslak, İstanbul, Turkey*

The existence of superposition as a resource delivers significant performance gains on many information processing tasks that cannot be classically achievable. Given a particular set of resources, a fundamental aspect of any quantum resource theories [1] is the manipulation of these resources. This task deals with whether it is possible to transform one resource into another under free operations. In superposition theory, an initial state can be probabilistically transformed to another target state via superposition-free operations only when the target has an equal or lower superposition rank with the initial state [2]. Nevertheless, under what condition(s) a superposition-free transformation can be achieved deterministically is still an open problem.
In this work, we study the transformations of single copies of the pure superposition states [3]. More precisely, using the tools of resource theory of superposition, we give the conditions for a class of superposition state transformations. These conditions strictly depend on the scalar products of the basis states and reduce to the well-known majorization condition for quantum coherence in the limit of orthonormal basis. To further superposition-free transformations of d-dimensional systems, we provide superposition-free operators for a deterministic transformation of superposition states. Moreover, as a particularly important subject, we determine the maximal superposition states—the state with the greatest resource value—which are valid over a certain range of scalar products. By the definition, a d-dimensional superposition state is said to have maximal superposition if it can be used to generate all other d-dimensional states deterministically using free operations. We show that states with the symmetric superposition of the basis states is the maximally resourceful one for a given set of pure superposition states. Such contributions are undoubtedly important for our understanding of resource theory of superposition.

[1] E. Chitambar and G. Gour, *Quantum Resource Theories*, Rev. Mod. Phys. **91**, 025001 (2019).
[2] T. Theurer, N. Killoran, D. Egloff, and M.B. Plenio, *Resource Theory of Superposition*, Phys. Rev. Lett. **119**, 230401 (2017).
[3] G. Torun, H.T. Şenyaşa, and A. Yildiz*, Resource theory of superposition: State transformations,* Phys. Rev. A **103**, 032416 (2021).

**First Principles Calculations in Correlated Materials**

Turan Birol

*University of Minnesota*

Solid state, crystalline compounds are rife with emergent phenomena such as a variety of magnetic, correlated, and topological phases. While simple models, for example the Hubbard and Heisenberg models, can often capture the essence of the emergent phases, quantitative details depend on the material specific physical properties. Over the course of past decades, first principles (ab initio) approaches reached a high level of reliability and reproducibility, and are now commonly utilized not only to reproduce and explain, but also to predict emergent properties of crystalline materials. In this talk, I will first introduce the most common ab initio method, the density functional theory, and discuss what physics it captures - and where it fails. I will then discuss first principles dynamical mean field theory, which allows going beyond the single determinant electronic states and reproduce phenomena that are essentially beyond density functional theory.

**Atomic metamaterials: progress and challenges**

Deniz Yavuz

*University of Wisconsin Madison*

Metamaterials are engineered structures with optical properties that cannot be found in nature. Over the last two decades, there has been a growing interest in metamaterials with a negative index of refraction ($n<0$) due to their possible exciting practical applications. For example, it has been predicted that such metamaterials can be used to construct lenses that can image objects with a resolution much smaller than the wavelength of light.

Negative index metamaterials are traditionally constructed from periodic metal or metal/dielectric structures whose resonances are engineered to produce the desired optical response. We have been exploring an alternative approach where we use sharp optical resonances of atomic or ionic ensembles: i.e, we use the resonances provided to us by nature. In this talk I will review this "atomic metamaterials" approach. Although we have not yet been able to achieve a negative index with this approach, we were able to overcome one of the key obstacles and obtain magnetic response in the optical region. I will discuss our recent experiments where we studied optical magnetic response from a europium-doped crystal at cryogenic temperatures.

**Using Quantum Mechanics To Detect Covid-19 Disease**

Marian Scully

*Texas A&M, Princeton, and Baylor Universities*

For the past six months IQSE scientists have been researching the application of, e.g., quantum coherence ~nd quantum entanglement to detect SARS-CoV-2 lgG antibodies [1] and/or RNA [2,3]. Related work mapping the surface of a single COVID-19 virus [4] and measuring the binding free energy [Sl of the virus to the ACE-2 site will be discussed. The connection, if any, between quantum coherence in brain microtubules [6] and superradiance [7] will be presented as time allows.

[1] "Enhancing Sensitivity of Lateral Flow Assay with Application to SARS-CoV-2", T. Peng, X Liu, LG. Adams, G. Agarwal, B. Akey, J. Cirillo, V. Deckert, S. Delfan, E. Fry, Z. Han, P. Hemmer, G. Kattawar, M. Kim, MC Lee, CY Lu, J Mogford, R. Nessler, B. Neuman, XV Nie, JW Pan, J Pryor, N Rajil, Y Shih, A Sokolov, A Svidzinsky, D Wang, ZH Yi, A Zheltikov, and M Scully., Applied Physics Letters (in press).
[2] "A Fiber Optic-Nanophotonic Approach to the Detection of Antibodies and Viral Particles of COVID-19", N. Rajil, A. Sokolov, Z. Vil, LG. Adams, G. Agarwal, V. Belousov, R. Brick, K. Chapin, J.D. Cirillo, V. Deckert, S. Delfan, S. Esmaeili, A. Fernandez-Gonzalez, E. Fry, Z. Han, P. Hemmer, G. Kattawar, M. Kim, M. Lee, C. Lu, J. Mogford, J. Pan, T. Peng, V. Poor, S. Scully, Y. Shih, S. Suckewer, A. Svidzinsky, A. Verhoef, D. Wang, K. Wang, L Yang, A. Zheltikov, S. Zhu, S. Zubairy, M. Scully, Nanophotonics (accepted); DOI: 10.1515/nanoph-2020-0357
[3] "Photonic toolbox for fast real-time polymerase chain reaction", C. Vincent, A. Vor,pnin, K. Sower, V. Belousov, A. Sokolov, M. Scully, and A. Zheltikov, submitted
[4] "Laser Spectroscopic Technique for Direct Identification of a Single Virus I: FASTER CARS", V. Deckert, T. DeckertGaudig, D. Cialla-May, J. Popp, R. Zell, Stefanie Deinhard-Emmer, A. V. Sokolov, Z. Yi, and M. 0. Scully, PNAS (submitted).
[5] "Light and corona: guided-wave readout for coronavirus-spike-protein-host-receptor binding", l.V. Fedotov, Z. Yi, A. Voronin, A. Svidzinsky, K. Sower, X. Liu, E. Vlasova, T. Peng, X. Liu, S. Moiseev, V. Belousov, A. Sokolov, M. Scully, and A. Zheltikov, Optics Letters (accepted).
[6] "Quantum Coherence in (Brain) Microtubules and Efficient Energy and Information Transport", N. Mavromatos and D. Nanopoulos, Journal of Physics: Conference Series, 329, 012026 (2011)
[7] "The Super of Superradiance", M. Scully and A. Svidzinsky, Science, 325, 1510-1511 (2009).

**Machine Learning with Quantum Dynamical Systems**

Hakan Türeci

*Princeton University*

Recent experiments on quantum hardware have demonstrated the immense expressive power of large-scale quantum systems. When employed for computation, these complex systems receive information-carrying signals of classical or quantum origin, under which they evolve to high-dimensional quantum states that must then be read out and processed to achieve a particular computational task. This raises the question of an optimal approach to encoding information in, and subsequently extracting the processed information from a large quantum system, for which various approaches including machine learning have been explored.

I will discuss an analog neural network approach that receives information to be processed as electromagnetic signals and encodes the intermediate state of computation into the natural continuous time evolution of a large interconnected network of non-linear quantum oscillators, which are continuously measured. I will present a proposal for the implementation of this framework with Josephson parametric oscillators and its application to the simultaneous readout of a multi-qubit quantum system [1]. Focusing on potential small scale near-term devices, I will discuss a physical interpretation of the nonlinear processing capabilities of such a processor as a function of its physical parameters. This analog neural network approach appears to suggest a fairly general information processing framework that employs the natural time evolution of a physical system in that it is valid across a wide regime of drive and nonlinearity strengths. This allows a controlled approach from effectively classical regimes of operation with thousands of photons to a well-defined quantum limit at low powers.

[1] Angelatos et. al., arXiv:2011.09652

**Quantum Information processing with Femtosecond Laser-Induced Control**

Debabrata Goswami

*Indian Institute of Technology Kanpur*

dgoswami@iitk.ac.in

Quantum information processing exploits the quantum-mechanical nature of matter to exist in multiple possible states simultaneously, which promises to revolutionize the present form of computing. A critical aspect of quantum information processing relies on the aspect of controlling quantum processes and avoid decoherence. In this approach towards quantum computing with ultrafast lasers, we have developed ultrafast laser pulse shaping, particularly the acousto-optic modulator-based Fourier-Transform pulse-shaper, which can rapidly modulate programmatically ultrafast laser pulses. We argue such optical pulse shaping approach to be an attractive route to quantum computing since shaped pulses can be transmitted over optical hardware, and the same infrastructure can be used for computation and optical information transfer. We also discuss how to address the problem of extending coherence aspects of femtosecond laser-induced processes.

**Quantum sensing of correlations inaccessible to nonlinear spectroscopy**

Renbao Liu

*Department of Physics, The Chinese University of Hong Kong*

Correlations of fluctuations are ubiquitous in quantum systems. Nonlinear spectroscopy is widely used to retrieve such correlations. However, many types of correlations are inaccessible to conventional spectroscopy using classical probes. By coupling a quantum sensor to a quantum object, which establishes entanglement between the two, the statistics of quantum measurement on sensor can be used to extract arbitrary orders and arbitrary types of the correlations in the target. Such quantum nonlinear spectroscopy of fluctuations provide a new approach to quantum sensing (such as classical-noise-free detection), testing the quantum foundation (such as the violation of higher-order Leggett-Garg inequalities), and studying quantum many-body physics.

This work is supported by Hong Kong RGC (143000119).

**Extrinsic magnetism in a two-dimensional noble metal dichalcogenide**

Ahmet Avşar

*Newcastle University, UK*

Defects are ubiquitous in solids and often introduce new properties that are absent in pristine materials especially at their low-dimensional limits [1]. For example, atomic-scale disorder in two-dimensional (2D) transition metal dichalcogenides is often accompanied by local magnetic moments, which can conceivably induce long-range magnetic ordering in these otherwise nonmagnetic materials. In this talk, I will present magneto-transport properties of ultrathin $PtSe_2$ crystals down to monolayer thickness and demonstrate the emergence of such extrinsic magnetism [2-3]. Electrical measurements supported by first-principles calculations and aberration-corrected transmission electron microscopy imaging of point defects show the existence of either ferromagnetic or anti-ferromagnetic ground state orderings depending on the number of layers in this ultra-thin material. Finally, I will briefly discuss how this induced magnetism can be further manipulated and used in novel 2D spintronics device applications, taking into account that this material has a unique thickness-dependent electronic property arises from the strong coupling between layers [4].

[1] D. Rhodes et al., Nat. Mater. 18, 541-549 (2019)
[2] A. Avsar et al., …A. Kis, Nat. Nanotechnol., 14, 674-678 (2019)
[3] A. Avsar et al., …A. Kis, Nat. Commun., 11, 4806 (2020)
[4] A. Ciarrocchi, A. Avsar, D. Ovchinnikov and A. Kis, Nat Commun., 9, 919 (2018)

**Distributed Quantum Information Processing with Spin Networks**

Irene D'Amico

*University of York*

As Noisy Intermediate-Scale Quantum (NISQ) devices grow in number of qubits, determining good or even adequate parameter configurations for a given application, or for device calibration, becomes a cumbersome task. We present [1] an evolutionary algorithm which allows for the automatic tuning of the parameters of any arrangement of coupled qubits, to perform a given task with high fidelity. The algorithm's use is exemplified with the generation of schemes for the distribution of quantum states and the design of multi-qubit gates. The algorithm is demonstrated to converge very rapidly, yielding unforeseeable designs of quantum devices that perform their required tasks with excellent fidelities. Given these promising results, practical scalability and application versatility, the approach has the potential to become a powerful technique to aid
the design and calibration of NISQ devices.

[1] Luke Mortimer, Marta P. Estarellas, Timothy P. Spiller, and Irene D'Amico, arXiv:2009.01706

**Ultrahigh-precision Rydberg atomic localization using standing waves and optical vortices**

Teodora Kirova[1], Ning Jia[2], Hamid Reza Hamedi[3], Jing Qian[4], and Gediminas Juzeliūnas[3]

[1]*Institute of Atomic Physics and Spectroscopy, University of Latvia, LV-1004, Latvia*
[2] *The Public Experimental Center, University of Shanghai for Science and Technology, Shanghai 200093, China*
[3]*Institute of Theoretical Physics and Astronomy, Vilnius University, LT-10257, Lithuania and*
[4]*State Key Laboratory of Precision Spectroscopy, Quantum Institute for Light and Atoms, Department of Physics, School of Physics and Electronic Science, East China Normal University, Shanghai 200062, China*

Schemes for strongly confined localization are proposed, using interacting Rydberg atoms in ladder configuration, where standing wave or optical vortex couples the second ladder step. We distinguish partial and full antiblockade regimes, both resulting in tight localization, while the first allows much stronger excited Rydberg levels localization.

Vortex beams provide ultraprecise 2D localization in the zero intensity center, with confined excitation region down to few nanometers.

Our results pave the way for localization experiments and applications on nanometer scales.

**Physics and Machine Learning Reunited**

Şener Özönder

*İstinye University, Faculty of Engineering, Istanbul, Turkey*

Physics has been one of the main sources of inspiration for the field of artificial intelligence [1]. Physics-inspired models such as Restricted Boltzmann Machines or the parallels between neural networks and spin glass models in condensed matter physics suggest that the salient similarities between these two disciplines warrants furthers investigation. Almost all state-of-the-art machine learning models were developed and applied only heuristically to the extent that even their hyperparameters are also optimized with the data used to train the model. Despite their good performance in digging out intricate correlations buried deep within the data or learning to separate the images of different objects, machine learning models are ultimately black boxes, and they suffer from lack of explainability and interpretability. The ideas in statistical and condensed matter physics may help build the theoretical foundations of deep learning. Apart from these, there's also a recent surge in the interest of utilizing various machine learning pipelines to solve problems in physics and to accelerate otherwise slow materials discovery processes. These promising endeavors may lead to automation of science and we may speak about "AI scientists" in the near future. In this talk, I will provide a bird's-eye-view of connections and common problems between physics and machine learning, and also discuss the possible directions towards a firm understanding of neural networks as well as automated scientific value production via artificial intelligence.

[1] Ş. Özönder, M. A. Ahmad, Physics inspired models in artificial intelligence, Proceedings of the 26th ACM SIGKDD International Conference on Knowledge Discovery & Data Mining (KDD2020), (2020) 3535-3536.

# Open Quantum-System Simulation of Faraday's Induction Law via Dynamical Instabilities

Farokh Mivehvar

*University of Innsbruck*

We have recently proposed a novel type of a Bose-Hubbard ladder model based on an open quantum-gas--cavity-QED setup to study the physics of dynamical gauge potentials. Atomic tunnelling along opposite directions in the two legs of the ladder is mediated by photon scattering from transverse pump lasers to two distinct cavity modes. In this talk, I show that the resulting interplay between cavity photon dissipation and the optomechanical atomic back-action then induces an average-density-dependent dynamical gauge field. The dissipation-stabilized steady-state atomic motion along the legs of the ladder leads either to a pure chiral current, screening the induced dynamical magnetic field as in the Meissner effect, or generates simultaneously chiral and particle currents. For sufficiently strong pump the system enters into a dynamically unstable regime exhibiting limit-cycle and period-doubled oscillations. Intriguingly, an electromotive force is induced in this dynamical regime as expected from an interpretation based on Faraday's law of induction for the time-dependent synthetic magnetic flux.

**Disorder-free localization in quantum walks**

B. Danacı, İ. Yalçınkaya*, B. Çakmak, G. Karpat, S. P. Kelly, A. L. Subaşı

*(*) Czech Technical University in Prague, Czech Republic*

The phenomenon of localization usually happens due to the existence of disorder in a medium. Nevertheless, specific quantum systems allow dynamical localization solely due to the nature of internal interactions. We study a discrete-time quantum walker which exhibits disorder-free localization. The quantum walker moves on a one-dimensional lattice and interacts with on-site spins by coherently rotating them around a given axis at each step. Since the spins do not have dynamics of their own, the system poses the local spin components along the rotation axis as a vast number of conserved moments. When the interaction is weak, the walker's spread shows subdiffusive behavior, having downscaled ballistic tails in the evolving probability distribution at intermediate time scales. However, as the interaction gets stronger, the walker gets completely localized in the absence of disorder in both lattice and the initial state. Using a matrix-product-state ansatz, we investigate the relaxation and entanglement dynamics of the on-site spins due to their coupling with the quantum walker. Surprisingly, we find that even in the delocalized regime, entanglement growth and relaxation occur slowly, unlike most other models displaying a localization transition.

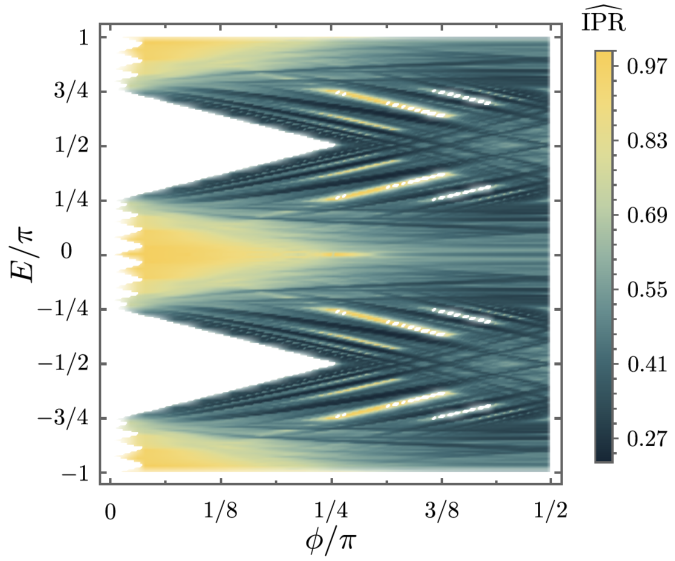


**Figure:** Quasi-energy E spectrum and the inverse participation ratio IPR of the corresponding eigenstates with respect to the interaction parameter (horizontal axis) for the quantum walker. After a critical value 1/4, the band gaps close and the quasi-energy eigenstates become localized.

**A hidden variable model for universal quantum computation with magic states on qubits**

Cihan Okay

*Bilkent University*

A central question in quantum information theory is to determine physical resources required for quantum computational speedup. In the model of quantum computation with magic states classical simulation algorithms based on quasi-probability distributions, such as discrete Wigner functions, are used to study this question. For quantum systems of odd local dimension it has been known that negativity in the Wigner function can be seen as a computational resource. The case of qubits, however, resisted a similar approach for some time since the nice properties of Wigner functions for odd dimensional systems no longer hold for qubits. In our recent work we construct a hidden variable model, which replaces the Wigner function representation, for qubit systems where any quantum state can be represented by a probability distribution over a finite state space and quantum operations correspond to Bayesian update of the probability distribution. When applied to the model of quantum computation with magic states the size of the state space only depends on the number of magic states.

This is joint work with Michael Zurel and Robert Raussendorf; Phys. Rev. Lett. 125, 260404 (2020).

**Quantum Radar**

Ahmad Salmanogli

*Çankaya University, Faculty of Engineering, Ankara, Turkey*

In this presentation, we try to show the performance of a theoretically designed quantum radar. The materials contain two parts. The first section starts with the quantum mechanically analysis of a new converter to generate the microwave entangled photons. To design, in contrast with the electro-opto-mechanical converter (a traditional converter to generate the entangled photons), some high frequency electronic elements such as Varactor diode and detector are used. We called that opto-electronic converter by which the thermally induced photons at the system are strongly decreased. This suppression helps the system to create the entangled photons at high temperature. In the following, the effect of the amplifier, propagation of the signal in the atmosphere and also the reflection from a target (radar cross-section) are simulated using the quantum approach.

In the second part, we focus on an operational quantum radar that generates the entangled microwave photons and is ready to propagate the signals into the atmosphere to detect a target. At this point, the quantum radar is operated like a classical radar. To do so, the system needs a transmitter to amplify the signals and also maintain the noise at a very low-level to increase the probability of detection. Finally, the returned signals from the target are detected by an ultra-low noise receiver and its performance is studied from a classical radar point of view.

**Waveguide QED is inherently non-Markovian**

Fatih Dinc

*Applied Physics Department, Stanford University, Stanford CA 94305, USA*

In my short-talk, I propose to revisit my work from last year (Phys. Rev. Research 1, 032042(R)) and discuss its finding in the light a new interpretation. In this work, we had considered multiple identical emitters that are coupled to a single waveguide and are located at a distance L from each other. We had proven that if the inter-qubit distance is close to a critical distance $L_c$, which scales as $N^{-2}$ with the qubit number, the collective system shows an enhanced superradiant behavior, stronger than Dicke superradiance, which we termed super-superradiance. This is a non-Markovian effect, meaning that photon propagation time between qubits cannot be neglected. At the time, we focused on the emergence of super-superradiance, but hadn't realized the following implication for the waveguide quantum electrodynamics research:

"The widely used Markov approximation, where one neglects inter-qubit photon propagation times, can no longer be employed in the large qubit limit!"

The literature had employed this approximation, as otherwise problems became too hard to solve analytically. A re-interpretation of our work indicates that Markovian results may not be as insightful as we would like to think. While omitting this simplifying assumption will lead to unpleasantly intractable problems in theoretical wQED research, it may be time that we choose to take on problems based on the need to solve them, rather than the ability to do so!

# *Önkayıtlı Konuşma / Prerecorded Talks*

**Static synthetic gauge field control of double optomechanically induced transparency in a closed-contour interaction scheme**

Beyza Sütlüoğlu and Ceyhun Bulutay

*Department of Physics, Bilkent University, Ankara, Turkey*

We theoretically study an optical cavity and a PT-symmetric pair of mechanical resonators, where all oscillators are pairwise coupled, forming an optomechanical system with a closed-contour interaction. Due to the presence of both gain and feedback, we first explore its stability and the root loci over a large coupling range. Under the red-sideband pumping, and for the so-called PT-unbroken phase it displays a double optomechanically induced transparency for an experimentally realizable parameter set. We show that both the transmission amplitude and the group delay can be continuously steered from lower transmission window to the upper one by the phase of the loop coupling parameter which acts as a static synthetic gauge field. In the PT-unbroken phase both the gain-bandwidth and delay-bandwidth products remain constant over the full range of the controlling phase. Tunability in transmission and bandwidth still prevails in the PT-broken phase. In essence, we suggest a simple scheme that grants coupling phase dependent control of the single and double OMIT phenomena within an effective PT-symmetric optomechanical system.

[1] B. Sütlüoğlu and C. Bulutay, arXiV:2104.04014 (2021).

**Hybrid Quantum-Classical Graph Neural Networks for Track Reconstruction**

Cenk Tüysüz[1], Carla Rieger[2], Kristiane Novotny[3], Bilge Demirköz[1], Daniel Dobos[3,4], Karolos Potamianos[3,5], Sofia Vallecorsa[6], Jean-Roch Vlimant[7], Richard Forster[3]

[1]*Department of Physics, Middle East Technical University, Ankara, Turkey*

[2]*Department of Physics, ETH Zürich, Zürich, Switzerland*

[3]*gluoNNet, Geneva, Switzerland*

[4]*Lancaster University, Lancaster, United Kingdom*

[5]*University of Oxford, Oxford, United Kingdom*

The Large Hadron Collider (LHC) at the European Organization for Nuclear Research (CERN) will be upgraded to further increase the instantaneous rate of particle collisions (luminosity) and become the High Luminosity LHC. This increase in luminosity, will significantly increase the number of particles interacting with the detector, yielding many more detector hits, which will pose a combinatorial challenge to track reconstruction algorithms responsible to determine particle trajectories from those hits. This work explores the possibility of converting a novel Graph Neural Network model, that can optimally take into account the sparse nature of the tracking detector data and their complex geometry, to a Hybrid Quantum-Classical Graph Neural Network that can benefit from using Quantum Variational layers. We show that the hybrid model can perform similar to the classical approach. Also, properties of Parametrized Quantum Circuits (PQC) such as expressibility and entangling capacity are compared with their training performance in order to quantify the expected benefits. These results can be used to build a future road map to further increase the performance of the current hybrid model.

**Subradiance via Entanglement in Atoms with Several Independent Decay Channels**

Laurin Ostermann (1), Martin Hebenstreit (1), Barbara Kraus (1), Helmut Ritsch (1)

*(1) Institute for Theoretical Physics, University of Innsbruck, Technikerstraße 21, A-6020 Innsbruck, Austria*

Spontaneous emission of atoms in free space is modified by the presence of other atoms in close vicinity inducing collective super- and subradiance. For two nearby atoms with a single decay channel the entangled antisymmetric superposition state of the two single excited states will not decay spontaneously. No such excited two-atom dark state exists, if the excited state has two independent optical decay channels of different frequencies or polarizations. However, we show that for an excited atomic state with N−1 independent spontaneous decay channels one can find a highly entangled N-particle dark state, which completely decouples from the vacuum radiation field. It does not decay spontaneously, nor will it absorb resonant laser light. Mathematically, we see that this state is the only such state orthogonal to the subspace spanned by the atomic ground states. Moreover, by means of generic numerical examples we demonstrate that the subradiant behavior largely survives at finite atomic distances including dipole-dipole interactions.

**Polariton Exchange Interactions in Multichannel Optical Networks**

Mohammadsadegh Khazali, Callum R. Murray, and Thomas Pohl

*Department of Physics and Astronomy, Aarhus University, Aarhus 8000, Denmark*

We examine the dynamics of Rydberg polaritons with dipolar interactions that propagate in multiple spatial modes[1]. The dipolar excitation exchange between different Rydberg states mediates an effective exchange between polaritons that enables photons to hop across different spatial channels. Remarkably, the efficiency of this photon exchange process can increase with the channel distance and becomes optimal at a finite rail separation. Based on this mechanism, we design a simple photonic network that realizes a two photon quantum gate with a robust $\pi$ phase, protected by the symmetries of the underlying photon interaction and the geometry of the network. These capabilities expand the scope of Rydberg electromagnetically induced transparency towards multidimensional geometries for nonlinear optical networks and explorations of photonic many-body physics.

[1] Khazali, Mohammadsadegh, Callum R. Murray, and Thomas Pohl. "Polariton Exchange Interactions in Multichannel Optical Networks." *Physical review letters* 123,113605 (2019).

**Modeling study of the hybrid microwave-magnon system for quantum frequency conversion and microwave applications**

Morteza Vafadar Yengejeh[1], S.Çiğdem Yorulmaz[1], Fikret Yıldız[1], Bulat Rameev[1,2],

[1]*Physics Department, Gebze Technical University, Gebze, Kocaeli 41400, Turkey*

[2]*Zavoisky Physical-Technical Institute – Subdivision of the Federal Research Center "Kazan Scientific Center of Russian Academy of Sciences", Kazan/Tatarstan, Russian Federation*

As a developing field of light-matter interaction in hybrid quantum systems, photon frequency conversion via coherent coupling with magnon material has attracted significant attention in recent years due to its promising applications in quantum information technologies [1]. For maximizing the conversion efficiency, long-coherence and low-damping materials (e.g., yttrium iron garnet, YIG) coupled to a high-quality microwave cavity have been extensively studied [2]. On the other hand, a similar system can also find many classical applications in microwave electronics. In this respect, we meet the issue of matching contradictory requirements of high conversion efficiency and wideband frequency operation of these magnon-based hybrid systems. Therefore, the development of hybrid systems with high bandwidth to answer the demands of both quantum and classical communication and information processing technologies is very desirable. In this work, a concept of the hybrid microwave-magnon system based on coupled multi-resonance configuration for operation in a wide frequency range has been proposed. Geometrical and structural optimization of the proposed concept using a commercial finite element modeling software (*CST Studio Suite*) has been done. Furthermore, an analytical model of the photon-magnon coupling between YIG and cavity configuration [3] has been applied to perform a numerical evaluation of the hybrid system.

This work was supported by NATO Science for Peace and Security Programme (NATO SPS project No. G5859).

[1] B. Bhoi and S. K. Kim, *Roadmap for photon-magnon coupling and its applications*, 1st ed., vol. 71. Elsevier Inc., 2020.
[2] J. W. Rao *et al.*, "Interferometric control of magnon-induced nearly perfect absorption in cavity magnonics," *Nat. Commun.*, vol. 12, no. 1, p. 1933, 2021.
[3] B. Bhoi, S. H. Jang, B. Kim, and S. K. Kim, "Broadband photon-magnon coupling using arrays of photon resonators," *J. Appl. Phys.*, vol. 129, no. 8, 2021.

*** Ground-state cooling of mechanical resonators by quantum reservoir engineering**

Muhammad Tahir Naseem and Özgür E. Müstecaplıoğlu,

*Department of Physics, Koç University, 34450 Sariyer, Istanbul Turkey*

Ground-state cooling of multiple mechanical resonators becomes vital to employ them in various applications ranging from ultra-precise sensing to quantum information processing. Here we propose a scheme for simultaneous cooling of multiple degenerate or near-degenerate mechanical resonators to their quantum ground-state, which is otherwise a challenging goal to achieve. As opposed to standard laser cooling schemes where coherence renders the motion of a resonator to its ground-state, we consider an incoherent thermal source to achieve the same aim. The underlying physical mechanism of cooling is explained by investigating a direct connection between the laser sideband cooling and "cooling by heating". Our advantageous scheme of cooling enabled by quantum reservoir engineering can be realized in various setups, employing parametric coupling of a cooling agent with the target systems. We also discuss using non-thermal baths to simulate ultra-high temperature thermal baths for cooling.

* Accepted in Communication Physics (2021)

**Quantum State Estimation from Partial Tomography Measurements by Imputation and Ensemble Machine Learning**

Onur Danaci[1], Sanjaya Lohani[2], Brian T. Kirby[3], Ryan T. Glasser[2]

[1] *IBM-HBCU Quantum Center, Howard University, Washington DC 20059, US*
[2] *Tulane University Physics Department, New Orleans LA 70118, US*
[3] *United States Army Research Laboratory, Adelphi, Maryland 20783, US*

Two-qubit systems typically employ 36 projective measurements for high-fidelity tomographic estimation. The overcomplete nature of the 36 measurements suggests possible robustness of the estimation procedure to missing measurements. In this paper, we explore the resilience of machine-learning-based quantum state estimation techniques to missing measurements by creating a pipeline of stacked machine learning models for imputation, denoising, and state estimation. When applied to simulated noiseless and noisy projective measurement data for both pure and mixed states, we demonstrate quantum state estimation from partial measurement results that outperforms previously developed machine-learning-based methods in reconstruction fidelity and several conventional methods in terms of resource scaling. Notably, our developed model does not require training a separate model for each missing measurement, making it potentially applicable to quantum state estimation of large quantum systems where preprocessing is computationally infeasible due to the exponential scaling of quantum system dimension.

# Multi-Spatial-Mode Intensity Difference Squeezing and Numerical Calibration for Hot Atomic Vapor Four-Wave Mixing Systems

Onur Danaci[1], Ryan T. Glasser[2]

*[1]IBM-HBCU Quantum Center, Howard University, Washington DC 20059, US*
*[2]Tulane University Physics Department, New Orleans LA 70118, US*

In this work we showed how the theories of Laguerre Gauss Beam Propagation Method (LG-BPM), semiclassical non-linear paraxial optics by 3D LG expansion, and full-quantum theory of multi-spatial squeezing of paraxial modes can be applied to hot atomic vapor fourwave mixing experiments under the perfect phase-matching approximation. Using those we modeled why using Gaussian type pumps in seeded FWM, albeit how large they are, can never lead to the generation and two-mode squeezing coupling of singular probe and conjugate modes. We connected the consequences of this to the naive interpretations of intensity difference squeezing experiments, and how the strength of some spatially allowed quantum resources (squeezing strength when ignoring other variables such as temperature, frequency or beam intensity but focusing on the spatial overlap alone) are underestimated because they can not be directly accessed in these experiments. Lastly, we proposed a series of steps, we named Control Spatially Allowed Target Squeezing by Adjacent p (CSATSAP), to generate whatever spatial modes we want to generate, and the number of squeezed quantum channels through hot atomic vapor FWM by means of structuring the pump and probe modes using holograms. We numerically simulated two cases as a demonstration of CSATSAP, and we complemented them by a new homodyne measurement scheme to access the underlying vacuum squeezed modes that are shrouded by the bright parametrically amplified modes.

**Hardware of Quantum Computers: A Literature Review**

Zeynep Pelin Yıldırım[1*], Ahmed Asaf Toprakçı[2], İlke Ercan[3]

[1] *Electrical and Electronics Engineering Department, Boğaziçi University, İstanbul, Turkey*
**zeyneppelin.yildirim@boun.edu.tr*
[2] *Physics Department, Bilkent University, Ankara, Turkey*
[3] *Department of Microelectronics, Technical University of Delft, Delft, the Netherlands*

The realization of quantum computing technologies faces a wide range of engineering challenges from circuit to architectural level. In this talk, we provide an extensive literature review on hardware constraints of quantum circuits that depend on physical limitations stemming from given technology-bases. We discuss the building blocks of proposed quantum computers and the impact of different physical circuit structures used to realize this hardware: We provide a comparative analysis of spin qubits, Nitrogen-Vacancy (NV) center qubits, superconducting qubits and topological qubits. We also present our physical analysis of a specific superconducting circuit structure to provide a comprehensive bottom-up discussion. Our work provides a crash-course on the physical constraints of quantum computers.

**Feedback Control Algorithms for Quantum Batteries**

Sergey Borisenok[1,2]

[1]*Department of Electrical and Electronics Engineering, Faculty of Engineering, Abdullah Gül University, Kayseri, Turkey*
[2]*Feza Gürsey Center for Physics and Mathematics, Boğaziçi University, Turkey*

Quantum Battery (QB) is a quantum device that satisfies few criteria: it can be charged with energy, it can efficiently store the charged energy, and finally it can transfer the storage energy to consumption centers. The theoretical and experimental study of quantum batteries is placed nowadays at the frontier of scientific research. To compare with classical ones, such quantum devices demonstrate a set of outstanding features for the energy storage, for instance, they can be designed not to lose their charge virtually forever.

There are many physical realizations of qubit-based quantum batteries (Dicke QB, spin QB, harmonic oscillator QB) together with the different topology of the battery-charger systems. Here we discuss a model for a single-qubit based QB in the form of quantum oscillator in a Markovian bath environment.

Feedback algorithms allow controlling the basic characteristics of quantum batteries: the ergotropy, the charging power, the storage capacity and others. The control algorithms applied to QBs could be based on Fradkov's speed gradient (SG) or, alternatively, on Kolesnikov's target attractor (TA) feedback. The difference between SG and TA approaches is related to the energy consumption for the control: SG drives the system 'gently' towards the control goal, while TA constructs a 'rigid' attractor locking the system evolution in its neighborhood.
We discuss pros and cons of both methods for the efficient control over the ergotropy and charging power of bosonic QB. The proposed algorithms are robust; they are stable under the perturbation of the initial conditions in the system and under the application of a relatively small external noise. Both algorithms could be adopted also for different physical realizations of quantum batteries, and for all working stages of the quantum battery (charging, long time storage and the energy transfer to a consumption center or engine).

**Keywords:** Quantum battery, ergotropy, charging power, feedback control.

**Quantum communication using SU(2)–invariant 2 x N level separable states**

Sooryansh Asthana_, Rajni Balay, and V. Ravishankarz

*Department of Physics, Indian Institute of Technology Delhi, New Delhi, India-110016.*

Bloch vector contains the information encoded in a qubit. Employing this fact, we propose protocols for remote transfers of information in a known and an unknown qubit to qudits using SU(2) – invariant 1/2 ⊗ S discordant states as a quantum channel. These states have been identified as separable equivalents of the two-qubit entangled Werner states in [Bharath & Ravishankar, Phys. Rev. A 89, 062110]. Due to SU(2) x SU(2) symmetry of these states, the remote qudit can be changed by performing appropriate measurements on the qubit. We also propose a protocol for transferring information of an unknown qudit to a remote qudit using a ½ ⊗ S state as a channel. Finally, we propose a protocol for swapping of quantum discord from ½ ⊗ S– systems to S ⊗ S– systems. All the protocols proposed in this paper involve separable states as quantum channels. Employing these protocols, we believe that quantum information processing can be performed using highly mixed separable higher dimensional states.

**A Computer Science-Oriented Approach to Introduce Quantum Computing To A New Audience**

Özlem Salehi, Zeki C. Seskir, İlknur Tepe

*Özyeğin University Computer Science Department, METU Physics Department*
*ozlem.koken@ozyegin.edu.tr, zseskir@metu.edu.tr*

In this study, we have assessed the effectiveness of a three-day hands-on training material-based workshop material called Bronze, prepared and administered by QWorld initiative. Gathered data consists of pre and post-test results of 317 participants from 22 workshops held between May of 2019 and March of 2020 at ten countries. We assessed the increase in basic knowledge of quantum computing concepts at participants through a series of questions on quantum phenomena, quantum logic gates, and quantum algorithms. The main finding of this study is that the workshop material utilized for this series of workshops was most beneficial to participants with lesser or no initial understanding of the concepts. Having noted that, we have found that the knowledge levels of participants on quantum computing have increased for all levels of education (high school, B.Sc., M.Sc., Ph.D.), regardless of department or gender. Therefore, we demonstrate that hands-on programming tasks-based training workshop is an effective way to teach quantum computing.

# *Posterler / Posters*

**Inter-substances "Natural Quantum Communication" investigation by atomic exchange observation with photonic wave-particle duality quantisation**

Ahmet Orun

*De Montfort University, Faculty of Computing, Engineering and Media*
*Gateway House, Leicester LE1 9BH, United Kingdom*
*E-mail: aorun@dmu.ac.uk ; Phone: +44(0)116 3664408*

We have managed to observe the magnitudes of atomic exchange activities between the chemical substances by quantization of interferometric (Mach-Zehnder) quantum eraser pattern's motions caused by photonic wave-particle duality shifting. Such characteristic shiftings substantially support our Natural Quantum Communication theory which indicates that the Interferometer's photons attempt to access or gain complementary information provided by "naturally communicated" substances in the chemical reaction tube located along the lower arm of interferometer, which consequently exhibit characteristic wave-particle duality shifting. The proposed theory may explain, how medications provide curing effect on "diseased organic tissues" via transmitting a complementary quantum information that is normally missing in the receiver domains, or natural quantum communication between vaccine and immune system. Furthermore, in the future some related advance technique would be expected to replace natural substance style supplements (e.g. human cells' need of Oxygen) with only (Oxygen's) quantum information instead.

**Study of the optical response and coherence of a quadratically coupled optomechanical system.**

Akash Kundu*, Chao Jin**, and Jia Xin Peng***

*Institute of Theoretical and Applied Informatics, Polish Academy of Sciences, Baltycka 5, 44-100 Gliwice, Poland.
**Institute for Computational Materials Science, School of Physics and electronics, International Joint Research Laboratory of New Energy Materials and Devices of Henan Province, Henan University, Kaifeng 475004, People's Republic of China.
***State Key Laboratory of Precision Spectroscopy, Quantum Institute for Light and Atoms, Department of Physics, East China Normal University, Shanghai 200062, People's Republic of China.

In this article, we theoretically investigate a quadratically coupled optomechanical system with a two-level atom. At steady-state, we examine the variation of transmission intensity with various parameters of the system as well as investigate the transmission in lower/upper sidebands. Moreover, taking into account the quantum fluctuations, we extend our investigation towards the study of quantum coherence for the optomechanical system. The result shows that the coherence inside the proposed cavity can be efficiently controlled by varying atom-to-photon coupling and modified optical detuning. We also discuss and provide a physical explanation of why the atomic coherence can surpass the optical and mechanical ones.

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# Coherence harvesting with moving qubits

Dimitris Moustos*

*Department of Physics, University of Patras, 26504 Patras, Greece*
**dmoustos@upatras.gr*

We study the effects of motion on the amount of coherence extracted onto a two-level system when it interacts with a scalar coherent field in 1+1 dimensional flat spacetime. We find that for certain values of the initial energy of the field and the duration of the interaction it is possible to harvest a larger amount of coherence for a qubit moving with constant speed or uniform acceleration than a static one. This phenomenon becomes more intense for increasing values of the qubit's velocity and acceleration, and is mostly observed for long interaction durations, when the initial energy of the field is lower than the gap between the qubit's energy levels, and for shorter interaction durations but larger field energies. As a result, the rate at which coherence is lost is sometimes slower for a moving qubit than a static one.

[1] N. K. Kollas, D. Moustos and K. Blekos, Phys. Rev. D **102**, 065020 (2020).

**Tunable multiwindow magnomechanically induced transparency, Fano resonances, and slow-to-fast light conversion**

Kamran Ullah, M. Tahir Naseem and Özgür E. Müstecaplıoglu

*Department of Physics, Koç University, Sarıyer, Istanbul 34450, Turkey*
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We investigate the absorption and transmission properties of a weak probe field under the influence of a strong control field in a cavity magnomechanical system. The system consists of two ferromagnetic-material yttrium iron garnet (YIG) spheres coupled to a single cavity mode. In addition to two magnon-induced transparencies (MITs) that arise due to magnon-photon interactions, we observe a magnomechanically induced transparency (MMIT) due to the presence of nonlinear magnon-phonon interaction. We discuss the emergence of Fano resonances and explain the splitting of a single Fano profile to double and triple Fano profiles due to additional couplings in the proposed system. Moreover, by considering a two-YIG system, the group delay of the probe field can be enhanced by one order of magnitude as compared with a single-YIG magnomechanical system. Furthermore, we show that the group delay depends on the tunability of the coupling strength of the first YIG with respect to the coupling frequency of the second YIG, and vice versa. This helps to achieve larger group delays for weak magnon-photon coupling strengths.

**Single Atom Quantum Heat Engine in Asymmetric Harmonic Oscillator Trap by Optomechanical model**

Mohsen Izadyari[1], Mehmet Öncü[2], Kadir Durak[3], and Özgür E. Müstecaplıoğlu4

[1] *Koç University, Physics Department, Istanbul, 34450, Turkey (mizadyari18@ku.edu.tr)*
[2] *Özyein University, Physics Department, Istanbul, 34794, Turkey (mehmet.oncu@ozu.edu.tr)*
[3] *Özyeğin University, Physics Department, Istanbul, 34794, Turkey (kadir.durak@ozyegin.edu.tr)*
[4] *Koç University, Physics Department, Istanbul, 34450, Turkey (omustecap@ku.edu.tr)*

We propose a single-atom heat engine by using an optomechanical-like model when the atom is trapped in a two-dimensional asymmetric potential. We show how the coupling coefficient between radial and axial axes effects on power and efficiency of the engine. To examine the model, we suppose our atom trapped in an assymetric Paul trap, based on single-atom heat engine experiment [1], and investigate the effects of axial and radial frequency and geometry of the trap on coupling coefficient and therefore on power and efficiency of the heat engine.

Also, we show that our proposed system can be used as a general model for different systems such as an assymetric magneto-optical trap.

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**Assisted catalysis of coherence from quantum fields**

Nikolaos Kollas

*Physics department university of Patras*

The process of coherence extraction from a reservoir exhibits a surprising feature. Although the state of the reservoir is disturbed after each extraction it can be reused resulting in the same amount of coherence each time. This process known as *catalytic coherence* depends on the state of the reservoir and usually requires a maximally coherent state of a very large dimension. For this reason catalysis of coherence in quantum information has been criticized as unnatural and therefore of no interest. By studying coherence extraction for a qubit interacting with a scalar field through a time derivative interaction it is shown that a modified version of this process called *assisted catalysis,* in which a fixed amount of energy is required for each extraction, is possible in the limit of an instantaneous interaction. Surprisingly, in this case, the process is universal and only requires a field with a non-vanishing coherence amplitude distribution. Due to the fact that this toy model resembles closely the interaction of a dipole with an electromagnetic field seems to suggest that catalysis is experimentally achievable, contrary to what was previously thought.

**Quantum conferencing based on Mermin's contextuality inequality**

Rajni Bala[1], Sooryansh Asthanay[2], and V. Ravishankarz[3]

*[1,2,3] Department of Physics, Indian Institute of Technology Delhi, New Delhi, India-110016.*

Quantum key distribution (QKD) is one of the first application of quantum physics which has entered the commercial market. The security of QKD protocols relies on the quantum nature of the physical system used. In this work, we present a quantum conferencing protocol, security of which depends upon the contextuality of single qudit system. Thus, our protocol come under the prepare and measure scheme. It has been shown[1] that nonlocality inequalities probes contextuality in single qudit system of suitable dimensions. We use this result and for the purpose of pedagogy, show that with appropriate mapping Mermin's nonlocality inequality[2] detects contextuality in a single qudit system of suitable dimensions. In the proposed protocol, Mermin's contextuality inequality act as a security check. Unlike the non-locality based protocol, this protocol does not involve entangled states, whose generation is very difficult. The proposed protocol can be implemented without any compromise in the key generation rate in certain noisy channels. The experimental key generation rate of the protocol will also be high if one uses weak coherent pulses instead of the limited brightness of entangled photon pair sources. With the advancement in generation and manipulation of higher dimensional orbital angular momentum(OAM) states of light[3, 4], our protocol can be realised experimentally.

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**Interferences and Correlations in Multi-Photon Quantum Walk**

Yusuf Karlı, Özgür Çakır

*University of Innsbruck*

Quantum walks can be described as quantum analogues of classical random walks. In quantum walks, the direction of the walker is dictated by the quantum state of a coin in a coherent fashion. Unlike classical random walk with a fair coin, quantum walk has non-Markovian property. We studied average photon number correlations for 1-D quantum walk with many body bosonic walkers, like different light sources, to investigate quantum interference effects and we showed the second-order intensity correlations function (g (2) (τ)) in terms of the probability amplitudes of the 1-D quantum walk with Hadamard coin. We compared the resulting correlations for various initial many photon states.