# POSTER ABSTRACTS

## Jonathan P. Dowling Memorial Conference
## On Quantum Science and Technology

**A Celebration of the Life and Work of World-Renowned Professor**
**Jonathan P. Dowling (1955 – 2020)**

**May 12-13, 2022**
**Louisiana State University**
**Digital Media Center Theatre**

**Paul Alsing**
**Air Force Research Laboratory, Information Directorate, Rome, NY**

Title: **The Hong-Ou-Mandel Effect is Really Odd**

Authors: Paul M. Alsing, Richard J. Birritttella, Christopher C. Gerry, Jihane Mimih and Peter L. Knight

Abstract:

We show that any odd parity state entering one input port of a 50:50 beam splitter, with an arbitrary state entering the other input port, produces zero coincidence counts. This result extends the HOM effect to a broader, more general class of states than just single photons. In addition, we show how even just a single photon produces a dramatic effect on the output probability distribution of the photons exiting a beam splitter, even when acting on ``classical-like'' states such as coherent states or thermal states, as well as other non-classical odd parity pure and mixed states. We discuss the derivation of these effects, and simulate experiments, including loss, for how this effect might be experimentally observed in light of today's photon number-resolving detectors.

**Anshuman Bhardwaj**
**Department of Physics & Astronomy, Louisiana State University**

Title: **Entanglement in a BEC analogue of cosmological inflation**

Authors: Anshuman Bhardwaj, Dimitrios Kranas, Justin Wilson, Daniel E. Sheehy & Ivan Agullo

Abstract:

Recent experiments have employed rapidly-expanding toroidal Bose-Einstein condensates (BECs) to mimic the inflationary mechanism in the early universe [1]. One signature of inflation in such experiments is spontaneous particle creation (of phonons) which is observable in density-density correlations [2]. In this work, we study entanglement of these particles, which are known to result in a two-mode squeezed state. We use the techniques of Gaussian states for continuous-variables systems to quantify the entanglement generated in this system [3]. We also develop a protocol to experimentally measure the correlations entering the covariance matrix, allowing an experimental quantification of the entanglement properties of the inflationary BEC.

[1]. S. Eckel et al, Phys. Rev. X 8, no. 2, 021021 (2018).
[2]. A. Bhardwaj, D. Vaido & D. E. Sheehy, Phys. Rev. A 103, 023322 (2021).
[3]. A. Serafini, Quantum continuous variables (2017).

**Noah Davis**
**University of Texas at Austin**

Title: **Sample-Depth Trade-Off for NISQ Amplitude Amplification**

Authors: Noah Davis, Andrew Lanham

Abstract:

Many quantum computing algorithms, such as amplitude amplification, provide improvements in time or the number of samples necessary to complete a computation through clever usage of quantum oracles. However, the circuit depth required for these algorithms challenges the coherence of current quantum computers. In particular, algorithms based on amplitude amplification must repeatedly apply a characteristic quantum oracle. We use the well-known swap test to explore the trade-off between circuit depth and required computational time in order to identify useful parameter regimes for NISQ devices.

**Stav Haldar**
**Louisiana State University**

Title: **Global Precision Time Distribution Network via Satellite-Based Entangled Photon Sources - A precursor to the Quantum Internet**

Authors: Stav Haldar, Ivan Agullo, James Troupe

Abstract:

We propose the near-term implementation of a hybrid quantum network of satellite and ground based clocks with the ability to implement a quantum clock synchronization (QCS) protocol to the picosecond level. In contrast to classical techniques, QCS does not require an apriori knowledge of time of travel between two parties, instead both time of travel and clock offset can be extracted independently. It utilizes the tight time-correlations between entangled photons and the information transfer efficiency gains offered by optical communication using single photon detection over radio frequency (RF) based classical communication. Using the polarization correlations, the QCS protocol also has quantum security. In this work, we provide analytical and simulation results for the sync outcomes for cities across the continental United States using a minimalist constellation of satellites, low-cost entanglement sources, portable atomic clocks, and avalanche detectors. Such precision levels are currently not achievable over these distance scales ($\approx 4000$ km). More specifically, the effect of range-rate change due to relative motion of satellite and ground station clocks on the success of the QCS protocol proposed in reference \cite{AntiaQCS} is studied. This allows us to assess the feasibility of implementing this protocol over long distances by establishing time transfer links between satellites and ground stations. Satellites can then act as intermediaries and transfer time from one ground station to another ground station thousands of kilometers away. A QCS network will form the basis of future quantum networks like the Quantum Internet, distributed quantum sensing and Quantum GPS.

**Sabre Kais**
**Purdue University**

Title: **Statistical Analysis on Random Quantum Sampling by Sycamore and Zuchongzhi Quantum Processors**

Authors: Sangchul Oh and Sabre Kais

Abstract:

Random quantum sampling, a task to sample bit-strings from a random quantum circuit, is considered one of suitable benchmark tasks to demonstrate the outperformance of quantum computers even with noisy qubits. Recently, random quantum sampling was performed on the Sycamore quantum processor with 53 qubits [Nature 574, 505 (2019)] and on the Zuchongzhi quantum processor with 56 qubits [Phys. Rev. Lett. 127, 180501 (2021)]. Here, we analyze and compare statistical properties of the outputs of random quantum sampling by Sycamore and Zuchongzhi. Using the Marchenko-Pastur law and the Wasssertein distances, we see that quantum random sampling of Zuchongzhi is more closer to classical uniform random sampling than those of Sycamore.  Some Zuchongzhi's bit-strings pass the random number tests while both Sycamore and Zuchongzhi show similar patterns in heatmaps of bit-strings. It is shown that statistical properties of both random quantum samples change little as the depth of random quantum circuits increases. Our findings raise a question about computational reliability of noisy quantum processors that could produce statistically different outputs for the same random quantum sampling task.

**Brian La Cour**
**Applied Research Laboratories, The University of Texas at Austin**

Title: **Classical model of “loophole free” experimental violation of the Leggett-Garg inequality**

Authors: Brian R. La Cour

Abstract:

Leggett-Garg inequalities are used to test macrorealism, which, in the context of photonic interferometry experiments, is the assertion that a photon is present in exactly one arm of the interferometer at any given time. A recent photonic experiment has demonstrated a violation of the Leggett-Garg inequality in a manner that the authors describe as being free of all relevant loopholes. This conclusion is found to be unwarranted, as the experimental method fails to close the detection loophole. We illustrate this with a classical model of the experiment that reproduces a violation under similar constraints and analysis methods and is in excellent agreement with the quantum mechanical predictions. We conclude that the experiment does not demonstrate true quantum behavior, although it is consistent with a rejection of macrorealism.

**Jacob Leamer**
**Tulane University**

Title: **Classical Optical Analogue of Quantum Discord**

Authors: Jacob M. Leamer, Wenlei Zhang, Nicholas J. Savino, Ravi K. Saripalli, Sanjaya Lohani, Ryan T. Glasser, Denys I. Bondar

Abstract:

Quantum discord has been shown to be a resource for quantum advantage in addition to quantum entanglement. While many experiments have demonstrated classical analogies of entanglement, none have done so for discord. We present a proof-of-concept demonstration for creating a classical analogue of quantum discord using classical light that takes advantage of the analogy between the state of two qubits and the spatial modes of a Laguerre-Gauss beam. We demonstrate the validity of this approach by comparing the intensity profiles of theoretical simulations to experimental results for different values of discord. Such a classical analogue of quantum discord may provide further insight in understanding and development of quantum information technologies that make use of discord.

**Sanjaya Lohani**
**University of Illinois Chicago**

Title: **Data-Centric approach to Machine Learning in Quantum State Reconstruction**

Authors: Sanjaya Lohani, Joseph M. Lukens, Ryan T. Glasser, Thomas A. Searles, Brian T. Kirby

Abstract:

We propose a series of data-centric heuristics for improving the performance of machine learning systems when applied to problems in quantum information science. In particular, we consider how systematic engineering of training sets can significantly enhance the accuracy of pre-trained neural networks used for quantum state reconstruction without altering the underlying architecture. For further clarity, we also include a "toy model" demonstration of how spurious correlations can inadvertently enter synthetic data sets used for training, how the performance of systems trained with these correlations can degrade dramatically, and how the inclusion of even relatively few counterexamples can effectively remedy such problems.

**Ian Nodurft**
**University of Illinois at Chicago**

Title: **Polarization Entanglement Generation by Quantum Zeno Dynamics**

Authors: Ian C. Nodurft, Brian T. Kirby, Ryan T. Glasser, Harry C. Shaw, Thomas A. Searles

Abstract:

The quantum Zeno effect reveals that the continuous observation of a quantum system can result in significant alterations to its evolution. Here we present a method for establishing polarization entanglement between two initially unentangled photons in coupled waveguides via the quantum Zeno effect. We support our analytical analysis with numerical simulations of the underlying Schrodinger equation describing the system. Further, we extend our technique to three coupled waveguides in a planar configuration and determine the parameter regime required to generate three-qubit W-states. Our findings present a powerful quantum state engineering approach applicable to systems of coupled waveguides.

**Sangita Regmi**
**University of Illinois Chicago**

Title: **Quantum state tomography for systems with different dimensions using neural network.**

Author: Sangita Regmi, Sanjaya Lohani, Joseph M. Lukens, Ryan T. Glasser, Thomas A. Searles, Brian T. Kirby

Abstract:

We show that our technique does not need to match the dimensionality of a system being analyzed exactly with the dimensions of a trained model. We use a machine learning model trained on four qubits to demonstrate the effectiveness of our method to reconstruct quantum states from randomly sampled systems of one, two and three qubits.

**Nicholas Savino**
**Tulane University**

Title: **Coherent Control of Evanescent Waves via Beam Shaping**

Authors: Nicholas Savino, Jacob Leamer, Wenlei Zhang, Ravi Saripalli, Ryan Glasser, Denys Bondar

Abstract:

Evanescent waves are central to many technologies such as near-field imaging that beats the diffraction limit and plasmonic devices. They provide a classical analog to quantum tunneling. Frustrated total internal reflection (FTIR) is an experimental method commonly used to study evanescent waves. We shape the incident beam of the FTIR process with a Mach-Zehnder interferometer and measure light transmittance while varying the path length difference and interferometric visibility. Our results show that the transmittance varies with the path length difference and, thus, the intensity distribution of the shaped beam. Experiment and finite element method simulation produce results that agree. We also show, through simulation, that the transmittance can be controlled via other methods of beam shaping. Our work provides a proof-of-concept demonstration of the coherent control of the FTIR process, which could lead to advancements in numerous applications of evanescent waves and FTIR. Our results may also be used to model quantum tunneling and provide insight on how it can be controlled.

**Kaushik Seshadreesan**
**University of Pittsburgh**

Title: **Multiplexed quantum repeaters based on dual-species trapped-ion systems**

Authors: Prajit Dhara, Norbert Linke, Edo Waks, Saikat Guha, Kaushik Seshadreesan

Abstract:

Trapped ions form an advanced technology platform for quantum information processing with long qubit coherence times, high-fidelity quantum logic gates, optically active qubits, and a potential to scale up in size while preserving a high level of connectivity between qubits. These traits make them attractive not only for quantum computing but also for quantum networking. Dedicated, special-purpose trapped-ion processors in conjunction with suitable interconnecting hardware can be used to form quantum repeaters that enable high-rate quantum communications between distant trapped-ion quantum computers in a network. In this regard, hybrid traps with two distinct species of ions, where one ion species can generate ion-photon entanglement that is useful for optically interfacing with the network and the other has long memory lifetimes, useful for qubit storage, have been proposed for entanglement distribution. We consider an architecture for a repeater based on such dual-species trapped-ion systems. We propose and analyze a repeater protocol based on spatial and temporal mode multiplexing for entanglement distribution across a line network of such repeaters. Our protocol offers enhanced rates compared to rates previously reported for such repeaters.

**Dmitry Uskov**
**Brescia University, Owensboro KY and Tulane University, New Orleans LA**

Title: **Vector Properties of Entanglement in a Three-Qubit System**

Authors: Dmitry Uskov and Paul Alsing

Abstract:

Vector Properties of Entanglement in a Three-Qubit System

Dmitry B. Uskov 1,2*, Paul M. Alsing 3
1Department of Mathematics and Natural Sciences, Brescia University, Owensboro, Kentucky 42301, USA
2Department of Physics and Engineering Physics, Tulane University, New Orleans, Louisiana 70118, USA
3Air Force Research Laboratory, Information Directorate, Rome, New York 13441, USA

Abstract: We develop a dynamical vector model of entanglement in a three qubit system based on homeomorphism between SU(4) and SO(6) Lie groups. We introduce three complex-valued vectors (denoted here as A, B and C). Magnitudes of these vectors determine two- and three-qubit entanglement parameters of the system.
We show that evolution of vectors A, B and C under local operations is identical to evolution of single-qubit Bloch vectors of qubits a, b and c correspondingly. At the same time, general two-qubit Hamiltonians incorporating a-b, a-c and b-c two-qubit coupling terms generate more general coupling between vectors A and B, A and C, and A and B correspondingly. It turns out that dynamics of entanglement induced by different two-qubit coupling terms is determined by mutual orientation of vectors A, B, C.
We illustrate the power of this vector description of entanglement by solving quantum control problems involving transformations between W, Greenberg-Horne-Zeilinger (GHZ) and biseparable states.

https://journals.aps.org/pra/pdf/10.1103/PhysRevA.102.032401

**Wenlei Zhang**
**Tulane University**

Title: **Experimental Violation of the Leggett-Garg Inequality Using the Polarization of Classical Light**

Authors: Wenlei Zhang, Ravi K. Saripalli, Jacob M. Leamer, Ryan T. Glasser, Denys I. Bondar

Abstract:

In contrast to Bell's inequalities, which test the correlations between multiple spatially separated systems, the Leggett-Garg inequalities test the temporal correlations between measurements of a single system. We experimentally demonstrate the violation of the Leggett-Garg inequality in a classical optical system using only the polarization degree of freedom of a laser beam. Our results show maximal violations of the Leggett-Garg inequality.