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28 - 30 September

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Preliminary Program

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12.45 PM	Lunch + Exhibition (MAS Atrium)			
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2 Plenary sessions

We have several distinguished plenary speakers this year – with a nice overview of recent activities in physical sciences in Singapore.

P1: The Geometry and Shape of Nature

Asst. Prof. YONG Ee Hou,
School of Physical and Mathematical Sciences,
Nanyang Technological University
Email: eehou@ntu.edu.sg

Wednesday, 28 September, 9:45am, Venue: LT1

Abstract

The study of forms and patterns in nature is a fascinating one that goes back to antiquity and really evolved into a formal discipline after the pioneering work of D'Arcy Thompson, whose century-old classic "On growth and form" is still in print! Since then, there has been an increasing appreciation of the role in which geometry, elasticity, and topology play in the morphology of things. In this talk, I will present my foray into this wonderful world, and try to bridge perspectives from morphology, ecology, evolution, and development.

[1] E. H. Yong, F. Dary, L. Giomi, and L. Mahadevan: *Statistics and topology of fluctuating ribbons*, Proc. Natl. Acad. Sci. 119 (32), e2122907119 (2022).

[2] M. C. Stoddard, E. H. Yong, D. Akkaynak, C. Sheard, J. Tobias, and L. Mahadevan: *Form, Function and Evolution of Avian Egg Shape*, Science 356, 1249–1254 (2017).

P2: Light-matter interaction in the flatland: recent advances and novel applications

Asst. Prof. Denis Bandurin, NUS Presidential Young Professor

Wednesday, 28 September, 10:15am, Venue: LT1

Abstract

Since the first isolation of graphene, devices based on novel low-dimensional materials (LDM) and their heterostructures have become a gold mine for exploring new fundamental phenomena. Reduced dimensionality, peculiar band structures, quantum geometry, and strong quasiparticle interactions in a unique way determine the response of LDM to external fields thereby offering a powerful setting by which to probe novel radiation-matter interaction effects and prototype future optoelectronic technology. In the first (fundamental) part of my talk, we will discuss light-matter interaction effects arising in LDM due to the excitation of plasmons. I will present our recent results on the quasi-relativistic Fizeau drag effect [1]. Predicted by Fresnel in the XIX century and demonstrated by Fizeau, dragging of light by the flow of water was among the cornerstones of Einstein's special relativity. Our experiments on graphene materialized the electronic version of this fundamental effect in which the flow of electrons on par with the moving medium was found to alter the surface plasmon polaritons (SPP) dispersion (Fig. 1). The importance of the observed plasmonic Fizeau drag is that it enables breaking of time-reversal symmetry and reciprocity at infrared frequencies without resorting to magnetic fields or chiral optical pumping. Next, we will discuss peculiar effects arising in graphene plasmonics when the latter is subjected to a perpendicular magnetic field. I will show that graphene supports the propagation of slow Bernstein collective modes whose diverging density of plasmonic states results in strong magnetoabsorption at THz frequencies [2]. In the second (applied) part of my talk, I will show that with a proper processing, atomically thin high-temperature cuprate superconductors can be used in single-photon detection technology. We will discusshow to fabricate superconducting nanowires out of thin flakes of $Bi_2Sr_2CaCu_2O_{8+\delta}$ (BSCCO) and $La_{1.55}Sr_{0.45}CuO_4/La_2CuO_4$ (LSCO-LCO) bilayer films and then, look at their response to visible and infrared light. I will show, that both materials feature single-photon operation above liquid helium temperature as revealed through the linear scaling of the photon count rate on the radiation power. For the BSCCO detectors, we observed single-photon sensitivity at the technologically important 1.5 μm telecommunications wavelength up to 25 K [3].

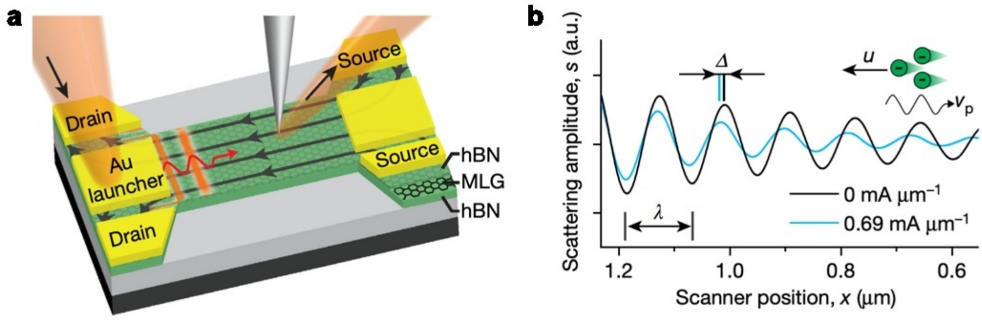

Figure 1: Fizeau drag in graphene plasmonics. a, Schematic of a graphene device with a constricted channel. Under the illumination of an infrared laser, the gold launcher excites propagating SPPs, which were visualized by near-field tip-based imaging techniques. Black streamlines represent carrier drift directions. b, SPP line profiles without d.c. current (black) and with $J_{dc} = 0.69\,\text{mA}\,\mu\text{m}^{-1}$ (blue), illustrating a reduction of the SPP wavelength.

[1] Dong, Y., Xiong, L., Phinney, I.Y., Sun, Z., Jing, R., McLeod, A.S., Zhang, S., Liu, S., Ruta, F.L., Gao, H., Dong, Z., Pan, R., Edgar, J.H., Jarillo-Herrero, P., Levitov, L.S., Millis, A.J., Fogler, M.M., Bandurin, D.A., Basov, D.N.: *Fizeau drag in graphene plasmonics*, Nature 594, 513–516 (2021).

[2] Bandurin, D.A., Mönch, E., Kapralov, K., Phinney, I.Y., Lindner, K., Liu, S., Edgar, J.H., Dmitriev, I.A., Jarillo-Herrero, P., Svintsov, D., Ganichev, S.D.: *Cyclotron resonance overtones and near-field magnetoabsorption via terahertz Bernstein modes in graphene*, Nat. Phys. 18, 462–467 (2022).

[3] Charaev, I., Bandurin, D.A., Bollinger, A.T., Phinney, I.Y., Drozdov, I., Colangelo, M., Butters, B.A., Taniguchi, T., Watanabe, K., He, X., Božović, I., Jarillo-Herrero, P., Berggren, K.K.: *Single-photon detection using high-temperature superconductors*, arXiv:2208.05674v1 (2022).

P3: Many-body Interactions and Induced Superconductivity in a 2D Topological Insulator

Asst. Prof. Bent Weber, Nanyang Assistant Professor and NRF Fellow
School of Physical and Mathematical Sciences,
Nanyang Technological University
Email: b.weber@ntu.edu.sg

Thursday, 28 September 11:00am, Venue: LT1

Abstract

The interplay of topology, superconductivity, and many-body correlations has become a subject of intense research for the pursuit of non-trivial superconducting pairing. The boundaries of atomically-thin 2D topological insulators – amongst them the quantum spin Hall (QSH) insulator [1] – provide a natural realization of strictly 1D electronic structure with linear dispersion and spin-momentum locking (helicity), in which electronic interactions have been predicted to give rise to a low-temperature correlated ground state. As one of the most promising materials realizations of the quantum spin Hall state, we show that atomic monolayers of the transition metal dichalcogenide 1T'-WTe_2 provide a unique testbed for the 1D helical states, and towards non-trivial superconducting pairing therein [2].

[1] M.S. Lodge, S.A. Yang, S. Mukherjee, and Bent Weber*: *Atomically Thin Quantum Spin Hall Insulators*, Advanced Materials **33**, 2008029 (2021).

[1] W. Tao, Z.J. Tong, A. Das, D.-Q. Ho, Y. Sato, M. Haze, J. Jia, Y. Que, F. Bussolotti, K.E.J. Goh, B. Wang, H. Lin, A. Bansil, S. Mukherjee, Y. Hasegawa, and Bent Weber*: *Multiband superconductivity in strongly hybridized 1T′-WTe_2 / $NbSe_2$ heterostructures*, Physical Review B **105**, 094512 (2022)

P4: Observing gravitational-wave sources with space-based detectors

Asst. Prof. Alvin CHUA
Department of Physics,
National University of Singapore

Thursday, 30 September, 9:30am Venue: LT1

Abstract

Seven years on from LIGO's first detection of gravitational waves (GWs), astrophysical GW sources are now routinely observed by a growing network of ground-based detectors at both high and low frequencies. In the next decade, space interferometers such as the LISA mission will probe the mid-frequency GW band, where the richest population of sources radiate. My talk today will include a broad update on the present status of ground-based observing, followed by a brief introduction to the distinctive challenges of space-based GW astronomy. I will also discuss how modern computational and statistical techniques are being brought to bear on a variety of open problems in LISA scientific analysis.

P5: Molecular Gas Diagnostics of AGN Feedback

Asst. Prof. Chelsea SHARON
YaleNUS College and Department of Physics,
National University of Singapore

Friday, 30 September, 10:00am, Venue: LT1

Abstract

Theoretical work has suggested that active galactic nuclei (AGN) play an important role in quenching star formation in massive galaxies. However, direct observational evidence of AGN affecting molecular gas (the fuel for star formation) via outflows is challenging to obtain, particularly at high redshift when cosmic star formation rates were at their highest. Indirect evidence for AGNs' impact on their host galaxies' cold gas phase may be provided by measurements of the gas excitation. I will present recent observations of high-excitation CO lines from the Atacama Large Millimeter/submillimeter Array for a small sample of $z \approx 2-6$ purely star-forming galaxies and known AGN host galaxies. We find that the CO spectral line energy distributions are somewhat heterogenous, even at high excitation. We will discuss why these objects may have produced such mixed results, and how other observables, such as line widths, may add clarity to the gas heating mechanisms.

P6: Many-body physics and quantum information science in the age of noisy, intermediate-scale quantum (NISQ) devices

Asst. Prof. HO Wen Wei
Department of Physics,
National University of Singapore

Friday, 15 March, 10:30am, Venue: LT1

Abstract

There is currently a tremendous global effort invested into building quantum computing technologies. While today's devices are still far from having the fault-tolerance required to perform reliable large-scale computation, they are nevertheless exceptional platforms ideal for the investigation of quantum many-body physics in regimes that go beyond conventional material experiments. This stems from their unprecedented capabilities for control and measurement. In this talk I will demonstrate how such capabilities allow for the probing of a novel phenomenon in dynamics, namely a deeper form of quantum thermalization (the process by which systems settle down over time), in which not just local observables relax to universal values but also conditional post-measurement wave-functions acquire a universally random distribution. Quantum information theoretic concepts are used to characterize this, showing the importance of the union of many-body and quantum information frameworks to yield new insights into fundamental phenomena. Time-permitting, I will sketch how such universal randomness can in fact be used as a resource for applications in quantum information science, like quantum state learning.

3 Posters

Unfortunately, we can not hold the poster session in the usual way. We therefore have to link to the posters hosted by the authors. As many links were not available when this booklet as printed, we suggest to either download the latest program at https://ipsmeeting.org, or use the online programme there to access posters via links.

PO.8 A simple and compact cold atomic source using laser ablation

Chung Chuan Hsu, Rémy Larue, Chang Chi Kwong*, David Wilkowski (Nanyang Technological University, Singapore)

The cold atomic system is a promising platform for numerous quantum technological applications, including quantum computing and quantum sensing. However, a typical cold atomic source could be bulky, composed of various components such as an oven, a Zeeman slower, and a 2D magneto-optical trap (MOT). This is especially the case for atomic species with low saturated vapour pressure, such as strontium [1]. Here, we develop a simple and compact source for strontium atoms based on thermal ablation of a pure strontium granule using a focused high-power laser beam [2]. The strontium vapour released during this laser-induced thermal ablation (LITA) process is directly captured in a 3D MOT operating on the ${}^1S_0 \rightarrow^1 P_1$ dipole-allowed transition, reducing significantly the complexity of the setup. We trap up to 3.5 million cold atoms in the MOT. Furthermore, the remaining atoms in the strontium vapour adsorb rapidly on the walls of the vacuum chamber, leading to a relatively long MOT lifetime of 4 s that is limited by the background pressure of the chamber. Importantly, since the underlying process to release the atomic vapour is thermal based, the LITA source can be easily extended to other atomic species, including other alkaline earth metals, transition metals, and lanthanides.

[1] T. Yang et al., ”A high flux source of cold strontium atoms”, Eur. Phys. J. D 69, 226 (2015) [2] C. C. Hsu et al., ”Laser-induced thermal source for cold atoms”, Sci. Rep. 12, 868 (2022)

PO.15 A novel realization of AKLT state on a NISQ-era quantum computer

Tianqi Chen*, Ruizhe Shen, Bo Yang (NTU)

In 1988, Affleck, Kennedy, Lieb, and Tasaki (AKLT) constructed an isotropic spin-1 model which shows an excitation gap and exponentially decaying correlation functions. The ground state of this model is therefore termed as AKLT state, which exhibits fractionalized excitations at its boundaries. For a one-dimensional AKLT model, it has been experimentally realized in the trapped-ion as well as the photonic systems. In spite of this, AKLT state itself has promising applications in measurement-based quantum computation (MBQC). However, so far there still lacks a direct implementation of AKLT state on a quantum circuit in NISQ-era quantum devices, as the projection operator acting on each pair of auxiliary spin-1/2's is non-unitary. We propose an algorithm to realize AKLT state on the IBM Q quantum processor by constructing a unitary operator for each pair of auxiliary spin-1/2's together with an additional ancilla qubit. By simultaneously projecting each ancilla qubit onto the space of spin-up $|0\rangle$, an AKLT state will be subsequently obtained by a measurement of all the other physical qubits. Our preliminary results of the characterization of this implementation on the IBM Q quantum processor, as well as the error mitigation approaches for the results are also discussed.

PO.22 Superconductivity in graphite-diamond hybrid

Yanfeng Ge* (SUTD)

Search for new high-temperature superconductors and insight into their superconducting mechanism are of fundamental importance in condensed matter physics. The discovery of near-room temperature superconductivity at more than a million atmospheres ushers in a new era for superconductors. However, the critical task of identifying materials with comparable superconductivity at near or ambient pressure remains. Carbon materials can always lead to intriguing surprises due to their structural diversity and electronic adjustability. Insulating diamond upon doping or external stimuli has achieved superconducting state. Thus, it still has a great opportunity to find superconducting ones with higher transition temperature (Tc). Here, we report an intrinsic superconducting graphite-diamond hybrid through first-principles calculations, whose atomic-resolution structural characteristics have been experimentally determined recently. The predicted Tc is approximated at 39 K at ambient pressure, and strain energizing can further boost Tc to 42 K. The strong electron-phonon coupling associated with the out-of-plane vibration of carbon atoms at the junction plays a dominant role in the superconducting transition. Our work demonstrates the great potential of such carbon materials as high-Tc superconductors, which will definitely attract extensive research.

PO.23 Retrodicting Complicated Channels in both Classical & Quantum Regimes

Clive Cenxin Aw*, Valerio Scarani, Francesco Buscemi (Centre for Quantum Technologies)

In thermodynamics and statistical mechanics, a comparison between the process that happens and a corresponding ”reverse process” is typically used to describe the notion of ”irreversibility”. This comparison has been extensively studied through fluctuation relations. Here, we discuss this comparison primarily by identifying the reverse process with applying Bayesian retrodiction on the channel of interest. Doing so with (1) both classical and quantum regimes in mind and (2) when the target process is a marginal of a global dilation and, finally, (3) when there non-Markovian dynamics are involved. With simply Bayes’ rule as a foundation, an informationally insightful and physically sound view of irreversibility emerges.

PO.29 Witnessing entanglement in two harmonic systems

Pooja Jayachandran*, Lin Htoo Zaw, Valerio Scarani (Centre for Quantum Technologies)

The time evolution of a harmonic oscillator in both, quantum and classical mechanics, is a uniform precession in phase space. Detecting entanglement between coupled oscillators usually relies on the assumption that the system is quantum (the assumption of zero-point motion is necessary to not witness entanglement in classical states). We provide an entanglement witness for two harmonic systems that builds on Tsirelson’s criterion for quantumness of an oscillator, hence only assuming that the systems precess with a well-defined frequency. Our criterion detects states that are missed by other criteria that may also not be fooled by classical states. We discuss conditions for pure and mixed state entanglement, and quantify the minimum achievable entanglement in each case.

PO.36 Non-Hermitian topological systems with eigenvalues that are always real

Yang Long*, Haoran Xue, Baile Zhang (SPMS at NTU)

The effect of non-Hermiticity in band topology has sparked many discussions on non-Hermitian topological physics. It has long been known that non-Hermitian Hamiltonians can exhibit real energy spectra under the condition of parity-time (PT) symmetry—commonly implemented with balanced loss and gain—but only when non-Hermiticity is relatively weak. Sufficiently strong non-Hermiticity, on the other hand, will destroy the reality of energy spectra, a situation known as spontaneous PT-symmetry breaking. Here, based on nonreciprocal coupling, we show a systematic strategy to construct non-Hermitian topological systems exhibiting bulk and boundary energy spectra that are always real, regardless of weak or strong non-Hermiticity. Such nonreciprocal-coupling-based non-Hermiticity can directly drive a topological phase transition and determine the band topology, as demonstrated in a few non-Hermitian systems from one dimensional to two dimensional. Our work develops a theory that can guarantee the reality of energy spectra for non-Hermitian Hamiltonians, and offers an avenue to explore non-Hermitian topological physics.

PO.38 Where is the gas? Molecular gas maps for galaxies in the early universe

Bijaya Luitel* (Yale-NUS College)

The star formation rate (SFR) of a galaxy is related to its molecular gas mass by the Kennicutt-Schmidt law, which posits a power-law relationship between the two variables. Whilst this empirically derived law has previously been observed in galaxies over a wide range of redshift, we observed several galaxies at high redshift that show non-detections or only marginal detections of the usual gas mass tracer, the carbon monoxide (CO) J=1-0 transition. We fit a spectral energy distribution (SED), using data in the ultraviolet and optical bands from the Hubble space telescope and the millimetre bands from the Atacama Large Millimetre Array (ALMA) to our sample of galaxies in order to constrain their SFR, using which we make predicted (CO) J=1-0 maps. Thereafter, we compare our results with the observational non-detections.

PO.40 Quantum-tailored Probabilistic Cellular Automata

Heitor Casagrande*, Vinitha Balachandran*, Dario Poletti* (Singapore University of Technology and Design)

Cellular Automata models, although remarkably simple, are still able to provide insight over many different phenomena, over a wide array of subjects. Here, we develop an algorithm to derive Probabilistic Cellular Automata states (PCAs) from a quantum system under Hamiltonian evolution and analyze the resulting chain of states. We show that, given a 1D system, a principal component analysis of the Correlation Matrix (CM) derived from the PCAs allows us to characterize the underlying quantum dynamics.

PO.44 Ground state search by local and sequential updates of neural network quantum states

Wenxuan Zhang, Xiansong Xu*, Zheyu Wu*, Vinitha Balachandran*, Dario Poletti* (Singapore University of Technology and Design)

Neural network quantum states are a promising tool to analyze complex quantum systems given their representative power. It can however be difficult to optimize efficiently and effectively the parameters of this type of ansatz. Here we propose a local optimization procedure which, when integrated with stochastic reconfiguration, outperforms previously used global optimization approaches. Specifically, we analyze both the ground state energy and the correlations for the non-integrable tilted Ising model with restricted Boltzmann machines. We find that sequential local updates can lead to faster convergence to states which have energy and correlations closer to those of the ground state, depending on the size of the portion of the neural network which is locally updated. To show the generality of the approach we apply it to both 1D and 2D non-integrable spin systems.

PO.48 Shadow tomography and extreme machine learning with bosonic modes

Adrian Copetudo*, Clara Fontaine*, Pengtao Song* (Centre for Quantum Technologies)

Logical qubits can be encoded in the multi-photon states of superconducting cavities for hardware-efficient error correction. However, high-dimensional bosonic systems are hard to characterize efficiently. Shadow tomography and extreme machine learning (EML) are two approaches to characterizing complex multi-mode states with very few measurements. Shadow tomography builds quantum state estimators from random measurements. These estimators do not contain full information about the state but suffice to predict the expectation values of operators of interest. EML performs a quantum state reconstruction using a model based on random unitary evolutions. The technique is extensible to arbitrary state preparation and gates. In our work, we engineer, simulate, and implement shadow tomography and EML protocols on a two-cavity superconducting device with ancillary transmon qubits. Our project will help pave the way toward efficient state estimation and reconstruction for complex quantum systems.

PO.58 Designing non-Hermitian real spectra through electrostatics

Russell Yang*, Jun Wei Tan*, Tommy Tai, Jin Ming Koh, Linhu Li, Stefano Longhi, Ching Hua Lee* (National University of Singapore)

Non-hermiticity presents a vast newly opened territory that harbors new physics and applications such as lasing and sensing. However, only non-Hermitian systems with real eigenenergies are stable, and great efforts have been devoted in designing them through enforcing parity-time (PT) symmetry. In this work, we exploit a lesser-known dynamical mechanism for enforcing real-spectra, and develop a comprehensive and versatile approach for designing new classes of parent Hamiltonians with real spectra. Our design approach is based on a new electrostatics analogy for modified non-Hermitian bulk-boundary correspondence, where electrostatic charge corresponds to density of states and electric fields correspond to complex spectral flow. As such, Hamiltonians of any desired spectra and state localization profile can be reverse-engineered, particularly those without any guiding symmetry principles. By recasting the diagonalization of non-Hermitian Hamiltonians as a Poisson boundary value problem, our electrostatics analogy also transcends the gain/loss-induced compounding of floating-point errors in traditional numerical methods, thereby allowing access to far larger system sizes.

PO.64 Squeezed cat state in three-dimensional microwave cavity

Xiaozhou Pan*, Jonathan Schwinger*, Nini Huang*, Yvonne Gao* (Centre for Quantum Technologies)

Cat state, which spans high-dimensional Hilbert space, has been proven to be an attractive candidate for redundantly encoding in superconducting quantum circuits. Usually, such cat state is easily affected by loss, which inevitably leads to the decoherence. One important method to improve the quantum properties of quantum states is to squeeze their quadrature amplitude and quadrature phase. Here we generate a squeezed cat state in a three-dimensional microwave cavity which is coupled with a transmon. We study the effect of noise such as dephasing and loss on the squeezing. In addition, we demonstrate that the squeezing can resist the decoherence of cat state by studying the decay of the negativity of Wigner function.

PO.65 Variational Decoupling of Quantum Dynamics

Ximing Wang*, Mile Gu* (Nanyang Technological University)

Here we propose an algorithm that learns the independent features of a system and partitions it accordingly. The partitioning of systems plays an important role in the study of nature. Consider how the decomposition of forces simplifies the description of the projectile motions, which reveals the break of symmetry due to gravity. However, such extraction of the features from a system can be hard in general. It can be even worse in quantum systems, where intuitions fail. To solve the problem, we adapt the ideas of feature learning to quantum systems, which utilize machine learning techniques. Despite the exponentially growing number of parameters concerning the size of quantum systems, by carefully choosing the measurements, the cost functions can be evaluated efficiently in our algorithm. We expect this NISQ-device-compatible algorithm to help simplify dynamics in quantum simulations and to inspire other variational tools for processing quantum dynamics.

PO.66 Planar resonators for bosonic circuit QED

Atharv Joshi*, Pengtao Song, Yvonne Gao (Centre for Quantum Technologies)

Materials engineering has been a major enabler of low-loss circuit QED devices [1]. Recently, transmon qubits made with α-tantalum capacitor pads showed longer lifetimes compared to their all-aluminium counterparts [2, 3]. Inspired by this finding, we study the effect of varying selected design parameters on the performance of planar tantalum resonators. Frequency-multiplexed resonators patterned on sapphire chips are measured in separate waveguides in a seamless enclosure [4]. The enclosure provides a controlled testing environment and multiplexing increases the sample throughput per cooldown. Correlating specific design choices with observed device characteristics will enable us to consistently make resonators with desirable operational requirements such as long coherence times. Our work takes a step towards developing high-quality planar resonators, which are key building blocks for realizing robust information encoding in multi-photon bosonic states.

References

[1] Murray, C. E. (2021). Material matters in superconducting qubits. Materials Science and Engineering: R: Reports, 146, 100646.

[2] Place, A. P., Rodgers, L. V., Mundada, P., Smitham, B. M., Fitzpatrick, M., Leng, Z., ... & Houck, A. A. (2021). New material platform for superconducting transmon qubits with coherence times exceeding 0.3 milliseconds. Nature communications, 12(1), 1-6.

[3] Wang, C., Li, X., Xu, H., Li, Z., Wang, J., Yang, Z., ... & Yu, H. (2021). Transmon qubit with relaxation time exceeding 0.5 milliseconds. arXiv preprint arXiv:2105.09890.

[4] Axline, C., Reagor, M., Heeres, R., Reinhold, P., Wang, C., Shain, K., ... & Schoelkopf, R. J. (2016). An architecture for integrating planar and 3D cQED devices. Applied Physics Letters, 109(4), 042601.

PO.68 Lightweight stable near-concentric cavity design

Florentin Adam*, Adrian Utama, Wen Xin Chiew, Christian Kurtsiefer (Centre for Quantum Technologies)

In order to engineer and achieve coherent interaction between atoms and photons, optical resonators are fundamental candidates. Governed by cavity quantum electrodynamics, cavity systems require to contain photons in a small mode volume to perform strong atom-light interaction. Conventionally, this small mode volume is achieved through the use of small high-finesse optical resonators. However, a different cavity configuration can also implement small mode volumes, namely large optical resonators operated in the near-concentric regime. Due to their configuration, near-concentric cavities provide a large optical access between the mirrors and only require low-finesse to operate. Nevertheless, a stable cavity length is necessary to perform interaction with a single atom. We present a lightweight near-concentric cavity design to address the cavity length stability required for single atom interaction. In our new structure, we make use of the equivalence of the transverse and rotational displacements in the near-concentric regime to manage the cavity alignment. We then compare the two movement configurations and demonstrate the superiority of a tip-tilt cavity structure in terms of cavity length stability for the near-concentric regime.

PO.69 Orbital modelling of charge dipole moments of quantum dot qubits

Guangzhao Yang*, Teck Seng Koh* (Nanyang Technological University)

In recent years, experiments utilizing spin-charge hybridization of quantum dot qubits have achieved strong coupling between single electron spins and microwave photons in semiconductor quantum dot–circuit quantum electrodynamics (QED) devices. In this regime, the coupling strength between the photon's electric field and the charge dipole moment of the quantum dot qubit is larger than the qubit dephasing and cavity loss rates. In this project, we map out the dipole moments of quantum dot spin qubit systems through orbital modeling of multi-electron wavefunctions, across the parameter space of the quantum dot qubit. Together with the knowledge of qubit dephasing rates, this should enable the identification of optimal working points in quantum dot–circuit QED devices.

PO.71 An apparatus for ultracold lithium quantum gases

Pranshu Dave, M. Zirdi Syukur, Nguyen Phong Le, Zixiong Liu, Ben Olsen* (Yale-NUS College)

At Yale-NUS College, we are building an experimental apparatus to prepare and study low-dimensional quantum gases of ultracold lithium. We describe the design and construction of

several components of this apparatus, including an ultrahigh vacuum (UHV) chamber, Bitter-type electromagnets for the Zeeman slower and bias magnetic fields, and home-built stabilized diode lasers. Several sensors are set up around the main apparatus to track the conditions of the laboratory environment. We use raspberry pi devices to collect and upload information from the sensors to a laboratory server, including various lab temperatures, cooling water flow rates, and optical table vibrations. This lab-wide sensor system is complemented by an application with a graphical user interface (GUI) that displays time series of the various measurements. This enables us to quickly spot changes and patterns in lab conditions, both historically and in real time. We will discuss these subsystems as well as prospects for laser cooling and trapping lithium gases in the near future.

PO.72 Characterising the Onset of Lasing Using Interferometric Photon Correlations

Xi Jie Yeo*, Leow Alvin, Lijiong Shen, Peng Kian Tan, Christian Kurtsiefer (Centre for Quantum Technologies)

The threshold current is a key characteristic of a semiconductor laser diode. The laser diode emits coherent laser light when operating above this current, and behaves as a light-emitting diode (LED) when operating below. A common method to determine the threshold current is to identify the injection current where the emitted optical power changes sharply. However, the intensity measurement cannot determine whether the light emitted has changed from being incoherent (LED) to coherent laser radiation. To do this, one can measure its second-order photon correlation $g^{(2)}$, where LEDs exhibit a "bunching" signature $g^{(2)}(0) > 1$ associated with chaotic light, while coherent light exhibit $g^{(2)} = 1$. However, amplitude noise in the lasing regime may result in second-order photon correlation measurements exhibiting $g^{(2)}(0) > 1$, when $g^{(2)} = 1$ is expected. Thus, a method to investigate the transition of the nature of the emitted light is required to identify the onset of coherence. We present a technique to characterize the onset of coherence in a semiconductor laser diode using interferometric photon correlation measurements, and we observe with increasing injection current a transition of light emitted by the diode from chaotic, to a chaotic-coherent light mixture, to coherent.

PO.73 Continuous Variable Geometry Phase Gate with Trapped Ions

Ko-Wei Tseng*, Chi Huan Nguyen*, Jaren Gan*, Mu Young Kim*, Dzmitry Matsukevich* (Centre for Quantum Technologies, Natl. Uinv. of Singapore)

Continuous variable approach to the quantum computations and simulations where quantum states are encoded in the motional modes of the trapped ions offers potential advantage due larger accessible Hilbert space in the same physical system, compared to qubit based schemes. Universal set of quantum operations includes in the case of continuous variables Gaussians operations, such as squeezing and beamsplitter transformations, as well as a nonlinear gate. Following a recent theoretical proposal, we experimentally demonstrate how a combination of two spin-dependent displacement interactions, typically used in geometric phase gates, can be employed to implement linear Gaussian operations such as beamsplitter. We also discuss preliminary experimental results on non-gaussian transformations of motional modes, in particular on implementation of a tri-squeezing gate, which is closely related to a cubic phase gate.

PO.83 Seismic Sensing with Optical Fibres

Thormund Tay*, Yicheng Shi*, Fabio Joel Auccapuclla*, Hou Shun Poh*, Christian Kurtsiefer* (Centre for Quantum Technologies)

Widespread deployed optical fibre networks form the backbone of modern telecommunication infrastructure. Mechanical forces from sources of ambient vibrations, e.g. seismic and human activities, cause strains in the fibres which in turn induce phase shifts in the light travelling through them. Thus, by measuring these phase shifts at the end points, information about the initial vibration events can be obtained, making them the ideal candidate for the application of distributed seismic sensing.

We implemented a fibre-based Michelson interferometer phasemeter for distributed seismic sensing. Light from a fibre-Bragg-grating stabilised 1550 nm laser (linewidth ~ 100 Hz) is split by a 50:50 coupler into two arms; measurement and reference arm. To maximise the visibility of the interference, Faraday rotator mirror are installed at the end of each arm ensure the retro-reflected light arrives back at the 50:50 coupler with the same polarisation.

The frequency of the light in the reference arm is shifted by ~ 140 MHz by a double pass through an AOM. The interference signal at the output port, detected by a fast photodiode (bandwidth > 2.0 GHz), is sampled at a frequency ~ 560 MHz. I/Q demodulation is then performed on the recorded data to reconstruct the phase information.

With the above configuration we were able to resolve the phase evolution (lasted for a duration of ~ 500 ms) that correspond to a force impulse being applied near to the phasemeter with an equal length of fibres in both two arms. The next step would be to attempt to detect the possible diurnal change in vibration events due to man-made activities by using various length of deployed fibres in the test arm.

PO.84 Circuit quantum electrodynamics with spin qubits

Si Yan Koh*, Teck Seng Koh* (SPMS, Nanyang Technological University)

We theoretically consider the interaction between semiconductor spin qubits mediated by a superconducting resonator in a spin-circuit quantum electrodynamics device. Here, we compare the effective coupling between distant spin qubits with local electric dipole-dipole coupling.

PO.88 Single step electroactive in-situ phase nucleation and poling in ferroelectric polymer for self-powered pyroelectric applications

Varun Gupta, Dipankar Mandal* (Institute of Nano Science and Technology (INST) Mohali)

Polyvinylidene fluoride (PVDF) and its polymorphs are considered as one of the potential polymer materials in terms of their electroactive properties responsible for piezo-, pyro- and ferro-electricity.[1] Hence, it is possible to utilize PVDF, with external stimuli such as pressure, temperature and electric fields to fabricate the devices based on memory, sensors, actuators and energy harvesters applications.[2] In order to obtain the electroactive phase in PVDF, prior information on crystalline phase transformation is essential. So far, most adopted techniques to nucleate the electroactive phase in PVDF are uni- or bi-axial stretching and hot-pressing techniques, which limits several applications due to inhomogeneous thickness and film formation. Moreover, it also requires further electrical poling, in order to aligned molecular dipoles, so to obtain effective piezo-and pyro-electric properties. In contrast, here we have shown a potential approach by which in-situ poling and electroactive phase nucleation in PVDF film, is possible to achieve simultaneously. To monitor different phase nucleation, different combination solvents, casting temperatures and electric field strengths were selected under corona generation. The results indicate that in-situ poling approach requires much less electric field strength in comparison to external poling, thus electrical breakdown phenomena is possible to avoid. Finally, we have also demonstrated some potential applications of the obtained electroactive film as a self-powered pyroelectric device. The fabricated pyroelectric nanogenerator[3] is efficiently able to capture the thermal fluctuations that could be useful as a breathing sensor. The pyroelectric signals were also recorded at different frequencies to explore the practical application range as sensor.

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PO.91 Low Temperature Response in m-bromophenethylammonium-based $(m\text{-}C_6H_4FC_2H_4NH_3)_2PbI_4$ 2D Perovskites (m = 2, 3, or 4)

Brandon Ong*, Yulia Lekina*, Benny Febriansyah, Zexiang Shen* (Nanyang Technological University)

Recent studies have shown that tailoring the organic cation component of two-dimensional (2D) organic-inorganic hybrid perovskite (OIHP) has led to an alteration in its electronic properties despite not chemically changing the structure of the inorganic component, which is mainly responsible for the electronic properties of the 2D OHIP. Furthermore, studies have also shown that when a Br atom is substituted with a H atom onto the ortho position of the phenyl ring of a phenethylammonium-based perovskite, the organic cation of the perovskite transforms into an anti-gauche confirmation from the original gauche confirmation. In this study, the structural and optoelectronic properties of the derivatives of phenthylammonium lead iodide, in which a single bromine atom is substituted on the different positions of the phenyl ring (ortho, meta & para) of the organic cation are studied in low-temperature conditions. It is demonstrated out of the different perovskites analysed, only the ortho-substituted Br atom showcases an anti-gauche confirmation in the organic cation component of the perovskite while the rest shows a gauche confirmation. Furthermore, due to the presence of this anti-guache confirmation, the photoluminescence and absorbance peaks have been significantly blueshifted and its bandgap is more susceptible to change when temperature varies, as compared to the other gauche confirmation perovskites.

PO.92 Thermal State Preparation on Bosonic-Mode Circuit QED

Fernando Valadares*, Aleksandr Dorogov, Daniel Leykam, Dimitris G. Angelakis, Yvonne Gao (Centre for Quantum Technologies, NUS)

Thermal states are defined by the density matrix that minimizes the free energy of certain hamiltonian at a given temperature. The creation of well-defined thermal quantum states is not a straight forward task, as it involves non-unitary transformations. To bypass this requirement, we apply unitary operations to prepare a purification of the thermal state, the Thermofield Double (TFD) state. The operations are derived from an optimized ansatz inspired in the Quantum Approximate Optimization Algorithm. The experimental implementation will be performed on continuous-variable circuit quantum electrodynamics devices, for which thermal state creation has not yet been demonstrated. The results of this work will expand the available resources for bosonic systems: the simulation of finite-temperature physics allows the study of thermodynamics phenomena, while TFD states are useful to simulate correlations in many-body quantum systems.

PO.93 Coherent transfer of ^{6}Li–^{40}K absolute ground state

Canming He*, Anbang Yang*, Xiaoyu Nie*, Victor Avalos*, Sofia Botsi*, Sunil Kumar*, Kai Dieckmann* (Centre for Quantum Technologies)

We report on the creation of $X1\Sigma+$ rovibrational ground state of ^{6}Li–^{40}K molecules by employing a two-photon Raman process via a singlet pathway. A coherent oscillation between Feshbach state and ro-vibrational ground state with a period of 16us is observed at a 582 MHz Raman detuning. To achieve a highly efficient ground state transfer, two long cavity ECDL are built to reduce the phase-noise related to the coherent transfer, and tapered amplifiers are set up to offer higher transition Rabi frequency. Apart from phase-noise and Rabi frequency, the stability of detuning frequency is also crucial for ground state transfer. The drift of detuning frequency caused by cavity length drift is canceled by modifying EOM with a software feedback loop.

PO.94 Randomness of Quantum Objects

Shuyang Meng*, Valerio Scarani* (Centre for Quantum Technologies, National University of Singapore)

One of the most counterintuitive aspects of quantum theory is its claim that there is "intrinsic" unpredictability (i.e. randomness) in the physical world. This is not only a mind-boggling curiosity, as randomness is a resource for computing, sampling and secrecy. Thus, quantum systems are natural sources of randomness. Research in the quantitative aspects of quantum randomness is relatively recent. The major theoretical advance has been the discovery of "device-independent" certification of randomness, which becomes possible whenever a Bell inequality is violated. Meanwhile, a wide range of random number generators based on quantum phenomena have been demonstrated, and some commercialized. Our study focuses on one question, which, somewhat surprisingly, has not been systematically studied: how much randomness is present in a given quantum state, or in a given measurement. Indeed, given both the state and the measurement, the amount of extractable randomness can be efficiently computed using semi-definite optimization. However, if only (say) the state is given, one must first find the optimal measurement: the optimization becomes then a min-max problem, whose full solution is known only for states of one qubit. The first evidence for the solution is shown in the case of states of one qutrit.

PO.100 Large Cross-Kerr effect induced by microwave-dressed Rydberg state at telecom-band

Wenfang Li*, Jinjin Du*, Mark Lam*, Wenhui Li* (Centre for Quantum Technologies, NUS)

Rydberg atoms with extremely large polarizability, are very sensitive to electric fields ranging from DC to microwave, and even to terahertz waves. This makes atomic Rydberg gases particularly suitable for connecting these electromagnetic bands to optical frequency for a wide variety of applications, such as sensing and communication. In our work, we study telecom-wavelength spectra of a Rydberg state in an atomic vapor with a three-photon excitation scheme. Then we investigate the change of refractive index of optical communication frequency by microwave via a giant Cross-Kerr effect enabled by Rydberg atoms in a hot vapor. We measure the third-order Cross-Kerr coefficient to be six orders of magnitude larger than that in usual media. We demonstrate fast modulation of the light field by microwave modulation. The transfer of modulation signal between these frequency bands is particularly relevant to integrating wireless and fiber-optical networks.

PO.101 Fast Single-shot Imaging of Individual Ions via Homodyne detection of Rydberg-Blockade-Induced Absorption

Jinjin Du*, Thibault Vogt, Wenhui Li (cqt)

We demonstrate single-shot non-destructive imaging of individual ions in an ion-atom mixture. Well separated 87Rb+ ions are introduced to an atomic ensemble by microwave ionization of Rydberg excitations made in a deeply blockaded regime. Probe photons under electromagnetically induced transparency with the upper level being a Rydberg state (Rydberg EIT) are scattered at the vicinity of an ion due to the Rydberg level shift from the long-range interaction with the ion. By using the homo-dyne detection technique, the absorption spot around one ion is resolved for a single-shot with 1 μs exposure time. The acquired single-shot images allow us to determine ion-Rydberg interaction blockade, as well as to reconstruct blockaded Rydberg excitations from which ions are generated. This capability of imaging individual ions in a single shot is of interest for investigating collision dynamics in hybrid ion-atom systems.

PO.112 Low-Phase-Noise Diode Laser Systems for the STIRAP transfer of Ultracold LiK Molecules

Victor Avalos*, Xiaoyu Nie, Canming He, Anbang Yang, Kai Dieckmann* (Centre for Quantum Technologies, National University of Singapore)

LiK molecules in their ro-vibrational ground state possess a relatively large permanent electric dipole moment of 3.6 Debye, which makes them good candidates for studying quantum many-body physics and quantum chemistry. We have built two sub-kHz linewidth external cavity diode laser (ECDL) systems to transfer weakly-bound $^{6}Li^{40}K$ molecules to their ground state using Stimulated Raman Adiabatic Passage (STIRAP). Excessive residual laser phase-noise and scattering from unwanted intermediate levels have been identified as the two major contributions for the low transfer efficiency in our experiment. The cavity length of the ECDLs are extended from 3 cm to 20 cm to narrow the free-running laser linewidth. This leads to a reduction of integrated phase-noise from 200 mrad to 48 mrad in 10 MHz bandwidth. To suppress the scattering from unwanted states, a large single-photon detuning should be used in upcoming experiments. Tapered amplifiers have been integrated in the ECDL systems for achieving higher Rabi frequencies while preserving the low phase-noise of the long-cavity ECDLs.

We also investigated a digital laser frequency stabilizing scheme facilitated by Red-Pitaya, which is a commercial multifunctional platform. By comparing the residual laser phase noise after stabilization using Red-Pitaya with the residual noise after locked by a fast analog lockbox, we demonstrate that for laser systems with sub-MHz modulation bandwidths Red-Pitaya is a good candidate for laser frequency stabilization.

PO.113 Computational screening for the bulk photovoltaic effect in van der Waals heterostructures

Meng-Fu Chen*, Shaffique Adam* (National University of Singapore)

Properties of 2D heterostructures are not just a superposition of their individual components, but a combined outcome of factors such as interlayer coupling, twist and strain effects, and symmetry breaking. This leads to the emergence of interesting new phenomena, one of which is the bulk photovoltaic effect (BPVE), a nonlinear optical process that converts light into current in solids. In this work, we aim to develop a procedure for discovering novel van der Waals heterostructures that exhibit strong BPVE. The effect of twist angle on BPVE is examined theoretically using continuum models.

PO.117 Universal features of conductance fluctuations in 2D strong Anderson localised regime.

Nyayabanta Swain*, Gabriel Lemarie* (Centre for Quantum Technologies, National University of Singapore)

We present numerical studies of the conductance distribution and their fluctuations in two-dimensional Anderson model in the strongly localised regime. While the conductance shows a non-Gaussian distribution in this regime; the fluctuations follow universal distributions that depend on the type of leads attached to the system. We provide in-depth analysis of this behaviour along with the 2D-to-1D crossover in this regime. Furthermore, we compare these results with the free energy distributions and their fluctuations of a directed polymer in a random medium. The distribution of the free energy fluctuations is the same as those fluctuations in conductance in the strong Anderson localised regime, indicating that it is a characteristic feature of all the systems described by the Kardar-Parisi-Zhang equation in 1+1 dimensions. We discuss the possibility of these results being observed in experiments.

PO.128 Measuring the crystal axis orientation from second harmonic generation

Aswin Alexander Eapen, Sarthak Das, Aravind Padath Antur* (IMRE)

In material synthesis, nanofabrication and nanophotonics it is very critical to know the crystal orientation of the active layer. We create a simple scheme utilizing second harmonic generation (SHG), which along with the theory of thin film propagation can measure the crystal orientation of mono-layers and thin film accurately, even when the crystal axis is rotated. Our method can be used to selectively probe the crystal axis orientation from different layers, even when there are multiple layers that can give SHG. Here, we study the polarization dependence of SHG signal from WS_2 monolayer with a femto-second laser. We do not require cooled or avalanche detectors for our measurements. Our system use Ocean Optics spectrometer for the measurements. Our system is also compact, since we collect the SHG in the reflection geometry.

PO.129 Development of Superconducting Quantum Processor

Rangga Perdana Budoyo*, Long Hoang Nguyen, Yuanzheng Paul Tan, Kun Hee Park, Patrick Bore, Senthil Kumar Karuppannan, Christoph Hufnagel, Yung Szen Yap, Rainer Dumke (Centre for Quantum Technologies)

We report on the recent development of our superconducting qubit processor. We developed a fabrication process mainly done at MNFF and E6 clean rooms at NUS. This results in fixed frequency transmon qubits with typical characteristic times of order 10 microseconds. Improvements in our control and measurement systems allow us to perform single-qubit randomized benchmarking with fidelities as high as 99.8%. Furthermore, to allow scaling to larger qubit processors, we also developed a control and measurement system with radio frequency system-on-chip (RFSoC) device. We discuss the characteristics of this system.

PO.130 Design and Applications of Atomic Sensors

Fong En Oon*, Nathan Shettell*, Rainer Dumke, Kai Sheng Lee, Christoph Hufnagel (Centre for Quantum Technologies)

Atomic interferometry has witnessed a surge of experimental progress and interest within the physics community in the past few decades. Atoms, exhibit wave-like properties in certain circumstances, such as interference; one can tailor the design of an interferometer to extract desired quantities from the interference pattern. In our case, we have designed an atomic interferometer which can measure gravity, better known as an atomic gravimeter, at an extremely precise resolution of 3.8×10^{-9} g. In addition, our gravimeter does not suffer from bias-drift, which is an inevitable hindrance to classical gravimeters. Here, we present the design and construction of our gravimeter. It is module based, which allows for a compact design and facilitates performing maintenance. One of the crucial modules is for vibration cancellation, this is what allows our gravimeter to attain such a high resolution. Additionally, we discuss future plans for our gravimeter: i) an environmental survey a Pulau Tekong, and ii) a hybridization with a classical sensor to further increase the resolution. Additionally, we discuss the construction of an atomic accelerometer, which is similar in design to the gravimeter, and how an array of such accelerometers can in principle emulate an atomic gyroscope.

PO.131 Atomtronic BEC setup for Matter-wave Interferometry

Koon Siang Gan* (Nanyang Technological University)

Atomtronics is the study of atomic systems analogous to electronic circuits and components, where the carriers are neutral atoms instead of electrons. These Atomtronic experiments require great flexibility and precision to manipulate the parameters of the system. This can be achieved using superfluid Bose-Einstein Condensates(BECs) as the medium, and Digital Micromirror Devices(DMDs) for manipulation. Specifically, ring-like potentials are vital in Atomtronics as it forms the basis of many interesting Atomtronic systems such as ring lattices and stacked rings. Additionally, pseudo- 2D systems can be readily realised in such setups. Hence, an Atomtronic setup is presented here to demonstrate the ease of loading a BEC into arbitrary optical potentials derived from a DMD. A dynamical evolution of an optical potential is performed to create 2 independent condensates, where the coherence of the BEC is largely preserved, revealed by a 2D interference fringe of the condensates. This is a starting point to further experiments with ring geometries, with possible applications in quantum sensing and analog simulation.

PO.132 Bi-color atomic beam slower and magnetic field compensation for ultracold gases

Jianing Li*, Kelvin Lim, Swarup Das, Thomas Zanon-Willette, Chang Chi Kwong, Shau-Yu Lan, David Wilkowski (Nanyang Technological University)

We implemented a new scheme of hybrid bi-color atomic beam slower in a compact experimental setup for the preparation of ultracold strontium-88 atoms, which can increase number of atoms in 461 nm MOT by a factor of 9. Also, an active feedback of magnetic field control system is developed to compensate the stray magnetic field down to mG level during the experiment. With this compact experimental setup, a total number of 9×109 atoms are achieved in the 461 nm MOT, and we also observe the magnetically induced spectroscopy in bosonic strontium-88 with a linewidth of 600 Hz. The setup can be useful for quantum sensing, quantum metrology, as well as quantum simulations.

PO.134 Time-domain optics for atomic quantum matter

Simon Kanthak*, Matthias Gersemann, Ekim Hanimeli, Mikhail Cheredinov, Sven Abend, Ernst M. Rasel, Markus Krutzik (Humboldt University, Berlin)

We investigate time-domain optics for atomic quantum matter. Within a matter-wave analog of the thin-lens formalism, we study optical lenses of different shapes and refractive powers to precisely control the dispersion of Bose-Einstein condensates. Anharmonicities of the lensing potential are incorporated in the formalism with a decomposition of the center-of-mass motion and expansion of the atoms, allowing to probe the lensing potential with micrometer resolution. By arranging two lenses in time formed by the potentials of an optical dipole trap and an atom-chip trap, we realize a magneto-optical matter-wave telescope. We employ this hybrid telescope to manipulate the expansion and aspect ratio of the ensembles. The experimental results are compared to numerical simulations that involve Gaussian shaped potentials to accommodate lens shapes beyond the harmonic approximation. This work is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under Grant No. 50WM1952 (QUANTUS-V-Fallturm).

PO.137 Temperature-Dependent Phase-Field Microstructure Simulation of Anisotropic Grain Growth in Metal

Antony Hartanto*, Ivan Erofeev, Khakimjon Saidov, Utkur Mirsaidov* (National University of Singapore)

Continuous miniaturization of integrated circuits (ICs) inevitably leads to a decrease in the cross-sectional area of metal interconnect, which has dropped to about 100 nm^2 for the lowest metallization level in the current generation of chips. The resulting increase in resistance is detrimental to the chips' performance, therefore thermal annealing of interconnects remains an essential process step as it reduces metal resistance by increasing the mean grain size and decreasing the surface roughness of grains in metal. As the industry is looking for alternatives to copper as interconnect material, there is a need to find the optimal annealing parameters for a range of different metals. It is logical to approach the task of scanning and optimizing the relevant process parameters such as temperature and time with computer simulations. Phase-field modelling is a fast and reliable method to simulate grain structure evolution in polycrystalline materials. However, the general phase-field models lack details such as grain boundary faceting due to crystal anisotropy, which is prominent at the nanoscale. Additionally, most traditional models employ periodic boundary conditions, which is not suitable for quasi-1D structures such as metal nanowires. We propose an anisotropic, temperature-dependent phase-field model with a dynamic grain boundary energy term that varies with the grain misorientation and grain boundary inclination. The model features an additional phase representing the environment surrounding the polycrystalline metal grains, making it possible to simulate structures like metal interconnects of ICs. Metal interconnects are simulated at different temperatures and compared qualitative and quantitatively with experimental results from in situ TEM. After initial calibration, the proposed model is capable of not only quantitatively match new results obtained in experiments but also predicting more complex phenomena such as the formation of triple junction grooves at the environment-grain interface, surface faceting, and surface diffusion. The simulation also accurately predicts the limited growth of crystal grains due to the triple junction grooves as well as the deepening of the grooves with increasing temperature.

PO.139 Atomic Layer Deposition of Waferscale Crystalline WS_2 Thin Films for Back-End-of-Line Applications

Muhammed Juvaid M*, Hao Tan, Hippolyte P.A.G. Astier, Jing Yang Chung, Chandan Das, John Sudijono, Silvija Gradečak* (NUS Singapore)

With the continuous scaling of silicon integrated circuits, identifying alternative materials for both the front-end-of-line (transistors) and back-end-of-line (BEOL, interconnects) technology is becoming increasingly important. The forthcoming sub-5 nm technology node requires a 20 nm interconnect half-pitch size, resulting in the conventional barrier and liner materials thicknesses of less than 4 nm. However, the traditional barriers like TaN/Ta occupy a significant portion of the interconnect cross-section, and this down-scaling reduces the Cu ion blocking efficiency. Two-dimensional (2D) transition metal dichalcogenides (TMDs) have been recently explored as promising candidates for Cu diffusion barrier and liner applications. However, most 2D TMDs are grown at elevated temperatures ($> 800\,^{\circ}$C) using chemical vapor deposition, making them incompatible with BEOL processes. Plasma-assisted growth can reduce the growth temperature, but poor conformality and plasma-induced defects remain a challenge. Furthermore, some 2D TMDs growth approaches can only deliver micrometer-scale flakes, and BEOL requires films that are uniform over large areas for circuit integration. We report a BEOL-compatible growth process of wafer-scale crystalline WS_2 thin films ($\approx$2 nm) on dielectric substrates via atomic layer deposition. This thermal growth technique offers precise thickness control and large-area conformality. We have successfully deposited high-quality WS_2 thin films on 8-inch SiO_2/Si wafer. The quality of the WS_2 thin film is confirmed by microscopic (atomic force microscopy and transmission electron microscopy,) as well as spectroscopic (Raman spectroscopy, x-ray photoelectron spectroscopy, Rutherford backscattering spectrometry, and energy dispersive x-ray spectroscopy) measurements. Electrical characterization of the WS_2 thin films was used to evaluate their properties for diffusion barrier and liner applications. We will discuss the potential of the thermal ALD growth of 2D TMDs for Back-End-of-Line applications beyond the 5 nm node.

PO.140 Wafer-Scale Deposition of Boron Nitride Thin Films via Low-Temperature PECVD Process

Soumyadeep Sinha*, Hippolyte P.A.G. Astier, Muhammed Juvaid M, Jing Yang Chung, Chandan Das, John Sudijono, Silvija Gradečak* (National University of Singapore)

Modern device technologies require a transfer-free, uniform, and low-temperature growth process of ultra-thin semiconducting films with a low defect density to continue the downscaling of silicon-integrated circuits. Recently, 2D materials have drawn significant research interest for further thickness scaling due to their superior electrical properties at few-atomic-layer thicknesses. Among the several 2D materials, boron nitride (BN) shows unique physical and chemical properties, like strong resilience to high temperature, resistance to oxidation, heat conduction, electrical insulation, and chemical stability due to the special non-metallic polar bond between the constituent elements. Furthermore, it can be developed with a hexagonal (h-BN) crystal structure, or in an amorphous form as a 2D material system. Several bottom-up approaches, including thermal chemical vapor deposition (CVD), plasma-enhanced CVD (PECVD), electron beam evaporation, sputtering, or atomic layer deposition (ALD) have been used to deposit BN thin films. However, the lack of precise control of the thickness and structural quality of BN films during large-scale deposition, particularly at CMOS-compatible deposition temperatures, still limits its practical realization.

In this work, we demonstrate the deposition of BN thin films with the controlled thickness on the large-area substrates at low-temperature by using the PECVD process. The stoichiometry of BN thin films was controlled using different N-plasma sources. The film properties were characterized and correlated with the growth parameters using several characterization methods. X-ray photoelectron spectroscopy (XPS) analysis was carried out to confirm the stoichiometric ratio of the constituent elements across the film thickness. Scanning transmission electron microscopy (STEM), high-resolution TEM (HRTEM) analysis, and energy-dispersive X-ray spectroscopy (EDX) were conducted in a cross-sectional view to determine the film thickness, structural properties, and elemental distribution, respectively.

PO.142 Exfoliation of two-dimensional boron from non-van der Waals crystals

Jing Yang Chung, Yanwen Yuan, Silvija Gradecak-Garaj*, Slaven Garaj* (Department of Physics, National University of Singapore)

Inspired by the discovery of borophene – graphene-like structure made from boron atoms, in-situ grown on flat surfaces in ultra-high vacuum – several reports demonstrated synthesis of two-dimensional boron flakes (2D-boron) via liquid-phase exfoliation from the bulk boron crystals, and explored their physical and chemical properties. While the other 2D materials are exfoliated from layered van der Waals crystals, 2D boron is synthesized from the covalently-bonded bulk crystal, without any preferential, cleavable crystal direction. The synthesis would require breaking of the covalent bonds, and neither the exfoliation mechanism nor the atomic structure of the resulting 2D boron is understood. In this work, we explored the liquid-phase exfoliation of 2D boron from different types of bulk crystals. Using Raman spectroscopy and atomically-resolved scanning transmission electron microscopy (STEM), we compared the structures of the bulk source and the resulting 2D boron, We proposed the structure for 2D-boron, and a possible exfoliation mechanism. Boron makes highly complex crystal structures, so a meticulous analysis and modeling of the STEM data is needed. We show that the resulting images are highly sensitive on the thickness and the tilt of the flakes, probably fueling early confusion on the structure of the 2D-boron. The understanding of 2D-boron could inspire strategies for discovery of a new class of 2D materials that do not require van der Waals crystals.

PO.146 Screening new copper diffusion barriers for interconnects using electrical measurements

Hippolyte P.A.G. Astier*, Muhammed Juvaid Mangattuchali, Meldrick Kuan, Soumyadeep Sinha, Jing Yang Chung, Saurabh Srivastava, Chandan Das, John Sudijono, Silvija Gradecak (Department of Materials Science and Engineering, National University of Singapore)

Copper (Cu) is the industry's preferred metal for wires in interconnect technology, due to its low resistance and relative availability. However, Cu is known to diffuse in standard dielectrics used in interconnect layers, which leads to early performance degradation of the circuitry or failures due to short circuits. To prevent this diffusion-driven failure, modern interconnect structures incorporate a DB as a layer surrounding the Cu wire. TaN has been used extensively as a DB layer, along with bilayer structures with Ta for improved adhesion; other materials include Co and TiN [1]. As the industry is approaching sub-5 nm technology nodes, interconnect back end of line (BEOL) technology will be required to match this miniaturization with half-pitches reduced to 20 nm. For conventional DBs, this downscaling represents a challenge as they are expected to become ineffective against Cu diffusion for small thicknesses, or occupy too large a portion of the wire's diameter if they are kept at the same thickness, thus increasing the resistance substantially and causing RC delays. A thorough study of the thickness dependence of barrier performance is, however, still lacking.

These limitations have motivated the search for replacement DBs, and recent reports have demonstrated the use of 2D materials such as graphene and transition metal dichalcogenides (TMCs) as DBs [2]–[7]. Such 2D materials are promising candidates for two reasons: they can be made as thin as a few atomic layers, and 2D stacked layers do not share their grain structure with one another, while it is believed that Cu diffusion through barriers occurs preferentially along grain boundaries. It is important to establish how standard DBs, and the newly proposed 2D material barriers perform as a function of their thickness. This dependence is expected to differ between standard polycrystalline materials and 2D stacked layers.

Here, we report on a protocol to screen new materials as future DBs, using electrical breakdown measurements. We show a fully dry fabrication scheme, agnostic to the material's chemical structure, to integrate films into breakdown device structures. We present and compare two measurement schemes [8], and demonstrate them to be consistent with each other on control samples. We then assess the thickness dependence of industry-standard TaN films using these methods. Finally, we present initial results on 2D-material barriers grown by us.

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materials in back-end-of-line interconnect scaling," J. Appl. Phys., vol. 128, no. 8, 2020. [5] R. Mehta, S. Chugh, and Z. Chen, "Transfer-free multi-layer graphene as a diffusion barrier," Nanoscale, vol. 9, no. 5, pp. 1827–1833, Feb. 2017. [6] L. Li et al., "Cu diffusion barrier: Graphene benchmarked to TaN for ultimate interconnect scaling," in Digest of Technical Papers - Symposium on VLSI Technology, 2015, vol. 2015-Augus, pp. T122–T123. [7] S. S. Roy and M. S. Arnold, "Improving graphene diffusion barriers via stacking multiple layers and grain size engineering," Adv. Funct. Mater., vol. 23, no. 29, pp. 3638–3644, Aug. 2013. [8] A. Kerber, L. Pantisano, A. Veloso, G. Groeseneken, and M. Kerber, "Reliability screening of high-k dielectrics based on voltage ramp stress," Microelectron. Reliab., vol. 47, no. 4-5 SPEC. ISS., pp. 513–517, 2007.

PO.147 Towards Luminosity Transit Coronagraphy

Gillian Foo*, Darren Koh, Xi Jie Yeo, Jae Suk Hwang, Christian Kurtsiefer*, Peng Kian Tan* (Centre for Quantum Technologies)

The exoplanets discovered in the past two decades have largely been "hot Jupiter" types due to limitations in common techniques, including aperture-induced diffraction limit in the luminosity transit method responsible for 76% of all detections. To increase the opportunity for detecting other exoplanet types – such as smaller, slower "Earth-like" exoplanets, we propose a proof-of-concept method on a simplified model for transit measurements, to increase transit signal-to-noise ratio. A Mach-Zehnder interferometer with image inversion separates the photon shot noise of a star from the shot noise associated with the transit signal into different detection channels. By maximising interferometric visibility, the signal-to-noise ratio could be increased by up to an order of magnitude compared to the scenario of using the transit method with a 1m telescope aperture, which can improve on the angular resolution of a traditional imaging system.

PO.148 Rapid Quantum Squeezing by Jumping the Harmonic Oscillator Frequency

Wui Seng Leong, Mingjie Xin, Zilong Chen, Yu Wang, Shau-Yu Lan* (Nanyang Technological University)

Quantum sensing and quantum information processing use quantum advantages such as squeezed states that encode a quantity of interest with higher precision and generate quantum correlations to outperform classical methods. In harmonic oscillators, the rate of generating squeezing is set by a quantum speed limit. Therefore, the degree to which a quantum advantage can be used in practice is limited by the time needed to create the state relative to the rate of unavoidable decoherence. Alternatively, a sudden change of harmonic oscillator's frequency projects a ground state into a squeezed state which can circumvent the time constraint. Here, we create squeezed states of atomic motion by sudden changes of the harmonic oscillation frequency of atoms in an optical lattice. Building on this protocol, we demonstrate rapid quantum amplification of a displacement operator that could be used for detecting motion. Our results can speed up quantum gates and enable quantum sensing and quantum information processing in noisy environments.

PO.149 Exciton polaritons in J-aggregates coupled to dielectric metasurfaces

Marco Marangi*, Jingyi Tian, Maciej Klein, Guglielmo Lanzani, Cesare Soci* (1 Centre for Disruptive Photonic Technologies, SPMS, TPI, NTU)

J-aggregates, consisting of coupled molecular emitters in which dipole transition moments are naturally aligned, have been widely studied for their superradiant properties. Theoretically, the increase in luminescence intensity induced by coherent and cooperative spontaneous emission of the coupled emitters should be proportional to their number square. Practically, this feat is hard to achieve, especially at room-temperature. In this work, dielectric metasurfaces are used to resonantly enhance the emission of molecular J-aggregates by the Purcell effect and induce superradiance at room-temperature. Different metasurface designs are studied by numerical simulations to relate the coupling strength between the dielectric resonators and the emissive aggregates to the superradiant behaviour. Evidence of weak and strong coupling are provided by the dispersion of angle-dependent transmission spectra. A degree of anisotropy is also added to the metasurface design to favour physical alignment of the molecular aggregates and realize highly polarised polaritonic devices which are currently under development. We argue that coupling of molecular J-aggregates with designer metasurfaces provides a new avenue to control the radiative properties of exciton polaritons and may find application in ultrabright and fast-switchable light-emitting devices or sensors.

4 Technical Sessions

Please observe the technical instructions for talks to comply wiht regulations. We will leave a copy for each chair in the rooms.

T1: 2D materials I

Time: Wednesday 28 Sept, 11:15am; Venue: LT2; Chair: tbd
Time allocated for keynote/invited talks is 20/15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T1.133 Out-of-equillibrium criticalities in graphene superlattices

Alexey Berdyugin* (National University of Singapore)
11:15am – 11:30am

In thermodynamic equilibrium, current in metallic systems is carried by electronic states near the Fermi energy, whereas the filled bands underneath contribute little to conduction. Here, we describe a very different regime in which carrier distribution in graphene and its superlattices is shifted so far from equilibrium that the filled bands start playing an essential role, leading to a critical-current behavior. The criticalities develop upon the velocity of electron flow reaching the Fermi velocity. Key signatures of the out-of-equilibrium state are current-voltage characteristics that resemble those of superconductors, sharp peaks in differential resistance, sign reversal of the Hall effect, and a marked anomaly caused by the Schwinger-like production of hot electron-hole plasma. The observed behavior is expected to be common to all graphene-based superlattices.

T1.136 2D electrolytes: theory, synthesis, characterization, and applications

Mariana C. F. Costa* (NATIONAL UNIVERSITY OF SINGAPORE)
11:30am – 11:45am

We have demonstrated theoretically and experimentally a group of functional materials that shares the properties of two-dimensional (2D) materials and electrolytes, called 2D electrolytes. 2D electrolytes have the ability to dissociate in aqueous-based solvents and change their morphology in response to their surroundings. Particularly, the arrangement from 2D flat sheets to 1D-scrolled arrangements and more complex structures in liquid media is mainly determined by external factors, such as pH, temperature and ionic concentration. The interplay between Coulomb forces, elastic energy and van der Waals interactions are key to understand the different morphological configurations. Several examples of 2D electrolytes have been synthesized, using graphene and its derivatives (graphene oxide – GO, and reduced graphene oxide, rGO) and lithium-intercalated molybdenum disulphide ($LixMoS_2$), and a number of different characterization techniques together with a theoretical framework are presented. Since these materials show stimuli-responsive behavior to the environmental conditions, 2D-electrolytes can be considered as a novel class of smart materials that expands the functionalities of 2D materials and are promising for dynamic applications that require stimuli-responsive demeanor, such as drug-delivery, filtration membranes, artificial muscles, and energy storage systems.

T1.126 Contact and dielectric engineering of 2D semiconductors for quantum applications

Chit Siong Aaron Lau* (Institute of Materials Research and Engineering)
11:45am – 12:00pm

2D semiconductors have potential for many applications including quantum but progress is severely hindered by contact and dielectric engineering. I will discuss our group's efforts to establish high-quality contacts at cryogenic temperatures where we revealed new insights into the nature of metal/2D semiconductor interface. Next, I will discuss our work on the influence of dielectrics and interface roughness on carrier transport and present our measurements on the first gate-defined chemical vapour deposition grown bilayer WS_2 quantum dot. Finally, we will share some of our latest work on integrating ultrathin metal oxides printed from liquid metals with 2D materials, and how they can potentially address crucial device engineering challenges in 2D materials.

C.S. Lau, J.Y. Chee et al., 'Quantum Transport in Two-Dimensional WS_2 with High-Efficiency Carrier Injection through Indium Alloy Contacts', ACS Nano, 14 (10), 13700-13708 (2020) C.S. Lau, J.Y. Chee et al., 'Gate-Defined Quantum Confinement in CVD 2D WS_2, Advanced Materials, 2103907 (2021)

T1.89 Conformational Effect on Optical Properties and High Pressure Response in 2D Perovskites

Yulia Lekina*, Brandon Ong, Benny Febriansyah, Ze Xiang Shen* (Nanyang Technological University)
12:00pm – 12:15pm

Two-directional (2D) hybrid organic-inorganic perovskites have attracted considerable attention as promising materials for solar cells and light emission. Their improved moisture stability and quantum-well electronic structure are explained by the hydrophobic and insulating organic layers, naturally inserted between the perovskite sheets. The diversity of the suitable organic cations allows fine property tuning and extends the chemical engineering potential. Phenylethylammonium (PEA) cation and its derivatives are the most widely applied and studied. However, in most known 2D perovskites, the molecule is present in the gauche conformation. Ortho-$BrPEA_2PbI_4$ perovskite is one of the rare anti-conformers, while bromine substitution in meta- and para- form the conventional gauche PEA cation. In this work, we demonstrate how the shape of the organic cation affects its optical properties and high-pressure response. Ortho-$BrPEA_2PbI_4$ (anti) and para-$BrPEA_2PbI_4$ (gauche) are taken for the comparison. The properties of the former one differ from the other PEA-based perovskites. The excitonic energy is blue-shifted by over 20 nm due to the octahedra tilting caused by the different orientations of the NH_3 end. Applying high pressure causes a much less significant change of the band gap as in the gauche PEA-based perovskites, which is related to the flexibility of the Pb-I-Pb angle between the octahedra. This feature can be applied to matching lattice parameters in films and heterostructures.

T1.114 Atomic relaxation in van der Waals heterostructures

Gayani Pallewela, Adam Shaffique* (Yale-NUS)

12:15pm – 12:30pm

The discovery of correlated insulating phases and superconductivity in twisted bilayer graphene has boosted the field of twistronics where strong electron-electron interactions play a dominant role in the physics. Atomic relaxation plays a vital role in the van der Waals heterostructures. Relaxation of the atomic positions is a generic consequence of the moiré pattern and generate many implications for the physical properties. Hence the accurate representation of the relaxation is important. Nowadays, molecular dynamics simulations are widely used to include the relaxation of the van der Waals heterostructures. Many force field parameters have been developed to implement the inter-layer and intra-layer interactions of these systems. In this theoretical work, we examine the force field dependence of the structural relaxation and changes in the electronic band structures. We determine the out-of-plane corrugation amplitudes, in-plane relaxation, potential energy for different force fields.

T1.6 Organic-2D material heterostructures: A promising platform for Exciton Condensation and Multiplication

Kanchan Ulman*, Su Ying Quek* (NUS)

12:30pm – 12:45pm

Bose-Einstein condensation (BEC) is an exotic state of matter generally observed at extremely low temperatures, where all the bosons in the system occupy the ground state. Excitons, bound electron hole pairs generated in matter by the absorption of photons, are capable of undergoing BEC at higher temperatures due to their smaller bosonic mass compared to atoms. However, in order for BEC to be achieved, the excitons need to have long lifetimes, high densities, and small exciton momenta. While experiments on $MoSe_2/WSe_2$ bilayers exhibit excitonic BEC at high temperatures of $\approx$100 K, precise alignment of the layers is required to maintain coherence and hence BEC [1]. Using first-principles GW-BSE calculations, we predict that the lowest energy charge transfer excitons in ZnPc-MoS_2 organic-2D material heterostructures are ideal candidates for BEC [2]. These charge transfer excitons arise from direct transitions, are strongly bound (localized in $\approx$1-2 nm) and have long lifetimes of the order of nanoseconds, leading to BEC transition temperatures of $\approx$50-100 K. Furthermore, our calculations also reveal the presence of inter-molecular excitons stabilized by indirect substrate mediation. These inter-molecular excitons can be important for realizing singlet fission and exciton multiplication, which can help overcome the Shockley-Queisser limit in solar cells.

References: [1] Mak et al., "Evidence of high-temperature exciton condensation in two-dimensional atomic double layers", Nature 2019, 574, 76. [2] K. Ulman and S. Y. Quek, "Organic-2D Material heterostructures: A Promising Platform for Exciton Condensation and Multiplication", Nano Letters 2021, 21, 8888.

T2: Quantum Foundations

Time: Wednesday 28 Sept, 11:15am; Venue: LT3; Chair: tbd
Time allocated for keynote/invited talks is 20/15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T2.13 On the possibility of detecting gravity of an object frozen in a spatial superposition by the Zeno effect

Peter Sidajaya*, Wan Cong, Valerio Scarani (Centre for Quantum Technologies)
11:15am – 11:30am

While quantum probes surely feel gravity, no source of gravity has been prepared in a delocalised quantum state yet. Two basic questions need to be addressed: how to delocalise a mass sufficiently large to generate detectable gravity; and, once that state has been prepared, how to fight localisation by decoherence. We propose to fight decoherence by freezing the source in the desired state through the Zeno effect. Successful implementation can be verified by scattering a probe in the effective potential generated by the source. Besides putting forward the idea, we provide a first estimation of the values of the parameters required for the proposal to be feasible. Overall, the proposal seems as challenging as other existing ones, although the specific challenges are different (e.g. no entanglement needs to be preserved or detected, but the Zeno freezing must be implemented).

T2.90 Entanglement based precision test of gravitational coupling at quantum length scales

Ankit Kumar*, Tanjung Krisnanda, Paramasivan Arumugam, Tomasz Paterek (Indian Institute of Technology Roorkee)
11:30am – 11:45am

Due to the weakness of gravitational coupling, all quantum experiments up to date in which gravity plays a role utilised the field of the Earth. Since this field undergoes practically undetectable back-action from quantum particles, it effectively admits a classical description as a fixed background. This strongly motivates comprehensive research towards a demonstration of gravitation between two quantum entities. One of the promising ways to do so is to look for the gravitationally induced quantum. We aim to provide an entanglement based precision test of gravitational coupling between two nearby quantum masses. The idea is to push the particles towards each other and monitor the momentum dependence of position-momentum correlations. One expects that this configuration will gather more entanglement than the one at rest due to an ever-increasing interaction strength. We show that this is the case only when the system evolves into non-Gaussian states. A closer look reveals the pivotal role of the force gradient across reduced mass wave packet as the primary driver of quantum correlations. Closed-form expressions for entanglement are derived, which agree with numerical simulations showing a linear dependence on the initial relative momentum. From a quantum optics / information perspective, one can interpret the findings as a momentum witness of non-gaussian entanglement.

T2.14 Bounding the Minimum Time of a Quantum Measurement

Nathan Shettell*, Federico Centrone, Luis Pedro Garcias-Pintos (Centre for Quantum Technologies)
11:45am – 12:00pm

Quantum measurements play a crucial role in many domains of quantum theory and quantum information alike, yet they are one of the most enigmatic controversial aspects of the quantum realm. Although most agree on the the end result of said measurement, the dynamics has been a subject of debate since the initial 'quantum-boom' in the the early twentieth century. Arguably, the most famous interpretation of the quantum measurement is the 'collapse of the wave function', which was later codified by Von Neumann in his mathematical formulation of quantum mechanics, where a quantum measurement is defined as a probabilistic, irreversible, and instantaneous process. This is in direct contention with another postulate of quantum mechanics: that all microscopic processes are unitary (ergo reversible). This peculiar exemption for measurements (along with other concerns) is dubbed the 'measurement problem'.

Decoherence theory is one of the most successful attempts at addressing the measurement problem without changing the fundamental postulates of quantum mechanics. In our study, we utilize decoherence theory along with tools from quantum speed limits to derive a general bound on the minimum time it takes for a quantum measurement occur. The measurement model we consider consists of a quantum system which is subjected to the measurement process, an apparatus which records the outcome of the measurement, and an external environment which drives the measurement by interacting with the apparatus. The bound we derive is based on the principle that a measurement is a change in entropy of the state of the quantum system and apparatus to the environment, and that this change in entropy takes a finite amount of time. Using inequalities pertaining to quantum speed limits, we show that the the time it takes for a measurement to occur, τ, is bounded via

$$\tau \geq \frac{\hbar \delta S}{2\Delta S \Delta H_{\text{int}}},$$

where δS is the change in entropy of the state of the quantum system and apparatus, ΔS is the varentropy (which can be bounded with respect to the number of unique outcomes of the measurement), and ΔH_{int} is the standard deviation of the interaction Hamiltonian between the environment and the apparatus. This inequality allows one to determine a bound without needing to solve for the exact (and typically very complicated) dynamics induced by the environment.

T2.27 Negativity measure for quasiprobability representations of quantum mechanics: equivalence class and minimal representation

Kelvin Onggadinata*, Dagomir Kaszlikowski* (National University of Singapore)
12:00pm – 12:15pm

The quasiprobability representation is an alternative framework of quantum mechanics from the usual Hilbert space formalism where generalized notions of probability theory is used. In this representation, negativity appears to be prevalent in any quasiprobability representations and has been regarded to be signature of nonclassicality. Understanding of how much negativity is required in several quantum phenomenon is critical in the study of quantum computation. In this work we proposed a measure of negativity for both the frame and dual frame that induces the negativity of that representation. We show that there is an equivalence class of representations where total negativity is constant. Additionally, we describe the general map for the transformation between two representations and show there can be trade-off in their frame and dual frame's negativity. Lastly, we used the measure proposed here to find the representations with minimal negativity.

T2.3 Detecting quantumness with precessions in harmonic and anharmonic systems

Lin Htoo Zaw*, Clive Cenxin Aw, Zakarya Lasmar, Valerio Scarani (Centre for Quantum Technologies)

12:15pm – 12:30pm

Quantum features are not expected to be found in the dynamics of a harmonic oscillator, as its time evolution—whether quantum or classical—is a simple precession. In an unnoticed work, Tsirelson put forward a scheme that counters this belief: if a quantum harmonic oscillator were prepared in a suitable state, its nonclassicality can be detected by probing the system at different times [1]. We extend this scheme to present a family of protocols that detect the nonclassicality of suitable states of a single quantum system, under the sole assumption that its time evolution is a uniform precession [2]. This includes both finite-dimensional spins (uniform precession in real space) and the harmonic oscillator (uniform precession in phase space). The approach can also be extended to detect nonclassicality of system undergoing anharmonic dynamics.

[1] Tsirelson, B. (2006). How often is the coordinate of a harmonic oscillator positive?. arXiv:quant-ph/0611147.

[2] Zaw, L. H., Aw, C. C., Lasmar, Z., & Scarani, V. (2022). Detecting quantumness in uniform precessions. arXiv:2204.10498.

T2.78 A unified approach to the computation and additivity of entanglement monotones

Roberto Rubboli*, Marco Tomamichel (Center for Quantum Technologies (CQT))

12:30pm – 12:45pm

We study entanglement monotones based on Rényi divergences, a framework that encompasses the geometric measure of entanglement, the relative entropy of entanglement and the generalized robustness. We find necessary and sufficient conditions for the closest separable state of each entanglement monotone. We show that these conditions provide a unified way to compute these monotones by considering some states of interest. We then generalize the existing results on additivity of these monotones by showing that the monotones are additive when at least one of the two states belongs to some special classes. Some examples of such classes are pure states, maximally correlated states, Bell diagonal states and isotropic states. We then prove that the antisymmetric (Werner) states provide a unified counterexample to the additivity of these monotones. We formulate some of our technical results in a general resource theory framework and expect that they could be used to investigate other resource theories.

T3: Climate and Plasma Physics

Time: Wednesday 28 Sept, 11:15am; Venue: LT4; Chair: tbd
Time allocated for keynote/invited talks is 20/15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T3.35 Is thermal expansion of the ocean a linear function of the excess energy in the earth's climate system?

Benjamin Grandey*, Zhi Yang Koh, Dhrubajyoti Samanta, Benjamin Horton, Justin Dauwels, Lock Yue Chew (Nanyang Technological University)
11:15am – 11:30am

Sea level change integrates diverse physical processes across a wide range of spatial and temporal scales in the earth's climate system. Careful consideration of these processes is required in order to assess possible future impacts of sea level change over the coming decades and centuries. State-of-the-art global climate models represent many of the important processes, facilitating exploration of the earth's climate system. Here, we focus on one important process: thermal expansion of the ocean. Physical considerations suggest that the global mean thermal expansion should be linearly related to the excess energy in the earth's climate system. Global climate model results suggest that the thermal expansion can indeed be approximated as a linear function of excess energy. Nevertheless, departures from linearity are found, providing an opportunity to question the assumptions underlying the simplified linear model.

T3.121 Two-dimensional particle-in-cell simulation of physical vapor deposition plasmas

Po-Yen Lai*, Wen Jun Ding (A*STAR IHPC)
11:30am – 11:45am

Physical vapor deposition (PVD) is an essential technique which is widely applied for the fabrication of thin films and surface coatings for industrial purposes. Plasma simulations have been widely used for studying the ion density and particle energy evaluation in the PVD plasma chamber for parametric chamber design. Instead of the conventional fluid model, the particle-in-cell (PIC) approach describes the self-consistent particle-wave interactions, particle-particle collisions, and impact ionization kinetically. In this study, we propose the electromagnetic circuit-integrated PIC model considering the stochastic collisions and ionizations to fairly realize the plasma conditions in the chamber. Based on the PIC simulation simulations, plasma density and kinetic energy can be evaluated for the chamber design, including under any gas pressure conditions, multiple targets, and various bias voltages. The impact of the external magnetic field has also been considered in the 2D PIC simulations for understanding magnetron sputtering and further improving the PVD system.

T3.141 Plasma oxidation of patterned Mo nanostructures for precise and uniform dry etching

Muhaimin Mareum Khan, Ivan Erofeev*, Utkur Mirsaidov* (National University of Singapore)

11:45am – 12:00pm

A major challenge for the continued downscaling of integrated circuits is the rapid increase in copper (Cu) resistivity at wire width under 20 nm as this is well below the electron mean free path in Cu (40 nm), which means a higher contribution to resistivity from electron scattering off the metal surface and reflections at grain boundaries. The need for a diffusion barrier between Cu and the surrounding dielectric makes the effective wire cross-section even smaller. This limitation motivates extensive research into metals that outperform Cu at this scale. Molybdenum (Mo) is a promising metal for applications requiring low resistivity interconnect or contact lines in small dimensions due to its better figure of merit $\rho_0 \times \lambda$ (ρ_0 the bulk resistivity and λ the electron mean free path). Additionally, Mo does not require a barrier, and Mo nanostructures can be directly patterned from a film, which simplifies the production of multilayer stacks. However, precise wet etching of polycrystalline metals like Mo is very challenging because of facet-dependent etch rates, usually yielding rough surface and non-uniform recess. To achieve a precise uniform recess of Mo, we implemented a two-step dry etching method comprising sequential oxidation and selective oxide removal by chlorination, whereby the recess depth is controlled purely by oxidation. Here we have extensively studied and characterized the oxidation step by exposing patterned Mo nanowires ($\approx$32 nm width) to isotropic air plasma. We demonstrated that a uniform oxide layer of pre-defined thickness can be achieved by controlling RF power and gas pressure. Preliminary data from chlorination experiments show highly selective oxide etching, confirming the suggested method is precise and reliable.

T3.145 A thermoplasmonic metasurface as a tunable mid-infrared absorber

Rosmin Elsa Mohan*, Eng Huat Khoo*, Hong Son Chu* (Agency for Science Technology and Research)

12:00pm – 12:15pm

The ability to release heat using nanomaterials allows for a broad range of applications encompassing industry and research. Recently thermoplasmonic properties have been reported in the battle against the pandemic through the use of photothermal responsive respirators. One of the primary advantages with using metal nanoparticles is the enhancement of light-matter interactions exhibited at the plasmonic resonance. The use of such nanoparticles introduces thermal hotspots by means of electromagnetic confinement to act as nano-sources of heat. By variation in the nanoparticle geometry, the nanoparticles can be optimized for a specific wavelength range and application. In this contributed talk, we discuss a metasurface geometry which includes a noble metal component on SiO_2 dielectric substrate for tuning the thermal emission in the mid-infrared range between 9-12 μm. With changes in the metasurface geometry, the absorption peak can be tuned across the wavelength range with a maximum absorption of 75.6% observed about 11 μm. Selective near unity mid-infrared absorption can further be achieved by variation in the metasurface geometry which will be discussed. Such designs may be used as a modeling guide in the potential fabrication of mid-infrared gas sensors, thermal energy harvestors, plasmon assisted thermo-voltaic cells or for targeted thermal action for cancer cells.

T3.47 Radiative cooling in Singapore: challenges and strategies

Jaesuk Hwang* (Centre for Quantum Technologies)
12:15pm – 12:30pm

An object on the earth's surface can lose heat by emitting infrared radiation towards the outer space, which is at 3K temperature. A passive cooling device can be implemented by arranging a body to emit efficiently in 8 to 14 microns wavelength range, so-called the sky window, where the atmosphere is partially transparent. Recently, radiative cooling attracted attention as a promising source of sustainable and renewable energy since it was demonstrated that radiative cooling is possible during the day. However, the daytime radiative cooling in a tropical weather, such as in Singapore, has been deemed challenging. This is mainly because the atmosphere within the sky window becomes more opaque with the increasing humidity level of a given area. To this end, radiative cooling in a tropical weather region requires additional enhancement schemes compared to that in a dry weather region. We present a preliminary measurement of daytime radiative cooling using optical concentrator structures. We also discuss the strategies for implementing the radiative cooling devices for all-day operation in a tropical weather.

T4: AMO Physics

Time: Wednesday 28 Sept, 11:15am; Venue: LT5; Chair: tbd
Time allocated for keynote/invited talks is 20/15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T4.9 Atomtronic multi-terminal Aharonov-Bohm interferometer

Jonathan Wei Zhong Lau*, Koon Siang Gan, Rainer Dumke, Luigi Amico, Leong Chuan Kwek, Tobias Haug (Centre for Quantum Technologies)
11:15am – 11:30am

We study a powerful multi-functional device for cold atoms with a three-terminal ring circuit pierced by a synthetic magnetic flux. The flux controls the transport through the ring via the Aharonov-Bohm effect. Our device can measure the flux in-situ via a flux-induced transition of the reflections from an Andreev-like negative density to positive density. In the non-equilibrium regime, the flux directs the atomic current into specific output ports, realizing a flexible non-reciprocal switch to connect multiple atomic systems. By changing the flux linearly in time, we convert constant matter wave currents into alternating currents. This effect can be used to realize an atomic frequency generator and study fundamental problems related to the Aharonov-Bohm effect. We demonstrate the viability of the setup by loading a Bose-Einstein condensate into a light-shaped optical potential of the three-terminal ring. Our work opens up novel atomtronic devices for practical applications in quantum technologies.

T4.70 Emergent s-wave interactions between identical fermions in quasi-one-dimensional geometries

Ben Olsen*, Kenneth Jackson, Colin Dale, Jeff Maki, Kevin Xie, Denise Ahmed-Braun, Shizhong Zhang, Joseph Thywissen (Yale-NUS College)
11:30am – 11:45am

One-dimensional models of spin-polarized Fermi gases with tunable zero-range interactions have been the subject of numerous theoretical investigations, but are as yet unrealized in ultracold systems. Here we study the two-body correlation strength of spin-polarized fermionic potassium (^{40}K) in the quasi-one-dimensional (q1D) regime, using radio-frequency spectroscopy. The strength and spatial symmetry of interactions are tuned by a nearby p-wave Feshbach resonance and by confinement anisotropy. Surprisingly, we find a scattering channel that has even particle-exchange parity along the q1D axis. These emergent s-wave collisions are enabled by orbital singlet wave functions in the transverse directions, which also confer high-momentum components to low-energy q1D collisions. We measure both the q1D odd- and even-wave "contact" parameters for the first time, and compare them to theoretical predictions of one-dimensional many-body models. We find an even-wave contact that is comparable to the theoretical unitary value, whereas the maximum observed odd-wave contact is two orders of magnitude smaller than its unitary limit. The discovery of emergent s-wave interactions reveals a new route to studying strongly correlated ensembles of spin-polarized fermions with zero-range interactions.

T4.45 Magneto-optical trapping of a Group III atom

Xianquan Yu, Jinchao Mo, Tiangao Lu, Ting You Tan, Travis Nicholson* (CQT, NUS Department of Physics)

11:45am – 12:00pm

Over the past 30 years, ultracold physics has focused on three types of atoms: alkalis, alkaline earths, and dipolar lanthanides. Meanwhile the majority of the Periodic Table remains unexplored in the ultracold regime. We report on the achievement of a magneto-optical trap of a new type of ultracold atom, namely one from Main Group III of the Periodic Table (known as the "triel elements"). This atom (indium) contains many remarkable properties only found in isolation in the other types of ultracold atoms, such as sparse Feshbach spectra, optical clock transitions, and anisotropic light-matter interactions. Together these properties offer superior control of internal and many-body states, rich spinor gas properties with a large number of magnetic orderings, and the ability to realize long-coherence many-body spin-orbit coupling. Additionally, indium contains exotic properties that cannot be found in other ultracold atom types. The challenge with achieving ultracold indium is that no Group III atom has been laser cooled before. Using a closed UV transition out of a metastable state, we have successfully laser cooled 10^6 indium atoms to $\approx$1 mK temperatures. We observe a one-body lifetime consistent with background gas collisions and a two-body rate comparable to those found in alkali metals. These results open a broad new research direction in ultracold physics.

T4.110 (INVITED) Demonstration of Datta-Das transistor in a cold atomic system

Chetan Sriram Madasu*, Mehedi Hasan, Ketan Damji Rathod, Chang Chi Kwong, David Wilkowski (Nanyang Technological University)

12:00pm – 12:20pm

We experimentally demonstrate an atomtronic analogue of the Datta-Das transistor (DDT) by resonantly coupling three Zeeman ground states of strontium-87 to an excited state in the form of a tripod system. We map two degenerate dark states of the tripod system to a pseudo-spin 1/2 system. We work within the adiabatic approximation resulting in the appearance of a synthetic gauge field in the effective hamiltonian. By varying the intensity of one of the tripod beams, we can control the degree of pseudo-spin rotation, with a tuneable sensitivity. Since the spin rotations result from geometric transformations within the dark state manifold, the DDT operation is robust against decoherence and residual spread in atomic velocity.

T4.98 Creation of an Ultracold Gas of Ground State Dipolar ^{6}Li–^{40}K Molecules

Xiaoyu Nie*, Anbang Yang, Canming He, Victor Avalos, Sofia Botsi, Sunil Kumar, Kai Dieckmann* (Centre for Quantum Technologies (CQT), Department of Physics, National University of Singapore, Singapore 117543)

12:20pm – 12:35pm

We report on the creation of bosonic ^{6}Li–^{40}K molecules in their absolute rovibrational ground state via two-photon detuned Raman process. We create ultracold gases with up to 86.4% by employing singlet pathway, two long cavity ECDLs (low phase noise), one-photon detuning cancellation with EOM compensation. We observe a coherent oscillation between the Feshbach state and ro-vibrational ground state with a period of 16us at a 582 MHz two-photon detuning, and 12 MHz laser Rabi frequency. Employing the tunability and strength of the permanent electric dipole moment of ^{6}Li–^{40}K, we induce dipole moments of up to 1.9 D with four electrodes. Dipolar systems of ^{6}Li–^{40}K molecules are uniquely suited to explore long-range interaction and phase transitions in dipolar quantum matters.

T5: Solid State Physics I

Time: Wednesday 28 Sept, 2:00pm; Venue: LT2; Chair: tbd
Time allocated for keynote/invited talks is 20/15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T5.107 Microscopic theory of ionic motion in solids

Aleksandr Rodin*, Keian Noori, Alexandra Carvalho, Antonio Castro Neto (Yale-NUS College)

2:00pm – 02:15pm

Drag and diffusion of mobile ions in solids are of interest for both purely theoretical and applied scientific communities. This work proposes a theoretical description of ion drag in solids that can be used to estimate ionic conductivities in crystals, and forms a basis for the rational design of solid electrolyte materials. Starting with a general solid-state Hamiltonian, we employ the nonequilibrium path integral formalism to develop a microscopic theory of ionic transport in solids in the presence of thermal fluctuations. As required by the fluctuation-dissipation theorem, we obtain a relation between the variance of the random force and friction. Because of the crystalline nature of the system, however, the two quantities are tensorial.

T5.125 Dimensional transmutation from non-Hermiticity

Hui Jiang, Ching Hua Lee* (National University of Singapore)
02:15pm – 02:30pm

Dimensionality plays a fundamental role in the classification of novel phases and their responses. In generic lattices of 2D and beyond, however, we found that non-Hermitian couplings do not merely distort the Brillouin zone (BZ), but can in fact alter its effective dimensionality. This is due to the fundamental non-commutativity of multi-dimensional non-Hermitian pumping, which obstructs the usual formation of a generalized complex BZ. As such, basis states are forced to assume “entangled” profiles that are orthogonal in a lower dimensional effective BZ, completely divorced from any vestige of lattice Bloch states unlike conventional skin states. Characterizing this reduced dimensionality is an emergent winding number intimately related to the homotopy of non-contractible spectral paths. We illustrate this dimensional transmutation through a 2D model whose topological zero modes are protected by a 1D, not 2D, topological invariant. Our findings can be readily demonstrated via the bulk properties of non-reciprocally coupled platforms such as circuit arrays, and provokes us to rethink about the fundamental role of geometric obstruction in the dimensional classification of topological states.

T5.123 Non-monotonic temperature dependence and universality of viscosity of monolayer and bilayer graphene

Indra Yudhistira*, Ramal Afrose, Aydin Cem Keser, Shaffique Adam* (National University of Singapore)
02:30pm – 02:45pm

The advancements in technology in recent years have allowed for the experimental realization of ultraclean monolayer and bilayer graphene samples where impurity or phonon scattering are

no longer the dominant scattering mechanism. The strong electron-electron interaction in these ultraclean samples results in the emergence of hydrodynamic electron behaviour where electron transport is governed by an electronic Navier-Stokes equation analogous to classical fluids. In this theoretical study, we carry out a theoretical calculation of dynamic viscosity in monolayer and bilayer graphene from a microscopic theory. We find a non-monotonic temperature dependence of the dynamic viscosity in both monolayer and bilayer graphene that approaches a universal limit at high temperature and strong electron-electron interaction. All of our predictions occur in a range of temperature and carrier density that is experimentally accessible.

T5.4 Charge Transfer Screening and Energy Level Alignment at Complex Organic–Inorganic Interfaces: A Tractable Ab Initio GW Approach

Nicholas Lin Quan Cheng*, Fengyuan Xuan, Catalin D. Spataru, Su Ying Quek (National University of Singapore)

02:45pm – 03:00pm

The energy level alignment (ELA) at organic-inorganic interfaces is critical for determining charge injection barriers in organic and molecular electronic devices. Many-body perturbation theory in the GW approximation enables the quantitative prediction of ELA in many systems, but can be computationally challenging for large interfaces. We have recently developed an approach [1] to perform GW calculations on large interface systems, which involves the expansion of the polarizability (chi) matrix from a unit cell to the supercell, the Addition of chi from the two subsystems, and the use of wavefunctions from the Full interface to compute the self-energies. This XAF-GW method has been shown to work even in the presence of interface hybridization to form bonding and anti-bonding orbitals. Here, we show that the XAF-GW method fails in some cases with significant interface charge transfer. We modify the XAF-GW approach to specifically account for many-body interactions due to charge transfer effects and obtain excellent agreement with benchmark GW calculations with significantly reduced computational cost [2]. We show that many-body interactions lead to gate-tunable molecular HOMO-LUMO gaps in a F4TCNQ/graphene interface. By comparison with a two-dimensional electron gas model, we also show the importance of explicitly accounting for intraband transitions in determining the charge transfer screening in organic-inorganic interface systems.

This work is funded by grant MOE2016-T2-2-132.

[1] F. Xuan, Y. Chen, S. Y. Quek, J. Chem. Theory Comput. 15, 3824 (2019) [2] N. L. Q. Cheng., F. Xuan, C. D. Spataru, S. Y. Quek, J. Phys. Chem. Lett. 12, 8841 (2021)

T5.1 Phononic real Chern insulator with protected corner modes in graphynes

Jiaojiao Zhu*, Shengyuan Yang (Singapore University of Technology and Design)

03:00pm – 03:15pm

Higher-order topological insulators have attracted great research interest recently. Different from conventional topological insulators, higher-order topological insulators do not necessarily require spin-orbit coupling, which makes it possible to realize them in spinless systems. Here, we study phonons in 2D graphyne family materials. By using first-principle calculations and topology/symmetry analysis, we find that phonons in both graphdiyne and γ -graphyne exhibit a second-order topology, which belongs to the specific case known as real Chern insulator. We identify the nontrivial phononic band gaps, which are characterized by nontrivial real Chern numbers enabled by the spacetime inversion symmetry. The protected phonon corner modes are verified by the calculation on a finite-size nanodisk. In addition, we show that a 3D real Chern insulator state can be realized for phonons in 3D graphdiyne. Our study extends the scope of higher-order topology to phonons in real materials. The spatially localized phonon modes could be useful for novel phononic applications.

T6: Quantum Statistics I

Time: Wednesday 28 Sept, 2:00pm; Venue: LT3; Chair: tbd
Time allocated for keynote/invited talks is 20/15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T6.26 Superfluidity vs thermalisation in a nonlinear Floquet system

Sen Mu*, Nicolas Macé, Jiangbin Gong, Christian Miniatura, Gabriel Lemarié, Mathias Albert
(Department of Physics, National University of Singapore)
2:00pm – 02:15pm

We show that superfluidity can be used to prevent thermalisation in Floquet nonlinear systems. Generically, periodic driving boils a many-body system to a featureless infinite temperature state. Fast driving is a known strategy to postpone Floquet heating with a large but always finite boiling time. In contrast, we show the existence, for a nonlinear quantum kicked rotor, of a continuous class of initial states which do not thermalise at all. This absence of thermalisation is associated to the existence of a superflow in momentum space.

T6.49 Machine learning quantum criticality in the spin-1/2 quantum antiferromagnets on the square lattice with plaquette structure

Tanja Duric* (Nanyang Technological University)
02:15pm – 02:30pm

The power of machine learning algorithms to automatically classify different phases of matter and detect quantum phase transitions without necessity to characterize phases by various quantities like local order parameters or topological invariants as in conventional approaches defined machine learning phases of matter as a new research frontier and basic research tool in condensed matter and statistical physics. We study quantum criticality in the spin-1/2 square-lattice J1-J2 model with additional plaquette structure by combination of reinforcement and supervised machine learning techniques. In our calculations the ground-state spin-spin correlation matrices for several system sizes are first found by restricted Boltzmann machine based variational Monte Carlo method, equivalent to reinforcement learning, and then used as a training data for convolutional neural network based supervised machine learning algorithm for phases classification. The model exhibits a quantum phase transition from paramagnetic plaquette resonating valence bond state to an antiferromagnetic state and has been a topic of great interest because of its close connection to cuprate superconductors and possibility of realization in cold atoms experiments. We consider both frustrated and unfrustrated regimes and compare our results with the results obtained previously with other methods. We find that our results are in good agreement with the results obtained by coupled cluster and real space renormalization group methods for both frustrated and unfrustrated regimes. The quantum Monte Carlo and finite-size scaling result for the unfrustrated case however slightly differs from our result for the critical value of the inter-plaquette coupling strength, although the results are still in reasonable agreement.

T6.63 Reduce the memory resources for generating quantum sampling states

Chengran Yang*, Marta Florida Llinas, Thomas Elliott, Mile Gu* (School of Mathematical and Physical Sciences, Nanyang Technological University)

02:30pm – 02:45pm

Quantum information processing promises computational speed up in analyzing stochastic processes, which underlie a broad range of scientific areas. Most of these quantum algorithms require the preparation of a quantum state (q-sample) superimposed with all possible outcomes of the stochastic process. The preparation of the q-sample requires a certain amount of memory to maintain the correlation between the past and the future of the stochastic processes. Here, we identify a wide range of stochastic processes and demonstrate a significant reduction in the memory of the corresponding quantum model in the preparation of the approximate q-sample. Furthermore, we develop a systematic algorithm to find quantum models with a given amount of memory resource that allows us to prepare accurate q-samples for any stochastic processes. To demonstrate the effectiveness, we apply our algorithm to both Markovian and non-Markovian processes – the future behaviors depend on near/far in the past. We show that the resultant q-samples present high accuracy. Furthermore, the processes obtained by measuring the q-samples in a computational basis are more accurate than processes generated by any classical models of the same memory resource. Thus, our results establish the potential of resource savings in generating accurate q-samples.

T6.21 Game Dynamics and Quantum Bilinear Optimization

Wayne Lin*, Georgios Piliouras, Ryann Sim, Antonios Varvitsiotis (Singapore University of Technology and Design)

02:45pm – 03:00pm

This work focuses on learning dynamics in quantum identical-interest games, where players have density matrices ρ, σ as strategies and share a common bilinear utility function $\mathrm{T}r(R(\rho \otimes \sigma))$. Equivalently, from an optimization standpoint, the players are trying to solve a bilinear optimization problem over the product of density matrices, $\max\{\mathrm{T}r(R(\rho \otimes \sigma)) : \rho, \sigma \succeq 0, \mathrm{Tr}\,\rho = \mathrm{Tr}\,\sigma = 1\}$, known as the Best Separable State (BSS) problem. In this work we introduce the linear matrix multiplicative weights update MMWU_ℓ, a new projection-free update rule for decentralized learning in quantum identical-interest games that only relies on first-order information. In terms of its properties, we show that if the players update their strategies using MMWU_ℓ in a decentralized manner, their utility is strictly increasing (except at fixed points). MMWU_ℓ is obtained as a discretization of the q-quantum replicator dynamics, a continuous-time learning process introduced in this work which generalizes classical q-replicator dynamics to the non-commutative setting. Reinterpreting the BSS problem as a quantum identical-interest game, MMWU_ℓ corresponds to an algorithm for the BSS problem, under which the objective function is strictly increasing (except at fixed points) and interior fixed points are KKT. Experimentally, we find that MMWU_ℓ closely approximates the optimal value ($\approx 0.97\,\mathtt{OPT}$) for small instances of the BSS problem. Lastly, the BSS problem is the mixed extension of an identical-interest game where players choose unit vectors and share a biquadratic utility. Our experiments reveal that, for BSS, the players' states concentrate to rank-1 density matrices, which means that

MMWU_ℓ can be interpreted as a learning algorithm for solving biquadratic optimization over the product of unit spheres $\max\{(x \otimes y)^\dagger R(x \otimes y) : \|x\|_2 = 1, \|y\|_2 = 1\}$.

T6.82 Can Quantum Agents Better Adapt to Complex Environments?

Thomas Elliott, Andrew Garner, Mile Gu*, Jayne Thompson* (Horizon Quantum Computing)
03:00pm – 03:15pm

The world is awash with complex, interacting systems. Predators chasing prey, investors trading stocks, grandmasters playing chess: all share that they process information from their environment and act appropriately in response.

Could the quantum mechanical laws that govern fundamental particles provide a tool to surmount this challenge? Such prospects may first sound surprising. How can a theory designed to model the dynamics at the level of photons and electrons aid in the understanding of systems with no quantum effects?

In this talk, we detail recent work illustrating that quantum-enhanced agents - automated machines capable of processing data quantum mechanically – can better isolate essential data for modelling, adapting, or manipulating complex environments [1]. We demonstrate how this leads to reduced memory resource costs and how this advantage can scale without bound when optimal performance necessitates tracking information about events far into the past. Time permitting, we outline ongoing research in potential applicative and fundamental consequences in analysis of stochastic data and thermally efficient edge computing.

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Note, this talk will primary focus on Phys. Rev. X 12, 011007.

T6.77 "NRF2021-QEP2-02-P05" Multi-armed quantum bandits: Exploration versus exploitation when learning properties of quantum states

Josep Lumbreras*, Erkka Haapasalo*, Marco Tomamichel* (National University of Singapore)
03:15pm – 03:30pm

We initiate the study of tradeoffs between exploration and exploitation in online learning of properties of quantum states. Given sequential oracle access to an unknown quantum state, in each round, we are tasked to choose an observable from a set of actions aiming to maximize its expectation value on the state (the reward). Information gained about the unknown state from previous rounds can be used to gradually improve the choice of action, thus reducing the gap between the reward and the maximal reward attainable with the given action set (the regret). We provide various information-theoretic lower bounds on the cumulative regret that an optimal learner must incur, and show that it scales at least as the square root of the number of rounds played. We also investigate the dependence of the cumulative regret on the number of available actions and the dimension of the underlying space. Moreover, we exhibit strategies that are optimal for bandits with a finite number of arms and general mixed states.

T7: Superconductivity

Time: Wednesday 28 Sept, 2:00pm; Venue: LT4; Chair: tbd
Time allocated for keynote/invited talks is 20/15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T7.87 Superconducting single-photon detectors for the infrared region

Shuyu Dong, Miloš Petrović, Lijiong Shen, Harish Krishnamoorthy, Christian Kurtsiefer, Cesare Soci*, Ming Zhi Koh (Nanyang Technological University)
2:00pm – 02:15pm

Superconducting nanowire single-photon detectors (SNSPDs) and superconducting microbridge single-photon detectors (SMSPDs) are becoming attractive alternatives to conventional counterparts for single-photon sensing at telecom wavelengths. Within the framework of near-infrared single photon detection, SNSPDs are known to outperform the traditional semiconductor-based detectors, particularly in terms of detection efficiency, detection rate, and timing resolution [1]. Similarly, SMSPDs also possess advantages of facile fabrication procedure, short recovery times, and good temporal resolution, allowing prospective integration into photon circuits where a high response rate is desirable [2]. We explore both of these designs using NbTiN as a superconducting material and demonstrate reliable single photon detection at 1550 nm with a timing jitter of 50 ps and reset times below 5 ns. In addition, considering single photon detection closer to the mid-infrared region, which is crucial for a variety of applications, such as biomolecule spectral analysis and astronomy, we are developing SNSPDs based on MoSi, which is an amorphous superconductor. Amorphous materials offer several advantages over polycrystalline superconductors, including a small superconducting energy gap, more homogenous structure, and defect-tolerant fabrication [3]. We have successfully fabricated high-quality amorphous MoSi SNSPDs with a wire width of 40 nm and a fill factor of 30%, paving the way to develop infrared single-photon detectors at 2 μm and beyond.

References [1] Marsili, F., et al., Detecting single infrared photons with 93% system efficiency. Nature Photonics, 2013. 7(3): p. 210-214. [2] Korneeva, Y.P., et al., Optical Single-Photon Detection in Micrometer-Scale NbN Bridges. Physical Review Applied, 2018. 9(6): p. 064037. [3] Reddy, D.V., et al., Superconducting nanowire single-photon detectors with 98% system detection efficiency at 1550 nm. Optica, 2020. 7(12): p. 1649-1653.

T7.2 Pairing and superconductivity in quasi one-dimensional flat band systems

Si Min Chan*, George Batrouni*, Benoît Grémaud* (Aix-Marseille University)
02:15pm – 02:30pm

Flat band systems are ideal in furthering our understanding of the effects of strong correlations and topology in condensed matter. In this study, we focus on the superconducting phase. We analyze theoretically and computationally the validity of the BCS approach in describing superconductivity on topological flat bands and compare the results with exact density matrix renormalisation group (DMRG) computation. We show with the full multiband mean-field decomposition of the Hubbard interaction term, that the superfluid density on the flat band is not necessarily proportional to the quantum metric. The breakdown of the BCS mean field approach is evident for systems with inequivalent sublattices, where the pairing order parameter and sublattice fillings are distinct. Additionally, with several examples, we establish that the full mean-field can qualitatively and quantitatively describe the superconductivity across the entire range of interaction.

[1] S. M. Chan, B. Grémaud, G. G. Batrouni, Physical Review B 105, 024502 (2022)

T7.122 The role of gate screening in superconductivity in twisted bilayer graphene

Liangtao Peng, Shaffique Adam* (Centre for Advanced 2D Materials Singapore; National University of Singapore)

02:30pm – 02:45pm

Since the discovery of superconductivity (SC) in magic-angle twisted bilayer graphene (MATBG), identifying the microspecies mechanism of SC becoming an outstanding open problem. Some recent experimental works show that the gate screening will suppress the insulating phase while SC phase persists, which suggests that those two phases have different origins. Inspired by this, we systemically investigate the dielectric properties of MATBG under gate screening. Furthermore, we apply Eliashberg theory to compute the critical temperature mediated by long-range Coulomb interaction. We show that the gate screening will significantly suppress the plasmon modes and critical temperature in some cases. Finally, the role of gate screening in MATBG and the comparison with experiment works are briefly summarized.

T7.118 Periodic Anderson model in singlet and triplet superconductivity

Shangjian Jin, Shaffique Adam* (National University of Singapore)

02:45pm – 03:00pm

Recently, our collaborative partners found that cobalt doped $NbSe_2$ (Co-$NbSe_2$) exhibits a Kondo effect below superconducting critical temperature Tc. This Kondo effect is suppressed by magnetic field, indicating a spin-triplet order parameter in Co-$NbSe_2$. Unlike the common superconductors, the microscopic mechanisms of competition between the Kondo effect and triplet superconductivity remain unclear. It is well known that magnetic field enhances the pair-breaking action in singlet superconductors and leads to a drastic suppression of transition temperature. However, magnetic field may have almost no impact on triplet superconductors since one of the three triplet states would be preserved. We build a periodic impurity Anderson model to study the Kondo effect in singlet and triplet superconductors. By applying the Bardeen–Cooper–Schrieffer (BCS) weak coupling assumption and Green's function approach, we solve the gap equations and obtain the pair-breaking equations for singlet and triplet superconductors. Both singlet and triplet pair-breaking equations give three transition temperatures at certain doping concentration. As temperature is lowered, the system goes into the SC phase at the first transition temperature, T_{c1}, before entering a Kondo region with finite resistance at the second transition temperature, T_K, and finally achieving zero resistance again at the third transition temperature, T_{c2}. However, singlet and triplet SC behave differently under magnetic field. As expected, singlet SC is suppressed by magnetic field while triplet SC is almost unaffected by field. Since the resistance upturn of Kondo effect relies on spin-flip processes, the magnetic field suppresses two of the three triplet states and thus reduces the spin-flip scattering events. Therefore, the magnetic field would suppress the Kondo effect drastically only in the triplet case. Our theoretical results fit the Co doped $NbSe_2$ very well, indicating that ferromagnetic order impurity induces spin-triplet order parameter in Co-$NbSe_2$. Such unusual properties in triplet superconductors allow potential applications in superconducting spintronics.

T8: Quantum Optics

Time: Wednesday 28 Sept, 2:00pm; Venue: LT5; Chair: tbd
Time allocated for keynote/invited talks is 20/15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T8.67 (INVITED) Scaling up of Rb triangular arrays for quantum simulation (NRF2021-QEP2-02-P09)

An Qu*, Weikun Tian, Wen Jun Wee, Billy Jun Ming Lim, Vanessa Pei Wen Koh, Prithvi Raj Datla, Huanqian Loh* (Centre ofr Quantum Technologies, National University of Singapore)
2:00pm – 02:20pm

Rydberg atom arrays are a promising platform for the quantum simulation of quantum many-body physics. We present our first step in building a Rydberg atom array quantum simulator: a 2D triangular tweezer array with hundreds of singly trapped rubidium atoms. Since the array is generated by one pair of acousto-optic deflectors (AODs) oriented at 60 degrees, the Talbot effect is suppressed, allowing the atoms to be confined in a single plane. Further, by applying D1 gray molasses cooling to the tweezer array, we can reach stochastic loading probabilities as high as 77% in a 20-by-20 backbone array. The deterministic preparation of defect-free arrays is implemented by another pair of AODs. Our platform provides a scalable approach for generating large triangular atom arrays and paves the way for quantum simulators with frustrated geometries.

T8.138 (INVITED) Autoheterodyne Characterisation of Narrow-Band Photon Pairs

Vindhiya Prakash*, Aleksandra Sierant, Morgan W. Mitchell (ICFO-Institut de Ciencies Fotoniques)
02:20pm – 02:40pm

Narrow-band photon pairs with $\approx$MHz bandwidths are important for applications in quantum information where material systems such as atoms or ions serve as storage or processing units [1,2]. Applications in quantum networking, e.g. entanglement-swapping with memory-compatible photons, require pure, indistinguishable, narrow-band photons. Exploring this physics motivates non-classical light sources in which both photons are resonant and matched in bandwidth to an atomic transition. Cavity-Enhanced Spontaneous Parametric Downconversion (CE-SPDC) has proven to be a reliable technique to generate bright and narrow-band photons for interaction with matter [3]. The frequency correlations of SPDC photon pairs are revealed through analysis of the photon-pair joint spectral amplitude (JSA) or intensity (JSI). While are several techniques to characterise the JSI of broadband SPDC photons such as using monochromators/ passive filters or interference based methods [4,5]. However, so far, the only technique to characterise the JSI of narrow-band photons has been stimulated parametric down-conversion [6], in which laser photons are used to seed the downconversion and map the difference frequencies generated vs those suppressed. This requires an additional well-characterized laser source and careful matching of spatial modes. Here we present a simpler and more efficient alternative, a technique to resolve narrow frequency differences between photons with a high frequency resolution [7]. The technique, which we call autoheterodyne characterisation (AHC), can measure the photon-pair joint spectra by detecting the time-correlation beat note when non-degenerate photon pairs interfere at a beamsplitter. It implements a temporal analog of the Ghosh-Mandel [8] (GM) effect with one photon counter and a time-resolved Hong-Ou-Mandel (HOM) [5] interference with two. We analyse the application of this technique to photon pairs that are produced by narrow-band pumping and are strongly anti-correlated in frequency, and to pairs with reduced frequency correlations produced by broadband pumping.

Following the theoretical overview, we present experimental results from applying AHC to narrow-band photons pairs matched in frequency and linewidth to the D1 line in atomic Rubidium. We briefly introduce a filtered CE-SPDC source for narrow-band single frequency-mode photons-pairs where the frequency of each photon in the pair can be tuned independently with MHz precision [3]. The photons from this source are separated in frequency to values $\approx$200 MHz and the AHC is applied to accurately measure the frequency difference. From the results, we quantify the performance of our photon-pair source and verify the accuracy of our model for the two-photon joint spectra from this source. The talk comprises of results reported in [7].

References [1] E. Distante, P. Farrera, A. Padrón-Brito, D. Paredes-Barato, G. Heinze and H. de Riedmatten, “Storing single photons emitted by a quantum memory on a highly excited Rydberg state,” Nature Communications, vol. 8, p. 14072, 2017. [2] A. Asenjo-Garcia, M. Moreno-Cardoner, A. Albrecht, H. J. Kimble and D. E. Chang, “Exponential Improvement in Photon Storage Fidelities Using Subradiance and “Selective Radiance” in Atomic Arrays,” Phys. Rev. X, vol. 7, no. 3, p. 031024, August 2017. [3] V. Prakash, L. C. Bianchet, M. T. Cuairan, P. Gomez, N. Bruno and M. W. Mitchell, “Narrowband photon pairs with independent frequency tuning for quantum light-matter interactions,” Opt. Express, vol. 27, p. 38463–38478, December 2019. [4] K. Zielnicki, K. Garay-Palmett, D. Cruz-Delgado, H. Cruz-Ramirez, M. F. O’Boyle, B. Fang, V. O. Lorenz, A. B. U’Ren and P. G. Kwiat, “Joint spectral characterization of photon-pair sources,” Journal of Modern Optics, vol. 65, pp. 1141-1160, 2018. [5] C. K. Hong, Z. Y. Ou and L. Mandel, “Measurement of subpicosecond time intervals between two photons by interference,” Phys. Rev. Lett., vol. 59, no. 18, p. 2044–2046, November 1987. [6] I. Jizan, B. Bell, L. G. Helt, A. C. Bedoya, C. Xiong and B. J. Eggleton, “Phase-sensitive tomography of the joint spectral amplitude of photon pair sources,” Opt. Lett., vol. 41, p. 4803–4806, October 2016. [7] V. Prakash, A. Sierant and M. W. Mitchell, “Autoheterodyne Characterization of Narrow-Band Photon Pairs,” Phys. Rev. Lett., vol. 127, no. 4, p. 043601, July 2021. [8] R. Ghosh and L. Mandel, “Observation of nonclassical effects in the interference of two photons,” Phys. Rev. Lett., vol. 59, no. 17, p. 1903–1905, October 1987.

T8.46 Observation of Mollow Triplet from optically confined single atom

Boon Long Ng*, Chang Hoong Chow, Christian Kurtsiefer (CQT)
02:40pm – 02:55pm

Resonance fluorescence spectrum of a two-level system consists of a single peak that evolves into a triplet structure, known as Mollow triplet, when it is driven by a radiation field above its saturation intensity. Particularly, photons originating from different peaks of the triplet show distinct photon correlations, which allows the fluorescence to be engineered as a useful light source for quantum information processing purposes. We experimentally study the fluorescence spectrum of an optically trapped single Rb-87 atom by exciting a closed two-level transition with a near-resonant laser at different powers. The second-order intensity correlation measurement demonstrates the photon anti-bunching characteristic from a single atom emission as well as the Rabi oscillation of the atom. We also measured the cross correlation between photons coming from the two opposite sidebands of the fluorescence spectrum when an off-resonant field is applied to the atom. The asymmetry in the timing correlation clearly indicates that there is a preferred time-ordering for the photon emission process in the two sidebands. The cascaded generation of time-correlated fluorescence photons with a tunable frequency difference will be useful for quantum optics experiments and quantum communication protocols.

T8.86 Superconducting nanowire single photon detectors integrated on etchless polymer waveguides

Filippo Martinelli*, Harish Krishnamoorthy, Anton Vetlugin, Milos Petrovic, Cesare Soci (NTU)

02:55pm – 03:10pm

We integrated a superconducting nanowire single photon detector on etchless polymer waveguides based on a bound states in the continuum. Such detector shows absorption efficiency comparable to standard integration approaches. Recently, SNSPDs gained interests as a primary choice for realizing fast and efficient on-chip detection schemes for integrated quantum photonic circuits [1]. The integration workflow used nowadays is undermined by fabrication challenges and scattering losses around the nanowire contacts [2]. Our approach promises to mitigate these issues by avoiding etching the guiding medium. The light confinement is achieved in the form of a bound-state-in-the-continuum (BIC) [3]. We designed and fabricated polymer waveguides on a silicon-on-insulator substrate. The nanowire detector is placed at the interface between the polymer and the substrate to ensure maximum absorption efficiency by maximizing the overlap with the guided mode. This integration configuration represents an important proof-of-concept that sets the way towards facile integration of SNSPDs on unconventional substrates.

1. Ferrari, S., C. Schuck, and W. Pernice, Waveguide-integrated superconducting nanowire single-photon detectors. Nanophotonics, 2018. 7(11): p. 1725-1758. 2. Vetter, A., et al., Cavity-Enhanced and Ultrafast Superconducting Single-Photon Detectors. Nano Lett, 2016. 16(11): p. 7085-7092. 3. Yu, Z., et al., Photonic integrated circuits with bound states in the continuum. Optica, 2019. 6(10).

T8.30 Quantum interferometry for broadband infrared sensing

Anna Paterova*, Zi Siang Desmond Toa, Hongzhi Yang, Leonid Krivitsky* (Institute of Material Research and Engineering, A*STAR)

03:10pm – 03:25pm

Infrared (IR) wavelengths is a range of big importance, since many molecules present their fingerprint absorption properties at this region. A promising method for the IR spectroscopy is using an induced coherence phenomenon [1-4], which allows inferring IR properties of a specimen from the detection of visible light. However, the short optical path of the IR light through the medium under study is one of the limitations of previous IR spectroscopy schemes

[3, 4]. Here, we introduce a modified configuration of a common path nonlinear interferometer for a broadband IR spectroscopy, where the optical path of the IR light through the medium is increased. We introduce the parabolic mirror into the interferometer, which allows compensating for the transverse phases acquired by spontaneous parametric down converted (SPDC) light generated at the forward pass of the pump beam through the nonlinear crystal. Therefore, the interference pattern is observed across the whole spectrum of the SPDC light.

References: [1] X. Y. Zou et al, Physical Review Letters 67, 318-321 (1991) [2] G. B. Lemos et al, Nature 512, 409-412 (2014) [3] D. A. Kalashnikov et al, Nature Photonics 10, 98-101 (2016) [4] C. Lindner et al, Optics Express 29(3), 4035-4047 (2021) [5] A. V. Paterova et al, ACS Photonics 9(6), 2151–2159 (2022)

T9: 2D Materials II

Time: Wednesday 28 Sept, 4:00pm; Venue: LT2; Chair: tbd
Time allocated for keynote/invited talks is 20/15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T9.31 Realizing topological states on a quantum computer

Ching Hua Lee* (National University of Singapore)
4:00pm – 04:15pm

The ascendency of quantum computing technologies, particularly cloud quantum computing, has made the physical realization of various elusive quantum Hamiltonians possible. In this talk, I shall discuss recent realizations of various topological states with the IBM quantum computer, including but not limited to the Kitaev chain, Chern states and higher-order topological states. To circumvent the limited qubit numbers of present-day NISQ devices, higher-dimensional non-interacting lattices are mapped onto a 1D interacting chain. This technique takes advantage of the quantum many-body nature of the quantum hardware in realizing higher-dimensional states of unprecedented complexity.

T9.61 Topological memory in nonlinear driven-dissipative photonic lattices

Subhaskar Mandal*, Gui-Geng Liu, Baile Zhang* (Nanyang Technilogical University, Singapore)
04:15pm – 04:30pm

We theoretically propose a topological memory in a photonic lattice of nonlinear lossy resonators subjected to a coherent drive, where the system remembers its topological phase. Initially, the system is topologically trivial. After the application of an additional coherent pulse, the intensity is increased, which modifies the couplings in the system and then induce a topological phase transition. However, when the effect of the pulse dies out, the system does not go back to the trivial phase. Instead, it remembers the topological phase and maintains its topology acquired during the pulse application. We further show how the pulse can be used as a switch to trigger amplification of the topological modes. Our work can be useful in triggering the different functionalities of the active topological photonic devices as well as in storing information with topological protection.

T9.24 Encyclopedia of emergent particles in three-dimension magnetic crystals

Zeying Zhang*, Gui-Bin Liu, Zhi-Ming Yu, Shengyuan A. Yang, Yugui Yao (Singapore University of Technology and Design (SUTD))
04:30pm – 04:45pm

The research on emergent particles in condensed matters has been attracting tremendous interest, and recently it is extended to magnetic systems. Here, we study the emergent particles stabilized by the symmetries of type-III and IV magnetic space groups (MSGs) based on our classification of emergent particles in 230 gray space groups [Yu et al., Sci. Bull. 67, 375 (2022)]. We present a complete classification of emergent particles in type-III and IV magnetic space groups by studying all possible (spinless and spinful, essential and accidental) particles in each MSGs. Particularly, the detailed correspondence between the emergent particles and the MSGs that can host them are given in easily accessed interactive tables, where the basic information of the emergent particles, including the symmetry conditions, the effective Hamiltonian, the band dispersion, and the topological characters, can be found. Our work not only deepens the understanding of the symmetry conditions for realizing emergent particles but also provides specific guidance for searching and designing materials with target particles.

T9.18 Eightfold periodic symmetry algebras and induced topological phases from T -invariant gauge fluxes

Yue-Xin Huang*, Xiaolong Feng, Y. X. Zhao*, Shengyuan Yang* (Singapore University of Technology and Design)

04:45pm – 05:00pm

Real Clifford algebras play a fundamental role in the eight real Altland-Zirnbauer symmetry classes and the classification tables of topological phases. Here, we present another elegant realization of real Clifford algebras in the d-dimensional spinless rectangular lattices with π flux per plaquette. Due to the T -invariant flux configuration, real Clifford algebras are realized as projective symmetry algebras of lattice symmetries. Remarkably, d mod 8 exactly corresponds to the eight Morita equivalence classes of real Clifford algebras with eightfold Bott periodicity, resembling the eight real Altland-Zirnbauer classes. The representation theory of Clifford algebras determines the degree of degeneracy of band structures, both at generic k points and at high-symmetry points of the Brillouin zone. Particularly, we demonstrate that the large degeneracy at high-symmetry points offers a rich resource for forming novel topological states by various dimerization patterns, including a 3D higher-order semimetal state with double-charged bulk nodal loops and hinge modes, a 4D nodal surface semimetal with 3D surface solid-ball zero modes, and 4D Möbius topological insulators with a eightfold surface nodal point or a fourfold surface nodal ring. Our theory can be experimentally realized in artificial crystals by their engineerable Z 2 gauge fields and capability to simulate higher dimensional systems.

T9.52 Using Neural Networks to Draw Insight on Different Topological G4 Sequences

Liew Hou Feng Donn*, Yong Ee Hou (Nanyang Technological University)

05:00pm – 05:15pm

G-Quadruplexes (G4) are non-canonical secondary structures of nucleic acids formed in guanine-rich sequences. In vivo, G4s form in genomic regions (e.g. telomeres, promoters) known to perform regulatory functions. G4s are known to mediate critical biological functions such as deoxyribonucleic acid (DNA) replication, DNA transcription, messenger RNA (mRNA) translation, telomere maintenance, and epigenetic modification. Due to the many biological functions involving G4s, G4s have become promising drug targets in antisense-therapy. Although efforts have been made to identify G4s in human genomes, minimal research has been done to predict G4 variations from sequences. We compile a list of known G4 structures (categorised via topological features) and attempt to draw insight using deep learning methods. We present three key findings: 1. sequence motifs that predict G4 topological features; 2. correlation of nucleotide proportions and various G4 topological features; 3. an observed correlation between sequence permutations and different G4 topologies.

T10: Photonics and Plasmonics

Time: Wednesday 28 Sept, 4:00pm; Venue: LT3; Chair: tbd
Time allocated for keynote/invited talks is 20/15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T10.143 (INVITED) Rich Physics of Collective Mie Resonances

Thanh Xuan Hoang*, Thanh Xuan Hoang, Thanh Xuan Hoang (A*STAR)
4:00pm – 04:20pm

Mathematically, the sum of the infinite series $\sum_{n=1}^{\infty} 1/n$ diverges to infinity despite the fact that the additive term 1/n converges to zero when n increases to infinity. On contrary, the sum of $\sum_{n=1}^{\infty} 1/(n(n+1))$ converges to one when n increases to infinity. In mathematical modelling of electromagnetic scattering problems, sums of infinite series appear ubiquitously, especially in the theory of multiple resonant scattering. In this presentation, based on exact analytical solutions to the Maxwell equations that govern the electromagnetic scattering by a cluster of spherical particles, we interpret different electromagnetic scattering phenomena by close analogies with the above two diverging and converging sums. For single spherical particles, the stationary scattering phenomenon can be accounted for by the Mie scattering coefficients but one must invoke infinite Debye series to account for the dynamics of the scattering phenomenon. We show that the sum of the infinite Debye series converges to the corresponding Mie scattering coefficient. For a cluster of spherical particles, we show that the collective behavior of the cluster would result in an infinite series of scattering events corresponding to a mathematical sum diverging to infinity when the number of particle increases to infinity. This collective response of the particle cluster results in collective Mie resonances. In the framework of these collective resonances, we present design concepts for photonic and plasmonic high-performance nanocavities, including gap modes, collective Mie resonances, Feshbach-type BIC modes, photonic-crystal flat bands.

References [1] T. X. Hoang, et al., "Collective Mie Resonances for Directional On-Chip Nanolasers," Nano Lett. 20 5655-5661 (2020). [2] T. X. Hoang, et al., "High-Performance Dielectric Nano-cavities for Near- and Mid-infrared Frequency Applications," J. Opt. 24 094006 (2022).

T10.102 Oscillating bound states in non-Markovian photonic lattices

Kian Hwee Lim*, Wai-Keong Mok, Leong Chuan Kwek (NUS Centre for Quantum Technologies)
04:20pm – 04:35pm

It is known that the superposition of two bound states in the continuum (BIC) leads to the phenomenon of an oscillating bound state, where excitations mediated by the continuum modes oscillate persistently. We show the existence of oscillating BIC in a 1D photonic lattice by coupling it at multiple points with a "giant atom". We provide novel conditions for oscillating BIC which are distinct from those previously found in continuous waveguide systems. We also show that non-Markovianity is necessary for the existence of oscillating BIC. Crucially, the amplitude of the BIC increases with the characteristic delay time of the giant atom interactions. Our work can be experimentally implemented on current photonic waveguide array platforms and opens up new prospects in utilizing reservoir engineering for the storage of quantum information in photonic lattices.

T10.76 Non-Hermitian Squeezed Polarons

Fang Qin*, Ruizhe Shen*, Ching Hua Lee* (Department of Physics in National University of Singapore)

04:35pm – 04:50pm

Recent experimental breakthroughs in non-Hermitian ultracold atomic lattices have dangled tantalizing prospects in realizing exotic, hitherto unreported many-body non-Hermitian quantum phenomena. In this work, we discover and propose an experimental platform for a radically new non-Hermitian phenomenon dubbed polaron squeezing. It is marked by a dipole-like accumulation of fermions arising from an interacting impurity in a background of non-Hermitian reciprocity-breaking hoppings. Unlike Hermitian polarons which are symmetrically localized around impurities, non-Hermitian squeezed polarons localize asymmetrically in the direction opposite to conventional non-Hermitian pumping, and non-perturbatively modify the entire spectrum, despite having a manifestly local profile. Also, unlike well-known topological or skin localized states, squeezed polarons exist in the bulk, independently of boundary conditions. We base our calculations on a proposed ultracold atomic setup where a squeezed polaron can be readily detected and characterized by imaging the spatial fermionic density.

T10.12 Cavity spectral-hole-burning to suppress decoherence in plexcitonic systems

Wenjie Zhou*, Jiabin You, Xiao Xiong, Yuwei Lu, Lay Kee Ang, Jingfeng Liu, Lin Wu (Singapore University of Technology and Design)

04:50pm – 05:05pm

Plexciton, coherently coupled plasmon and exciton, brings strong light-matter interaction to room temperature, thus opening up the possibility for quantum manipulation at single-QE limit under ambient conditions. However, plexcitonic system suffers from its inherent losses, which severely induce decoherence and limit quantum operation time. Inspired by the concept of spectral-hole-burning (SHB) for frequency-selective bleaching of the emitter ensemble, we propose “cavity SHB” by introducing cavity modes with moderate quality factors to the plexcitonic system to boost its coherence. We show that the detuning of the introduced cavity mode deviated from the original plexcitonic system, which defines the location of the cavity SHB, is the most critical parameter. Based on the eigenvalues of the system Hamiltonian, we find a general guideline for the selections of resonant energies and coupling rates of the introduced microcavity modes. For instance, simultaneously introducing two cavity modes of opposite detunings, the excited-state population of the emitter can be enhanced by 4.5 orders of magnitude within 300 fs, and the attenuation of the emitter’s population can be slowed down by about 56 times. This theoretical proposal provides a new approach for cavity engineering to enhance the plasmon-emitter strong coupling systems’ coherence, which is important for realistic hybrid-cavity design for applications in quantum technology.

T10.103 Quantum metric plasmons: The role of quantum geometry in intrinsic bulk non-reciprocal plasmonics

Arpit Arora*, Mark Rudner*, Justin Song* (Nanyang Technological University and Institute of High Performance Computing)

05:05pm – 05:20pm

Wavefunction engineering holds immense potential to reveal new possibilities in light-matter interaction. Here, we unveil one such possibility by illustrating a new class of plasmons – quantum metric plasmons (QMPs), in strongly interacting Fermi liquids. QMPs are intrinsically non-reciprocal, i.e., $\omega(q) \neq \omega(-q)$, in the bulk. This is in contrast to currently available schemes utilizing out of equilibrium driving or magnetohydrodynamics for non-reciprocal plasmonic responses. We show that QMPs are passively generated by bulk directional currents in presence of broken parity and time reversal symmetries. Interestingly, we find that QMPs can even thrive in symmetric bands by responding to the symmetry breaking order captured in wavefunction texture. We anticipate that QMPs can be realized in readily available parity-violating magnets, especially in moiré heterostructures where the quantum geometric responses are pronounced (e.g., twisted bilayer graphene heterostructures).

T11: Quantum Statistics II

Time: Wednesday 28 Sept, 4:00pm; Venue: LT4; Chair: tbd
Time allocated for keynote/invited talks is 20/15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T11.37 (INVITED) Emergence in out of equilibrium systems: handling complexity via the full Boltzmann equation

Marco Battiato* (Nanyang Technological University)
4:00pm – 04:20pm

Emergence is the phenomenon by which a system with many heterogeneous degrees of freedom develops behaviours that are qualitatively different from its simpler parts. A famous example is life. Describing and predicting emergence requires handling the system in its full complexity: if simplified, or if degrees of freedom are removed, entire behaviours will simply not happen.

Femtosecond laser pulse-generated out-of-equilibrium states of materials are a very fertile ground for emergence, as being away from the rather strict requirements of equilibrium or near equilibrium conditions frees up a large number of degrees of freedom. Spectacular examples of emergence in these cases are, among others, the superdiffusive spin transport, [1-4] spintronic THz emitters [4] and the giant spin injection in semiconductors. [5,6]

Such effects are the results of the complex interplay of the far-from-equilibrium state of the system, spin-, band- and momentum-dependent thermalisation, transport of excited quasiparticles and interaction with electromagnetic fields. To address the cull complexity of the situation without losing the emergent behaviours, one has to move beyond usual treatments.

We have developed the, so far, only available numerical algorithm to solve the full Boltzmann transport and scattering equation for realistic band structures, and, for the first time, no close to equilibrium approximation. [7] We will show how this allows us unprecedented insights in THz emission of carbon nanotubes [8] as well as their time resolved spectra, [9] and unconventional thermalisation pathways in GeTe. [10]

[1] M. Battiato, K. Carva, P.M. Oppeneer, Phys Rev. Lett. 105, 027203 (2010). [2] D. Rudolf*, C. La-O-Vorakiat*, M. Battiato* et al., Nature Comm. 3, 1037 (2012). [3] A. Eschenlohr,* M. Battiato,* et al., Nature Mater. 12, 332 (2013). [4] T. Kampfrath, M. Battiato, et al, Nature Nanotechnol. 8, 256 (2013). [5] M. Battiato and K. Held, Phys Rev. Lett. 116, 196601 (2016). [6] L. Cheng et al., Nature Physics (2019). [7] M. Wais, K. Held, M. Battiato, Comput. Phys. Commun. 264, 107877 (2021). [8] F. R. Bagsican, et al, Nano Letters 20, 3098 (2020). [9] S. Dal Forno, et al, Carbon 186, 465 (2022). [10] O. J Clark, et al, Advanced Materials (2022)

T11.53 Optimal Encoding of Classical Information on Passive Linear Thermal Operations

Andrew Tanggara*, Syed Assad, Ranjith Nair, Varun Narasimhachar, Spyros Tserkis, Jayne Thompson, Ping Koy Lam, Mile Gu (Centre for Quantum Technologies)

04:20pm – 04:35pm

We study the amount of classical information that can be reliably transmitted over a practically-motivated family of quantum channels called the thermal channels, which mixes its input quantum system with the environment followed by a phase shift, hence requiring no external energy source. Given an input quantum state with finite energy and a certain environment temperature, we maximize the Holevo information of the thermal channel, to quantify its capacity, over encoding procedures that distribute the channel's mixing and phase-shift parameters. We show that the maximum Holevo information can be achieved by a class of encodings that uniformly distributes the channel's phase-shift parameter. Moreover for some families of input quantum states, any maximizing encoding necessarily and sufficiently has a support over the channel mixing parameter with finite cardinality, forming a finite number of rings around the origin in the phase space. Other properties pertaining to its information capacity given different families of input states, environment temperature, and energy constraints are investigated analytically and numerically.

T11.28 Qubit from the classical collision entropy

Kelvin Onggadinata*, Pawel Kurzynski, Dagomir Kaszlikowski* (National University of Singapore)

04:35pm – 04:50pm

A central problem in quantum foundations is to derive quantum theory from a simple and physically motivated principles. The standard formalism, one that is built upon the complex Hilbert space formalism, consists of axioms that are incredibly ad-hoc and unintuitive. A desire for a more intuitive set of postulates arises in the hope that a simple and minimal formulation is sufficient for the construction of quantum theories. In this work, we propose a simple information-theoretic postulate where we look for a generalized dynamics in which certain Renyi entropies remain invariant for any given state. We find that the classical collision entropy is conserved under this and by demanding continuity of dynamical evolution, we can recover the full qubit system and its quantum dynamics. Therefore, constructing the basic elements of quantum theories without invoking Hilbert space at all.

T11.39 Non-Hermitian solitons in coupled rock-paper-scissors cycles & Volterra lattices

Russell Yang*, Ching Hua Lee* (National University of Singapore)

04:50pm – 05:05pm

Non-hermitian physics encompasses a large class of phenomena with exciting yet disparate applications in seemingly unrelated fields such as cold atoms, photonics, metamaterials and electrical circuits. Here, we find yet another application of non-Hermitian dynamics in the context of non-linear systems. Specifically, we found a manifestation of the non-Hermitian phenomena

in the non-Hermitian Lotka-Volterra Equation (NLVE) which described, for example, predator-prey interactions and the dynamics of rock-paper-scissors (RPS) cycles. On a one-dimensional RPS chain the presence of solitons are observed and we explain how non-Hermiticity affects their evolution. In addition we also show that the minimal condition for the existence of such solitons lies in the special case of NLVE known as a non-Hermitian Volterra Lattice.

T11.108 Engines for predictive work extraction from memoryful quantum stochastic processes

Ruo Cheng Huang*, Paul Riechers*, Varun Narasimhachar* (Nanyang Technological University)
05:05pm – 05:20pm

Quantum information-processing techniques enable work extraction from a system's inherently quantum features, in addition to the classical free energy it contains. Meanwhile, the science of computational mechanics affords tools for the predictive modelling of non-Markovian classical and quantum stochastic processes. We combine tools from these two sciences to develop a theoretical prototype for a predictive quantum engine: a machine that charges a battery by feeding on a multipartite quantum system whose parts are temporally correlated via a classical stochastic process. In other words, the engine's fuel is a classical stochastic process with quantum outputs. We also test the engine on simple models to benchmark the performance of our engine against various alternatives, including one without coherent quantum information-processing and one without predictive functionality; our predictive quantum engine is shown to outperform these alternatives in terms of work output. Finally, we evaluate the engine's performance on fuel processes with different degrees of temporal correlations and find the work yield to increase with such correlations. Additionally, our results suggest that there exists a phase boundary in parameter space where memory of past observations can enhance the work extraction. Our work opens the prospect of machines that harness environmental free energy in an essentially quantum, essentially time-varying form.

T11.50 Classification of quantum correlations in spacetime

Minjeong Song*, Varun Narasimhachar, Thomas Elliott, Bartosz Regula, Mile Gu* (Nanyang Technological University)
05:20pm – 05:35pm

The conventional representation of multipartite statistics in quantum information theory is through density operators, which implicitly treat the constituent subsystems as distinct degrees of freedom sharing the same temporal coordinate. But the pseudodensity operator (PDO) representation generalizes this to admit causal structures with subsystems associated with the same degrees of freedom at distinct time instants. Characterizing the set of possible PDO's and classifying their associated causal structures are still open problems, even in the bipartite case. Here we tackle these problems for two-qubit PDO's. We define the class $\mathcal{T}$ of PDO's compatible with a temporally distributed causal structure, and study its relation to the set $\mathcal{S}$ of density operators. We define an efficiently computable witness ("atemporality witness") for non-membership in $\mathcal{T}$. While all separable density operators are expected to be in $\mathcal{T}$, we find, somewhat surprisingly, that some entangled density operators are also in this class. Thus, within $\mathcal{S}$ atemporality seems to be a form of correlation stronger than entanglement, although a high enough presence of entanglement does appear to indicate atemporality.

T12: Single Photons

Time: Wednesday 28 Sept, 4:00pm; Venue: LT5; Chair: tbd
Time allocated for keynote/invited talks is 20/15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T12.55 Single-photon entangled states for quantum-optimal target detection

Guo Yao Tham* (Nanyang Technological University)
4:00pm – 04:15pm

Quantum-enhanced target detection provides enhanced detection performance under the consideration of signal energy constraints. Several possible applications include covert radar sensing and probing of sensitive targets. In this research, we compare the performances of three different probe states: Coherent State, Two-Mode Squeezed Vacuum (TMSV), and Single-Photon Entangled State (SPES). The former two states have been thoroughly investigated in multiple literatures. For a given total signal strength NS, coherent state has been determined to be the best classical probe state for target detection, while the TMSV performance exceeds the coherent state in probing target of small reflectivity $\eta \ll 1$ immersed in a bright thermal background of per-mode energy $NB \gg 1$ using per-mode signal strength $NS = NMS \ll 1$. SPES provides new insight to target detection as it remains non-classical after passing through a lossy attenuator operation. Furthermore, the ease of generating SPES using a single-photon source and a highly imbalanced beam-splitter makes it an extremely feasible physical probe. We characterise the performance of these states using the bound of error exponent, calculated from the fidelity and Bhattacharya bound between the receiver's state of the two Hypotheses (H0 : Object Absent, H1 : Object Present). The calculations involving coherent state and TMSV are performed in Continuous Variable regime, while SPES utilises truncated Discrete State calculations. Our numerical results show that for small NS, the error exponents bound of TMSV converges with that of the SPES, implying that for small signal energy, the performance of target detection using SPES is just as good as TMSV. Furthermore, for $NS \leq 0 : 47$, SPES provides a more accurate measurement as compared to using the best classical state, the coherent state. An analytical expression of the ultimate upper bound of the error exponent is also derived, with a comparison made to the three probe states. For low signal energy, both the TMSV and SPES converge towards the ultimate upper bound.

T12.62 Color-Tunable Single Photon Emission from Mixed-Cation Perovskite Quantum Dots

Qi Ying Tan, Marianna D'Amato, Quentin Glorieux, Alberto Bramati*, Cesare Soci* (Nanyang Technological University)
04:15pm – 04:30pm

The recent development of single photon emitters has demonstrated an exceptional route in achieving highly photo-stable, coherent solid-state photonic devices for applications in quantum information processing. Notable, color-tunability of these single photon emitters is a highly sought feature for wavelength division multiplexing. To date, conventional single photon emitters relied heavily on external perturbations such as strain, electric, and magnetic fields. These techniques, however, limits scalability and yields small spectral shift despite the application of strong strain and fields. In this work, we adopt a chemical approach to synthesize a family of mixed-cation lead halide perovskite ($Cs_{1-x}FA_xPbBr_3$) quantum dots which demonstrate highly compositionally tunable single photon emission at room temperature. By tailoring the stoichiometry of the Cs and FA cations, we are able to achieve fine-tuning of the emission wavelength across more than 30 nm in the visible while retaining excellent single photon emission characteristics. The relatively wider spectral tunability of these mixed-cation lead halide perovskite quantum dot single photon emitters, independent of any external perturbations, could potentially offer a new platform for the realization of color-tunable single photon emitters that could be integrated into a diversity of quantum photonic applications.

T12.109 Visible-light integrated PIN avalanche photodetectors

Victor Leong*, Karthik Shreekumar*, Thomas Ang, Salih Yanikgonul, Ching Eng Png (Institute of Materials Research and Engineering, A*STAR)
04:30pm – 04:45pm

Integrated photodetectors are key building blocks of scalable photonics platforms. Focusing on visible-light operation, we have been developing CMOS-compatible integrated avalanche photodetectors (APDs) which are monolithically integrated with a silicon nitride photonics circuit via end-fire coupling. Here, we extend our work with an in-depth study of multiple PIN doping profiles for the silicon devices, and find different optimal designs based on the desired operating regimes. At -49 dBm input power, they show 0.25 A/W (0.8 A/W) responsivity at reverse bias as low as 0.5 V (5.5 V), with corresponding dark current of $<$3 pA (50 pA). We also report fast RF response with an optimal 3 dB bandwidth of 11 GHz and gain-bandwidth product of 142 GHz, with all devices yielding open eye diagrams at 25 Gbps or above. These results are an important milestone towards achieving single-photon sensitivity, which will enable scalable photonics applications requiring photon counting in the fields of sensing, communications, and quantum technologies at visible wavelengths.

T13: Strongly Correlated Systems I

Time: Thursday 29 Sept, 9:00am; Venue: LT2; Chair: tbd
Time allocated for keynote/invited talks is 20/15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T13.115 Dirty bosons on the Cayley tree: Bose-Einstein condensation versus ergodicity breaking

Gabriel Lemarié* (MajuLab, CNRS; CQT and Phys. Dept., NUS)
9:00am – 09:15am

M. Dupont, A. Chakrabarti, N. Laflorencie, C. Martin, A. Berger, B. Georgeot, E. Brunet, and G. Lemarié

The study of disorder-induced localization in graphs of infinite effective dimensionality has attracted strong interest recently, due to the emergence of non-ergodic properties and the analogy with the many-body localization problem. Here, we consider the competition between interactions and disorder for hard-core bosons on the finite Cayley tree, using two methods: a quantum Monte Carlo (QMC) approach and the cavity method. With QMC, we characterize a phase transition between an ergodic Bose-Einstein condensation, and a non-ergodic Bose-glass [1]. With the cavity method, we describe its critical and non-ergodic properties [2].

[1] Dirty bosons on the Cayley tree: Bose-Einstein condensation versus ergodicity breaking, M. Dupont, N. Laflorencie, and G. Lemarié, Phys. Rev. B 102, 174205 (2020). [2] Traveling – non-traveling phase transition in the random field Ising model on the Cayley tree, A. Chakrabarti, C. Martin, N. Laflorencie, A. Berger, B. Georgeot, E. Brunet, and G. Lemarié, to be submitted (2022).

T13.106 A new approach to the quantum many-body problem: Single-particle-exact density functionals

Martin-Isbjoern Trappe*, Jun Hao Hue, Jonah Zi Chao Huang, Mikolaj Paraniak, Berge Englert (Centre for Quantum Technologies)
09:15am – 09:30am

In our density functional approach to the quantum many-body problem, all single-particle contributions to the energy are represented by exact functionals. Only the functional for the interaction energy requires an approximation in terms of the single-particle eigenstates. The variational variables are not the spatial densities as in standard density functional theory (DFT), but the occupation numbers of the single-particle part of the system. For simulating many-body systems, we minimize the consequently high-dimensional non-convex and constrained energy functional with the help of evolutionary algorithms. Our simulations of contact-interacting Fermi gases and of light atoms/ions—enabled by two novel schemes for constructing the required approximate density matrices—yield ground-state energies that are accurate at the one-percent level compared with Hartree–Fock results.

T13.85 Bulk-edge correspondence in Gaffnian fractional quantum Hall effect

Yoshiki Fukusumi*, Bo Yang* (Nanyang Technological University)
09:30am – 09:45am

Initiated from Laughlin's celebrating works, a wide variety of fractional quantum Hall wavefunction has been proposed. However, regardless of the general strategies for the constructions of the wavefunctions, determining whether they can be realized in the gapped phase of matter or not still has been a difficult problem to solve. In this presentation, based on existing theoretical and numerical works, we will show that the realization of the Gaffinian FQH state in the gapped phase of matter has difficulties when one assumes the bulk-edge correspondence.

T13.57 How to tackle dissipative quantum spin lattices with trajectory cumulants

Wouter Verstraelen*, Dolf Huybrechts, Tommaso Roscilde, Michiel Wouters, Timothy C.H. Liew (Nanyang Technological University)
09:45am – 10:00am

The onset of quantum information technologies is bringing along a number of platforms allowing for precise experimental control. Often, there is a significant optical component which gives the system a driven-dissipative and thus non-equilibrium nature. This naturally raises questions on the fundamental physics in such systems. Computational study of these systems is challenging, and requires a new set of methods. Here, we provide such a method and apply it to the dissipative XYZ spin model. Our approach is based on the quantum trajectory framework known from the study of open quantum systems, combined with a cumulant expansion. Together, they allow for a faithful and efficient modeling of both quantum and classical correlations, some preliminary work on a purely bosonic system in this regard was done in [Verstraelen et al., PRR 2, 022037(R)(2020)]. The dissipative XYZ model was originally introduced in [Lee et al., PRL 110, 257204 (2013)] and could be realized with Rydberg atoms in optical lattices. A very rich phase diagram was already predicted on the mean-field level, but a variety of higher order methods have shown contradictory results and failed to give a reliable characterization. As I will show however, our method does allow the study of hundreds of dissipative spins and with that, we were able to not only confirm the form of the phase diagram, but also extract the universality classes of the phase transitions and witness substantial amounts of entanglement.

T13.41 Deconfined Quantum Criticality in the extended Hubbard Model

Jon Spalding*, Pinaki Sengupta (University of California, Riverside)
10:00am – 10:15am

For over half a century, continuous phase transitions have been successfully described by the Landau-Ginzburg-Wilson (LGW) symmetry-breaking paradigm. Within this classical description of thermal phase transitions, interacting particles (spins in magnets or water molecules for instance) self-organize and become asymmetric at low temperatures and become disordered and symmetrical at high temperatures. By contrast, since 2004 it has been proposed that quantum variants of continuous phase transitions can defy the LGW description. By tuning an interaction parameter, a system at zero temperature can be continuously switched between two different ordered phases in a way that is impossible in a thermally-driven phase transition. In this talk, we present numerical results from a quantum monte carlo study of the extended Hubbard model in one dimension, which supports the possibility that this kind of transition may be possible for electrons interacting in one spatial dimension.

T14: Biophysics

Time: Thursday 29 Sept, 9:00am; Venue: LT2; Chair: tbd
Time allocated for keynote/invited talks is 20/15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T14.144 Fluorographene-based Hydrophobic Anti-biofouling Surface with Superior Properties

Ishita Agrawal, Rajesh Sharma, Slaven Garaj* (National University of Singapore)
9:00am – 09:15am

Surface coatings that can prevent biofouling - uncontrolled adhesion of biological materials and biofilms on membranous and other fluidic systems; protein and cell adhesion on medical devices; and the transmission of bacterial and viral pathogens on public surfaces - are becoming important for medical devices and cell therapy manufacturing, where even the smallest of the contamination could have cascading consequences. Here, we present hydrophobic two-dimensional fluorinated graphene membrane as an anti-biofouling surface with excellent protein repellent properties. We investigate the adsorption behavior of proteins using real-time quartz crystal microbalance with dissipation (QCM-D) technique and reveal the interactions that promote suppression of protein adsorption on the fluorinated graphene surface. Compared with most previously reported anti-biofouling membranes, fluorographene surface show remarkable reduction in BSA protein adsorption at only $\approx$30% surface coverage. This hydrophobic graphene derivative can be a useful coating not only for medical implants but also for bio-micro/nanofluidic systems.

T14.25 A free-energy profile study of a bipedal single-stranded DNA nanowalker's walking gaits

Hon Lin Too*, Zhisong Wang (National University of Singapore)
09:15am – 09:30am

DNA nanowalker is a class of dynamic DNA nanotechnology that exploit toehold mediated strand displacement and branch migration for movement. As one of the potential motor candidate for dynamic DNA nanotechnology, speed is a key performance indicator of a good walker. A walker's gait dictates its speed threshold. Here, we conducted a systematic free energy profile study on a 15nt long ssDNA nanowalker on a dsDNA track using oxDNA, a coarse-grained DNA model. We identified all possible gaits for a ssDNA nanowalker. From the free energy landscape, the average time for a forward step is estimated from the first passage time theory. The walker's performance is evaluated based on the shape of free energy landscape and the walker speed on a 10bp long and 20bp long track. From the free energy landscape, we found that a heel-to-heel walker on a 10bp long track contains a well-defined intermediate structure. Their speed is estimated through the first passage time theory, and we found that on a 10bp track, a head-to-head walker is the fastest walker, whereas on a 20bp track, a heel to head walker is the fastest walker.

T14.135 Green lithography for delicate materials

Artem Grebenko*, Anton Bubis, Albert Nasibulin (National University of Singapore)
09:30am – 09:45am

Electron-beam lithography is one of the most powerful techniques to create nano-devices. It delivers unprecedented resolution, positioning accuracy and is widespread in laboratories and clean-room shared facilities around the world. However, this technique has its limitations when delicate materials, such as biological nano-structures, organic crystals/polymers, metal-organic frameworks and many others are considered. Actually, most of these limitations can be overcome simply by replacing contemporary resist - intermediate films used to deliver a pattern on the surface of a target material. Here we report utilization of chitosan derivatives as a resist with enhanced compatibility. More than that, we report the principle how to design such solutions with respect to the particular sample requirements. Finally we show particular applications and cover technical details of the resist utilization.

T14.7 1/f Noise in Artificial Neural networks

Nicholas Jia Le Chong, Ling Feng* (National University of Singapore)
09:45am – 10:00am

Despite 1/f noise (a.k.a. pink noise) being ubiquitous in various natural systems, no general explanations for the phenomenon have received widespread acceptance. One particular system where 1/f noise has been observed in is the human brain, with the noise proposed by some to be important to the function of the brain. As artificial neural networks are loosely modelled after the human brain, and as they start to achieve human-level performance in specific tasks, it might be worth investigating if the same 1/f noise is present in these networks. Here we investigate the existence of 1/f noise in artificial neural networks - specifically Long Short-Term Memory (LSTM) networks in this work, since it is one of the most popular artificial neural network models used to learn sequential data. By drawing an analogy between the 1/f noise in the human brain and the artificial neural network, the presence of 1/f noise in LSTMs is found. In particular it is found present in the trained networks, and the exponents values are similar to that of the fMRI data from the biological brain.

T14.51 Investigation Of Physics Behind The Antibiotics Permeation Through Gram-negative Bacteria Using Molecular Dynamics Simulations

Javad Deylami*, Shu Sin Chng, Ee Hou Yong* (Nanyang Technological University)
10:00am – 10:15am

Antibiotic resistance has rapidly become a public health threat to humanity. In particular, improving the efficacy of antibiotics against Gram-negative bacteria is a significant challenge due to the robust permeability barrier imposed by its outer membrane (OM). Molecular dynamics (MD) simulations have become an invaluable tool to investigate the permeation mechanisms and physicochemistry of different solutes across various membranes. In this work, we describe the use of atomistic molecular dynamics (MD) to assess the passive permeability profiles, calculated using the inhomogeneous solubility-diffusion model (ISDM), of five commercial drugs, erythromycin, gentamicin, novobiocin, rifampicin, and tetracycline, through an asymmetric model of the outer membrane of the archetypical Gram-negative bacterium, Escherichia coli. We examined various types of interactions between the drugs and its surroundings as they permeate through the OM and found that sustained H-bond formation and drug-cation interactions negatively impact the energetics of passive permeation, specifically novobiocin and erythromycin. Our MD simulations corroborate well with experimental data and reveal previously unappreciated implications of solvation on drug permeability, overall advancing the possible use of computational prediction of membrane permeability in future antibiotic discovery.

T14.99 Geometrical approach to identify the topology of G-quadruplex

Farisan Dary*, Ee Hou Yong* (Nanyang Technological University)
10:15am – 10:30am

A guanine-rich DNA sequence can fold into extremely stable structures through the formation of four guanine bases in a square planar configuration called the G-tetrad. The stacking of G-tetrads forms a structure known as G-quadruplex, which may adopt a variety of topologies depending on the way the guanine sequences are linked. Experimentally, the topology of the G-quadruplex can be determined from the statistical analysis of its circular dichroism spectroscopy. Here we explore the possibility of identifying the topology of the G-quadruplex from its geometry. We use computational methods to track geometrical quantities such as twist, writhe, and handedness density along the phosphate backbone of the G-quadruplex. We further compare these quantities in G-quadruplex structures belonging to the same topology type and identify their salient features. Our approach offers a fresh outlook on geometrical analysis of G-quadruplex across different topological classifications and elucidates the role of geometry in the topology preference of G-quadruplex.

T15: Strained Systems

Time: Thursday 29 Sept, 9:00am; Venue: LT4; Chair: tbd
Time allocated for keynote/invited talks is 20/15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T15.95 Strain and magnetic field tuning of Casimir interaction for graphene-based materials

Wei Jie Chan*, Bing Sui Lu (Singapore University of Technology and Design (SUTD))
9:00am – 09:15am

The origin of Casimir interaction between materials can be attributed to the vacuum fluctuations of the electromagnetic field [1,2]. This interaction is crucial to help better design nanodevices by reducing unwanted stiction, friction or even adhesion. Graphene-based nanostructures like carbon nanotubes and graphene nanoribbons are examples of such nanostructures. The rapid development of graphene-based nanodevices can be attributed to their elusive electronic and optical properties, etc [3]. Recently, it has been shown that the sign of the Casimir force between graphene sheets is tuneable under an applied magnetic field [4]. The effect of uniform strains, however, does not have a measurable effect on the Casimir interactions [5] due to an effectively vanishing pseudo magnetic field generated. Recently, there have been different methods to induce a non-vanishing pseudo magnetic field in graphene-based materials [6-8]. These realizations, along with an externally applied magnetic field, will be utilized as a new way to further fine-tune the Casimir interactions through its magneto-optical conductivity between graphene-based materials. The findings in this work can further help in the development of nanodevices.
[1] H. B. G. Casimir and D. Polder, Phys. Rev. 73, 360 (1948). [2] B.-S. Lu, Universe 7, 237 (2021). [3] F. Akbar, M. Kolahdouz, S. Larimian, B. Radfar, and H. H. Radamson, J. Mater. Sci. Mater. Electron. 26, 4347 (2015). [4] W. K. Tse and A. H. MacDonald, Phys. Rev. Lett. 109, 1 (2012). [5] M. Bordag, I. Fialkovsky, and D. Vassilevich, Phys. Lett. A 381, 2439 (2017). [6] M. Bordag, I. Fialkovsky, and D. Vassilevich, Phys. Lett. A 381, 2439 (2017). [7] S. Zhu, J. A. Stroscio, and T. Li, Phys. Rev. Lett. 115, 1 (2015). [8] M. Bordag, I. Fialkovsky, and D. Vassilevich, Phys. Lett. A 381, 2439 (2017).

T15.32 Uniaxial strain induced third-order Hall effect in graphene

Hui Wang*, Yue-Xin Huang, Shengyuan Yang (Singapore University of Technology and Design)
09:15am – 09:30am

The transport phenomenon associated with the band geometric quantity has attracted a great deal of attention, and it has gone into the nonlinear terrain. Recently, the Berry connection polarizability has been discovered to be another intrinsic band geometric quantity that contributes to the third-order nonlinear Hall effect, which is prominent in nonmagnetic material with inversion symmetry or a twofold rotation. We find that graphene provides a promising platform for modulating third-order Hall response to applied electric field. By applying the uniaxial strain with breaking the 3-fold rotation symmetry, third-order Hall effect in graphene emerges and is estimated to be observable in experiments. This is attributed to the strain-induced anisotropy and tilt of the energy spectrum. Moreover, the sign of transverse conductivity is opposite for two different strain directions: along the zigzag and armchair directions. Through the strain engineering, our results indicate the possible nonlinear Hall effect in a large number of two-dimensional materials with time-reversal symmetry and inversion symmetry.

T15.120 Interplay between magnetic and Moire length in van der Waals heterostructures

Udvas Chattopadhyay* (National University of Singapore)
09:30am – 09:45am

Spontaneous local rearrangements in van der Waals heterostructures lead to local strains and spontaneous pseudomagnetic fields which can be tuned by twist and external strains. Here we study the landau levels formed due to the pseudomagnetic field and competing length scales that are relevant for experimental probing.

T15.5 Shear Modes in a 2D Polar Metal

Wen He*, Maxwell T. Wetherington, Kanchan Ajit Ulman, Jennifer L. Gray, Joshua A. Robinson, Su Ying Quek* (National University of Singapore)
09:45am – 10:00am

We elucidate the nature of low-frequency Raman modes in a recently synthesized 2D polar metal1, 2D Ga covalently bonded to a SiC substrate, using a first-principles Green's function-based approach2 to account for the interaction between the 2D metal and the semi-infinite SiC substrate. The low-frequency Raman modes are dominated by the interlayer shear modes in Ga, coupled to SiC phonons, while the breathing modes are too strongly coupled to the substrate to show up as peaks in the phonon spectra. Away from the zone center, the surface resonance modes evolve into surface-localized modes due to decoupling from the SiC bulk phonons. In contrast to traditional van der Waals layered materials, the effective interlayer force constants in 2D Ga increase as the thickness of Ga increases, and the highest frequency shear mode blue-shifts significantly with increasing Ga thickness. Experimental Raman spectra on 2D Ga reveal the presence of low-frequency Raman peaks with frequencies close to those for the predicted shear modes, demonstrating the presence of shear modes in 2D polar Ga.

References: (1) Briggs, N.; Bersch, B.; Wang, Y.; Jiang, J.; Koch, R. J.; Nayir, N.; Wang, K.; Kolmer, M.; Ko, W.; De La Fuente Duran, A.; et al. Atomically Thin Half-van Der Waals Metals Enabled by Confinement Heteroepitaxy. Nat. Mater. 2020, 19 (6), 637-643. (2) He, W.; Wetherington, M. T.; Ulman, K. A.; Gray, J. L.; Robinson, J. A.; Quek, S. Y. Shear Modes in a 2D Polar Metal. J. Phys. Chem. Lett. 2022, 13 (18), 4015-4020.

T16: Quantum Communication

Time: Thursday 29 Sept, 9:00am; Venue: LT5; Chair: tbd
Time allocated for keynote/invited talks is 20/15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T16.96 (INVITED) QEP-P1: From coherent absorption to coherent detection of quantum light

Anton N. Vetlugin*, Filippo Martinelli*, Ruixiang Guo*, Nikolay I. Zheludev*, Cesare Soci* (Nanyang Technological University)
9:00am – 09:20am

Optical quantum technologies place high demands on light detection performance: detectors should provide high detection efficiency at the single-photon level and, in many cases, resolve the number of incoming photons. Traditional schemes of quantum light detection, which rely on detecting traveling waves, cannot meet both requirements, not sacrificing other parameters of detection like rate of operation, temporal response, etc., making them impractical. To overcome these challenges, we introduce a coherent scheme of quantum light detection which relies on the detection of standing rather than traveling waves. Firstly, we discuss our recent theoretical and experimental studies of coherent absorption of quantum light: from local and remote switching between the regimes of perfect absorption and perfect transmission to the anti-Hong-Ou-Mandel effect and entanglement generation in quantum networks. Next, we show how coherent absorption can facilitate the problem of quantum light detection enabling detection schemes that simultaneously achieve perfect light absorption, efficient photon number resolution, high rate of operation, and improved temporal performance. Besides theoretical analysis, we present two possible schemes for quantum light detection with superconducting nanowire single-photon detectors in free space (fiber-coupled) and an integrated waveguide platform.

T16.79 (INVITED) CubeSat-based Space Laser Terminals

Christian Roubal*, Florian Moll (German Aerospace Center)
09:20am – 09:40am

The ongoing development of spaceborn instruments generating an increasing amount of data, such as higher sensor resolution, dynamic range or their quantity in a satellite, leads to the demand of a higher downlink rate from space to a ground station. Commonly used RF systems need a license, and are limited in bandwidth. Aside from that, they require a non-negligible amount of space, weight, electrical power and cost which is in particular critical for small satellites such as CubeSats. To overcome these drawbacks, the DLR Institute of Communications and Navigation has developed OSIRIS4CubeSat - a 1/3 U CubeSat laser-communication terminal for up to 100 Mbit/s downlinks. It has been launched in January 2021 on the 3U CubeSat PIXL-1 that takes high resolution images and transfers them to an optical ground station. The terminal is equipped with a closed loop tracking system for sustaining a stable link. Beside speed, another important aspect of data communication is its security. For future quantum-safe networks, satellite-based QKD is a key. The exponential decay in optical fibre limits the exchange distance to several hundred kilometres with reasonable key rates. In an optical free space link, the channel loss is quadratic to the distance. Therefore, satellite links are needed to interconnect quantum safe networks over large distances. For a cost- and time efficient development, a CubeSat-based approach is feasible to realise a QKD-Satellite. In the framework of the QUBE consortium, we develop a 1/3 U laser terminal to be used for quantum communication tests at wavelengths of 850nm and in the C-band. In order to meet the challenge of an achromatic design for the compact free space optical system, a compromise between beam divergence and tracking performance is made. A further development of this demonstrator will enable quantum key exchange. In the QUBE II consortium we will develop a laser terminal with a larger aperture for an increased link budget. This implies higher demands on the overall optical design and especially on the tracking system.

T16.60 Clear sky studies in Singapore for ground-to-satellite quantum key distribution and free space optical communication

Ayesha Reezwana*, Wong Su Yi Esther, Tanvirul Islam, Alexander Ling (Centre for quantum technologies)

09:40am – 09:55am

The clear sky is an essential prerequisite for successful satellite-to-ground quantum key distribution (QKD). We are constructing a satellite-based quantum communication infrastructure where QKD is to be performed when the satellite elevation is above 20 degrees with respect to our optical ground station (OGS) location at NUS. This gives us a region of interest in the sky around our OGS location where we need clear sky to perform QKD. To conduct this study, we collect the brightness temperature information of Singapore sky from the geostationary satellite Himawari-8 in band 15 (12.30 μm), band 16 (13.30 μm) and band 13 (10.35 μm) in the infrared region. The brightness temperature for Singapore region is recorded with (2 km $\times$ 2 km) /pixel in Himawari-8 and our region of interest around the OGS contains 900 pixels. We compute the clear sky for each pixel using brightness temperature difference of band 15 and band 16. Moreover, we compute the cloud-top altitude using band 13 brightness temperature information to determine the obstructed cloudy pixels in the line of sight between the ground and the satellite. Singapore's weather often changes drastically within short intervals. Therefore, it is important to analyze the historical cloud cover data to determine the feasibility of satellite-to-ground optical communication in local weather. For example, if a sun synchronous orbit is chosen to perform satellite based QKD, the satellite will always pass over the OGS at the same time during its lifetime. Given the standard satellite passes for optical communication is 5 to 6 minutes, we need to estimate the clear sky duration that allows a successful QKD run. We compute the number of usable clear nights when any low Earth orbit satellite can perform nighttime QKD employing our OGS. We also extend this study to compute the clear hours in day and night suitable for performing free space optical (FSO) communication. Here we report, the most suitable months and times, the total hours in each day of each month suitable to run QKD and FSO communication in Singapore weather. We also estimate the maximum secret keys to be obtained integrating our lab emulated secret keys in a QKD pass with the clear sky estimations.

T16.59 Distributing polarization entangled photon pairs with high rate over long distance through standard telecommunication fiber

Lijiong Shen, Chang Hoong Chow*, Justin Yu Xiang Peh, Xi Jie Yeo, Peng Kian Tan, Christian Kurtsiefer (Centre for Quantum Technologies)
09:55am – 10:10am

Distributing entanglement over long distances is crucial for quantum communication schemes, including some variants of quantum key distribution (QKD) and implementations of a quantum internet. Due to the low photon pair rates, some previous demonstrations were realized with sophisticated superconducting detectors. Dispersion effect has also caused some earlier studies to work with a dispersion-shifted fiber, compromising on its practicality. Here we demonstrate entanglement distribution over 50 km with a high rate in a standard telecommunication fiber [1]. The highly non-degenerate entangled photon pair source is based on type-0 spontaneous parametric down-conversion (SPDC) process. The signal photon (1310 nm) falls in the zero-dispersion window of a standard optical fiber and has an intrinsic sub-nanometer bandwidth because of the high non-degeneracy. The idler photon has a wavelength of 586 nm, allowing high detection efficiency for typical single-photon avalanche photodiodes (APDs). After transmitting through a 50-km fiber, the corrected entanglement visibility remains 97.1% with more than 10,000 photon pairs per second detected using a pair of APDs. With the presented source, the implementation of a high-rate entanglement-based QKD over metropolitan distances can be greatly simplified by integrating into existing telecommunication infrastructures with realistic detection devices.

[1] L. Shen, C. H. Chow, J. Y. X. Peh, X. J. Yeo, P. K. Tan, and C. Kurtsiefer, arXiv:2204.10571 (2022)

T16.80 Privacy and correctness trade-offs for information-theoretically secure quantum homomorphic encryption (Supported by QEP project NRF2021-QEP2-01-P06)

Yanglin Hu*, Yingkai Ouyang*, Marco Tomamichel* (National University of Singapore)
10:10am – 10:25am

Quantum homomorphic encryption, which allows computation by a server directly on encrypted data, is a fundamental primitive out of which more complex quantum cryptography protocols can be built. For such constructions to be possible, quantum homomorphic encryption must satisfy two privacy properties: data privacy which ensures that the input data is private from the server, and circuit privacy which ensures that the ciphertext after the computation does not reveal any additional information about the circuit used to perform it, beyond the output of the computation itself. While circuit privacy is well-studied in classical cryptography and many homomorphic encryption schemes can be equipped with it, its quantum analogue has received little attention. Here we establish a definition of circuit privacy for quantum homomorphic encryption with information theoretic security. Furthermore, we reduce quantum oblivious transfer to quantum homomorphic encryption. Using this reduction, our work unravels fundamental trade-offs between circuit privacy, data privacy and correctness for a broad family of quantum homomorphic encryption protocols, including schemes that allow only computation of Clifford circuits.

T17: Strongly Correlated Systems II

Time: Friday 30 Sept, 11:00am; Venue: LT2; Chair: tbd
Time allocated for keynote/invited talks is 20/15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T17.20 Phase Diagram of the Su-Schrieffer-Heeger-Hubbard model on a square lattice

Chunhan Feng, Bo Xing*, Dario Poletti, Richard Scalettar, George Batrouni (Singapore University of Technology and Design)
11:00am – 11:15am

The Hubbard and Su-Schrieffer-Heeger Hamiltonians (SSH) are iconic models for understanding the qualitative effects of electron-electron and electron-phonon interactions respectively. In the two- dimensional square lattice Hubbard model at half filling, the on-site Coulomb repulsion, U, between up and down electrons induces antiferromagnetic (AF) order and a Mott insulating phase. On the other hand, for the SSH model, there is an AF phase when the electron-phonon coupling λ is less than a critical value λc and a bond order wave when $\lambda > \lambda c$. In this work, we perform numerical studies on the square lattice optical Su-Schrieffer-Heeger-Hubbard Hamiltonian (SSHH), which combines both interactions. We use the determinant quantum Monte Carlo (DQMC) method which does not suffer from the fermionic sign problem at half filling. We map out the phase diagram and find that it exhibits a direct first-order transition between an antiferromagnetic phase and a bond-ordered wave as λ increases. The AF phase is characterized by two different regions. At smaller λ the behavior is similar to that of the pure Hubbard model; the other region, while maintaining long-range AF order, exhibits larger kinetic energies and double occupancy, i.e. larger quantum fluctuations, similar to the AF phase found in the pure SSH model.

T17.16 Sign-problem free quantum stochastic series expansion algorithm on a quantum computer

Dhiman Bhowmick*, Kok Chuan Tan*, Pinaki Sengupta* (Nanyang Technological University)
11:15am – 11:30am

A quantum implementation of the Stochastic Series Expansion (SSE) Monte Carlo method is proposed, and is shown to offer significant advantages over classical implementations of SSE. In particular, for problems where classical SSE encounters the sign problem, the cost of implementing a Monte Carlo iteration scales only linearly with system size in quantum SSE, while it may scale exponentially with system size in classical SSE. In cases where classical SSE can be efficiently implemented, quantum SSE still offers an advantage by allowing for more general observables to be measured.

T17.116 Evidence of many-body localisation in 2D from quantum Monte Carlo simulation

Nyayabanta Swain*, Ho Kin Tang, Darryl Foo, Brian Khor, Gabriel Lemarie, Fakher F. Assaad, Shaffique Adam, Pinaki Sengupta (Centre for Quantum Technologies, National University of Singapore)

11:30am – 11:45am

We use the stochastic series expansion quantum Monte Carlo method, together with the eigenstate-to-Hamiltonian construction, to map the localised Bose glass ground state of the disordered two-dimensional Heisenberg model to excited states of new target Hamiltonians. The localised nature of the ground state is established by studying the participation entropy, local entanglement entropy, and local magnetization, all known in the literature to also be identifying characteristics of many-body localised states. Our construction maps the ground state of the parent Hamiltonian to a single excited state of a new target Hamiltonian, which retains the same form as the parent Hamiltonian, albeit with correlated and large disorder. We furthermore provide evidence that the mapped eigenstates are genuine localised states and not special zero-measure localised states like the quantum scar-states. Our results provide concrete evidence for the existence of the many-body localised phase in two dimensions.

T17.119 A stabilization mechanism for many-body localization in two dimensions

Darryl Foo*, Nyayabanta Swain, Pinaki Sengupta, Gabriel Lemarie, Shaffique Adam (CA2DM)

11:45am – 12:00pm

Experiments in cold atom systems see almost identical signatures of many body localization (MBL) in both one-dimensional ($d = 1$) and two-dimensional ($d = 2$) systems despite the thermal avalanche hypothesis showing that the MBL phase is unstable for $d > 1$. Underpinning the thermal avalanche argument is the assumption of exponential localization of local integrals of motion (LIOMs). In this work we demonstrate that addition of a confining potential – as is typical in experimental setups – allows a non-interacting disordered system to have super-exponentially (Gaussian) localized wavefunctions, and an interacting disordered system to undergo a localization transition. Moreover, we show that Gaussian localization of MBL LIOMs shifts the quantum avalanche critical dimension from $d = 1$ to $d = 2$, potentially bridging the divide between the experimental demonstrations of MBL in these systems and existing theoretical arguments that claim that such demonstrations are impossible.

T18: Solid State Physics II

Time: Friday 30 Sept, 11:00am; Venue: LT3; Chair: tbd
Time allocated for keynote/invited talks is 20/15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T18.19 A size-consistent Gruneisen-quasiharmonic approach for lattice thermal conductivity

Chee Kwan Gan* (Institute of High Performance Computing)
11:00am – 11:15am

We present a size-consistent Gruneisen-quasiharmonic approach (GQA) for the calculation of the lattice thermal conductivity, which is of fundamental importance and crucial for the performance of thermal management, heat dissipation, thermoelectrics, and thermal barrier coatings. We identify the size-inconsistency problem of the original Slack formulae for the estimation of the lattice thermal conductivity. We then propose a way to resolve this issue by appealing to the expected variations of the constant-volume heat capacity. Using the recently proposed small-displacement method[1] and the phonon connectivity[2] to calculate accurately the Gruneisen parameters, we make prediction of the lattice conductivity for a range of materials from diamond, zincblende, rocksalt, and wurtzite structures. We expect this new GQA with the modified Slack formulae could be used as an effective and practical predictor for lattice thermal conductivity, especially for crystals with large number of atoms in the primitive cell.

[1] C. K. Gan, Y. Liu, T. C. Sum, and K. Hippalgaonkar, Comput. Phys. Comm. 259, 107635 (2021).

[2] C. K. Gan and Z.-Y. Ong, J. Phys. Commun. 5, 015010 (2021).

T18.17 Low-Frequency Divergence of Circular Photomagnetic Effect in Topological Semimetals

Jin Cao*, Chuanchang Zeng*, Xiao-Ping Li*, Maoyuan Wang*, Shengyuan A. Yang*, Zhi-Ming Yu*, Yugui Yao* (Beijing Institute of Technology)
11:15am – 11:30am

Novel fermions with relativistic linear dispersion can emerge as low-energy excitations in topological semimetal materials. Here, we show that the orbital moment contribution in the circular photomagnetic effect for these topological semimetals exhibit an unconventional ω^{-1} frequency scaling, leading to significantly enhanced response in the low frequency window, which can be orders of magnitude larger than previous observations on conventional materials. Furthermore, the response tensor is directly connected to the Chern numbers of the emergent fermions, manifesting their topological character. Our work reveals a new signature of topological semimetals and suggests them as promising platforms for optoelectronics and spintronics applications.

T18.124 Viscous electric transport across potential junction in 2D systems

Ramal Afrose*, Aydin Keser, Shaffique Adam* (National University of Singapore)
11:30am – 11:45am

When materials are made sufficiently clean, the collective electron motion can be described as a hydrodynamic flow. Recent breakthroughs in the fabrication of ultra-clean 2D systems have led to realization of the hydrodynamic regime. Also, recent experiments have been made on electron transport across a gate-tunable potential barrier in graphene. The results were mainly interpreted with the theory of ballistic and diffusive transport. However, experimental conditions for the hydrodynamic regime are easily realized and have not been studied. Here, we present our results for such a regime of transport and also explore its signature on magneto-resistance.

T18.74 Analytic exposition of the graviton modes in fractional quantum Hall effects and its physical implications

Yuzhu Wang*, Bo Yang* (Nanyang Tchnological University)
11:45am – 12:00pm

Neutral excitations in a fractional quantum Hall droplet define the incompressibility gap of the topological phase. Here, we show a set of analytical results for the energy gap of the graviton modes with two-body and three-body Hamiltonians in both the long-wavelength and the thermodynamic limit. These allow us to construct model Hamiltonians for the graviton modes in different FQH phases, and to elucidate a hierarchical structure of conformal Hilbert spaces (null spaces of model Hamiltonians) with respect to the graviton modes and their corresponding ground states. Numerical results of the Laughlin $\nu = 1/5$ and the Gaffnian $\nu = 2/5$ phases confirm that for gapped phases, low-lying neutral excitations can undergo a ”phase transition” even when the ground state is invariant. We will discuss the compressibility of the Gaffnian phase, the possibility of multiple graviton modes, and the transition from the graviton modes to the ”hollow-core” modes, as well as their experimental consequences.

T19: Quantum Computing

Time: Friday 30 Sept, 11:00am; Venue: LT4; Chair: tbd
Time allocated for keynote/invited talks is 20/15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T19.75 Coherent excitation of single sodium atoms to Rydberg states for quantum simulation (NRF2021-QEP2-02-P09)

Mohammad Mujaheed Aliyu*, Luheng Zhao*, Krishna Yellapragada*, Huanqian Loh* (Center for quantum technologies(CQT), Department of Physics, NUS)
11:00am – 11:15am

Optical tweezer arrays of highly excited Rydberg atoms have become a promising platform for simulating paradigmatic condensed matter models, spin Hamiltonians and quantum computation algorithms. The controlled anisotropic long-range interactions provided by the Rydberg atoms, together with the tunability and individual addressing afforded by the tweezer platform, allow for the engineering of a variety of spin Hamiltonians of interest. Here, we report on our progress towards realizing such a quantum simulator using singly trapped sodium atoms in optical tweezers. We first use tweezers at a D1 magic wavelength to trap and image single sodium atoms without any intensity modulation of the trapping and cooling light. We then excite the atoms to Rydberg states via a two-photon process. After locating the Rydberg resonances, we observed coherent Rabi oscillations between the ground and Rydberg states. These results set the stage for exploring strongly interacting quantum systems and interesting quantum phases of matter.

T19.54 Simulation of the open spin-boson model on a quantum computer

Andreas Burger*, Leong Chuan Kwek*, Dario Poletti* (SUTD)
11:15am – 11:30am

The spin-boson model is pervasive in quantum physics, from condensed matter to atom-optics. One of the relevant case studies is that of an atom in a cavity. In this case, the atom and the photon field are also under the effect of other dissipative phenomena like spontaneous emissions. Studying such systems, especially when more atoms are in the cavity, becomes particularly demanding on classical computers. Here we show a path towards studying the dynamics of these systems on a quantum computer. Specifically, we study the dynamics of the spin-boson model, with an amplitude damping channel acting on the spin. We approximate the time-evolution using Trotterization and repeated collisions with an ancilla with resets in between. To benchmark our approach, we implement one and two dissipating spin-1/2-particles coupled to an harmonic oscillator with four levels. We test our method on current IBM Quantum devices, as well as simulations of hardware with reduced noise, mimicking future devices. We present optimal time-step sizes in the trade-off of model accuracy with gate-induced noise. Our proof-of-principle shows simulation of open quantum dynamics of more complex systems is possible on near term quantum computers, including a possibility for quantitatively precise results when the noise is reduced.

T19.10 Convex optimization for non-equilibrium steady states on a hybrid quantum processor

Jonathan Wei Zhong Lau*, Kian Hwee Lim, Kishor Bharti, Leong Chuan Kwek, Sai Vinjanampathy (Centre for Quantum Technologies)
11:30am – 11:45am

Finding the transient and steady state properties of open quantum systems is a central problem in various fields of quantum technologies. Here, we present a quantum-assisted algorithm to determine the steady states of open system dynamics. By reformulating the problem of finding the fixed point of Lindblad dynamics as a feasibility semi-definite program, we bypass several well known issues with variational quantum approaches to solving for steady states. We demonstrate that our hybrid approach allows us to estimate the steady states of higher dimensional open quantum systems and discuss how our method can find multiple steady states for systems with symmetries.

T19.104 Deterministic and Entanglement-Efficient Preparation of Amplitude-Encoded Quantum Registers (QEP-SF2)

Prithvi Gundlapalli, Junyi Lee* (Institute of Materials Research and Engineering)
11:45am – 12:00pm

Quantum computing promises to provide exponential speed-ups to certain classes of problems. In many such algorithms, a classical vector b is encoded in the amplitudes of a quantum state $|b\rangle$. However, efficiently preparing $|b\rangle$ is known to be a difficult problem because an arbitrary state of Q qubits generally requires approximately 2^Q entangling gates, which results in significant decoherence on today's Noisy-Intermediate Scale Quantum (NISQ) computers. We present a deterministic (non-variational) algorithm that allows one to flexibly reduce the quantum resources required for state preparation in an entanglement-efficient manner. Although this comes at the expense of reduced theoretical fidelity, actual fidelities on current NISQ computers might actually be higher due to reduced decoherence. We show this to be true for various cases of interest such as the normal and log-normal distributions. For low entanglement states, our algorithm can prepare states with more than an order of magnitude fewer entangling gates as compared to isometric decomposition.

T19.56 Fundamental limits of quantum error mitigation

Ryuji Takagi*, Suguru Endo*, Shintaro Minagawa*, Mile Gu* (Nanyang Technological University)
12:00pm – 12:15pm

Noise remains a critical roadblock for practical quantum computing. Every gate has a chance of error, and their continuing accumulation will eventually destroy any potential quantum advantage. While quantum error correction enables in-principle means to suppress such error indefinitely, they involve measuring error syndromes and making adaptive corrections. In contrast, NISQ devices often cannot adaptively execute quantum operations. This technological hurdle has motivated the study of quantum error mitigation, resulting in a myriad of algorithms such as probabilistic error cancellation and error extrapolation. Instead of adaptive quantum operations, error-mitigation algorithms suppress errors by sampling available noisy devices many times and classically post-processing these measurement outcomes. Such algorithms have drastically reduced technological requirements, but to what extent does the abandonment of adaptive quantum operations limit their performance?

Here, we present recent research towards ascertaining the ultimate limits of quantum error mitigation. We introduce maximum estimator spread as a universal benchmark for error-mitigation performance — a quantity that tells us how many extra runs of a NISQ device guarantee that outputs are within some desired accuracy threshold. We then derive fundamental lower bounds for this spread — that no current or yet-undiscovered error-mitigation strategy can violate. We then outline two immediate consequences of our general bounds. The first is in the context of mitigating local depolarizing noise in variational quantum circuits, where the maximum estimator spread grows exponentially with circuit depth for the general error-mitigation protocol, confirming a suspicion that the well-known exponential growing estimation error observed in several existing error-mitigation techniques. Our second study shows that probabilistic error cancellation — a prominent method of error mitigation — minimizes the maximum estimator spread when mitigating local dephasing noise acting on an arbitrary number of qubits. These results showcase how our bounds can help rule out what error-mitigation performance targets are unphysical, and identify what methods are already near-optimal.

Reference: Ryuji Takagi, Suguru Endo, Shintaro Minagawa, Mile Gu, arXiv:2109.04457 (Accepted in principle to npj Quantum Information)

T20: Quantum Sensing

Time: Friday 30 Sept, 11:00am; Venue: LT5; Chair: tbd
Time allocated for keynote/invited talks is 20/15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T20.43 Continuum Emission and Spectral Index of the High Redshift Lensing Galaxy J0901 Through VLA S and L Band Observations

Qingxiang Chen*, Chelsea Sharon, Hiddo Algera (Yale-NUS College)
11:00am – 11:15am

In this talk, I will introduce our recent work on the continuum emission analysis for the galaxy SDSS J0901+1814, a strongly lensed star-forming galaxy at redshift 2.26. We obtain its continuum emission at 1.4 GHz and 3 GHz from VLA (L and S band). The VLA observations are conducted at both A and B configurations for S-band and A configuration for the L-band respectively, resulting in ≈1” spatial resolution at both wavelengths. We thus successfully resolve the flux distribution for all the three lensed arcs. With the help of previously observed VLA 35 GHz emission, we fit out a spectral index at the S-band of about -0.2. This leads to a star formation rate measurement of 142 $M_{\odot}$/year, consistent with the prediction from the H_{α}+TIR combined tracer. Besides, we use the new tclean tool provided in CASA to furnish a pixel-by-pixel measurement on spectral indices. I will discuss the measurement in different regions with a Gaussian smoothing technique implemented on both the alpha and error maps. Together with the combination of SED fitting analysis, we conclude that J0901 is free-free emission dominated at S-band. At small scales, however, the enormous energy output is due to synchrotron emission from AGN activities, which steepens the spectral indices to about -2.

T20.97 Precision bounds on simultaneous quantum estimation thoery

Jasminder Sidhu*, Yingkai Ouyang, Earl Campbell, Pieter Kok (University of Strathclyde)
11:15am – 11:30am

The estimation of multiple parameters in quantum metrology is important for a vast array of applications in quantum information processing. However, the unattainability of fundamental precision bounds for incompatible observables has greatly diminished the applicability of estimation theory in many practical implementations. The Holevo Cramér-Rao bound (HCRB) provides the most fundamental, simultaneously attainable bound for multi-parameter estimation problems. A general closed form for the HCRB is not known given that it requires a complex optimisation over multiple variables. In this work, we develop an analytic approach to solving the HCRB for two parameters. Our analysis reveals the role of the HCRB and its interplay with alternative bounds in estimation theory. For more parameters, we generate a lower bound to the HCRB. Our work greatly reduces the complexity of determining the HCRB to solving a set of linear equations that even numerically permits a quadratic speedup over previous state-of-the-art approaches. We apply our results to compare the performance of different probe states in magnetic field sensing, and characterise the performance of state tomography on the codespace of noisy bosonic error-correcting codes. The sensitivity of state tomography on noisy binomial codestates can be improved by tuning two coding parameters that relate to the number of

correctable phase and amplitude damping errors. Our work provides fundamental insights and makes significant progress towards the estimation of multiple incompatible observables.

T20.81 Optimal gain sensing of quantum-limited phase-insensitive amplifiers

Ranjith Nair*, Guo Yao Tham*, Mile Gu* (Nanyang Technological University)
11:30am – 11:45am

The quantum limits on the sensing of loss parameters have been well-explored, but work on the fundamental limits on sensing of gain is scanty. Here, we obtain the precision limits imposed by quantum mechanics on sensing the gain of quantum-limited phase-insensitive amplifiers optimized over quantum probes with a given number of modes and average photon number that may also be entangled with an ancilla system. We find that these two resources – photon and mode number – are equivalent and interchangeable resources for optimal gain sensing and trace the physical origin of this interesting phenomenon. We find an infinite class of optimal probes that include the multimode Fock states and multimode two-mode squeezed vacuum states, and specify explicit measurement procedures and estimators that achieve the quantum limit. Finally, we discuss the prospects of demonstrating quantum advantage in the laboratory by comparing the performance of laser probes and single-photon probes in the presence of detection loss.

T20.105 Building non-cryogenic centimeter scale magnetometers with 10 fT/sqrt(Hz) sensitivity in Singapore (NRF2021-QEP2-03-P03)

Junyi Lee* (Institute of Materials Research and Engineering)
11:45am – 12:00pm

Alkali atomic magnetometers can achieve similar or better sensitivities as compared to superconducting quantum interference devices but they can do so without requiring cryogenic cooling. Such sensitive magnetometers can potentially find applications in geosciences for mineral and geophysical surveys, or be employed for magnetic anomaly detection. Medically, they can be used for magnetoencephalography, magnetocardiography, and low-field magnetic resonance imaging. Their exquisite sensitivity can also enable low field nuclear magnetic resonance as well as nuclear quadrupole resonance for stand-off detection of narcotics and explosives. In this talk, we discuss our progress towards building a scalar magnetometer in Singapore capable of operating in Earth's field with a projected sensitivity of 10 fT/sqrt(Hz) at low frequencies (1 - 100 Hz), which is close to the atomic shot noise limit that is limited by fast spin-exchange collisions in Earth's field. We also discuss our future plans to develop multi-pass cells that can, together with conditional spin squeezing techniques and suppression of spin-exchange with light narrowing, potentially reduce the atomic shot noise limit by up to two orders of magnitude.

T20.127 Precision measurements with Levitated Ferromagnetic Particles

Tao Wang*, Ping Koy Lam (A*STAR)
12:00pm – 12:15pm

A ferromagnetic particle is predicted to precess about the magnetic field like the atoms at a Larmor frequency under conditions where its intrinsic spin dominates over its rotational angular momentum. Observing the atomic precession at a mesoscopic scale requires frictionless levitation to allow free precession and good magnetic shielding to reduce the orbital angular momentum. Such levitated freely precessing ferromagnetic particle is a correlated system of spins, which can rapidly average quantum uncertainty. The “artificial atom” can be used for developing the next-generation quantum sensors whose sensitivity can far beyond the standard quantum limit: gyroscopes, magnetometers, gravitometer, and accelerators. Another major application of such “artificial atom” is for quantum information and metrology. For example, coupling the Nitrogen-Vacancy (NV) center spin qubits in diamond to the diamagnetically levitated ferromagnetic particle enables single phonon experiments and quantum state preparation of a mesoscopic object.

(notes)

Author List

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