Symposium of Optical Quantum Technologies (SOQUTE2019)

Shanghai, Nov.5-7, 2019

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November 5th:

14:00 – 18:00	Register

November 6th:

8:50 – 9:00	Welcome
9:00 – 9:45	Stephen Bartlett, USYD
9:45 – 10:00	Hao Tang, SJTU
10:00 – 10:30	Tea Break
10:30 – 11:15	Ya Cheng, ECNU
11:15 – 12:00	Yidun Wan, FDU
14:00 – 14:45	Carlos Navarrete-Benlloch, SJTU
14:45 – 15:30	Hui Liu, NJU
15:30 – 16:15	Huangjun Zhu, FDU
16:15 – 16:45	Tea Break
16:45 – 17:30	Peng Xue, CSRC
17:30 – 18:15	Steve Flammia, USYD

November 7th:

9:00 – 9:50	Kadi Zhu, SJTU
9:45 – 10:00	Yao Wang, SJTU
10:00 – 10:30	Tea Break
10:30 – 11:15	Tim Byrnes, NYU Shanghai
11:15 – 12:00	Weiwei Zhang, USYD
14:00 – 14:45	Xiaopeng Li, FDU
14:45 – 15:30	Ben Brown, USYD
15:30 – 16:15	Feng Mei, SXU
16:15 – 16:45	Tea Break
16:45 – 17:30	Yanhong Xiao, SXU
17:30 – 18:15	Zi Cai, SJTU

Invited Speakers:

Stephen Bartlett	The University of Sydney
Weiwei Zhang	The University of Sydney
Ben Brown	The University of Sydney
Steve Flammia	The University of Sydney
Xiaopeng Li	Fudan University
Huangjun Zhu	Fudan University
Yanhong Xiao	Shanxi University
Yidun Wan	Fudan University
Hui Liu	Nanjing University
Tim Byrnes	New York University Shanghai
Feng Mei	Shanxi University
Ya Cheng	East China Normal University
Peng Xue	Beijing Computational Science Research Center
Kadi Zhu	Shanhai Jiao Tong University
Zi Cai	Shanhai Jiao Tong University
Carlos Navarrete-Benlloch	Shanhai Jiao Tong University

November 6th

Quantum Memories and Schroedinger's Cat

Stephen Bartlett
The University of Sydney

Quantum information is very fragile, but clever quantum engineers aspire to use error correction to keep information intact. Topologically ordered phases—wherein the most exotic properties of quantum physics such as entanglement are protected within a strongly-interacting material—are currently being commandeered as quantum error-correcting codes for today's quantum architectures. I'll introduce these as well as a new generation of theoretical materials that promise to self-correct themselves. Much like a real-world example of Schrödinger's Cat, a self-correcting quantum memory can protect quantum information in a thermal environment for an arbitrarily long time, without the need for active error correction. I'll demonstrate that symmetry can assist in giving self-correction in 3D spin lattice models. In particular, I'll present quantum codes corresponding to a 2D symmetry-enriched topological (SET) phase that appears naturally on the boundary of an exotic 3D symmetry-protected topological (SPT) phase.

Experimental two-dimensional quantum walks and quantum fast hitting on integrated photonic lattices

Hao Tang
Shanghai Jiao Tong University

Among a variety of physical quantum systems, photons are very suitable for analog quantum computing because their fast speed, a lack of the interaction with the environment and a high mobility enable flexible constructions of the Hamiltonian systems. In this talk, I'll demonstrate our large-scale two-dimensional quantum walks, a very important analog quantum algorithm, being implemented on the integrated photonic lattice. I shall also show our works on experimental quantum fast hitting that present impressive quantum advantages. I'll further introduce more of our waveguide engineering capabilities and our software that's specifically issued for photonic analog quantum computing.

Ultra-low loss lithium niobate nanophotonics

Ya Cheng
East China Normal University

Photonic integrated circuits (PICs) are expected to play the leading roles in the future optical communications and quantum information processing. From the material point of view, lithium niobate (LN) is almost perfect for PIC application, since it has a broad optical transparency window, a high nonlinear coefficient, a high refractive index, and a large electro-optic coefficient. Here, we present the recent breakthrough in the field of high quality LNOI PICs enabled by the recent development of chemo-mechanical polish lithography (CMPL). The technique holds the promise for realizing LNOI waveguides of ultra-low propagation loss approaching the absorption limit of LN, thereby opening a realistic pathway to the realization of large-scale reconfigurable PICs for on-chip quantum information processing, optical computations and communications, metrology, microwave photonics, and optical interconnection.

Quantum spacetime on a quantum simulator

Yidun wan
Fudan University

Abstract: Quantum simulation has shown its irreplaceable role in many fields, where it is difficult for classical computers to contribute much. On a four-qubit Nuclear Magnetic Resonance (NMR) quantum simulator, we experimentally simulate the spin network states by simulating quantum spacetime tetrahedra. The fidelities between our experimentally prepared quantum tetrahedra are all above 95%. We then use the quantum tetradedra prepared by NMR to simulate a spinfoam vertex amplitude, which displays the local dynamics of quantum spacetime. By measuring the geometric properties on the corresponding quantum tetrahedra and simulating their gluing, our experiment serves as a basic module that represents the Feynman diagram vertex in the spinfoam formulation of Loop Quantum Gravity(LQG). This is an initial attempt to study LQG and/or other quantum spacetime by quantum information processing.

Opportunities in bosonic quantum simulators subject to particle non-conserving processes

Carlos Navarrete-Benlloch
Shanghai Jiao Tong University

Many-body bosonic Hamiltonians are a cornerstone of condensed-matter physics. Quantum simulators, that is, quantum-controlled atomic, optical, or solid-state experimental platforms, hold the promise to explore such models with a degree of precision and flexibility unthinkable in real materials. Common Hamiltonians emerging in condensed-matter preserve the number of particles. In contrast, quantum simulators are intrinsically driven-dissipative systems, where processes that break particle-number conservation can be naturally induced either coherently or incoherently. We explore the physics of the extended Bose-Hubbard model under the action of down-conversion-type Hamiltonians which break particle-number conservation, but keep interesting Z2 or U(1) symmetries. The bare model accounts for tunneling and interactions between neighbours and on-site interactions, and presents a variety of phases ranging from superfluid to insulating (of Mott, density-wave, and Haldane types). We show that the introduction of down-conversion terms potentially adds more phases, e.g., predicting Ising-type spontaneous symmetry breaking or supersolid-like behavior under certain conditions.

As a side-product, we study general quadratic bosonic Hamiltonians, whose understanding is useful prior to adding interactions. In contrast to fermionic models, the particle-non-conserving terms can make the Hamiltonian turn from stable (bounded) to unstable (unbounded), with standard Bogoliubov theory covering only the former. We generalize such theory, providing a transformation for any Hamiltonian to a combination of just harmonic oscillators and resonant down-converters, which allow understanding the underlying physics of the model in a very clean and meaningful fashion.

As a second side-product, we provide an example of a single-mode Hamiltonian that presents a continuous quantum phase transition, a result that challenges the common intuition that only infinite-size systems present such behavior. In particular, we show that a harmonic oscillator subject to down-conversion and Kerr nonlinearity (contact interactions), which possess a Z2 symmetry, undergoes a quantum phase transition between symmetry-preserving to symmetry-breaking ground states. We prove that the transition satisfies all the standard requirements, specifically the presence of a sensitive thermodynamic limit and well-defined scaling laws, identifying all critical exponents. Our model is in the same universality class as the Dicke and Lipkin-Meshkov-Glick models, as well as the quantum Rabi model, which was found to be the first example of a zero-dimensional model presenting a quantum phase transition (but requires the interaction of the oscillator with a two-level system).

We discuss potential implementations of our ideas in modern quantum-controlled platforms such as trapped atoms and ions, nonlinear optics, superconducting circuits, and mechanical devices

Controlling Photons By Curved Space in Nanophotonics

Hui Liu
Nanjing University

The fact that the propagation of light in curved space is analogous to that in inhomogeneous media is the underlying principle of emulating General Relativity (GR) phenomena. In artificial structures,

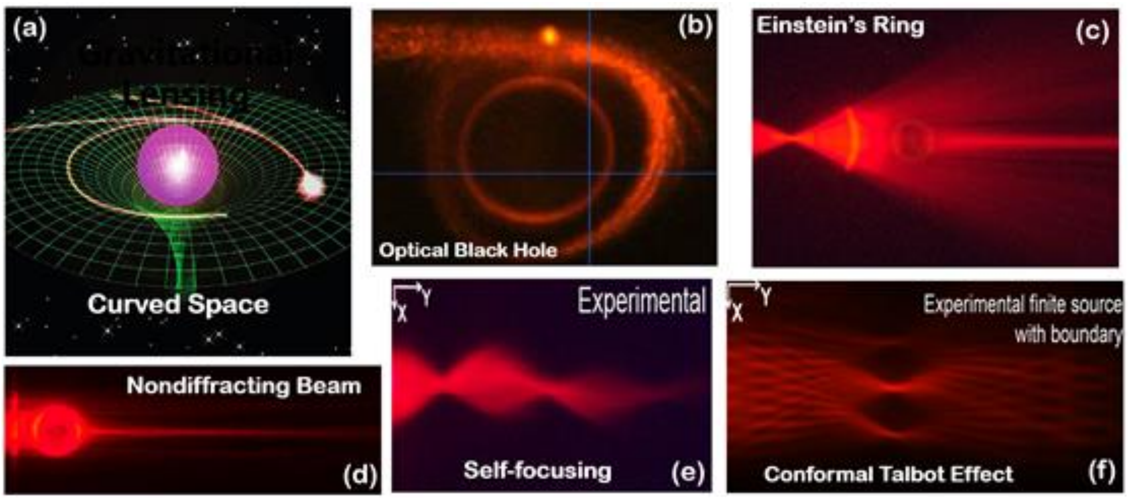

Figure 1. (a) curved space; (b) optical black hole; (c) photonic Einstein’s ring; (d) nondiffraction beam; (e) self-focusing; (f) conformal Talbot effects.

the refractive index are structured to vary according to the curvature of space, giving rise to unique trajectories and controlling the diffraction of light. In this tutorial talk, I will introduce the recent progress about the light controlling by mimicking curved space in nanophotonics, such as optical black hole, photonic Einstein's rings, conformal Talbot effects, and some other interesting works from different international research groups.

References:

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Efficient verification of quantum states and quantum gates

Huangjun Zhu
Fudan University

Quantum states and quantum gates are basic ingredients in quantum information processing. Efficient verification of quantum states and quantum gates based on local operations is a key to the development of quantum technologies, but is a daunting task as the system size increases. Here we present optimal or efficient protocols for verifying a number of important quantum states, including bipartite pure states, GHZ states, hypergraph states, and Dicke states. Furthermore, we present a simple and general framework for verifying unitary transformations that can be applied to both individual quantum gates and gate sets, including quantum circuits. This framework enables efficient verification of all bipartite unitaries, Clifford unitaries, generalized controlled-Z gates, generalized CNOT gates, and CSWAP gate.

Parity-time-symmetric quantum walks

Peng Xue
Beijing Computational Science Research Center

The study of non-Hermitian systems with parity-time (PT) symmetry is a rapidly developing frontier in recent years. Experimentally, PT-symmetric systems have been realized in classical optics by balancing gain and loss, which holds great promise for novel optical devices and networks. Here we report the first experimental realization of passive PT-symmetric quantum dynamics for single photons by temporally alternating photon losses in the quantum walk (QW) interferometers. The

ability to impose PT symmetry allows us to realize and investigate Floquet topological phases driven by PT-symmetric QWs. We observe topological edge states between regions with different bulk topological properties and confirm the robustness of these edge states with respect to PT-symmetry-preserving perturbations and PT-symmetry-breaking static disorder. Our results pave the way for realizing quantum mechanical PT-synthetic devices and augur exciting possibilities for exploring topological properties of non-Hermitian systems using discrete-time QWs.

Scalable estimation of noise in quantum devices

Steve Flammia
The University of Sydney

I will discuss three results related to the scalable estimation of noise in a quantum device. First, the scalable estimation of Pauli channels that factorize over a bounded-degree Markov field, Pauli channels that have sparse error rates, and finally scalable estimation of Hamiltonians and Lindbladians comprising few-body terms. All of these protocols are scalable in n, the number of qubits and are robust to a large class of state preparation and measurements errors, making them suitable for use in characterizing noise in present-day and near-term quantum devices. This is joint work with Robin Harper, Tim Evans, and Joel Wallman.

November 7th

Ultrasensitive Optical Detection of Dark Matter & Dark Energy and Mass Based on Nano-optomechanical Systems

Kadi Zhu
Shanghai Jiao Tong University

The nature of dark energy and dark matter is a central mystery in cosmology, one possibility is that it consists of the scalar field which may drive the acceleration of the expansion of the universe directly. The new light degrees of freedom will couple to matter fields with strength comparable to, or exceed, the gravity. But this long-range fifth force that has not yet been detected on the Earth or in the solar system. One way to alleviate this tension between theory and observation is through the introduction of screening mechanisms. The number of ways of probing the chameleon screening mechanism in the laboratory are proposed or implemented in high vacuum, which have made efforts to derive new limits on the chameleon parameters. These include torsion-balance experiment and gravity resonance spectroscopy. Recent searches using microscopic test masses such as atoms, neutrons and the levitated microspheres often provide the strongest constraints. Also there has been interest in the possibility that dark matter carries a fractional or epsilon charge has been considered recently. The search for the epsilon charges for the range from keV to GeV is progressed through the efforts of many direct experiments and indirect observations over many years, but the evidence is still lacking. On the other hand, the optomechanical coupling between the electromagnetic degrees of freedom and the mechanical motion of mesoscopic objects is a promising method for studying the transition of a macroscopic degree of freedom from the classical to the quantum regime. These systems can also be of considerable effort for improving displacement measurement, force measurement and the detection of gravitational wave. In this talk, we will present a novel proposal based on single/double levitated microparticles or artificial molecules coupled to cavity to detect dark energy & dark matter and particle mass in an all-optical domain with ultrasensitive precision

Topologically Protecting the Quantum

Yao Wang
Shanghai Jiao Tong University

Single photons are ideal carriers of quantum information, and the correlated and entangled photons quantum behavior can become a computational advantage. However, for on-chip applications, the photons inevitably interact with the surrounding medium and can be lost, which is perhaps even more true for delicate entangled photons where the nonclassical correlations between the photons can fizzle out. Here we show that topology can provide protection for single photons, quantum-correlated photons and entangled photons against diffusion and disorder, even in the presence of ambient noise. Our results extend the protection mechanism of topological phases into the quantum regime to directly protect the quantum states, representing an emerging and alternative way of protecting quantumness using the topological phase. The confirmed compatibility between topological states and photons leads to a new avenue to the ‘quantum topological photonics’ and provides more possibilities for quantum materials and quantum technologies.

Remote quantum clock synchronization

Tim Byrnes
New York University Shanghai

A major outstanding problem for many quantum clock synchronization protocols is the hidden assumption of the availability of synchronized clocks within the protocol. In general, quantum operations between two parties do not have consistent phase definitions of quantum states, which introduce an unknown systematic phase error. We show that despite prior arguments to the contrary, it is possible to remove this unknown phase via entanglement purification. This closes the loophole for entanglement based quantum clock synchronization protocols, which are most compatible with current photon based long-distance entanglement distribution schemes. Starting with noisy Bell pairs, we show that the scheme produces a singlet state for any combination of (i) differing basis conventions for Alice and Bob; (ii) an overall time offset in the execution of the purification algorithm; and (iii) the presence of a noisy channel. Error estimates reveal that better performance than existing classical Einstein synchronization protocols should be achievable using current technology.

Realising quantum exotic properties with dynamics

Wei-Wei Zhang
The University of Sydney

Due to the rich controllability in both theoretical and experimental study of quantum walks (QW), researchers find it is a fertile platform for the analysis, simulation and engineering of exotic quantum properties. In this talk, I will give an introduction to the recent QW based schemes for generating cat states, characterising topological materials, generating topological biphoton states and machine-learned properties, and the corresponding experimental implementations in linear optical, photonic chips, silicon waveguide, cold atoms and ion traps.

Towards Optimal Quantum Simulations

Xiaopeng Li
Fudan University

Quantum simulations have been attracting tremendous efforts in the last decade. With the rapid developments in quantum control techniques in synthesised quantum systems such as optical lattices and trapped ions, we are at a stage to perform quantum simulations of complicated models. However the commonly existing problem of finite lifetime or finite coherence time in these systems requests quantum simulations to be performed in an optimal way. Considering the adiabatic approach, optimising quantum simulation performance is also fundamentally related to quantum computing complexity. In this talk, I will describe ways and examples to optimise the adiabatic approach of quantum simulations. The first one is about to optimize quantum simulations of doped Fermi-Hubbard model [1]. I will present an approach of quantum adiabatic doping using incommensurate optical lattices. Optimizing the quantum simulations from exponential complexity to polynomial in this problem turns out to be equivalent to driving a dynamical phase transition of the system from a localized to ergodic phase. The second one is about an automatic design of quantum adiabatic algorithm for Grover search that automatically leads to a quadratic quantum speedup [2]. This automated design of quantum adiabatic algorithms with optimal quantum speedup can be generalised to optimize quantum simulations.

References
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Majorana fermions and measurement-based quantum computation
Ben Brown
The University of Sydney

Owing to their abundance and their coherence time that is comparable to the age of the universe, photons are among the best systems we might choose to encode the physical qubits of a scalable quantum computer. This motivates us to find ways of encoding logical quantum information reliably using linear optics, even if some of the photons experience errors, and then to demonstrate that we can perform fault-tolerant quantum logical operations with the encoded information. Here we propose a new model of universal quantum computation that simulates the braiding and fusion of Majorana modes using linear optics. We derive our protocol by developing a framework that maps modern schemes of fault-tolerant quantum computation that are natively designed for the more familiar circuit-based model into the so-called measurement-based picture. While the latter model is computationally equivalent to the former, it offers a much more natural picture to describe photonic quantum computing. As such, our framework gives an explicit way of producing fault-tolerant models of universal quantum computation with linear optics. Given the remarkable performance that topological quantum computation with Majorana modes promises, our new proposal will provide a robust and resource efficient model of photonic quantum computation as this highly scalable technology approaches experimental realization.

Topological Quantum Circuits on Programmable Quantum Processors
Feng Mei
Shanxi University

Quantum circuits are the core of quantum processors and have been realized in different quantum computing platforms. Here, for the first time, we theoretically propose and experimentally demonstrate an approach to design topologically protected quantum circuits in which spin-orbital couplings and topological insulators could be digitally simulated. In particular, a low-depth topological quantum circuit is performed on both IBM and Rigetti quantum processors. Through measuring the qubit excitation probability distribution, we not only observe but also distinguish the 0 and π energy topological edge states, which has not been reported before. Our work thus opens the door for digital quantum simulation of spin-orbit couplings and topological phases of matter and also offers exciting opportunities for topological quantum information processing.

Novel quantum light sources using atomic coherence diffusion in a vapor cell

Yanhong Xiao
Shanxi University

Arrays of quantum light beams are desirable for multinode quantum networks and quantum sensing and imaging. Normally, one has to duplicate many sets of crystal-cavity setups in order to obtain many squeezed light beams, since squeezed light cannot be split into copies simply by using a glass-made beam splitter. We take advantage of atomic coherence diffusion in a coated vapor cell to generate an array of squeezed light beams. Several spatially separated laser beams can “help” each other to become squeezed. Each beam by itself cannot reach squeezing due to the weak laser power of ~miliwatt that cannot initiate the necessary nonlinear atom-light interaction required for squeezing. However, when all the beams are on, the atomic coherence can be created and then be shared by all the laser beams due to the quantum-state-preserving wall coating, which boosts the squeezing in all beams. A squeezed light array with near 3 dB squeezing in each beam has been experimentally demonstrated. Simulations show that an even larger array with more squeezing is possible. This points to a potential route for the scalable production of squeezed light beams.

Imaginary time crystal of thermal quantum matter

Zi Cai
Shanghai Jiao Tong University

Temperature is a fundamental thermodynamic variable for matter. Physical observables are often found to either increase or decrease with it, or show a non-monotonic dependence with peaks signaling underlying phase transitions or anomalies. Statistical field theory has established connection between temperature and time: a quantum ensemble with inverse temperature β is formally equivalent to a dynamic system evolving along an imaginary time from 0 to $i\beta$ in the space one dimension higher. Here we report that a gas of hard-core bosons interacting with a thermal bath manifests an unexpected temperature-periodic oscillation of its macroscopic observables, arising from the microscopic origin of space-time locked translational symmetry breaking and crystalline ordering. Such a temperature crystal, supported by Quantum Monte Carlo simulation, generalizes the concept of purely spatial density-wave order by mapping the time axis for Euclidean action to an extra space dimension for free energy.