# IPS Meeting 2024
# 2 - 4 October

Institute of Physics Singapore

# Conference Program

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# 1 Foreword

Dear fellow Physicists,

the past year has seen lots of activities in Physics in Singapore – and we happy to return to the School of Physical and Mathematical Sciences on the campus of the Nanyang Technological University. A big thanks to the relentless helper team at NTU again!

As usual, this event aims to give all researchers in physical sciences in Singapore an opportunity to get updated with the quickly evolving research landscape in Singapore, to explore new collaborations, to hunt for new research team members, or just to finally catch up with your colleagues in a relaxed setting with a focus on physics rather than administrative tasks. Most importantly, we need to step out of our usual silos, and make ourselves aware what researchers in other institutions are up to.

We try to highlight outstanding research activities in Singapore and beyond with plenary talks - both from newcomers to our Physical Sciences community in Singapore, as well as researchers who have built up a remarkable programme over a longer time. On the first day, we have plenary talks with an interesting combination of a talk on optical skyrmions from Yijie Shen from NTU, and a long-standing activity in Singapore on Carbon thin films by Antonio Castro-Neto from NUS. The second day features plenary talks that combine a theoretical review on quantum physics foundations by Berthold-Georg Englert from NUS, and applied flat optics aspects presented by Arseniy Kuznetsov from A*STAR. We packed three plenaries with a diverse spectrum of physical sciences into the morning of the third day, starting with phenomena in non-Hermitian lattices by Chong Yidong, followed by a visit of many-body quantum systems out of equilibrium by Dario Poletti from SUTD, rounded off by review of flatbands by Daniel Leykam, also from SUTD.

Our technical programme covers almost 200 contributions, with 107 oral presentations. To limit the overall time in talks, we had to limit the number of invited presentations to only 13 this year - we hope this is ok with everyone, and encourage to talk more to your colleagues in in the relaxed times over coffee and posters - where we managed to squeeze in a record number of 86 posters. Do join those who give a poster pitch in the Thursday slot, or nudge yourself to give one if you have not done so yet! As usual, the poster session in the middle of the meeting on Thursday afternoon is really a central part of this event, and as per tradition, of course transitions into a networking event with Pizza and Drinks to provide a proper setting.

We do feel that we should give an award to a long-term supporter of physical sciences in Singapore - so please do stay to honor this contributor on Thursday morning after the plenaries!

As every year, we are grateful for our institutional supporters, the Department of Physics and the Department of Materials Sciences at NUS, the School of Physics and Applied Physics at NTU, the Graduate Studies Program at SUTD, and the Center for Quantum Technologies at NUS. We also are grateful for the support by the Quantum Engineering Programme, the Institute of Advanced Studies at NTU, as well as A*STAR.

Last but not least, let's thank the record number of exhibitors this year, who again help with their generous support to make this conference possible. Without their help, we would not be able to put up this conference – so do spend some time and visit their booths to see what products or services they can offer for your research. Make sure they find this conference useful as well, as they are a pillar for this event to happen!

With this, we wish you an inspiring conference, a refreshing look up from your daily work, new ideas, new contacts, new collaborations for a successful new year of research in physical sciences ahead!

Your organizing team of the IPS meeting 2024

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# 2 Schedule

## Wednesday, 2 October

| | | | | |
|---|---|---|---|---|
| 8.30 AM | Registration (MAS Atrium) | | | |
| 8.50 AM | Opening Address (LT1) | | | |
| 9.00 AM | Plenary talk P1: Yijie SHEN (Venue: LT1) | | | |
| 9.45 AM | Plenary talk P2: Antonio CASTRO-NETO (Venue: LT1) | | | |
| 10.30 AM | Coffee/Tea Break + Exhibition (MAS Atrium) | | | |
| 11.00 AM | Technical Sessions | | | |
| | T1 (LT-2) Low-dimensional Materials 1 | T2 (LT-4) Machine Learning | T3 (LT-3) Photonics 1 | T4 (LT-5) Quantum Information |
| 12.30 PM | Lunch + Exhibition (MAS Atrium) | | | |
| 2.00 PM | Technical Sessions | | | |
| | T5 (LT-2) Low-dimensional Materials 2 | T6 (LT-4) Material | Physics T7 (LT-3) Photonics 2 | T8 (LT-5) Quantum Optics |
| 3.30 PM | Coffee/Tea Break + Exhibition (MAS Atrium) | | | |
| 4.00 PM | Technical Sessions | | | |
| | T9 (LT-2) Low-dimensional Materials 3 | T10 (LT-4) Plasma and Fusion Physics | T11 (LT-3) Photonics 3 | T12 (LT-5) Astrophysics |
| 5.30 PM | End of Wednesday sessions | | | |

### Thursday, 3 October

| | | | | |
|---|---|---|---|---|
| 9.00 AM | Plenary talk P3: Berthold-Georg ENGLERT (Venue: LT1) | | | |
| 9.35 AM | Plenary talk P4: Arseniy KUZNETSOV (Venue: LT1) | | | |
| 10.10 AM | Award Event (Venue: LT1) | | | |
| 10.30 AM | Coffee/Tea Break + Exhibition (MAS Atrium) | | | |
| 11.00 AM | Technical Sessions | | | |
| | T13 (LT-2) Electronic Materials and Devices 1 | T14 (LT-4) Many Body Physics 1 | T15 (LT-3) Topological Physics | T16 (LT-5) Atomic, Molecular and Optical Physics |
| 12.30 PM | Lunch + Exhibition (MAS Atrium) | | | |
| 14.00 PM | Rapid Fire poster Pitch session (Venue: LT-3) | | | |
| 3.30 PM | Coffee/Tea Break + Exhibition (MAS Atrium) | | | |
| 4.00 PM | Poster session + Exhibition (MAS Atrium) | | | |
| 5.30 PM | Poster awards + Pizza + Drinks (MAS Atrium) | | | |
| 6.30 PM++ | End of Thursday sessions | | | |

### Friday, 4 October

| | | | | |
|---|---|---|---|---|
| 9:00 AM | Plenary talk P5: CHONG Yidong (Venue: LT1) | | | |
| 9:30 AM | Plenary talk P6: Dario POLETTI (Venue: LT1) | | | |
| 10:00 AM | Plenary talk P7: Daniel LEYKAM (Venue: LT1) | | | |
| 10.30 AM | Coffee/Tea Break + Exhibition (MAS Atrium) | | | |
| 11.00 AM | Technical Sessions | | | |
| | T17 (LT-2) Electronic Materials and Devices 2 | T18 (LT-4) Many Body Physics 2 | T19 (LT-3) Mathematical Physics | T20 (LT-5) Quantum Photonics |
| 12.30 PM | Lunch + Exhibition (MAS Atrium) | | | |
| 2.00 PM | Quantum SG networking (MAS Executive Room 1) | | | |
| 3.30++ PM | End of Conference | | | |

(Notes)

# 3 Plenary sessions

## P1: Topological optical skyrmions of free space-time

Asst. Prof. Yijie SHEN
School of Mathematical and Physical Sciences and
School of Electrical and Electronic Engineering,
Nanyang Technological University, Singapore

Wednesday, 2 October 09:00am, Venue: LT1

### Abstract

Topological complex electromagnetic waves give access to nontrivial light-matter interactions and provide additional degrees of freedom for information transfer. For instance, topologically stable quasiparticles or skyrmions have been demonstrated in quantum fields, solid-state physics, and magnetic materials, but only recently observed in photonic fields, triggering fast expanding research across different spectral ranges and applications. Here I introduce an extended family of photonic skyrmions within a unified framework, starting from fundamental theories to experimental generation and topological control in spatiotemporally structured light. I will further highlight generalized classes of optical topological quasiparticles beyond skyrmions and outline their exotic topological robust properties, emerging applications, future trends, and open challenges. A complex vectorial field structure of optical quasiparticles with versatile topological characteristics controlled in ultrasmall and ultrafast space-time domain emerges as an important feature in modern spin-orbital optics, imaging and metrology, optical informatics, and topological and quantum technologies.

## P2: Carbon thin films for nano-electronics

Prof. Antonio Helio CASTRO NETO
Centre for Advanced 2D Materials and Graphene Research Centre and
Institute for Functional Intelligent Materials
National University of Singapore

Wednesday, 2 October, 9:45am, Venue: LT1

### Abstract

One of the greatest problems in modern nano-electronics is heat management. As the transistors get smaller that amount of heat generated becomes exponentially larger. Due to the stacked architecture of microprocessors a solution for the heat management requires materials that are extreme anisotropic for heat conduction. Using basic quantum mechanical principles of phase coherence and destructive quantum interference we created, at CA2DM, a thin film 3D carbon allotrope that is metallic at room temperature and has record breaking electrical and thermal transport anisotropies.

## P3: Uncertainty Relations: 97 Years Later

Prof. Berthold-Georg ENGLERT Centre for Quantum Technologies,
National University of Singapore

Thursday, 3 October, 09:00am, Venue: LT1

### Abstract

In addition to reviewing the history of uncertainty relations, starting with Heisenberg's work in 1927, the talk will discuss how all the standard inequalities – for products or sums of variances – follow from one basic equation.

Reference:
arXiv:2310.05039; Phys. Lett. A **494**, 129278 (2024).

## P4: Metasurface-based flat optics: from metalenses to nanoantenna spatial light modulators

Dr. Arseniy Kuznetsov
Institute of Materials Research and Engineering (IMRE),
A*STAR Research

Thursday, 3 October, 9:35am, Venue: LT1

### Abstract

Metasurfaces have recently emerged as a new class of optical devices, which can shape light beams at sub-wavelength scales. Due to their compact footprint and large-scale manufacturability using conventional semiconductor processes, they are currently attracting significant attention in optoelectronics as potential candidates to replace conventional lenses in future optical systems. They can not only mimic the functions of conventional optical elements but also offer unique functionalities not achievable by conventional optics. Particularly attractive is to make these components fully tunable to create dynamic sub-wavelength control of light. In this talk, I will first show several examples of flat optical elements demonstrating superior functionalities such as extra-large-numerical aperture focusing or extra-large field of view imaging. I will then switch to tunable metasurfaces demonstrating how dynamic control of individual metasurface pixels helps to create spatial light modulators with $\approx$1 micron pixel pitch for dynamic beam steering and tunable holography.

## P5: Novel Phenomena in Non-Hermitian Lattices

Prof. CHONG Yidong
Division of Physics and Applied Physics
Nanyang Technological University, Singapore

Friday, 4 October, 9:00am, Venue: LT1

### Abstract

Hermitian symmetry is commonly imposed on quantum Hamiltonians, to ensure the conservation of probability. In recent years, however, researchers have realized that non-Hermitian Hamiltonians, which govern classical or quantum systems subject to probability or energy non-conserving effects, can have rich behaviors qualitatively distinct from the Hermitian case. In this talk, I describe several recently-discovered phenomena in non-Hermitian periodic media, including gain/loss induced topological states, non-Hermitian Dirac quasiparticles, and bound states forming complex energy continua. These phenomena challenge well-established principles from the Hermitian world, such as the strict dichotomy between bound states and free states. They can be realized and studied on a variety of accessible experimental platforms, such as synthetic photonic lattices.

## P6: Many-body quantum systems out of equilibrium

Assoc. Prof. Dario POLETTI,
Engineering Product Development,
Singapore University of Technology and Desgin, and
Centre for Quantum Technologies

Friday, 4 October, 09:30am, Venue: LT1

### Abstract

Large quantum systems typically thermalize, which is in itself a very interesting problem. On their way to thermalization, we show that large quantum systems can manifest different dynamics which can be classified depending on their symmetries and the observables we are considering.

We will also present how non-equilibrium steady states can be understood as a prethermal state emerging while the system is on the path towards thermalization, and how this can help their experimental study in today's quantum processors. Last, we will discuss recent trends for the simulation of such many-body quantum systems, with an emphasis on neural network quantum states.

## P7: Flatbands: then and now

Assoc. Prof. Daniel LEYKAM
Science, Mathematics and Technology Cluster,
Singapore University of Technology and Desgin

Friday, 4 October, 10:00am, Venue: LT1

### Abstract

Flatbands arise in certain periodic lattices when symmetries or fine-tuning produce energy bands with a vanishing wave group velocity, resulting in perfect wave localization. Flatband-induced localization leads to remarkably sharp sensitivity to perturbations, enabling a variety of interesting quantum and classical strong interaction phenomena. Originally a theoretical curiosity, advances in nanofabrication now allow flatband physics to be observed in a variety of settings including electronic moire materials and photonic crystals. In this talk I will survey the history of this field before discussing emerging applications to the design of giant light-matter interactions using fine-tuned arrays of silicon nanoparticles.

# 4 Posters

As previously, we have a full session (Thursday after lunch) with no parallel technical sessions where all IPS participants get your audience for a supershort (3 minutes) presentation on a poster if the authors want to participate. In order to encourage authors to participate, we will choose the Best Poster Award this year form those submissions where there was short presentation in this session.

For this, we just project your poster on the screen in the lecture hall (please provide us with a PDF file for that purpose). You can email this to us via posters@ipsmeeting.org, or leave it with the reception desk.

## IPS Best Poster Award

During the conference the program committee will select the three best poster presentations for the IPS Best Poster Award. The award will be handed over to the winners at the Pizza session after the end of the poster session on Thursday evening, probably around 5.30pm-6.30pm.

## General poster presentation

### Format

The poster walls fit a A1 sized poster (portrait orientation).

### Poster Abstracts

#### PO.6 Beyond Newton: A Comprehensive Approach to Applied Force Equations

Amritpal Singh Nafria* (Lovely Professional University)

This paper explores the historical journey of applied force equation, from ancient philosophical roots to Newton's seminal $F = m \cdot a$. Highlighting the oversight of resistance forces in classical formulations, a new equation, $F = r + m \cdot a$, is proposed to fill this gap. By integrating resistance, this framework provides a more holistic understanding of force dynamics, aligning with special relativity principles without invoking relativistic mass increase. Practical implications are discussed, underscoring the model's utility in real-world scenarios and its contribution to advancing scientific understanding of physical phenomena.

#### PO.8 The interplay of topology and antiferromagnetic order in two-dimensional van der Waals crystals of $(Ni_xFe_{1-x})_2P_2S_6$

Nasaru Khan*, Deepu Kumar, Vivek Kumar, Yuliia Shemerliuk, Sebastian Selter, Bernd Buchner, Koushik Pal, Saicharan Aswartham, Pradeep Kumar (Indian Institute of Technology Mandi)

Mermin-Wagner theorem forbid spontaneous symmetry breaking of spins in one/two-dimensional systems at finite temperature and rules out the stabilization of this ordered state. However, it does not apply to all types of phase transitions in low dimensions such as topologically ordered phase rigorously shown by Berezinskii-Kosterlitz-Thouless (BKT) and experimentally realized in very limited systems such as superfluids, superconducting thin films. Quasi two-dimensional van der Waals magnets provide an ideal platform to investigate the fundamentals of low-dimensional

magnetism. We explored the quasi two-dimensional (2D) honeycomb antiferromagnetic single crystals of $(Ni_xFe_{1-x})_2P_2S_6$ (x = 1, 0.7, 0.5, 0.3 & 0) using in depth temperature dependent Raman measurements supported by first-principles calculations of the phonon frequencies. Quite surprisingly, we observed renormalization of the phonon modes much below the long-range magnetic ordered temperature attributed to the topological ordered state, namely the BKT phase, which is also found to change as a function of doping. The extracted critical exponent of the order-parameter [spin-spin correlation length] evince the signature of topologically active state driven by vortex-antivortex excitations. As a function of doping, a tunable transition from paramagnetic to antiferromagnetic ordering is shown via phonons reflected in the strong renormalization of the self-energy parameters of the Raman active phonon modes. The extracted exchange parameter (J) is found to vary by $\approx$100 % with increasing the value of doping, ranging from  6 meV (for x = 0.3) to 13 meV (for x = 1).

### PO.13 Nonlocal Dispersion Compensation in Long-Distance Distribution of On-Chip Polarization Entangled Photons

Jinyi Du*, Xingjian Zhang, Arya Chowdhury, Tanvirul Islam, Jia Boon Chin, En Teng Lim, George F.R. Chen, Hongwei Gao, Dawn Tan, Alexander Ling (Centre for Quantum Technologies, National University of Singapore)

We developed a polarization-entangled photon source using a silicon chip with a raw entangled photon rate of 460,000 counts per second (cps) and a fidelity of 98%. This brightness is 3 orders of magnitude higher than the previous reports. The entangled photons were successfully transmitted through 93 km of metropolitan deployed fiber, resulting in an observed entangled pair rate of 20 cps. By employing nonlocal dispersion compensation technology, we improved the fidelity to  94%.

### PO.18 Small satellite-based quantum communication and quantum key distribution; challenges and outlook

Tanvirul Islam*, Jasminder S Sidhu, Brendon Higgins, Thomas Brougham, Tom Vergoossen, Daniel Oi, Thomas Jennewein, Alexander Ling (National University of Singapore)

In this talk we discuss challenges towards implementing a small satellite-based quantum key distribution (QKD) and quantum communication system in low Earth orbit. We discuss simulated QKD performance of CQT-Sat. This model encompasses several upcoming missions. Building on this, we show how the system requirements and performance would scale if higher altitude orbits were considered. Finally, we highlight the short and long-term perspectives on the challenges and potential future developments in small-satellite-based QKD and quantum networks.

### PO.20 Witnessing Non-Gaussian Entanglement in cQED Devices With Conditional Displacement Gates

Lin Htoo Zaw* (Centre for Quantum Technologies)

In weakly-dispersive cQED devices, conditional displacement (CD) gates are used to probe the characteristic function of cavity states. However, most existing continuous variable entanglement witnesses are based on Wigner function measurements or quadrature correlations, so past demonstrations of entanglement have resorted to state tomography, which is an expensive operation. As an alternative, I recently proposed a non-Gaussian entanglement witness that uses only CD gates and qubit readouts [Phys. Rev. Lett. 133, 050201 (2024)]. The witness is a consequence of a result from harmonic analysis and a surprising connection between two negativities: that of the reduced Wigner function, and that of the partial transpose. It requires as few as four points of the characteristic function, and simultaneously lower bounds both the Wigner negativity volume and an entanglement monotone conjectured to be the partial transpose negativity.

### PO.21 An even-parity precession protocol for detecting nonclassicality and entanglement

Jinyan Chen*, Jackson Tiong*, Lin Htoo Zaw*, Valerio Scarani* (Centre for Quantum Technologies; Department of Physics, National University of Singapore)

We introduce an even-parity precession protocol that can detect nonclassicality of some quantum states using only measurements of a uniformly-precessing variable at different points in time. Depending on the system under study, the protocol may detect the Wigner negativity of a single quantum harmonic oscillator or of a single spin $j \geq 2$; the non-Gaussian entanglement of two harmonic oscillators; or genuine multipartite entanglement of a spin ensemble, whose total spin is integer. Unlike other nonclassicality tests, simultaneous or sequential measurements are not required. Our protocol can also detect states that commute with the parity operator, which were missed by similar protocols built from Tsirelson's original precession protocol. This work also closes a long-standing gap by showing the possibility of detecting the Greenberger–Horne–Zeilinger entanglement of an even number of qubits using only collective spin measurements.

### PO.22 Tsirelson's Precession Protocol: A Theory-independent Bound Saturated by Quantum Mechanics

Lin Htoo Zaw*, Mirjam Weilenmann, Valerio Scarani (Centre for Quantum Technologies)

Tsirelson's precession protocol certifies the nonclassicality of a system by asking how often a uniformly-precessing variable is positive at one of three equally-spaced points in time [arXiv:quant-ph/0611147]. It does not require simultaneous or sequential measurements like other nonclassicality tests, and has also been shown to be useful for detecting Wigner negativity and entanglement. Recently, we studied the precession protocol in a theory-independent manner for systems with finitely many measurement outcomes, and derived a general bound which depends only on certain values of the outcomes [arXiv:2401.16147]. We prove that, unlike Bell and noncontextuality inequalities, quantum theory saturates the general bound. Notably, it is saturated by the angular momentum of a spin-3/2 particle. As such, the precession protocol falsifies any general theory that does not also saturate this bound.

### PO.25 Resolving Measurement Incompatibility through Optimal Control of Spin-Dependent Displacement and Squeezing

Wen Han Png*, Travis Nicholson*, Haonan Liu* (IonQ)

We present a novel quantum multiparameter sensing protocol based on quantum measurement model, and resolve the measurement incompatibility issue due to residual entanglement between the pointer and the probe. We consider a quantum sensor with collective qubits (pointer) sharing a common sensor bus (probe). Our sensing protocol estimates multiple correlated parameters from linear perturbations on the bus. Information transfer via (i) spin-dependent displacement or (ii) spin-dependent squeezing is then readout using (i) the collective spin operator or (ii) the interacting spin operator. We show that optimal control on laser amplitude and sensing duration decouples the bus from the qubits and remove measurement incompatibility, achieving the quantum Cramér-Rao bound (QCRB) for Heisenberg and "super-Heisenberg" limits. We then confirm the QCRB scaling through numerical simulations with a 1D trapped ion chain estimating centre-of-mass position of 2 charges.

### PO.28 Classically Spoofing System Linear Cross Entropy Score Benchmarking

Andrew Tanggara*, Mile Gu, Kishor Bharti (Centre for Quantum Technologies)

In recent years, several experimental groups have claimed demonstrations of "quantum supremacy" or computational quantum advantage. A notable first claim by Google Quantum AI revolves around a metric called the Linear Cross Entropy Benchmarking (Linear XEB), which has been used in multiple quantum supremacy experiments since. The complexity-theoretic hardness of spoofing Linear XEB has nevertheless been doubtful due to its dependence on the Cross-Entropy Quantum Threshold (XQUATH) conjecture put forth by Aaronson and Gunn, which has been disproven for sublinear depth circuits. In efforts on demonstrating quantum supremacy by quantum Hamiltonian simulation, a similar benchmarking metric called the System Linear Cross Entropy Score (sXES) holds firm in light of the aforementioned negative result due to its fundamental distinction with Linear XEB. Moreover, the hardness of spoofing sXES complexity-theoretically rests on the System Linear Cross-Entropy Quantum Threshold Assumption (sXQUATH), the formal relationship of which to XQUATH is unclear. Despite the promises that sXES offers for future demonstration of quantum supremacy, in this work we show that it is an unsound benchmarking metric. Particularly, we prove that sXQUATH does not hold for sublinear depth circuits and present a classical algorithm that spoofs sXES for experiments corrupted with noise larger than certain threshold.

### PO.29 Skyrmion Nucleation and Stability in Two-Dimensional Magnetic Lattices

Vitalii Kapitan*, Egor Vasiliev (National University of Singapore)

Magnetic systems, in which magnetic vortex textures, skyrmions, appear due to competition between the direct Heisenberg exchange and the Dzyaloshinskii-Moriya interaction (DMI), were studied using the Metropolis algorithm. At the fundamental level, skyrmions are model systems for topologically protected spin textures and can be considered as analogs of topologically protected states, emphasizing the role of topology in the formation of complex states of condensed matter. In our research, the conditions for the nucleation and stable existence of magnetic skyrmions in two-dimensional magnetic films were considered within the framework of the classical Heisenberg model. We studied several types of flat lattices: a honeycomb lattice with 3 nearest neighbors (NN), a square lattice with 4 NN, and a hexagonal or triangular lattice with 6 NN. To analyze the data obtained during the Monte Carlo simulation, a convolutional neural network was used for recognizing different phases of the spin system depending on various simulation parameters such as DMI, external magnetic field (B), and temperature (T). Based on these data, two types of phase diagrams (B,T) and (D,B) were plotted. The various states of the systems under observation were visualized, and the boundaries between the different phases, such as spiral, skyrmion, and others, were defined. In addition, we investigated several methods for controlling the motion of skyrmions during Monte Carlo simulations. Funded by Singapore MoE Tier 1 grant entitled "MAPLE" with grant number 22-5715-P0001.

### PO.31 Incorporating 3D pore interconnectivity into disordered carbon towards reliable supercapacitors at harsh cycling conditions

Carlos Limpo*, Jong Hak Lee, Barbaros Ozyilmaz (National University of Singapore)

Recent findings suggest that increasing the structural disorder of carbons can play a crucial role towards overcoming energy density limitations associated with EDLCs, in a non-trivial way. However, it is expected that disorder-driven capacitance compromises on the lifespan of the device, because modes of structural disorder inevitably increase the electrochemical reactivity of the system, thereby enabling irreversible electrolyte degradation, leading to pore blocking and loss of access to charge storage sites. Here we present Nanoporous Amorphous Carbon (NAC) with a high degree of 3D pore interconnectivity and propose how a 3D interconnected pore architecture proves instrumental to enhancing the cycling resilience of disordered carbon-based devices. A highly 3D interconnected and hierarchical pore structure provides multiple paths of access to charge storage sites, thereby avoiding premature pore clogging and immediate loss of performance especially under high voltages or high temperatures. By further comparing the performance of a disordered carbon against commercial carbon as well as a highly crystalline alternative, we conclude that developing this approach can overcome the limitations of disordered carbons and work synergistically to create resilient devices for future applications.

### PO.32 Quantifying the Limits of Classical Machine Learning Using Quantum Contextuality

Eric R. Anschuetz, Mariesa Teo*, Willers Yang*, James Sud, Christopher Kang, Teague Tomesh, Frederic T. Chong (Department of Computer Science, University of Chicago)

Classical machine learning models struggle with learning and prediction tasks on data sets exhibiting long-range correlations. To quantify this observation we introduce a new quantity we call strong k-contextuality, develop efficient algorithms to estimate the strong k-contextuality of an empirical data set, and prove that the presence of strong k-contextuality lower-bounds the classical resources required to model the associated distribution. We also show that this correlation measure does not induce a similar bound for quantum generative models, and thus propose strong k-contextuality as an empirical measure for evaluating whether a given machine learning task is better suited for quantum models than classical models.

### PO.33 Measurement of total phase fluctuation in cold-atomic quantum simulator

Taufiq Murtadho*, Federica Cataldini, Sebastian Erne, Marek Gluza, Jörg Schmiedmayer, Nelly Huei Ying Ng* (Nanyang Technological University)

Studying the dynamics of quantum many-body systems is often constrained by the limitations in probing relevant observables, especially in continuous systems. A prominent example is two parallel 1D Bose gases, which simulate 1D quantum field theories through the phase difference probed by interference. Here we introduce a method to extract the total phase of the combined system based on a general principle of reconstructing phase gradient from density dynamics using continuity equation. This approach reveals the previously hidden sector of the sum mode of the two 1D Bose gases. Knowledge about the dynamics in the sum sector becomes important when studying long-time thermalisation behaviour or testing the validity of the quantum field simulators, which rely on a separation of the difference and sum sectors. We validate our technique numerically and demonstrate its effectiveness by analysing data from selected experiments, showcasing how our method expands the scope and capabilities of cold-atomic quantum simulators.

### PO.34 Realizing strong atom-light coupling with near-concentric cavities

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

In the field of cavity quantum electrodynamics (CQED), optical cavities are used to engineer strong atom-light interactions, making them a promising platform in implementations of atom-light interfaces. While there has been a lot of research involving the use of small, near-planar cavities to reach high coupling strengths, similar coupling strengths can also be achieved with larger cavities by strongly focusing the cavity mode at the center of the cavity in a near-concentric configuration. While this configuration offers high cooperativity values even when using relatively low reflectivity mirrors, near-concentric cavities are highly sensitive to transverse misalignments between the mirrors. Previous attempts to construct a near-concentric cavity with a 3D stage faced difficulties in stabilizing the cavity length. Here, we present a near-concentric cavity design using only tip-tilt adjustments to realign the cavity. We demonstrate operation very close to the edge of the stability criterion while still exhibiting good stability. Using this cavity, we managed to load multiple Rb atoms into a single cavity mode to achieve a strong collective coupling strength. Through observation of the vacuum Rabi splitting effect, we measure a coupling strength of $g = 2\pi \times 25.3(4)\,\text{MHz}$. With cavity and atomic decay rates of $(\kappa, \gamma) = 2\pi \times 21(1), 3.03\,\text{MHz}$, this puts us in the strong coupling regime with cooperativity of C = 5.

### PO.35 Defect-mediated ionic transport in layered beta and beta prime prime aluminas

Suchit Negi*, Alexandra Carvalho*, Antonio Castro Neto* (National University of Singapore)

Alkali metal $\beta/\beta''$ aluminas are among the fastest ionic conductors, yet little is understood about the role of defects in the ion transport mechanism. We used density functional theory (DFT) to investigate the crystal structures of $\beta$ and $\beta''$ phases, and vacancy and interstitial defects in these materials. We find that charge transport is likely to be dominated by alkali metal interstitials in $\beta$-aluminas and by vacancies in $\beta''$ aluminas. Lower bounds for the activation energy for diffusion are found by determining the minimum energy paths for defect migration. The resulting migration barriers are lower than the experimental activation energies for conduction in Na $\beta$ and $\beta''$ aluminas, suggesting a latent po tential for optimization. The lowest activation energy of about 20 meV is predicted for correlated vacancy migration in K [1]

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### PO.37 Limits on Prediction in Quantum Mechanics

Graeme Berk*, Jayne Thompson, Mile Gu* (Nanyang Technological University)

Fundamental limits set the boundaries of what even the most futuristic technologies can achieve. In this work, we find a lower bound on the memory required for prediction under quantum mechanics.

Decades ago, the provably memory-minimal classical model of a classical process, known as its epsilon-machine, was first described. Epsilon-machines are constructed by invoking causal equivalence of future morphs (CEFM) — if two sequences of past observations lead to the same future statistics, they are stored in the same memory state. Since then, epsilon-machines have been implemented to gain an information-theoretic understanding of notoriously complex systems like financial markets, and states of consciousness in a fly brain. However, quantum models can be more memory-efficient than even the best classical model, and the universe is fundamentally quantum, not classical. Thus, the ultimate limit on prediction is that on quantum models of quantum processes. However, no fully quantum analogue of epsilon-machines has yet been found, perhaps most notably because the existence of quantum superpositions renders CEFM insufficient to reduce quantum processes.

In this work, we present the linear dependence of future morphs (LDFM), which reproduces the pairwise comparison of CEFM, but more generally defines a global linear dependence test that we prove encapsulates causal equivalence in quantum mechanics. Using LDFM, we present a model reduction algorithm, with a simple analytically solvable demonstration. Finally, we prove a lower bound on the memory required to implement a quantum predictive model of a quantum process.

### PO.40 All-Transparent Optical Routers for a Quantum Network

Hou Shun Poh*, Xiao Duan, Matthew Wee, Yu Cai, Jing Yan Haw, Hao Qin, Christian Kurtsiefer, Michael Kasper, Euk Jin Alexander Ling (Centre for Quantum Technologies, National University of Singapore)

Quantum networks could potentially be embedded in the existing telecom optical fibre networks provided the routes between the nodes are transparent, preserving the quantum states of the transported photons. Commercial-off-the-shelf optical fibre switches were found to be suitable for use in establishing such transparent routes between different nodes. Based on a possible network topology, we implemented optical routers that incorporated these optical fibre switches.

A commercial QKD system that implements BB84 in a prepare and measure protocol with phase-encoding was used to test these routers under real world conditions. Without the routers, a key rate of 655 kbps$\pm$4% and QBER of 2.5% were observed. The routers were then introduced to periodically switch between two fibres, both with comparable lengths as the fibres in the earlier measurement, serving as different quantum channels between the sender and receiver. Over a 24-hour period, key rates 329 kbps$\pm$2 % and 419 kbps$\pm$2% were obtained with the two quantum channels, respectively. These results indicate an insertion loss of $<$0.3 dB and a high degree of switching repeatability in the routers. Over the same period, no change in QBER was observed due to the routers.

One of the applications for these optical routers in quantum networks is in the automated failover in an event of failure of the primary to a standby quantum channel. This was demonstrated with the same QKD system with a primary and standby quantum channels consisting of deployed dark fibre with lengths of 20 km and 28 km, respectively.

### PO.42 Quantum Relativistic vs. Quantum Non-Relativistic Free Rotor Factorization Scheme in the Non-Relativistic Regime

Yohashama P Sivagnana Kumaran*, Lan Boon Leong (Methodist College Kuala Lumpur)

It is known that the autocorrelation function of the non-relativistic quantum free rotor can be used as an effective factorization scheme. However, as actual quantum systems are more accurately described by relativistic quantum theory, and it has been shown that there can be discrepancies between the relativistic and non-relativistic quantum free rotor over time even in the non-relativistic regime. It is not known whether the relativistic quantum free rotor's autocorrelation function be used to factorize any integer before its breakdown of agreement with the non-relativistic quantum free rotor. Hence, here we evaluated the properties of the non-relativistic quantum free rotor's autocorrelation function that is useful for factorization and showed that the relativistic autocorrelation function is well approximated by its non-relativistic counterpart for a finite time proportional to the square root of the radius of the rotor. Therefore, in theory, the number that can be factored with the relativistic quantum free rotor approaches infinity as the radius approaches infinity in the non-relativistic regime.

### PO.43 Electrical transport in graphene proximitized with $Ta_2NiSe_5$ nanoflakes

Leonid Elesin*, Andrei Kudriashov, Denis Bandurin* (Department of Materials Science and Engineering, National University of Singapore)

Graphene, one of the most extensively studied two-dimensional materials, is frequently employed to investigate other Van der Waals crystals by placing them in close proximity. Deviations in the electronic transport of graphene in such systems can be easily distinguished and potentially attributed to interface phenomena or the intrinsic properties of the material under study. In this research, we examine the electronic transport properties of graphene placed atop $Ta_2NiSe_5$, a promising candidate for an excitonic insulator, both with and without a thin hBN spacer between them. While the major properties of graphene remained largely unchanged, we observed two significant differences: an abnormal p-doping of graphene in contact with $Ta_2NiSe_5$ with suppressed back gating, which we interpret as charge transfer from graphene to $Ta_2NiSe_5$, and an unconventional ferroelectric transition ($T_c \approx 12$K) in encapsulated graphene on top of $Ta_2NiSe_5$, potentially indicative of excitonic ferroelectricity.

### PO.50 A temperature-insensitive source of polarization-entangled photon pairs using a single-domain crystal through Noncritical Birefringent Phasematching

Jia Boon Chin*, Diane Prato, Alexander Ling (Centre for Quantum Technologies, National University of Singapore)

Noncritical birefringent phasematched (NBPM) Type-II spontaneous parametric downconversion (SPDC) was used to produce polarization-entangled photon pairs with a 50mm single-domain potassium titanyl phosphate (KTP). The KTP was pumped with a laser at 405.75nm to produce highly non-degenerate photon pairs, with the signal photon at 562nm and the idler photon at 1455nm. The source was robust to temperature changes, with the central wavelength of the idler photon was observed to change by 11nm over a temperature change of 80 degrees

Celsius. The average entanglement visibility was maintained above 95% throughout the temperature range. The high temperature stability makes this approach of generating and distributing polarization-entangled photon pairs suitable for field deployment without temperature control.

### PO.55 Anomalous interference pattern in $NbSe_2/Bi_2Se_3$ SQUID

Andrei Kudriashov*, Xiangyu Zhou, Leonid Elesin, Denis Bandurin* (Department of Materials Science and Engineering, National University of Singapore, Singapore 117575, Singapore)

Hybrid structures composed of superconductors (S) and topological insulators (TIs) offer an important platform for realizing and exploring novel quantum states of matter. One particularly interesting example is an S/TI/S Josephson junction, which is often considered a model platform for searching for Majorana states (MS), critical for realizing topological quantum computing. Experimental signatures of such states are fairly limited and, at present, remain controversial. Among the various methods for identifying MS in S/TI/S Josephson junctions, direct measurements of their current-phase relation stand out due to expected MS-enabled anomalies when the magnetic flux through the junction is close to an integer number of flux quanta. To explore this effect, we fabricated a superconducting quantum interference device (SQUID) using two $NbSe_2/Bi_2Se_3/NbSe_2$ Josephson junctions, employing all-2D Josephson junctions. Our experiments revealed an unusual interference pattern in the vicinity of Fraunhofer minima. In this presentation, we will discuss the possible origins of these anomalies and their relation to Majorana physics.

### PO.57 Towards efficient quantum state tomography

Yanglin Hu*, Enrique Cervero-Martin*, Elias Theil*, Laura Mančinska*, Marco Tomamichel* (National University of Singapore)

Quantum state tomography is the fundamental physical task of learning a complete classical description of an unknown state of a quantum system given coherent access to many identical samples of it. The complexity of this task is commonly characterised by its sample-complexity, the minimal number of samples needed to reach a certain target precision of the description. While the sample complexity of quantum state tomography has been well studied, the memory complexity has not been investigated in depth. Indeed, the bottleneck in the implementation of naïve sample-optimal quantum state tomography is its massive quantum memory requirements. In this work, we propose and analyse a streaming quantum state tomography algorithm which retains sample-optimality but is also memory-efficient.

### PO.58 One-step Synthesis of Interface-fortified monolithic structural supercapacitor for high multifunctional efficiency

Yifan Rao*, Jonghak Lee, Barbaros Özyilmaz, Yanhui Pu, Yongkang Ong (National University of Singapore, Materials Science and Engineering)

Structural supercapacitors, potential game-changers for various applications such as aerospace, automotive, and construction industries, offer a combination of energy storage and load-bearing functionalities. Conventional methods, however, have been hindered by a significant decrease in overall energy storage performance due to the inherent separation of energy storage components and structural reinforcement elements, resulting in a mere juxtaposition of these distinct functionalities. In this study, through the one-step integration of multi-layered precursors, we fabricated robust all-in-one structural supercapacitors with interlocking electrode-separator interface engineering. This integrated device can tailor the conventional trade-off problem between energy capacity and mechanical strength by ensuring that the essential components for energy storage have high mechanical properties. As a result, our structural supercapacitor demonstrates exceptional structural integrity, as evidenced by its high flexural modulus. Moreover, our supercapacitor stands out in terms of energy storage capacity, boasting superior volumetric energy density. This achievement in electrochemical performance is truly extraordinary, outperforming the current state-of-the-art. Our novel strategy not only provides a groundbreaking way to fabricate structural supercapacitors but also paves the way for other structural energy storage devices with higher multifunctional efficiency.

### PO.60 Entanglement Phase Transition Due to Reciprocity Breaking without Measurement or Postselection

Gideon Lee*, Tony Jin, Yu-Xin Wang, Alexander McDonald, Aashish Clerk (University of Chicago)

Despite its fully unitary dynamics, the bosonic Kitaev chain (BKC) displays key hallmarks of non-Hermitian physics, including nonreciprocal transport and the non-Hermitian skin effect. Here, we demonstrate another remarkable phenomena: the existence of an entanglement phase transition (EPT) in a variant of the BKC that occurs as a function of a Hamiltonian parameter g and which coincides with a transition from a reciprocal to a nonreciprocal phase. As g is reduced below a critical value, the postquench entanglement entropy of a subsystem of size l goes from a volume-law phase, where it scales as $l$, to a supervolume-law phase, where it scales like $lN$, where N is the total system size. This EPT occurs for a system undergoing purely unitary evolution and does not involve measurements, postselection, disorder, or dissipation. We derive analytically the entanglement entropy out of and at the critical point for the cases of $l = 1$ and $l/N \ll 1$.

### PO.62 Purcell enhancement of Erbium emission using High-Q microring resonators on Lithium Niobate

Karthik Dasigi*, Kah Jen Wo, Pavel Dmitriev, Steven Touzard* (Center for Quantum Technologies, NUS)

Telecom frequencies are ideal for room-temperature quantum networks due to the presence of existing infrastructure comprising of optical fibers with low propagation loss and. However, most quantum devices currently operate at microwave frequencies, whose photons attenuate quickly in non-cryogenic environments and are incompatible with fiber-optic architecture. Therefore, a critical component of a quantum network would be an efficient microwave-optical transducer which implements the required frequency conversion. One promising candidate to implement such a conversion are $Er^{3+}$ ions due to their accessible telecom and microwave frequency energy splittings with large lifetimes at cryogenic temperatures. To effectively utilize $Er^{3+}$ ions for this purpose, it is necessary to achieve Purcell enhancement and a large collective coupling with a frequency resonator. Engineering such a device presents challenges, including selecting an appropriate host crystal for $Er^{3+}$, finding an integrated photonics platform capable of implementing low-loss resonators with frequency tuning at cryogenic temperatures, and ensuring interaction between the telecom mode on the integrated photonics chip and the spins in the host crystal. To this end, in our poster, we present our proposed transducer scheme using Lithium Niobate (LN) for the integrated photonics and Calcium Tungstate ($CaWO_4$) as a suitable host for $Er^{3+}$ ions. In particular we present our progress in reliably fabricating low loss, high-Q mirroring resonator circuits in LN, and the tuning of their resonance frequencies leveraging the Pockel's effect. Moreover, we discuss our advancements in flip-chip bonding Er:$CaWO_4$ to LN integrated photonic circuits that survive thermal cycling to cryogenic temperatures.

### PO.63 Quantum Pattern Engine

Huang Ruocheng*, Paul Riechers, Mile Gu, Varun Narasimhachar (NTU)

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 modeling of non- Markovian classical and quantum stochastic processes. We combine tools from these two sciences to develop a technique for predictive work extraction from non-Markovian stochastic processes with quantum outputs. We demonstrate that this technique can extract more work than non-predictive quantum work extraction protocols, on the one hand, and predictive work extraction without quantum information processing, on the other. We discover a phase transition in the efficacy of memory for work extraction from quantum processes, which is without classical precedent. Our work opens up the prospect of machines that harness environmental free energy in an essentially quantum, essentially time- varying form.

### PO.64 Thulium-doped fiber amplifier intensity stabilization for quadrupole transition

Jia-Yang Gao*, Jasper Phua Sing Cheng, Morteza Ahmadi, Manas Mukherjee (Centre for Quantum Technologies, National University of Singapore)

Intensity noise is a factor limiting the coherence time of qubits in trapped ion quantum systems. Previously, we observed that using a Thulium-doped fiber amplifier (TDFA) introduces intensity fluctuations to the input seed laser, thus limiting the coherence time. To address this issue, we developed an intensity stabilization setup for a 1762 nm laser used for quadrupole transition, employing an acousto-optic modulator (AOM) with an electrical feedback servo. Our results demonstrate that this setup can reduce intensity noise by up to 20 dB from DC to 10 kHz without introducing additional phase noise to the input signal. The phase noise of the laser was analyzed using delayed self-heterodyne interferometry (DSHI). We tested the stabilized beam with a single ion in our ion trap setup. Based on the Rabi oscillation, we suspect that there is another dominant noise source (servo bump phase noise from PDH locking) masking the improvement from the intensity stabilization. Removing this servo bump phase noise is our next step.

### PO.65 Certification of genuine multipartite entanglement in spin ensembles with measurements of total angular momentum

Khoi-Nguyen Huynh-Vu*, Lin Htoo Zaw, Valerio Scarani (Centre for Quantum Technologies)

We introduce entanglement witnesses for spin ensembles which detect genuine multipartite entanglement using only measurements of the total angular momentum. States that are missed by most other angular-momentum-based witnesses for spin ensembles, which include Greenberger-

Horne-Zeilinger states and certain superpositions of Dicke states, can be effectively detected by our witness. The protocol involves estimating the probability that the total angular momentum is positive along equally-spaced directions on a plane. Alternatively, one could measure along a single direction at different times, under the assumption that the total spins undergoes a uniform precession. Genuine multipartite entanglement is detected when the observed score exceeds a separable bound. Exact analytical expressions for the separable bound are obtained for spin ensembles $j_1 \otimes j_2 \otimes \cdots \otimes j_N$ such that the total spin is a half-integer, and numerical results are reported for the other cases. Finally, we conjecture an expression for the separable bound when the total spin is not known, which is well supported by the numerical results.

### PO.66 Topological 5d N=2 Gauge Theory: Novel Floer Homologies, their Dualities, and an A-infinity-category of Three-Manifolds

Arif Er*, Zhi-Cong Ong, Meng-Chwan Tan (National University of Singapore)

We show how one can define novel gauge-theoretic Floer homologies of four, three and two-manifolds from the physics of a certain topologically-twisted 5d N=2 gauge theory via its supersymmetric quantum mechanics interpretation. They are associated with Vafa-Witten, Hitchin and $G_C$-BF configurations on the four, three and two-manifolds, respectively. We also show how one can define novel symplectic Floer homologies of Hitchin spaces, which in turn will allow us to derive novel Atiyah-Floer correspondences that relate our gauge-theoretic Floer homologies to symplectic intersection Floer homologies of Higgs bundles. Furthermore, topological invariance and 5d "S-duality" suggest a web of relations and a Langlands duality amongst these novel Floer homologies and their loop/toroidal group generalizations. Last but not least, via a 2d gauged Landau-Ginzburg model interpretation of the 5d theory, we derive, from the soliton string theory that it defines and the 5d partition function, a Fukaya-Seidel type A-infinity-category of Hitchin configurations on three-manifolds and its novel Atiyah-Floer correspondence. Our work therefore furnishes purely physical proofs and generalizations of the mathematical conjectures of Haydys, Abouzaid-Manolescu, and Bousseau, and more.

### PO.68 Tunable carrier-mediated ferromagnetism in a Van der Waals semiconductor up to room temperature

Chang Xiao, Qu Tingyu*, Barbaros Oezyilmaz* (National University of Singapore)

Ferromagnetic semiconductors, marrying electrical tunability with nonvolatility, herald promise for the innovation of spin-based logic devices. However, the realization of room-temperature ferromagnetic order has been elusive despite relentless pursuits spanning decades. In this study, we exploit the ability to intercalation-dope layered Van der Waals semiconductors, ensuring minimal disruption to lattice coherency, resulting in the achievement of ferromagnetism in Co-doped black phosphorus (Co-BP) up to room temperature while preserving its semiconductor characteristics. This heralds a transformative advance, as evidenced by the gate-tunable, carrier-mediated room-temperature ferromagnetism, further authenticated through its resilient performance as a ferromagnetic contact in semiconducting tunnelling spin-valves and a notable anisotropic magnetoresistance. This work unveils the capability of electric field in dictating the dominant majority/minority spins, facilitating unprecedented gate-controllable inversion and a deliberate suppression of tunnelling magnetoresistance as needed. The Anomalous Hall Effect is presented to substantiate the consistent lateral transport performance of Co-BP, reinforcing the manifesta-

tion of ferromagnetism within the system. This breakthrough not only unveils a novel class of ferromagnetic semiconductors but also inaugurates a versatile pathway to imbue atomically-thin layered materials with engineered ferromagnetism, broadening the horizon of feasible applications of magnetic semiconductors previously conceived.

### PO.70 Fabrication of All-2D Planar Josephson Junctions Using Air-Sensitive vdW Materials

Xiangyu Zhou, Andrei Kudriashov*, Leonid Elesin, Sergey Grebenchuk*, Denis Bandurin* (Department of Materials Science and Engineering, National University of Singapore, Singapore 117575, Singapore)

Van der Waals (vdW) materials placed in close proximity between two superconductors can form unique types of Josephson Junctions (JJ), offering a promising platform for investigating new fundamental phenomena and prototyping future technologies. Applications such as superconducting (topological) quantum bits, infrared single-photon detectors, bolometers, superconducting diodes, and sensitive magnetometers are just a few examples where vdW-based JJs could pave the way for the design of novel devices with on-demand properties. However, the typical approach for fabricating JJs, such as sputtering superconducting contacts, is challenging and requires precise tuning of parameters to achieve good contact with the non-superconducting region. Additionally, when dealing with air-sensitive vdW materials, sputtering can degrade the surface, resulting in a poor interface.

To address this issue, we utilize cracked $NbSe_2$ to build planar JJs [Nano Lett. 2023, 23, 13, 6102–6108] in the inert environment of an argon-filled glovebox. This approach allows us to use the standard dry-transfer technique for vdW materials to assemble our JJs, preventing exposure to air and degradation from metal deposition. Using this method, we successfully constructed JJs with Bernal-stacked bilayer graphene and the topological insulator $Bi_2Se_3$ as weak links. Both types of devices exhibit gate-tunability and high-density critical currents, indicating high-quality interfaces between superconducting and non-superconducting vdW compounds. Our approach makes all-2D JJs an exciting platform for investigating further effects arising from the interplay between superconductivity and various new quantum phases recently discovered in the flatland.

### PO.72 THz photoresponse of Schwinger-driven electron-hole plasma in graphene

Mikhail Kravtsov*, Artur Shilov*, Yaping Yang, Mikhail Kashchenko, Olga Popova, Maria Titova, Daniil Voropaev, Kirill Shein, Mikhail Lukianov, Andrei Kudriashov*, Adam Shaffique, Konstantin Novoselov, Maxim Trushin, Denis Bandurin* (Department of Materials Science and Engineering, National University of Singapore, 117575 Singapore)

Interacting electron fluids in low-dimensional materials exhibit a series of intriguing effects when they are driven out-of-equilibrium. By subjecting an electron system to a strong electric field, a Fizeau drag effect [1, 2] and Cherenkov phonon emission [3] was observed in graphene. Recent experiments showcase another unusual effect embedded by its high-energy physics analogy - the Schwinger effect [4, 5].

In relativistic quantum field theory, when the electric field becomes large enough, it can split apart virtual particles, forming a particle and an antiparticle out of empty space. In condensed matter physics, if the speed of light is substituted with the Fermi velocity, the quasi-relativistic energy spectrum of graphene can give rise to a solid-state counterpart of this effect. Since created particle-antiparticle pairs are analogous to electron-hole plasma, the mesoscopic Schwinger effect can be observed at electric fields much lower than those expected from high-energy physics and such phenomena become accessible in the lab.

Here we report the anomalous response of Schwinger-driven electron-hole plasma to incident electromagnetic radiation with a frequency of 140 GHz. The observed behaviour of our biased graphene device carries the potential implications for understanding the mechanisms behind this exotic out-of-equilibrium state of matter, including far-IR photovoltaics and radiation-driven Zener-Klein tunneling. The observed effect might be described as a quasi-relativistic analogue of the EM-wave induced ionization Keldysh effect [6]. The further investigation of the complex behaviour of relativistic electron-hole plasma under sub-THz and THz incident radiation in biased devices can, in principle, open a backdoor to otherwise challenging to probe experimentally high energy physics studies using condensed matter physics toolbox.

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## PO.73 Variational Quantum Approach to the Nonlinear Schrödinger Equation on Superconducting NISQ Processors

Muhammad Umer*, Eleftherios Mastorakis, Sofia Evangelou, Dimitris G. Angelakis (Centre for Quantum Technologies, National University of Singapore, 3 Science Drive 2, Singapore 117543)

Variational quantum algorithms have garnered significant interest due to their potential in addressing complex computational problems. In this study, we leverage a variational algorithm [1-2], originally conceived within the framework of computational fluid dynamics, to determine the ground state of the nonlinear Schrödinger equation on superconducting quantum processors. We evaluate the expressivity of a real-amplitude ansatz in capturing the system's physics across a spectrum of interaction regimes, each characterized by varying strengths of nonlinearity. Our findings indicate that, despite the detrimental effects of quantum noise on the evaluation of the energy cost function, small-scale problem instances consistently converge to the correct ground state. Extensive simulations were conducted on IBM Q devices, wherein the impact of hardware noise on the quality of solutions was rigorously analyzed. Discrepancies in the energy components were examined, and state fidelity was computed from experimental data, demonstrating a strong correlation with theoretical predictions and noiseless simulations for these problem instances. This comprehensive analysis offers crucial insights into the practical implementation and progression of variational algorithms for nonlinear quantum dynamics on Noisy Intermediate-Scale Quantum (NISQ) devices.

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### PO.76 Precision Ellipsometry for Studies of Molecular Interactions

Nikolai Yakovlev* (National University of Singapore)

Ellipsometry, as optical analytical technique, gains it sensitivity from measurement of phase shift between components of light polarisation rather than intensity. Precision ellipsometry (PREL) uses modulation of polarisation, which makes it even more sensitive: in the range of micro-radians. This translates to 0.01 nm of oxide or organic molecules on silicon substrate. Recent innovations of polarisation modulators allowed making PREL systems compact, low in power consumption, and even portable keeping same sub-nanometre sensitivity. They enable quantitative real-time measurements of molecular interactions, binding, adsorption and desorption on a reflecting substrate in liquid, gas or vacuum. A review of the results on binding of small molecules (amino-silane, tannin) and macromolecules (polyelectrolytes, proteins) will be presented. The most recent innovation is imaging PREL, where a video camera is synchronised with the polarisation modulator. When several receptors are placed on the substrate, it enables measurement of selectivity and affinity of each receptor to one target molecule supplied in solution in one run. All the results show that PREL combines quantitative measurement in real time with high sensitivity and at low cost. Thus it has high analytical potential.

### PO.77 Coherence manipulation by memory-assisted Markovian thermal operations

Xueyuan Hu* (School of Information Science and Engineering, Shandong University)

We investigate the limitations on coherence evolution via Markovian thermal processes (MTP) assisted by a finite-dimensional memory. Here the memory is a d-dimensional quantum system with trivial Hamiltonian and initially in a maximally mixed state. By definition, the memory does not provide any resource such as enery, inequivalence, or coherence. We prove that for given population dynamics, the preserved coherence via memory-assisted Markovian thermal processes (MMTP) can be strickly larger than MTP. Precisely, we design a scheme, where a qubit system and a d-dimentional memory jointly go through a sequence of MTP, and show that the coherence in the reduced state of the qubit can surpass the limitation set by MTP. It means that, the memory, although being unable to hold coherence due to its trivial Hamiltonian, can be helpful in the manipulation of coherence contained in the qubit system. Our result can be helpful in studying the role of memory in non-Markovian thermal processes.

### PO.79 ML-assisted Search for Solid Electrolytes

Artem Maevskiy*, Emil Sataev, Alexandra Carvalho, Keian Noori, Aleksandr Rodin, Andrey Ustyuzhanin (National University of Singapore, Institute for Functional Intelligent Materials)

The development of solid electrolytes advances energy storage technologies by promising safer, more stable batteries with higher energy density. However, typical solid electrolytes have lower ionic conductivity compared to liquid ones, making the discovery of new solids with higher ionic conductivity highly desirable. Traditional first-principles calculations for predicting this property are computationally intensive, limiting large-scale searches across a wide range of materials. In this work, we address this issue by utilizing a machine-learned interatomic potential to narrow down the list of promising candidates. Although machine learning models typically suffer from generalization errors, we mitigate this by creating efficient potential energy surface descriptors from atomic configurations where these errors are minimal. Our designed descriptors correlate well with the ionic conductivity of known and previously studied materials. Furthermore, we use these descriptors to predict new solid electrolyte candidates from the Materials Project database and validate a subset of our predictions using first-principles calculations. Due to their high interpretability, our descriptors can help identify the key features of atomic configurations and their interactions that are most important for ionic transport.

### PO.80 Towards the Entanglement of a Superconducting Qubit to Erbium defects

Kritika Mundeja*, Sakshi Mishra, Zhikun Han*, Steven Touzard* (Centre for Quantum Technologies, National University of Singapore)

Superconducting circuits are promising candidates for building quantum processors due to their scalability, design flexibility, fast gate operations and high fidelity. However, their operation at microwave frequencies presents challenges for integration with existing telecommunication infrastructure which relies on optical fibres for long-distance signal transmission at room temperature. To bridge this frequency gap, we aim to achieve fast and reliable optical-microwave entanglement using rare-earth ions as an intermediary. Our initial focus is on establishing entanglement between an Erbium ion ensemble and a Transmon qubit through a cavity. We leverage the Zeeman splitting of Erbium ions to align with the microwave regime of our superconducting cavity. Additionally, we employ chirped pulses to efficiently retrieve the excitation stored within the ensemble by using a revival of silenced echo protocol. This poster presents our entanglement protocol and results, demonstrating strong spin-resonator cooperativity and high Transmon qubit coherence in a magnetic field, marking a significant advancement in the integration of superconducting circuits with optical-microwave networks.

### PO.81 Energy Harvesting from Sky without Environmental Heating

Jaesuk Hwang* (Centre for Quantum Technologies)

The sun is a vast source of renewable energy and the solar energy is considered the main route in the transition to renewable energy. Although the efficiency of the solar energy harvesting devices has been continually increasing, a significant fraction of the captured solar radiation is unutilised and released into the environment as heat. The collective amount of rejected energy can cause environmental problems at a global scale such as the urban heat island (UHI). It is pointed out that renewable energy harvesting need not inevitably cause environmental heating if a radiative cooling surface is used as a heat sink such that the rejected energy can be radiated into the outer space and removed irreversibly from the earth. This idea is tested using a thermoelectric generator as a specific example of a heat engine. By embedding the radiative cooling surface and the thermoelectric generator within a high vacuum chamber, the conductive and convective heat loss from the heat sink to the surroundings are suppressed to be negligible [1]. The high degree of thermal insulation provided by the vacuum shield also acts to enhance the radiative cooling [2, 3]. A solar-absorbing and infrared-transmitting window of the vacuum chamber [1] enables, during the day, simultaneous harvesting and radiative dissipation within the same footprint and, at night, harvesting from the coldness of the sky, another complementary source of renewable energy. As a result, continuous all-day harvesting of electricity from the sky is demonstrated without releasing heat to the environment [4]. Our findings suggest that it is possible to address the two major environmental issues can in a balanced fashion, namely meeting the renewable energy demand and preventing the global warming.

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### PO.82 Progress Towards a Quantum Simulation of Fermions in Disordered 2D Optical Lattices

Athira Krishnan Sreedevi*, Haotian Song*, Rishav Koirala*, Kai Dieckmann* (Department of Physics, NUS and CQT, NUS)

We present our progress towards a quantum simulation of disordered 2D materials using ultracold fermionic lithium atoms in optical lattices with optical speckles. The setup is a 2D tubular square lattice made from far-detuned laser beams and an additional vertical lattice with tunable lattice constant to freeze the degree of motion in the third direction and ensure two dimensionality. Optical speckles can be focused on atoms to scramble the 2D lattice potentials and the tunneling as well as on-site interactions between the two spin states of the atoms can be tuned. The control to precisely tune these parameters helps study the interplay between interactions and disorder needed to explore different localization phenomena.

### PO.84 Direct imaging of ultracold ground state Li-K molecules

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

Imaging of molecules is commonly done indirectly, for example they are transfered to a weakly bound (Feshbach) state where the individual atoms can be adressed and imaged. This technique is restrictive because it will only image molecules in a single hyperfine state, also since it is done indirectly it involves more processes like cleaning of atoms that are not obtained from the molecules. Our goal is to find an appropiate direct imaging method for LiK molecules that is simpler and flexible than the indirect one.

Our work is towards imaging Li-K molecules via off-resonant techniques that do not rely on a cycling transition, which have been done only for atoms before. They rely on the polarizabilty of the transition, which for molecules is on the same order of magnitude as atoms. The only foreseeable difficulty is the much lower number of molecules that are usually obtained at the ground state, which will reduce the attainable signal-to-noise ratio. This could be solved by selecting an appropiate light detuning such that some molecules are lost to absorption but the polarizability would be high enough to compensate for the overall low number of molecules.

### PO.86 Attempts of nanodiamonds synthesis under room conditions using AFM probe

Denis Baranov*, Colin Woods (National University of Singapore, Institute for Functional Intelligent Materials)

Natural diamonds are formed under high pressure and temperature conditions, deep within the Earth's mantle, where carbon atoms are arranged in a crystal lattice structure. In the laboratory diamonds can be obtained through two main methods: High Pressure High Temperature (HPHT) synthesis and Chemical Vapor Deposition (CVD). But these are all methods for producing large, 3D diamonds from 3D carbon blanks. If we move towards decreasing sizes and, in the limit, move to 2D materials, then in this case the key role in the transformation of several layers of graphite into diamond will be played not so much by temperature and pressure, but also by surface chemistry, interface and interlayers interactions, concentration of defects and local voltage distribution, which may be the key to the low-energy transition from sp2 to sp3 transition. Also, over the past decade, progress has been made in the synthesis of other van der Waals 2D materials, from which it is also potentially possible to synthesize diamond-like structures with new intrigue properties that can be used in many applied problems. Here is an overview of various measurements made with a diamond-coated AFM probe for different numbers of graphene and boron nitride layers. The force that the probe can exert on a surface can vary from pN to tens of nN. However, the probe radius can be quite small $\approx$1 nm. With such a probe radius, the pressure exerted on the surface can reach potentially 10 GPa or even more, which could be sufficient for the synthesis of nanodiamonds or diamond like structures even at room temperatures.

### PO.88 Measurement statistics of Gaussian systems across space-time that cannot be generated from consecutive measurements

Minjeong Song*, Jayne Thompson, Matthew Winnel, Biveen Shajilal, Ping Koy Lam, Timothy Ralph, Syed Assad, Mile Gu* (School of Mathematical and Physical Sciences, Nanyang Technological University)

Quantum systems exhibit different spectra of spatiotemporal quantum correlations depending on their underlying causal distribution mechanisms. Possible causal mechanisms involve a temporal structure where a single quantum system evolves through a quantum channel to another. A natural question that arises is how to characterize these temporally compatible quantum correlations from the observed correlations alone. Specifically, we refer to the observed correlations as atemporal if they cannot be reproduced by any temporal structures. In this work, we examine Gaussian atemporality, atemporality particularly when Gaussian systems and Gaussian operations are considered. We introduce Gaussian atemporality, an efficiently computable indicator of Gaussian atemporality, and demonstrate that it can be interpreted as the robustness of the observed Gaussian state against noise. Having this, we discover key properties of Gaussian atemporality: (i) asymmetry under time-reversal; and (ii) Gaussian atemporality is a feature of quantum correlations that is different from other types of quantum correlations, for example, quantum entanglement.

### PO.98 Novel Dopant-Free Ferromagnetic Mott-like Insulator and High-Energy Correlated-Plasmons in Unconventional Strongly Correlated s Band of Low-Dimensional Gold

Muhammad Avicenna Naradipa*, Angga Dito Fauzi, Bin Leong Ong, Muhammad Aziz Majidi, Caozheng Diao, Ganesh Ji Omar, Ariando Ariando, Mark B. H. Breese, Eng Soon Tok, Andrivo Rusydi* (National University of Singapore)

Ferromagnetic insulators and plasmons have attracted a lot of interest due to their rich fundamental science and applications. Recent research efforts have been made to find dopant-free ferromagnetic insulators and unconventional plasmons independently both in strongly correlated electron systems. However, our understanding of them is still lacking. Existing dopant-free ferromagnetic insulator materials are mostly limited to complex d- or f-systems with extremely low Curie temperature, low-symmetry structure, and strict growth conditions on specific substrates, limiting their compatibility with industrial applications. Unconventional plasmon is, on the other hand, a quasiparticle that originates from the collective excitation of correlated-charges, yet they are rarely explored, particularly in ferromagnetic insulator materials. Herewith, we present a novel, room temperature dopant-free ferromagnetic Mott-like insulator with a high-symmetry structure in unconventional strongly correlated s band of low-dimensional highly oriented single-crystal gold quantum dots (HOSG-QDs) on MgO(001). Interestingly, HOSG-QDs show new high-energy correlated-plasmons with low-plasmonics-loss. With a series of state-of-the-art experimental techniques, we find that the Mott-insulating state is tunable with surprisingly strong spin-splitting and spin polarization accompanied by strong s-s transitions, disappearance of Drude response and generating new Mott-like gap. Supported with a series of theoretical calculations, the interplay of quantum confinement, many-body electronic correlations, and hybridizations tunes electron-electron correlations in s band and determines the ferromagnetism, Mott-like insulator, and high-energy correlated-plasmons. Our result shows a new class of room temperature dopant-free ferromagnetic Mott-like insulator and high-energy correlated-plasmons with low-loss in strongly correlated s band and opens unexplored applications of low-dimensional gold in spin field-effect transistors and plasmonics.

### PO.100 Spin-1 Heisenberg chain with RKKY like long-range interactions

Mohitha Adira*, Pinaki Sengupta (SPMS, NTU)

Unlike half-odd integer spin chains with antiferromagnetic (AFM) interactions between nearest neighboring spins, integer spin chains host a symmetry protected topological (SPT) ground state, termed Haldane phase. The long-range ordered AFM phase, which is the ground state of half-odd integer spin chains, needs additional long range interaction terms to break SU(2) symmetry for integer spin chains. This work investigates spin-1 antiferromagnetic Heisenberg model with RKKY (decaying with distance as power-law $\propto r^{-\alpha}$ ) like long-range interaction terms - with alternating ferro and antiferro-magnetic interaction terms - to understand how these two ground states relate to one another. A topological phase between SPT Haldane phase and long range ordered AFM phase from quantum monte-carlo (QMC) simulations has been shown to exist, as the interaction strengths of long-range term is varied using the power-law exponent $\alpha$. This critical point has been further characterized by various critical exponents of relevent correlation functions.

### PO.105 Coherence Over Energy: Optimal Discrimination of Optical Modes Under Energy Constraints

Shuyang Meng*, Jeremy Keng Chuan Ong, Valerio Scarani (NUS Physics)

We investigate information encoded in optical modes and the challenge of distinguishing between two modes under a strict energy constraint, determined by the maximum Fock component $N_{\text{max}}$. Interestingly, our findings reveal that the optimal quantum state for this task often possesses less energy but greater coherence, indicating that coherence can sometimes surpass energy in discrimination tasks. This discovery also highlights a similarity between mode discrimination and unitary channel discrimination, as in how the discrimination probability increases with the number of copies/energy constraints. We link this analysis to the discrimination of ”partially characterized” unitary channels, characterised by only one of their outcomes when applied to basis states. Our results show that, in most cases, full discrimination between two such channels is achievable by selecting an appropriate test state, akin to traditional unitary channel discrimination methods. As each optical mode can be viewed as products of such unitary channel, this finding may inspire new understanding about the information carried on by optical modes.

### PO.107 Energetics of VQE algorithm

Harshit Verma*, Rob Whitney, Thomas Ayral, Alexia Auffeves (CQT, NUS)

Quantum algorithms are typically compared on the basis of various metrics such as their computational complexity or time to solution. We assess the utility of VQE algorithms from the novel perspective of energetics. We build a VQE algorithm for computing the ground state energy of a spin chain system and evaluate its performance based on the accuracy of the ground state energy and the algorithmic resource consumption in the presence of noise. For this analysis, we adopt the Metric-Noise-Resource (MNR) framework which aims to identify the minimum amount of resource (energy) that is needed to achieve a target performance metric in the presence of noise. Using this framework, we find regions of maximal performance efficiency i.e. accuracy/energy for the VQE algorithm on the algorithmic resource landscape. Our results also motivate the possibility of a quantum energetic advantage i.e. the quantum algorithm could cost less energy than a comparable classical algorithm.

### PO.109 A Scalable Variational Ansatz Through the Superposition of Product States

Apimuk Sornsaeng*, Itai Arad, Dario Poletti* (Singapore University of Technology and Design)

The neural network quantum state approach employs artificial neural networks to offer a variational representation of quantum states. However, evaluating the expectation value of observables typically requires sampling from the quantum state’s probability distribution, a process commonly executed via sampling methods such as quantum Monte Carlo. To bypass the need for sampling, we introduce the variational ansatz of quantum states as the superposition of the product states. This ansatz features a number of parameters that scale linearly with the number of sites in the system rather than the entire Hilbert space. This approach enables a direct, efficient, and highly parallelizable computation of the expectation values of observables without the need for sampling. Through numerical simulations, we demonstrate the expressive power of the proposed ansatz in determining the ground state energy of one- and two-dimensional quantum spin systems. The scalability and expressivity of this ansatz have the potential to significantly enhance variational methods for studying complex quantum systems.

### PO.110 Topologically protected negative entanglement

Wentan Xue*, Ching Hua Lee* (Department of Physics of NUS)

The entanglement entropy encodes fundamental characteristics of quantum many-body systems, and is particularly subtle in non-Hermitian settings where eigenstates generically become non-orthogonal. In this work, we find that negative biorthogonal entanglement generically arises from topologically-protected non-orthogonal edge states in free fermion systems, especially within topological flat bands. Departing from previous literature which associated negative entanglement with exceptional gapless points, we show that robustly negative entanglement can still occur in gapped systems. Gapless 2D topological flat bands, however, exhibits novel $S_A \sim -\frac{1}{2}L_y^2 \log L$ super volume-law entanglement behavior which scales quadratically with the transverse dimension $L_y$, independent of system parameters. This dramatically negative scaling can be traced to a new mechanism known as non-Hermitian critical skin compression (nHCSC), where topological and skin localization in one direction produces a hierarchy of extensively many probability non-conserving entanglement eigenstates across a cut in another direction. Our discovery sheds light on new avenues where topology interplays with criticality and non-Hermitian localization, unrelated to traditional notions of topological entanglement entropy. This topologically protected negative entanglement also manifests in the second Rényi entropy, which can be measured through SWAP operator expecation values.

### PO.112 Quantum engine and its performance with a quantum load

Gauthameshwar Sundaravadivel*, Dario Poletti* (SUTD)

We look at the engine performance of a quantum load coupled to a three-level engine with Lindbladian baths providing energy to it. We also look at the regimes where this engine performs well, where it fails, and where it becomes a refrigerator.

### PO.114 Towards a compact and controllable laser-induced cold atomic source

Magdalena Glinka*, Chang Chi Kwong*, David Wilkowski* (CQT, NTU)

Cold atoms physics, with its recent developments in quantum sensing and quantum simulation, holds significant potential for real-world applications such as gravity mapping, navigation and communication. The common denominator in these applications is the cold atom source that maintains a low background pressure while providing sufficient vapour pressure for loading into a magneto-optical trap. It typically consists of an oven and Zeeman slower making the setup bulky and unfit for portable applications. In light of these constraints, the project focuses on building a compact and robust cold atomic source using laser ablation. In our previous work [1], directly shining the ablation laser onto the strontium led to unwanted vapour deposition on the glass cell, which eventually blocked the ablation beam. In this work, the 1064nm ablation laser pulses are reflected by a stainless steel mirror inside the vacuum system and focused on pure strontium granules, emitting strontium atomic vapour while preventing coating on the viewport. The vapour is subsequently trapped in a 3D MOT consisting of six counter-propagating 461nm laser beams. This work could potentially lead to a compact and controllable cold atom source which could be used in portable cold atom applications. References [1] C. C. Hsu, R. Larue, C. C. Kwong, and D. Wilkowski, Scientific Reports 12, 868 (2022).

### PO.115 Enhancing Bosonic cQED Systems: Integrating On-Chip Flux Line for Flux-Tunable Ancilla with Cavity Coherence Preservation

Aleksandr Dorogov*, Fernando Valadares*, Yvonne Y. Gao* (Centre for Quantum Technologies, National University of Singapore)

High-Q superconducting cavities interacting with non-linear elements provide a playground for versatile light-matter interaction physics. This work presents a novel bosonic circuit quantum electrodynamics architecture featuring on-demand frequency tunability via an optimized on-chip flux line.

### PO.116 Voltage-Controlled Half Adder Via Magnonic Inverse Design

Ze Chen*, Gerard Lim*, Calvin Ching Ian Ang*, Funan Tan*, Tianli Jin*, Wen Siang Lew* (NTU SPMS)

Magnonic devices offer a promising path for the development of low-power computing. This study introduces a magnonic device capable of dynamic control over magnon propagation. By leveraging voltage-controlled magnetic anisotropy (VCMA) on yttrium iron garnet (YIG) waveguides, we have carried out simulations of an active demultiplexer and half-adder designed using inverse design principles. A high output intensity multiplexer was similarly developed to mitigate the re-emission of magnons in commonly observed in Y-shaped combiners. Trapezoid electrodes were also introduced to minimize magnon intensity losses due to the magnetic anisotropy gradients across the cascading magnon circuit. The magnonic half-adder, constructed using active demultiplexers and a multiplexer, showcases the potential of magnonic logic circuits for binary addition operations. Our results highlight significant advancements in magnonic computing, particularly in achieving highly energy efficient.

### PO.117 Spin-orbit torque-driven GMR memristive devices

Zhang Bo*, Jin Tianli, Eng Kang Koh, Tan Funan, Gerard Joseph Lim, Cai Kaiming, Cao Jiangwei*, Wen Siang Lew* (School of Physical and Mathematical Sciences(SPMS) at NTU)

We present a Pt/Co/Cu/CoTb memristive device, which demonstrates a planar giant magnetoresistance (GMR) effect. This GMR memristive device combines both storage and logic functions within a single unit, using spin-orbit torque (SOT) to write the magnetization states and the GMR effect to read the states. By modifying the CoTb alloy composition to alternate the dominance between Co and Tb, multiple memristive states with opposite polarities have been achieved, offering an additional method to control non-volatile memristive states. Additionally, ten distinct storage states in the SOT-driven GMR memristive device by varying the amplitude of the driving current have also been shown. Synaptic plasticity, including long-term potentiation (LTP) and long-term depression (LTD), is achieved through the application of current pulses. This device has been used to construct an artificial neural network capable of performing tasks such as handwritten digit recognition and image visualization. Furthermore, basic Boolean logic functions have been implemented within a single GMR memristive device. The integration of memory and logic into a single planar GMR device provides a highly scalable solution for advanced memristive memory applications.

### PO.121 Examining Aluminide Coatings and Weldability of 9Cr Steels for Fusion Blanket Applications

Arunsinh Zala*, Vyom Desai, Nirav Jamnapara (NSSE, NIE, NTU)

9Cr-1Mo or P91 steels are structural steels extensively developed for power plant applications demanding higher creep resistance. Aluminide coating on P91 steels is widely reported for enhancing service life conditions in numerous applications such as petrochemical plant, turbinedriven systems, automobile industry and nuclear sector especially for test blanket module of fusion reactors. One of the critical issues associated with such aluminide coatings ($\alpha$-$Al_2O_3$ + FeAl) is the fabrication sequence. Considering the candidate aluminide coatings for different applications, it appears that fabrication followed by coating may not be a good option as diffusion heat treatment after the coating may induce distortions. Alternatively, the second option involving coating process followed by fabrication poses uncertainties of weldability of coated steels. Further, the weldability of aluminide coated P91 steel is scarcely reported. Weldability of aluminide coated structures is thus an area with lacunae and has been attempted to be addressed in this doctoral thesis work.

In this study, effects of aluminide coatings have been investigated by autogenous TIG welding through bead-on-plate trials. The weld microstructures were investigated using X-ray diffraction (XRD), scanning electron microscopy with energy dispersive x-rays (SEM-EDX) and microhardness tests. It was observed that the presence of alumina ($Al_2O_3$) on the top of coated samples resulted in an improved depth of penetration (DOP) due to arc constriction. The concentration of Al in the weld zone contaminated the weld metal and it supports the $\delta$-ferrite formation which deteriorates mechanical properties. Results shows that the $\delta$-ferrite has an average volume fraction of $\approx$5.09% in the weld metal with an average 192–198 Hv microhardness which is 52% lower compared to the martensitic laths (396–410 Hv). To mitigate these issues conventional TIG welding process has been attempted with V-groove design as per ASME standards. The resultant welds' microstructure has been again analyzed with respect to $\delta$-ferrite. SEM-EDS analysis exhibits the un-dissolved lumps of $Al_2O_3$ in irregular shape at the weld fusion line for coated steel which is susceptible to fracture. Despite such inclusions, the observed tensile strength of the weld joint for coated steel is 648 MPa$\pm$16M Pa which is in line with weld joint of un-coated steel (667$\pm$14 MPa) and substrate (643 MPa$\pm$18 MPa). The fracture surfaces of tensile specimen showcase trans-granular ductile failure for coated steel. The impact toughness tests were carried out at 0°C, -25°C and room temperature indicate that there is no drastic effect of $Al_2O_3$ lumps and coating on the toughness as values are acceptable as per the reported data. This talk will present the outline of the thesis work and briefly discuss the important results about the weldability aspects of aluminized P91 coated steels.

### PO.133 An alternative solid source to fabricate atomically precision lithography of phosphorus in H:Si(001) using scanning tunneling microscopy

Chengkun Lyu*, Calvin Pei Yu Wong*, Kuan Eng Johnson Goh* (IMRE,A*STAR; Department of Physics,NUS; School of Physical and Mathematical Sciences,NTU)

Over the past two decades, silicon-based quantum qubit devices have been extensively studied for spintronics and quantum computing applications, offering the potential to transcend Moore's law. These atomically precise $\delta$-doped electronic devices are fabricated using scanning tunneling microscopy (STM) and hydrogen-resist lithography to precisely position dopant atoms in silicon, followed by low-temperature silicon homoepitaxy. While various dopant precursors, such as arsine ($AsH_3$) and diborane ($B_2H_6$), have been explored, phosphine ($PH_3$) remains the most commonly used precursor for silicon-based $\delta$-doping fabrication. However, the toxic nature and risk of leakage associated with gas-phase dopant precursors present a critical challenge that must be addressed to advance industrial production. In this work, we explore an alternative solid source, gallium phosphide (GaP), to produce phosphorus doping and assess its compatibility with hydrogen-lithography on the H:Si(001) surface. We shall present the progress of this effort and discuss the remaining work ahead. Acknowledgements: K. E. J. G. acknowledges the funding support from the Agency for Science, Technology and Research (C230917006) and the Singapore National Research Foundation Grants CRP21-2018-0001 and NRF2021-QEP2-02-P07.

### PO.136 Parasitic Mode and Surface Treatment Considerations in the Development of Superconducting Qubit Chips

Rangga Perdana Budoyo*, Long Hoang Nguyen, Rasanayagam Sivasayan Kajen, Yuanzheng Paul Tan, Senthil Kumar Karuppannan, Kun Hee Park, Marina Kolpakova, Christoph Hufnagel, Yung Szen Yap, Rainer Dumke (Centre for Quantum Technologies, National University of Singapore)

To develop a working superconducting quantum processor, many aspects need to be considered during the process, including during the design and fabrication steps. Here, we discuss how the presence of parasitic modes, including the coplanar slot modes, can affect the performance of the qubits and resonators on the chip. We compare the simulated and measured parasitic modes and their contribution to qubit and resonator losses. We describe ways to mitigate the effect of these modes, including using on-chip wirebonds and superconducting air bridges. We also discuss the effects of surface treatment on the dielectric loss of the qubits and resonators. We compare the quality factors of resonators with different surface treatment processes, including by using a metal capping layer, and find the ozone cleaning process give the best resonator quality factors.

### PO.138 Quantum Causal Inference with Extremely Light Touch

Xiangjing Liu*, Yixian Qiu, Oscar Dahlsten*, Vlatko Vedral (Department of Physics, City University of Hong Kong)

We consider the quantum version of inferring the causal relation between events. There has been recent progress towards identifying minimal interventions and observations needed. We here give an explicit quantum causal inference scheme using quantum observations alone for the case of a bipartite quantum system with measurements at two times. In this scenario there may be combinations of temporal and spatial correlations. We derive a closed-form expression for the space-time pseudo-density matrix associated with many times and qubits. This matrix can be determined by coarse-grained quantum observations alone and the protocol is in that sense extremely light touch. We prove that if there is no signalling between two subsystems, the associated reduced state of the pseudo-density matrix cannot have negativity, regardless of the possible presence of initial spatial correlations. We further exploit the time asymmetry of the pseudo-density matrix to determine the temporal order of events. The negativity and time asymmetry are used to determine compatibility with 5 causal structures distinguished by the direction of causal influence and whether there are initial correlations or not. The protocol succeeds for a state with coherence undergoing a fully decohering channel, showing that coherence in the channel is not necessary for the quantum advantage of causal inference from observations alone.

### PO.140 Magnetic Domain Wall-Based Synapses Enabled by Modulated Dzyaloshinskii–Moriya Interaction (DMI)

Hasibur Rahaman*, Durgesh Kumar, Ramu Maddu, Bilal Jamshed, S.N. Piramanayagam* (NANYANG TECHNOLOGY UNIVERSITY)

Recently, neuromorphic computing (NC) has gained immense prominence from the research community as it can resolve the bottleneck of artificial intelligence (AI)1–3. Machine learning software for AI runs on the traditional Von Neumann architecture, which is energy inefficient. NC has been projected to replace this architecture by emulating the energy-efficient natural system of the human brain3,4. The general idea in NC is to take inspiration from the brain's structure and build a circuit composed of artificial neurons and synapse. Amongst several materials and devices, magnetic domain wall (DW) devices become potential candidates for NC due to minimal power consumption, non-volatility, and high endurance1,2,3. To emulate synapse (synaptic weight), DW device should exhibit multi-resistance/ intermediate magnetization states, which can be achieved by pinning of DW2,3,4. Researchers use different pinning processes of geometrical or magnetic origin to stop the domain wall at desired position1,2,3,4. Despite these, research is still needed to find a more efficient way of DW pinning. In this study, we investigated a DW-based synaptic device in Pt/Co/Pt heterostructure based on the concept of artificial pinning from the modulation of Dzyaloshinskii-Moriya interaction (DMI). Regions of modulated DMI as pinning sites along the length of the DW devices. When DW reaches such DMI-modified regions, it interacts with the local magnetic field (HDMI) and encounters a change in the energy landscape. This finally leads to the pinning of DW. In those pinning sites, perpendicular magnetic anisotropy and current density also alter from the pristine regions, which contribute to DW dynamics. We have performed both magnetic-field driven and spin-orbit torque (SOT) driven DW motion experiments in Kerr microscopy. We observed that pinning strength can be optimized with the depth of the DMI-modified region. To determine intermediate magnetization states, we have performed image processing of the Kerr images. The DW position (x) as a function of time (t) is plotted to represent the time evolution of z-component of magnetization mz. Field-driven and SOT-driven experiments both illustrate seven intermediate magnetization states, as shown by staircases in x vs. t plots. These experimental findings matched well with the micromagnetic simulation results. Our study paves a way for new device engineering to achieve synaptic DW device for NC.

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### PO.141 Understanding control infidelity in superconducting qubits

Paul Tan*, Yung Szen Yap, Rainer Dumke* (NTU)

Quantum algorithms currently offer a promising alternative to classical computation but are reliant on high fidelity quantum logic gates to achieve meaningful results. To improve this fidelity, it is essential to recognize the various sources of infidelity. In this work, we break down the various contributions to the error rates of superconducting qubits, including the control electronics. We propose a model on how the noise of the control electronics interacts with the qubit system and find that the qubit coherence time is currently the limiting factor towards high fidelity control.

### PO.142 Leaky-Integrate-Fire Neuron via Synthetic Antiferromagnetic Coupling and Spin-Orbit Torque

Badsha Sekh*, Durgesh Kumar, Hasibur Rahaman, Ramu Maddu, Jianpeng Chan, Mah Wai Lum William, S. N. Piramanayagam* (Nanyang Technological University (NTU))

Neuromorphic spintronics has gained a significant attention for last few years with the goal of improving power efficiency and scaling of solid-state devices by emulating the human brain functionality. It is a bit challenging task to imitate the leaky function of a biological neuron in the spin based artificial neurons. we proposed a self-reset neuron via Synthetic Antiferromagnetic (SAF) coupling which integrates through Spin Orbit Torque (SOT). After fabricating of our domain wall-based neuron device through successive steps of Optical lithography and etching by ion miller we have shown Anomalous Hall effect (AHE) measurements. The forward domain wall velocity during integration has been found to be increased due to larger spin orbit torque generated in the heavy metal layer. The key functionalities of the neuron also have been reproduced in several cycles following the same dynamics. Our experimental device results offer the controlling of return domain wall velocity by tuning the Ruderman–Kittel–Kasuya–Yosida (RKKY) interaction exchange coupling field during reset performance. The domain wall moves faster with respect to exchange coupling driving force. The maximum return domain wall velocity has been found at the largest exchange coupling field. The experimental outcomes are almost similar to our micromagnetic simulation findings. This device can be potentially used in electronic computing circuits due to its CMOS compatibility.

### PO.143 Enhanced damping-like efficiency originated from orbital and spin torques

Subhakanta Das*, Sabpreet Bhatti, Seidikkurippu Nellainayagam Piramanayagam* (Associate Professor, Nanyang Technological University.)

Spintronics-based devices use the spin degree of freedom of electrons in addition to their charge and have potential applications in data storage and computing. Researchers have explored many heterostructure materials and used various methods to enhance the spin current generation. Here, we investigated perpendicularly magnetised Pt/Co based heterostructures with an orbital torque-generating layer. Magnetic properties were studied using the magneto-optic Kerr effect (MOKE) and vibrating sample magnetometers. Measurements showed that the magnetic properties of the heterostructure changed after inserting the orbital orbital Hall layer. We employed photolithography and ion milling to fabricate Hall bars to carry out the AHE and loop-shift measurements. We found a significant (1.7 times) enhancement of Damping-like efficiency in the presence of the orbital Hall layers compared to the sample with only spin Hall layers. Further, we improved the crystal structure of the Orbital Hall layer by inserting a seed layer to enhance its orbital Hall effect. Interestingly we observed a 1.4-fold enhancement in Damping-like efficiency compared to the sample with no seed layers. These results open a window for exploiting orbital torque and spin torque response in different heterostructures for the advancement of spin current-based solid-state devices.

### PO.144 "Quantum-Grade" Diamond: Perspective on Synthesis, Characterization and Future Outlook"

Apoorva Chaturvedi*, Edwin Hang Tong Teo* (Nanyang Technological University SIngapore)

The emergence of a new technology is often preceded by advances in materials science. Solid-state quantum systems that possess long-lived spin and/or optical coherence are likely to play key roles in the development of a broad range of applications in quantum technology from quantum networks to information processing and quantum sensing. Ultra-pure 'quantum grade' crystals can act as a powerful platform and an enabler for emerging quantum technologies. MPCVD offers the potential to grow exceptionally pure diamond on a wafer scale. Although the CVD growth method is relatively mature, crystalline films that can deliver optimized performance in quantum technologies are yet not routinely produced. MPCVD-grown diamond films are emerging as a go to technology for obtaining 'quantum grade' diamond crystals, their availability and know-how remains limited. The overall thickness and size of 'quantum grade' diamond is relatively lower in comparison to applications such as power electronics and in gem industry. This puts more emphasis on researchers and engineers to indigenously design and device both the instrument (MPCVD reactor) and the synthesis protocols (fine control over experimental parameters) to achieve high quality, high purity diamond single crystals. In this presentation, I will broadly discuss the development carried out at Nanyang Technological University vis-à-vis the synthesis of ultra-pure diamond, their characterization and their future outlook for emerging applications.

### PO.147 Boson-boson interaction-induced ultra-strong localization in non-Hermitian systems

Mengjie Yang*, Luqi Yuan*, Ching Hua Lee* (Department of Physics, National University of Singapore)

Our work reveals that while the NHSE alone induces unidirectional boson pumping without localization, introducing inter-boson interactions dramatically alters this dynamic. Contrary to conventional knowledge, where boson-boson interactions are primarily considered repulsive, we demonstrate that in non-Hermitian systems, these interactions counterintuitively function as either traps or barriers. This novel mechanism of localization represents a fundamental shift in our comprehension of non-Hermitian physics and opens new avenues for controlling and manipulating bosons.

### PO.148 Theory of Quantum Decoherence in Rare-Earth Doped materials

Mohammad Ghadimimehr*, C. H. Raymond Ooi* (faculty physics, universiti malya)

This study investigates the dynamics of $Pr^{3+}$:$Y_2SiO_5$ using a full Hamiltonian framework within a master equation, with a focus on non-Markovian dynamics. Employing simulations with EasySpin software, we analyze how deviations from Markovian behavior emerge and how these non-Markovian effects, driven by the memory of the environmental bath, impact the system's performance and coherence. Additionally, we extend the theoretical calculations of the full Hamiltonian for $Pr^{3+}$:$Y_2SiO_5$ to incorporate NV centers. We compare the influence of environmental reservoirs on the system's dynamics. Our research explores the influence of temperature variations on the dissipative dynamics, i.e. we examine the system's behavior under different thermal conditions. By deriving and analyzing the master equation, we assess how environmental density of states and temperature affect the time evolution of the density matrix. We expect to gain insights into the important quantum properties such as coherence and correlations. This work provides a comprehensive understanding of the interplay between non-Markovian dynamics of thermal environment and temperature, enhancing our knowledge of their effects on the quantum dynamics of $Pr^{3+}$:$Y_2SiO_5$ and offering new perspectives on using quantum systems as probes of environmental features.

### PO.150 AttentiveGnL: A Framework for Automated Classification of Non-Hermitian Spectral Graphs

Xianquan Yan, Hakan Akgün, Kenji Kawaguchi, Ching Hua Lee* (National University of Singapore)

Topological physics is one of the most dynamic and rapidly advancing fields in modern physics. Conventionally, topological classification focuses on eigenstate windings, a concept central to topological insulators and practically all other Hermitian topological lattices. Beyond such notion of topology, we have discovered a distinct and diverse spectral graph topology in non-Hermitian systems, featuring exotic shapes like stars, kites, insects, and spaceships. To systematically classify this novel topology, we develop an automated engine to construct the spectral graph, given any Hamiltonian or its characteristic polynomial. A key challenge is to determine the characteristic polynomial of a given non-Hermitian spectral graph. To address the complexity of graph and utilize the auto-generated topology periodic table, we introduce AttentiveGnL, a novel graph neural network architecture that integrates attention mechanism and leverages line graphs as a dual channel to explicitly capture edge-level attention and triplet feature. Our model achieves a top-2 accuracy of 99.8% in predicting characteristic polynomials, substantially outperforming baseline models. This research not only provides a systematic resource for studying non-Hermitian systems / a large-scale dataset for graph machine learning, but also introduces a new GNN architecture with potential applications in molecular and protein analysis, offering a valuable tool for representation learning in complex systems.

### PO.151 Large scale quantum network with silicon micro ring resonator

Jinyi Du*, En Teng Lim*, Xingjian Zhang, Arya Chowdhury*, George F. R. Chen, Hongwei Gao, Dawn Tan*, Alexander Ling* (Centre for Quantum Technologies, NUS; Department of Physics, NUS)

Silicon chips have emerged as a promising technology for quantum technologies. The generation of polarization-entangled photon pairs has been demonstrated using a Sagnac configuration on silicon chips. Current designs mostly utilize silicon waveguides, which emit entangled photons with nanometer-level bandwidth. This broadband property brings significant chromatic and polarization mode dispersion (PMD) and degrades the quality of entangled photon pairs, particularly over extended distances. In this study, we present simulation results demonstrating that the narrow bandwidth of ring resonators significantly reduces chromatic and PMD. Our simulations show that by minimizing these dispersions, microring resonators can maintain high entanglement fidelity in long-distance entanglement distribution. Moreover, the comb-like spectrum produced by these resonators enables effective dense wavelength division multiplexing (DWDM). DWDM allows multiple entangled photon pairs to be transmitted to distant users simultaneously across different wavelength channels, increasing the volume of the quantum network. This multiplexing capability is particularly advantageous for scaling up quantum networks. The ability to integrate these resonators into existing silicon photonics platforms further enhances their use cases, as it enables seamless integration with other components necessary for quantum information processing. Overall, the combination of narrow bandwidth, reduced dispersion, and multiplexing potential positions microring resonators as a potential structure for advancing long-distance and large-scale quantum networks.

### PO.152 Toward Neutral Atom Array Quantum Processors in Singapore

Abhishek Jamunkar*, Tong-Yan Xia, Vasu Dev, Kai Xiang Lee, Jinyu Zhou, Vincent Mancois, Kelvin Lim, Jintao Yang, Zhengjiang Li, Mujahid Aliyu, Zilong Chen, David Wilkowski (Centre for Quantum Technologies, National University of Singapore)

The development of 200 qubits or more quantum processors is subdivided into multiple subtasks running in parallel to address the technical and conceptual challenges. On the technical side, we are working on developing an efficient 2D MOT, a science chamber for the 3D MOT with an extremely good ultrahigh vacuum environment, and the generation of an atom array with optical tweezers. The 2D MOT serves as a source of cold atoms. The atoms will be further cooled down to the microKelvin range in the 3D MOT and loaded in the tweezer array. On the conceptual side, we are evaluating key atomic transitions for the realization of quantum computing operations. We are also working on developing static tweezer arrays using spatial light modulators to trap the atoms. Subsequently, we will be developing mobile tweezers for the rearrangement of the atoms during the later stages of the project.

### PO.153 National Superconducting Quantum Computer

Christoph Hufnagel*, Yuanzheng Paul Tan*, Tan Le, Ye Jun, Rainer Dumke* (NTU)

We detail the setup of the superconducting quantum computer in the National Quantum Computing Hub (NQCH), which will host the 5 qubit IQM Spark Quantum Processing Unit (QPU), 8 qubit Lapan QPU designed by Professor Rainer Dumke's group and 20 qubit IQM Garnet QPU. This computer is supported by the IcarusQ control electronics platform and can be programmed via the Qibo open-source middleware. Monitoring systems have been set up to routinely examine the health of both the Leiden Cryogenics CF-CS110-1000M dilution refrigerator and QPU performance. To support cloud access to local researchers, we have also set up integration with the Slurm workload manager to provide a power user High Performance Computing (HPC)-like experience for QPU usage.

### PO.157 Pursuing Satellite Pointing for Space-Based Quantum Key Distribution

Shaik Muhammad Abdillah*, Ayesha Reezwana, Xi Wang, Moritz Mihm, Alexander Ling (Centre for Quantum Technologies)

Pursuing space-based quantum key distribution can potentially enable the development of a global quantum network, leveraging information theoretic security for communication. Pointing losses present a challenge towards achieving low bit error rates due to the large distances and beam geometry associated with optical communication. Typical course pointing strategies uses publicly available ephemeris data in the form of two-line element (TLE) sets. TLEs rely on simplified perturbation models that have insufficient accuracy to be reliably used for optical satellite tracking. Thus, we aim to observe and analyse the errors associated with TLE sets through optical satellite tracking. This culminates in a potential strategy for course pointing in upcoming satellite quantum key distribution missions.

### PO.159 Collective Effects Enhanced Many-Body Quantum Engines

Noufal Jaseem Poovakkattil*, Sai Vinjanampathy, Victor Mukherjee (CQT, NUS)

We explore the benefits of collective effects in many-body quantum heat engines and quantum information engines. Our analysis demonstrates how collective interactions lead to highly consistent engine performance by significantly reducing output fluctuations. By collectively coupling the working medium to thermal baths, we observe a quadratic enhancement in reliability for quantum Otto engines. Additionally, our model shows improved performance in quantum information engines compared to their independent counterparts.

### PO.160 Enhanced Stability and Tunability of ECDL Systems Using Saturation Absorption Spectroscopy

Noor Hafizah Abdul Halim*, Chong Heng Raymond Ooi* (Department of Physics, Universiti Malaya)

We describe an experimental approach for laser locking and stabilization which employs saturation absorption spectroscopy (SAS) to improve the performance of an external cavity diode laser (ECDL) with a diffraction grating. This system intends to provide narrow linewidth and wide-mode hop-free tuning, which are required for high-precision quantum optics and spectroscopy applications. The ECDL system uses a SAS arrangement with counter-propagating control and probe beams interacting with a Rubidium cell to produce a Doppler-free signal for laser frequency locking. A feedback loop containing a PID controller, and a lock-in amplifier analyzes the error signal to stabilize the laser frequency at a zero-crossing point, therefore eliminating frequency drift. The combined optical and electronic concepts provide a robust and versatile approach in developing ECDL with increased stability and tunability, appropriate for applications in atomic and molecular spectroscopy.

### PO.165 Toward Digital and Analogue Quantum Processors Using Neutral Atom Arrays

Zilong Chen*, Tong-Yan Xia, Abhishek Jamunkar, Jinyu Zhou, Mujahid Aliyu, Thanh Nguyen, Leong Chuan Kwek, Valerio Scarani, Hui Khoon Ng, Steven Touzard, Yijie Shen, Jose Ignacio Latorre, Shu Ann Chan, Kai Xiang Lee, Kelvin Lim, Vincent Mancois, Vasu Dev, Zhengjiang Li, Jintao Yang, David Wilkowski (CQT, NUS)

We are starting an ambitious project aiming to build digital and analogue quantum processor prototypes that should be delivered in 2029. During the period 2025-2027, six equivalent experimental machines will be mounted using neutral atoms tweezer array techniques. Our objective will be to have more than 200 atoms arranged in a defect-free lattice with state-of-the-art performances in term of lifetime, loading rate, robustness, and control of the phase and amplitude of the addressing lasers. After 2027, each experimental platform will be used to develop the prototypes in a parallel approach. We aim to achieve $> 99.9\%$ and $> 99\%$ single and two qubit gate fidelity, respectively. Error-correction codes should be implemented to reduce further the error rate.

### PO.168 Development of a Comprehensive Workflow for SNSPD Fabrication and Characterization

Shuyu Dong*, Darren Ming Zhi Koh, Filippo Martinelli, Pierre Brosseau, Giorgio Adamo, Anton Vetlugin, Mariia Sidorova, Christian Kurtsiefer, Cesare Soci (Nanyang Technological University)

Superconducting nanowire single-photon detectors (SNSPDs) are renowned for their exceptional performance, finding applications in various fields such as quantum technologies, astronomy, space communication, imaging, and LiDAR. This rising demand exceeds the current supply from commercial products, leading to a heightened focus on developing in-house SNSPD manufacturing utilizing versatile nano-fabrication techniques. In this work, we present a comprehensive workflow for SNSPD fabrication and characterization, including steps from superconducting film deposition to nanowire patterning and integration with electrical readout and optical characterization systems. A critical aspect of this research involved identifying the key parameters of our workflow and developing reliable procedures for their optimization. In addition, two different light sources are used for SNSPD system detection efficiency (SDE) calibration. Our results demonstrate SNSPDs with performance metrics comparable to commercial counterparts, including a reset time of 16 ns, timing jitter of 74 ps, sub-Hz dark count rate at 90% efficiency, 20 kHz dark count rate at maximum efficiency, and internal detection efficiency of approximately 95%. These attributes make our devices suitable for both fundamental research and practical applications, such as quantum key distribution (QKD), quantum communication, classical imaging, and LiDAR.

### PO.171 Nonlinear magnonic Moiré lattices

Bryan Cheng Wei Hao*, Chen Ze*, Calvin Ching Ian Ang*, Gerard Joseph Lim*, Wen Siang Lew* (NTU)

Moiré magnonics investigates magnetic phenomena in nanoengineered structures, offering new control over magnon behavior that remains largely unexplored. Nonlinear magnon scattering, involving three or four magnon interactions, is critical for devices like magnon transistors. However, understanding and controlling these nonlinear interactions in Moiré lattices remains untackled. In this study, we use micromagnetic simulations to observe a nonlinear magnonic Moiré lattice formed by rotating two Yttrium Iron Garnet (YIG) magnetic striplines. This lattice significantly enhances the nonlinear down-conversion from 6 GHz to 2 GHz via four-magnon scattering, showing improved efficiency over individual striplines. We also observe a chiral ratio of 3.9 between left- and right-propagating magnons at a magic angle of 26 degrees, indicating edge states in topologically nontrivial structures. Finally, a 14.5-fold enhancement in the nonlinear signal was simulated at the magic angle. Advances in nonlinear Moiré magnonics open new avenues for exploring nonlinear physics and potential improvements in neuromorphic computing and nonlinear devices.

### PO.173 Neural Network-assisted Quantum Compilation

Wenyu Guo, Qing Liu, Ximing Wang, Chengran Yang*, Rigui Zhou*, Mile Gu* (Nanyang Technological University; CQT National university of Singapore)

Introduction: Quantum computation is a transformative field with profound implications across various disciplines. Quantum compilation emerges as a pivotal solution to bridge the gap between the high-level abstraction of quantum algorithms and the intricate realities of physical qubits. The research landscape of quantum compilation is both diverse and dynamic, which encompasses various approaches. Neural networks, with their remarkable ability to recognize patterns in data, have shown great promise in a multitude of applications ranging from natural language processing to weather prediction. Leveraging the representational power of neural network provides researchers with the tools to gain deeper insights into quantum systems and improve the efficiency of quantum processes. We propose a novel method within this context, aimed at conserving quantum computational resources. By optimizing the depth of quantum circuits, our approach significantly reduces the resource requirements of quantum programs, a vital consideration given the limited and expensive nature of quantum computational power. Methods: We aim to find a means of compiling a quantum circuit that aligns with the NISQ regime – where data is limited and expensive to obtain. In this study, we explore the potential of machine learning, specifically neural networks, to optimize quantum compilation with a focus on reducing the number of measurements on quantum devices. Our approach builds on recent advancements in quantum machine learning, where neural networks is employed to estimate measurement statistics in many-qubit quantum systems. The algorithm operates within a hybrid loop that alternates between classical and quantum hardware. The process begins with a small dataset, which is iteratively refined based on the predictions of the neural network. This hybrid approach enables the classical optimizer to provide parameter sets that bring the quantum circuit's compilation cost close to the minimum. The new training dates are indicated by the neural network model through the backpropagation . Hence compared to adding new training dates from randomly selected parameters, this method enhances accuracy near the cost function's minimum. Results: This work presents a neural network-assisted quantum compilation algorithm that shows significant advantages over traditional optimization methods in terms of the number of evaluations, precision of fidelity, and cost convergence speed. The experimental results include the quantum compilation process and outcomes from circuits ranging from 1 qubit to 6 qubits, we explore the interrelations among several parameters, where we achieve higher accuracy. We compare neural network-assisted quantum compilation with other gradient-free and quasi-gradient optimization methods across various quantum compilation scenarios. Additionally, we explore the interrelations among several parameters, such as the number of qubits in a quantum circuit, the precision of the compilation, the number of neural network parameters, and the number of sample points required for training. Discussion: The results demonstrate that neural network-assisted quantum compilation can effectively exploit quantum correlations, leading to more efficient parameter optimization. Given its precision, comparable to other variational quantum compilation methods optimized by algorithms such as BFGS, Nelder-Mead, and Powell, this study highlights the importance of assessing the advantages of integrating machine learning into quantum compilation. We have shown that artificial neural networks are capable of optimizing quantum compilation parameters based on data from adaptive measurements of gate-model quantum computers. Our benchmarks suggest that neural network-based approaches can achieve similar performance to traditional methods like BFGS, Nelder-Mead, and Powell, while offering significant resource savings. This approach holds wide-ranging potential applications for any quantum device that requires gate synthesis. And it further more aims to promisingly reduce the associated use of quantum resources.

### PO.176 Residue-free wafer-scale direct imprinting of two-dimensional materials

Zhiwei Li*, Xiao Liu, Weibo Gao* (School of Physical and Mathematical Sciences Nanyang Technological University, Singapore)

Two-dimensional (2D) semiconductors hold great potential for next-generation electronics in extending Moore's law beyond silicon. However, despite pioneering advances in proof-of-concept device demonstration and wafer-scale crystal synthesis, its industrialization will be hampered by the lack of a compatible residue-free patterning technology. To overcome this limitation, we demonstrate a facile metal-stamp imprinting method for patterning 2D film into wafer-scale arrays of intrinsic quality. The three-dimensional (3D) morphology of metal-stamp forms a local contact at stamp-2D interface, ensuring that the 2D material could be selectively exfoliated and leaving 2D arrays on grown substrate. Furthermore, detailed microscopy and spectroscopy characterizations are conducted to confirm their clean surface and undamaged crystal structure. A statistical analysis of the 100 back-gated transistors and 500 top-gated logic circuits shows a marked improvement in device uniformity (20 times lower variation of threshold voltage) than traditional method, and a high device yield of 97.6% on 2-inch wafer. This work achieves a residue-free, time-saving, and widely applicable patterning technique for 2D materials and lays the foundation for the future integration of 2D electronics in industry.

### PO.182 A high-fidelity gyrokinetic surrogate model with machine learning

Chenguang Wan*, Zhisong Qu, Youngwoo Cho, Ruichen Zhang, Xavier Garbet (School of Physical and Mathematical Sciences (SPMS), Nanyang Technological University (NTU))

Energy confinement quality determines the size and cost of a tokamak. Plasma turbulence and transport cause fluctuations in the confinement time, leading to a few percent change in the hot core. Understanding the origin and properties of plasma turbulence is a critical issue in Tokamak's research. Gyrokinetic theory and models have been used to solve these problems, but these codes are expensive [1]. Plasma physicists develop different codes for different tasks, as computational speed and fidelity have been a trade-off.

The application of machine learning in constructing surrogate models has revolutionized the ability to achieve both high accuracy and efficiency. However, building these models necessitates a significant dataset of simulation results for ML model training, creating a challenge. While surrogate models aim to accelerate simulation code, the cost of gathering a large simulation result dataset, particularly for nonlinear gyrokinetic models, is prohibitively expensive.

To address this issue, we have developed a novel surrogate model construction methodology. We create a sizable simulation result dataset with low fidelity but rapidity results, then generate a small high-fidelity simulation result to fine tune our model. This method enables us to attain the ideal combination of precision and speed for the gyrokinetic surrogate model.

We are currently developing a surrogate model for the wave number spectrum (k) using GKW [2] and GX [3]. Our initial focus is on Ion Temperature Gradient (ITG) modes, characterized by four parameters, to demonstrate our approach. We collected 8800 simulation results using GX and 1097 high-fidelity results using GKW. Since obtaining the ground truth for gyrokinetic outputs (e.g., thermal diffusivity ) in tokamak experiments is challenging, we consider GKW results as the ground truth for testing our surrogate model. Therefore, we generated an additional 1000 high-fidelity GKW results. We used all GX results for model training and 100 GKW results for fine-tuning.

Our efforts have resulted in a successful surrogate model that is comparable in fidelity to GKW. The average similarities for and between surrogate model and GKW are 0.957 and 0.970. For , our results align well with theoretical predictions [4]. Additionally, it is orders of magnitude faster than GKW simulation. Moving forward, we plan to expand the model by incorporating additional parameters and conducting further research to create a complete gyrokinetic surrogate model.

The computational work for this article was partially performed on resources of the National Supercomputing Centre, Singapore (https://www.nscc.sg). This research is supported by the National Research Foundation, Singapore.

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### PO.185 Enlarged Sub-Poissonian Time Window in Unconventional Photon Blockade

You Wang*, Timothy C. H. Liew, Yidong Chong* (Nanyang Technological University)

In in unconventional photon blockade (UPB), fast oscillation of second order correlation has been observed. This fast oscillation diminishes the antibunching time window, which is detrimental for single photon generation applications. We theoretically reveal that the second order correlation's Rabi oscillation directly relates to the eigen-energy of single-particle modes of the cavity lattice. Thus by designing a four-cavity lattice that allows UPB with cavity loss much higher than all its eigen-energies, the unwanted oscialltion is suppressed. We find in this model interference between the Rabi-like oscillations conversely enlarge the antibunching time window, surpassing the limit of cavity lifetime. Under same cavity loss, this configuration allows for a substantially larger antibunching time window compared not only to the original UPB but also to the stongly nonlinear conventional photon blockade.

### PO.187 Quantum sensing with dual atom interferometer

Xinyuan Ma*, Jianing Li, Swarup Das, Chang Chi Kwong, David Wilkowski* (Center for Quantum Technologies)

Atom interferometers are powerful tools to sense gravity, rotation and acceleration with high precision. We report implementation of dual atom interferometer with Sr atoms in a superpostion of two internal states. The device can be used to test quantum weak equivalence principle as well as measure state-dependent forces induced by differential light shift between two internal states.

### PO.191 Turbulence Regulation with Energetic Particle in Tokamaks

Michael Go*, Zhisong Qu, Xavier Garbet, Virginie Grandgirard (NTU)

Turbulence regulation is a critical factor in achieving sustained fusion in tokamaks. Energetic Geodesic Acoustic Modes (EGAMs) have been identified as potential regulators of turbulence. However, the complex dynamics of the interaction between EGAMs and turbulence remain poorly understood. Here, we perform a numerical study of the EGAM-turbulence interaction using the gyrokinetic code GYSELA. Our results provide insights into how EGAMs can influence turbulence and identifying regimes where turbulence suppression is achievable.

### PO.193 Rapid Wavelength Modulation in Perovskite Metasurface Lasers: Microheaters for Electrical Control

Tim Meiler, Yutao Wang, Saurabh Srivastava, Giorgio Adamo, Ramon Paniagua-Dominguez*, Arseniy I. Kuznetsov*, Cesare Soci* (Centre for Disruptive Photonic Technologies, NTU)

Metasurfaces manipulate light with subwavelength structures, offering a promising path to miniaturizing optical devices. However, their properties are static after fabrication, prompting research into methods for achieving dynamic control in active metasurface. Perovskites present a compelling material choice for such applications not only due to their tunable optoelectronic properties but also due to their inherent optical gain while enabling low-cost fabrication. Our goal is to develop microscale light sources with electrical control over wavelength, polarization, and emission direction, surpassing current limits in modulation speed and device miniaturization.

We have developed a versatile microheater platform that rapidly modulates laser emission by heating the surrounding material. We structure indium tin oxide (ITO) films via photolithography into transparent microheater wires, which are then spin-coated with perovskite methylammonium lead iodide ($MAPbI_3$). A focused ion beam then mills a metasurface into this film, which hosts high-quality factor modes due to quasi bound states in the continuum in the waveguides.

Our results demonstrate 20 nm wavelength shifts of the optical modes in angle-resolved reflectance as well as photoluminescence when an electrical heater drives the material above its phase transition temperature. We observe linewidth narrowing, nonlinear increase of emission and coherence fringes above lasing threshold. Pulsed operations reach millisecond switching times at the instrument limit in this ultracompact device. We aim to control several adjacent electrodes in the future, extending applications of tunable metasurfaces to dynamic holography, LiDAR, and optical communications.

### PO.194 Novel Light Detection Through Time-Varying Material Modulation

Ayan Nussupbekov*, Juan-Feng Zhu, Yuryi Akimov, Gregory Ngirmang, Ping Bai, Ching Eng Png, Lin Wu (Institute of High Performance Computing, A-STAR)

Transition radiation (TR) is a light emission process that has gained interest due to its simple mechanism and lack of strict requirements like minimum particle velocity or phase matching. TR is widely used in high-energy physics for detecting, tracking, and identifying particles. This study introduces temporal transition radiation (t-TR), originating from time-modulated media. Unlike spatial TR, which involves spatial interfaces, t-TR features time-based interfaces, converting evanescent fields to radiating fields as electrons cross temporal boundaries. Our findings show that TR light emission can reveal material properties and temporal modulation, with radiated power depending exponentially on electron velocity and refractive index changes.

### PO.195 Field-free switching via interplay between spin-reorientation and synthetic antiferromagnetic coupling

Bilal Jamshed*, Hasibur Rahman, Durgesh Kumar, Ramu Maddu, S.N Piramanayagam* (NTU)

Current induced magnetization switching using spin-orbit torques (SOTs) has gained significant interest due to its low-power applications for non-volatile memory and spin logic applications. In conventional SOT structures with perpendicular magnetic anisotropy, when a charge current is passed through a heavy metal layer (Jc), an out-of-plane spin current via the spin Hall effect (SHE) is generated with spin polarization along the y-direction. Since the spin polarization is not aligned collinearly to the perpendicular magnetization, an external in-plane magnetic field is required to obtain deterministic magnetization switching. It may pose serious implications for building a compact spintronic device. Various approaches have been proposed to obtain field-free switching, such as utilizing interlayer exchange coupling, geometrical asymmetry, tilted magnetic anisotropy, using antiferromagnet, and vertical-spin polarization, etc. R. Sbiaa et al. showed that in an antiferromagnetically coupled Co and Co/Pd multilayer, the magnetization direction was reorientated from in-plane to out-of-plane due to Antiferromagnetic coupling (AFC) for a particular thickness of the Co layer. Despite significant progress made in achieving field-free switching, an industry-compatible solution for achieving field-free switching is still elusive. In this work, we have proposed a novel switching scheme where a field-free magnetization switching was achieved via spin reorientation. Efforts to achieve SOT-induced switching without an external magnetic field have been extensively studied. In this work, we utilised the reorientation of the magnetisation to examine SOTs in Ta (2 nm)/Pt(5 nm)/Co(t nm)/Ru(0.5 nm)/[Co( 0.5 nm)/Pt (0.8 nm)]x3/Pt(1.2 nm), where the spin current generated by SHE in Ru is combined with interface-generated spin currents. We measured SOT-induced practical fields by varying the Co thickness in Pt/Co and observed magnetization switching. Two key points were noted for samples with a thin Ru layer: the SOT sign is determined by the bottom Pt/Co layer (positive for Pt and negative for W), and SOT-induced switching occurs without an in-plane magnetic field. These results suggest that the interface-generated spin current in the FM Pt/Co layer governs the SOT in samples with a thin Ru layer. As Co thickness increases, the reorientation occurs at the Co, and after the thickness, the magnetization becomes the in-plane. This indicates that an effective magnetic field leads to field-free SOT switching due to reorientation. The effective magnetic field contribution is due to the competition between AFC and shape anisotropy. Selecting the appropriate FM/HM combination and material thickness can thus enhance SOT efficiency and achieve field-free SOT switching.

### PO.196 Free-running Waveguide-coupled Single Photon Avalanche Detector for Visible Light at Room Temperature

Anirudh R Ramaseshan, Aswin A Eapen, Thomas Yl Ang, Soe M Thar, Alexander Ling, Victor Leong* (Institute of Materials Research and Engineering, A*STAR)

To fully utilize the potential of photonic integrated circuits (PICs) in quantum computing and communications, integrating photon generation, manipulation, and detection in a single platform is essential. While superconducting nanowire detectors are effective for single-photon detection, they require cryogenic temperatures, which can be challenging for practical use. A recent report has demonstrated a room-temperature integrated single-photon avalanche detector (SPAD) for visible light [1], but its gated mode operation require pulsed or synchronized protocols, which can limit its use cases compared to a free-running detector.

Here, we report the first demonstration of a free-running integrated SPAD for visible light at room temperature. Our device consists of a doped silicon waveguide end-fire-coupled to a silicon nitride photonic circuit. Under passively quenched Geiger-mode operation with 685nm wavelength input light, we observed a photon detection efficiency of (0.44±0.04)%, which is likely severely limited by the very high dark count rate of $> 10^6$ counts/s. We will discuss the prospects of reducing the dark count rate and improving device performance.

[1] A. Govdeli et al., npj Nanophotonics 1, 2 (2024)

### PO.199 High Throughput Screening of Two-Dimensional Cold Metals for High Performance Electronic Devices

Sanchali Mitra*, Yee Sin Ang* (Science, Mathematics and Technology (SMT) Cluster, Singapore University of Technology and Design)

With the intensely increasing demand for miniaturization of metal oxide semiconductor field effect transistor (MOSFET), power consumption has become one of the most important issues. Reducing power consumption requires supply voltage and simultaneously threshold voltage to be lowered. As a consequence, the leakage current increases exponentially as the subthreshold swing (SS) in traditional MOSFET has a minimum value of 60 mV per decade at room temperature. In order to break this limit, various novel device concepts such as tunneling FETs, negative capacitance FETs have been proposed. Apart from such novel device configurations, sub-60-mV/decade SS can be achieved through 'cold' electron injection by engineering the density of states of source materials. Two dimensional (2D) 'Cold' metals with an intrinsic energy gap close to the Fermi level have been shown a great potential for cold electron injection. Different from conventional metals, 'cold' metals are equivalent to naturally doped semiconductors. The unique band structure of these metals allows to filter the transmission of high-energy electrons in the subthreshold region and reach the sub-60 mV/decade SS. Till date, only a handful of 'cold' metals including 2H $MX_2$ (M=Nb, Ta; X=S, Se, Te) are being explored as cold injection sources in diodes and transistors. However, the 2D material space has expanded much beyond transition metal dichalcogenides and it is extremely important to explore new materials to improve device performance.

In this work, we performed a systematic search for monolayers of 2D cold metals by scanning the C2DB database. We first extract materials with band gap $<0.05$ eV, energy above convex hull $<0.2$ eV/atom and formation energy $< 0$eV/atom, resulting in total 888 candidates. The selection criteria to identify 2D cold metals from these 888 materials is set as: the materials should have an energy gap within 1.5 eV from the Fermi level and the gap should be greater than 0.2 eV. We found 286 'cold' metals including 193 non-magnetic and 93 magnetic materials. Among them, the bulk form of 19 materials (10 magnetic and 9 non-magnetic) have already been experimentally synthesized. Among the rest 267 materials, we made a further screening based on high gamma point phonon stability, high stiffness stability, no presence of toxic elements and number of atoms $<10$, resulting in 151 materials. The screened 'cold' metals are classified in three categories: electron cold, hold cold and bipolar. Electron/hole cold metals are like heavily doped p/n-type semiconductors that have energy gap above/below the Fermi level. Bipolar metals have energy gaps on both sides of the Fermi level. From the database, we identified 90 'electron cold', 59 'hole cold' and 21 'bipolar cold' metals. The materials are further characterized using spin polarized Density Functional Theory calculations with projector augmented wave method and R2SCAN Meta-GGA functional. These new materials could aid the design of steep slope high-performance electronic devices.

### PO.201 Systematic Construction of Hamiltonians Hosting Non-Ergodic Many-Body Excited States

Nyayabanta Swain*, Darryl Chuan Wei Foo, Gabriel Lemarie, Pinaki Sengupta, Shaffique Adam (NUS)

Precisely computing highly excited many-body eigenstates using exact methods is a formidable challenge. Thus, accessing high-energy excited state physics via ground-state methods, for which efficient algorithms exist, is highly appealing. By using the ground state wavefunction of a given local Hamiltonian, one can construct a new Hamiltonian of the same local form through the eigenstate-to- Hamiltonian construction approach. The reliability of this method hinges on the vanishing of energy variance. We employ the stochastic series expansion quantum Monte Carlo method, along with the eigenstate-to-Hamiltonian construction, to develop a Heisenberg model with correlated disorder that exhibits many-body localization in its excited states. Similarly, we design a new spin Hamiltonian with spatially alternating exchange couplings that hosts quantum many-body scar states. Our approach offers a systematic way to create various families of designer Hamiltonians with non-ergodic excited state properties.

# 5 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: Low-dimensional Materials 1

Time: Wednesday 2 Oct, 11:00am; Venue: LT-2; Chair: Cedric Troadec, A*STAR
Time allocated for invited talks is 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.

### T1.178 Photochromism in 2D Perovskites with Intercalated Halide Ions

Yulia Lekina*, Benny Febriansyah, Ze Xiang Shen* (Nanyang Technological University)
11:00am – 11:15am

Hybrid halide perovskites have been the focus of extensive research for over a decade due to their exceptional optoelectronic properties and broad range of potential applications, including solar energy harvesting, light emission, sensing, and lasing. Their versatility is largely due to the almost limitless possibilities for compositional engineering and the fine-tuning of their properties.

This study explores new 2D perovskites exhibiting reversible photochromism and thermochromism. These materials darken when exposed to UV light, but this change can be reversed by brief annealing at moderate temperatures ($\approx 100°C$). Notably, these alterations do not affect the overall crystal structure, as confirmed by single-crystal X-ray diffraction studies. Although the bandgap and photoluminescence (PL) energy remain largely unchanged, the darkening effect is attributed to a weak, broad absorption band without a distinct edge. X-ray photoelectron spectroscopy (XPS) analysis shows a reduced electron density in the inorganic sublattice, likely due to an excess of holes (p-doping), while electrons localize around the amino groups of the organic component. This suggests that UV irradiation induces charge separation and changes the conductivity type of the material.

This novel photochromic behavior in perovskites paves the way for innovative applications in various advanced technologies. Potential applications include smart windows that adjust their tint in response to light, photovoltaic devices with enhanced functionality, and optical energy storage and memory systems. The ability to control material properties through external stimuli opens new avenues for developing responsive and adaptive materials for cutting-edge applications.

### T1.134 Two-dimensional conjugated metal-organic frameworks self-assembled on coinage metals and $MoS_2$ surfaces

Chengkun Lyu*, Calvin Pei Yu Wong*, Kuan Eng Johnson Goh* (IMRE,A*STAR; Department of Physics,NUS; School of Physical and Mathematical Sciences,NTU)
11:15am – 11:30am

A large variety of two-dimensional metal-organic frameworks (2D MOFs) has been designed utilizing on-surface coordination self-assembly. In particular, the 2D conjugated MOFs (c-MOFs), with highly delocalized $\pi$-electrons, promise high electrical conductivity or long-range magnetic ordering. They are anticipated to possess exotic electronic properties, such as superconductivity, topologically non-trivial band structure, half-metallic ferromagnetism, and quantum spin liquids, enabling broad applications in multi-functional electronic devices. However, synthesizing and characterizing single-layer c-MOFs remain a significant challenge to researchers. Specifically, the strong hybridization of adsorbed 2D c-MOFs with the underlying metallic substrate obscures the intrinsic electronic properties to be explored. In this work, using scanning tunneling microscopy (STM) measurements and density-functional theory (DFT) calculations, we systematically investigated the synthesis and characterization of 2D c-MOF, namely $M_3HAT_2$ (M=Ni, Co, Fe, Cu; HAT=1,4,5,8,9,12-hexaazatriphenylene), on multiple metallic substrates [1,2] and $MoS_2$ [3]. This work exemplifies how an on-surface-assembled 2D MOF adapts its structure and adsorption sites in response to different substrates according to the corresponding surface adsorption energy. Particularly, the framework grown on $MoS_2$ is nearly identical to its free-standing counterpart. It suggests that the 2D van der Waals (vdW) materials are good candidate substrates for building intrinsic 2D MOFs, which offer potential applications in next-generation electronic devices.

[1] C.-K. Lyu, et al, Synthesis of single-layer two-dimensional metal-organic frameworks M3(HAT)2 (M=Ni, Fe, Co, HAT=1,4,5,8,9,12-hexaazatriphenylene) using an on-surface reaction, Angew. Chem., Int. Ed. 61 (27) (2022) e202204528, doi.org/10.1002/anie.202204528. [2] C. Lyu, et al, On-surface self-assembly kinetic study of cu-hexaazatriphenylene 2D conjugated metal-organic frameworks on coinage metals and $MoS_2$ substrates, ACS Nano 18 (30) (2024) 19793-19801, doi.org/10.1021/acsnano.4c05838. [3] C. Lyu, et al, Two-dimensional conjugated metal-organic frameworks grown on a $MoS_2$ surface, Available at SSRN: dx.doi.org/10.2139/ssrn.4885082.

Acknowledgements: K. E. J. G. acknowledges the funding support from the Agency for Science, Technology and Research (C230917006) and the Singapore National Research Foundation Grants CRP21-2018-0001 and NRF2021-QEP2-02-P07.

### T1.175 Nonlinear finite-difference time-domain method for exciton-polaritons

Kevin Dini*, Helgi Sigurdsson, Nathan W. E. Seet, Paul Walker, Timothy C.H. Liew* (Nanyang Technological University)

11:30am – 11:45am

The spatial and temporal dynamics of exciton-polaritons in semiconductor microcavities is typically described by the 2D nonlinear Schrodinger equation, which has been largely successful in describing a wide variety of experimentally observed effects, for example: vortices, solitons, four-wave mixing, and various spin patterns. With advances in growth technology, many groups have developed and studied spatially patterned microcavities, where the planar geometry is patterned into arbitrary shapes. The theoretical description of these systems is typically made in an ad-hoc fashion, where a spatially varying potential is chosen phenomenologically to match the considered geometries. As the potential is not derived from first principles, its parameters, such as its depth, are only understood as fitting parameters. Furthermore, the effects of confinement on the polarization structure, such as polarization splitting in channels or pillars with broken circular symmetry can also only be described phenomenologically.

When considering the coupling between different parts of a structured microcavity, the possible mediation by modes propagating in the plane of the structure (such as guided modes) is inaccessible in the usual 2D Schrodinger model. These effects are better treated by solving Maxwell's equations. We show that this allows the reproduction of nonlinear effects, such as polariton bistability, where nonlinearity is included in the equation for the polarization field. [1,2]. This allows a model of exciton-polaritons in semiconductor microcavities with arbitrary spatial patterning, together with exciton-photon coupling, and exciton-exciton interactions.

As example applications, we show that this method is able to describe the coupling between localized polaritons and those travelling in waveguides. This gives rise to a fast mechanism of polariton signal propagation that can connect the nonlinear nodes of a polariton network or circuit.

### T1.87 Moiré flat bands and antiferroelectric domains in lattice relaxed twisted bilayer hexagonal boron nitride under perpendicular electric fields

Fengping Li*, Dongkyu Lee, Nicolas Leconte, Srivani Javvaji, Jung Jeil* (University of Seoul)
11:45am – 12:00pm

Local interlayer charge polarization of twisted bilayer hexagonal boron nitride (t2BN) is calculated and parametrized as a function of twist angle and perpendicular electric fields through tight-binding calculations on lattice relaxed geometries Lattice relaxations tend to increase the bandwidth of the nearly flat bands, where widths smaller than $\approx 1$,meV are expected for $\theta \leq 1.08^\circ$ for parallel BN/BN alignment, and for $\theta < 1.5^\circ$ for the antiparallel BN/NB alignment. Local interlayer charge polarization maxima of $\approx$2.6 pC/m corresponding to interlayer electron density differences of $\approx 1.3 \times 10^{12}\text{cm}^{-2}$ are expected at the AB and BA stacking sites of BN/BN aligned t2BN in the long moire period limit for $\theta \ll 1^\circ$, and evolves non-monotonically with a maximum of $\approx$3.5 pC/m at $\theta = 1.6^\circ$ before reaching $\approx$2 pC/m for $\theta = 6^\circ$. The electrostatic potential maxima due to the t2BN Moiré patterns are overall enhanced by $\approx$20% with respect to the rigid system assuming potential modulation depths of up to $\approx$300 mV near its surface. In BN/BN aligned bilayers the relative areas of the AB or BA local stacking regions can be expanded or reduced through a vertical electric field depending on its sign.

### T1.108 Room-Temperature Polariton Interactions and Applications in Van der Waals Superlattices

Jiaxin Zhao*, Antonio Fieramosca*, Kevin Dini, Ruiqi Bao, Daniele Sanvitto, Qihua Xiong, Timothy C. H. Liew* (School of Physical and Mathematical Sciences, Nanyang Technological University, Singapore 637371)
12:00pm – 12:15pm

Monolayer group-VI transition-metal dichalcogenides (TMDs), a new class of two dimensional semiconductors, have attracted significant research interest due to their sizable direct bandgap, exceptional optical and electronic properties. The presence of tightly bound excitons, characterized by a large oscillator strength, positions monolayer TMDs as ideal systems for exploring light-matter interactions within strong coupling regimes, particularly when integrated with optical cavities. The inherent layered structure of these monolayer TMDs further facilitates the fabrication of van der Waals heterostructures through vertical stacking, introducing new approaches to modulate strong light-matter interactions. Here, we have achieved systematic control over the coupling strength by embedding multiple WS2 monolayers within a planar microcavity.[1] By conducting time resolved pump-probe experiments at room temperature, we demonstrate the nature of polariton interactions, which are predominantly influenced by phase space filling effects. Furthermore, we have demonstrated the operation of all-optical polariton spin-switches [2]. Our findings pave the way for the development of polaritonic devices based on planar microcavities embedding multiple monolayers, potentially leading to future devices that exploit interaction-driven phenomena at room temperature.

[1] Zhao J, Fieramosca A, Dini K, et al. Exciton polariton interactions in Van der Waals superlattices at room temperature. Nature Communications, 2023, 14(1): 1512. [2] Zhao J, Fieramosca A, Bao R, et al. Room temperature polariton spin switches based on Van der Waals superlattices. Nature Communications, 2024

### T1.67 Observation of charge density wave in 2D semiconducting $Cr_2Se_3$

Sisheng Duan*, Andrew Wee*, Wei Chen* (National University of Singapore)
12:15pm – 12:30pm

Layered transition metal chalcogenides (TMCs) are ideal systems for exploring the effects of dimensionality on correlated electronic phases such as charge density wave (CDW) order. Here, we present an electronic characterization study of a two-dimensional TMC, $Cr_2Se_3$, by means of low-temperature scanning tunnelling microscopy/spectroscopy (STM/STS). Based on the detailed scanning probe microscopy investigation, we confirmed the charge density wave origin of the observed domain-like patterns at low temperatures. In addition, the substrate tunability of the charge ordering was revealed by examining the low-temperature behavior of the 2D $Cr_2Se_3$ grown on different substrates. The discovery of CDW phase in a semiconducting 2D TMC introduces a new avenue towards the fundamental inquiries and the extrinsic manipulation of electronic correlated phases in the 2D realm.

## T2: Machine Learning

Time: Wednesday 2 Oct, 11:00am; Venue: LT-4; Chair: Dario Poletti, SUTD
Time allocated for invited talks is 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.

### T2.186 (INVITED) Classification of Atomic Defects in Semiconductor Material Systems by Machine Learning

Calvin Pei Yu Wong*, Hiroyo Kawai, Kuan Eng Johnson Goh* (Institute of Materials Research and Engineering, A*STAR)
11:00am – 11:20am

Visualizing and identifying defects present on the semiconductor material surface is an important application of the scanning tunnelling microscope (STM). However, it can be difficult to interpret these images as the images show a convoluted picture of the local electronic structure and topography. Identifying the correct defect require comparisons to theoretical predictions and is often highly dependent on the skill of human experts. Thus, the identification of a large dataset is not only time consuming but may also result in inconsistency in the classification of experimental STM images due to human bias. In this work, we compare the performance of a convolutional neural network (CNN) trained solely using theoretical simulated defect images with human classifiers and discuss the implications of our results.

### T2.146 Paths towards time evolution with larger neural-network quantum states

Wenxuan Zhang*, Bo Xing*, Xiansong Xu*, Dario Poletti* (Science, Mathematics and Technology Cluster, Singapore University of Technology and Design)
11:20am – 11:35am

In recent years, the neural-network quantum states method has been investigated to study the ground state and the time evolution of many-body quantum systems. Here we expand on the investigation and consider a quantum quench from the paramagnetic to the anti-ferromagnetic phase in the tilted Ising model. We use two types of neural networks, a restricted Boltzmann machine and a feed-forward neural network. We show that for both types of networks, the projected time-dependent variational Monte Carlo (p-tVMC) method performs better than the non-projected approach. We further demonstrate that one can use K-FAC or minSR in conjunction with p-tVMC to reduce the computational complexity of the stochastic reconfiguration approach, thus allowing the use of these techniques for neural networks with more parameters.

### T2.24 Learning pure quantum states (almost) without regret

Josep Lumbreras*, Mikhail Terekhov*, Marco Tomamichel* (National University of Singapore)

11:35am – 11:50am

We initiate the study of quantum state tomography with minimal regret. A learner has sequential oracle access to an unknown pure quantum state, and in each round selects a pure probe state. Regret is incurred if the unknown state is measured orthogonal to this probe, and the learner's goal is to minimise the expected cumulative regret over $T$ rounds. The challenge is to find the balance between most informative and measurements incurring minimal regret. We show that the cumulative regret scales as $\Theta(\text{polylog}T)$ using a new sample-optimal tomography algorithm based on a median of means online least squares estimator.

### T2.111 Self-organization toward 1/f noise in deep neural networks

Ling Feng*, Nicholas Jia Le Chong (Institute of High Performance Computing, A*STAR Singapore)

11:50am – 12:05pm

1/f noise is a well-known phenomenon in biological neural networks and is believed to play a crucial role in information processing in the brain. In this study, we observed similar 1/f noise patterns in deep neural networks trained on natural language, mirroring those found in their biological counterparts. Specifically, we trained Long Short-Term Memory (LSTM) networks on the IMDb benchmark dataset and analyzed the neuron activations within the LSTM layer. Detrended fluctuation analysis (DFA) of the neuron time series revealed distinct 1/f patterns, which were absent in the time series of the inputs to the LSTM. Interestingly, when the neural network was overcapacity, with more neurons than necessary to achieve the learning task, the activation patterns shifted from 1/f noise towards white noise. This shift occurred because many neurons were underutilized, showing minimal fluctuations in response to input data. Additionally, we examined the exponent values in the 1/f noise within the "internal" and "external" activations of the LSTM cells, finding similarities with the variations in fMRI signals observed in the human brain. Our findings further support the hypothesis that 1/f noise is a signature of optimal learning.

### T2.103 Concept learning of parameterized quantum models from limited measurements

Beng Yee Gan*, Po-Wei Huang, Elies Gil-Fuster, Patrick Rebentrost (Centre for Quantum Technologies)

12:05pm – 12:20pm

Classical learning of the expectation values of observables for quantum states is a natural variant of learning quantum states or channels. While learning-theoretic frameworks establish the sample complexity and the number of measurement shots per sample required for learning such statistical quantities, the interplay between these two variables has not been adequately quantified before. In this work, we take the probabilistic nature of quantum measurements into account in classical modelling and discuss these quantities under a single unified learning framework. We provide provable guarantees for learning parameterized quantum models that also quantify the asymmetrical effects and interplay of the two variables on the performance of learning algorithms. These results show that while increasing the sample size enhances the learning performance of classical machines, even with single-shot estimates, the improvements from increasing measurements become asymptotically trivial beyond a constant factor. We further apply our framework and theoretical guarantees to study the impact of measurement noise on the classical surrogation of parameterized quantum circuit models. Our work provides new tools to analyse the operational influence of finite measurement noise in the classical learning of quantum systems.

## T3: Photonics 1

Time: Wednesday 2 Oct, 11:00am; Venue: LT-3; Chair: Giorgio Adamo
Time allocated for invited talks is 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.

### T3.130 (INVITED) Photonic bilayer Chern insulator with corner states

Subhaskar Mandal, Ziyao Wang, Rimi Banerjee, Hau Tian Teo, Peiheng Zhou, Xiang Xi*, Zhen Gao*, Gui-Geng Liu*, Baile Zhang* (Nanyang Technological University, Singapore)
11:00am – 11:20am

Photonic Chern insulators can be implemented in gyromagnetic photonic crystals with broken time-reversal (TR) symmetry. They exhibit gapless chiral edge states (CESs), enabling unidirectional propagation and demonstrating exceptional resilience to localization even in the presence of defects or disorders. However, when two Chern insulators with opposite Chern numbers are stacked together, this one-way nature can be nullified, causing the originally gapless CESs to become gapped. Recent theoretical works have proposed achieving such a topological phase transition in condensed matter systems using antiferromagnetic thin films such as $MnBi_2Te_4$ or by coupling two quantum spin/anomalous Hall insulators, but these approaches have yet to be realized experimentally. In a bilayer gyromagnetic photonic crystal arranged in an antiferromagnetic layer configuration, our experimental observations reveal that interlayer coupling initiates a transition from a Chern insulating phase to a higher-order topological phase. This transition results in the gapping of CESs and triggers the emergence of corner states within the bandgap [arXiv:2405.19267 ]. The corner mode energy within the gap can be attributed to CESs interaction, forming a Jackiw-Rebbi topological domain wall mode at the corner. These states exhibit heightened resilience against defects, setting them apart from their time-reversal symmetric counterparts.

### T3.197 Topological optical Skyrmion transfer to matter

Lucas Gabardos*, Chirantan Mitra, Chetan Madasu, Chang Chi Kwong, Yijie Shen, David Wilkowski, Janne Ruostekoski (Nanyang Technological University)
11:20am – 11:35am

The recent advances in the engineering of structured light have allowed for the creation of optical beams having non-trivial topologies. Notably, paraxial beams of light can carry a topological charge if the Stokes vector field has a spatially winding pattern, similar to the spin profile of a skyrmion. In this experiment, we create such a skyrmionic beam of light that coherently excites a gas of ultracold strontium atoms. The optical spin texture is mapped on the atomic dark state via adiabatic passage and the transferred topological charge is subsequently detected.

### T3.189 Electrically Tunable Amplified Light Emission in a Hybrid Photonic-Plasmonic Bound States in the Continuum Metasurface

Omar Abdelrahman Mohamed Abdelraouf*, Rasna Maruthiyodan Veetil, Tobias Ww Mass, Ramon Paniagua-Dominguez* (IMRE, A*STAR)

11:35am – 11:50am

Electrically tunable light-emitting metasurfaces are highly desirable for compact photonic devices and controlling light-matter interactions at the nanoscale. However, achieving this goal requires integrating and optimizing numerous parameters, such as high external quantum efficiency materials, high-quality resonant cavities, tunable optical materials with low optical losses, and fast tuning mechanisms. In this work, we designed, fabricated, and measured an electrically tunable amplified light emission in a hybrid plasmonic-photonic metasurface operating in the visible regime. The proposed hybrid metasurface supports Friedrich–Wintgen (FW) bound states in the continuum (BIC) resonances, theoretically boosting the optical cavity's quality factor to infinity and enhancing light-matter interactions. We observed amplified spontaneous emission up to 302 times greater compared to thin-film emission and achieved a wide bandwidth tunable amplified light emission of up to 60 nm by tuning the refractive index of liquid crystals. Additionally, we observed a phase shift of up to $2\pi$ with a reflection efficiency of more than 90%. These results enable better control of light emission wavefronts for future phase-gradient applications.

### T3.167 Strong coupling enhanced superradiance in J-aggregates

Marco Marangi*, Alexander Dubrovkin, Yutao Wang, Giorgio Adamo, Cesare Soci (NTU - CDPT)

11:50am – 12:05pm

J-aggregates, highly ordered molecular aggregates with naturally aligned dipole moments resulting in delocalized excitons, have long been classified as superradiant (SR) emitters based on their ultrafast and power-dependent dynamics. Decoherence effects caused by local disorder and thermal noise restrain most suitable superradiant systems, such as J-aggregates, to low temperatures. In our work, we overcome these limitations by inducing strong coupling between J-aggregates and silicon metasurfaces supporting a bound state in the continuum (BIC) resonance. The delocalized BIC field distribution acts as a common electromagnetic mode to foster cooperativity between spatially separate J-aggregates. We observe that hallmarks properties of SR, such as power-dependent super-linear emission intensity, rate, and photon bunching are all enhanced proportionally to the Rabi splitting of the strongly coupled system. We thus propose strong coupling with dielectric metasurfaces to be a prospective platform to enhance superradiant effects in emitters, creating new opportunities for power-efficient, bright, and ultrafast light-emitting devices.

## T4: Quantum Information

Time: Wednesday 2 Oct, 11:00am; Venue: LT-5; Chair: Marco Tomamichel, NUS
Time allocated for invited talks is 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.

### T4.61 Entropic Cost of Statistical Inference

Nathan Shettell*, Alexia Auffèves (CQT, MajuLab)
11:00am – 11:15am

Inferring an unknown quantity can be bisected into two tasks: a physical task of measuring an observable(s), and an information theoretic task of transforming the measurement results into an estimate, formally known as estimator [1]. The quality of an estimator is typically gauged by the means of a mathematical tool known as a statistical cost function (e.g. expected mean-squared error). This measure of efficacy is solely dependent on the measurement results, completely overlooking the fact that measurements implicate the use of some sort of physical meter, wherein the preparation, usage and subsequent reset of the meter invoke an energetic cost [2]. This energetic cost is not reflected in the value of the statistical cost function, despite being relevant given real-world limitations of finite resources.

To remedy this absence we propose a framework where the cost of measurements is reflected in the overall assessment of a statistical inference strategy. We attribute the energetic cost of using a meter, and the subsequent reset, to the bounds derived by Sagawa and Ueda: wherein the minimum cost is proportional to the change of entropy of the meter(s) [2]. We showcase our framework with a classical toy-model, where a noisy bit is used to infer the state of a secondary unknown bit: a statistical advantage arises by adopting a more energetically efficient measure-and-reset protocol. Our framework is especially useful for comparing two or more estimators which make use of different measurements. This is common practice in the realm of quantum metrology, where entangling qubits can lead to a statistical advantage [3]. However, the difference in entropic cost of measuring entangled versus separable states is not addressed.

[1] David Roxbee Cox. Principles of statistical inference. Cambridge university press, 2006.

[2] Takahiro Sagawa and Masahito Ueda. Minimal energy cost for thermodynamic information processing: Measurement and information erasure. Physical review letters, 102(25):250602, 2009.

[3] Vittorio Giovannetti, Seth Lloyd, and Lorenzo Maccone. Advances in quantum metrology. Nature photonics, 5(4):222– 229, 2011.

### T4.19 Commissioning of CQT Optical Ground Station

Ayesha Reezwana*, Xi Wang, Shaik Muhammad Abdillah Bin Hanifah Marican, Moritz Mihm, Alexandder Ling (CQT, National University of Singapore)
11:15am – 11:30am

We have built an optical ground station (OGS) on National University of Singapore campus for space-based quantum communication. The OGS is prepared to work with planned SatQKD missions in the coming years. In this work, we will discuss the commissioning of the OGS that includes calibration and alignment of the telescope system. We also highlight ongoing projects such as an optimization method of telemetry data for satellite tracking using optical observation from OGS. Lastly, we will give an overview of a cloud cover prediction model that can facilitate to schedule OGS operations.

### T4.44 A fixed-point algorithm for matrix projections with applications in quantum information

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

11:30am – 11:45am

We develop a fast fixed-point iterative method that computes the maximum fidelity with respect to the set of states that are invariant under some symmetry. We discuss several applications in quantum information theory.

(A longer abstract is attached)

### T4.27 Strategic Code: A Unified Spatio-Temporal Framework for Quantum Error-Correction

Andrew Tanggara*, Mile Gu, Kishor Bharti (Centre for Quantum Technologies)

11:45am – 12:00pm

The susceptibility of quantum systems to noise has hindered a scalable quantum computational speed-up, highlighting the need for quantum error-correcting codes (QECC). The emerging paradigm of dynamical QECC has revealed a plethora of possibilities on temporal noise-resilient encoding of quantum information through a sequence of operations, as opposed to a fixed spatial many-body encoding in conventional static QECCs. Although it has made a considerable progress towards fault-tolerant quantum information processing and have lead to discoveries of more resource-efficient QECCs, an understanding of the physical extent of error-correction is still limited due to the lack of a unified framework. We overcome this by proposing the "strategic code" framework, which is the most general QECC framework encompassing all existing and physically plausible QECCs to be discovered, as well as the most general noise with spatial and temporal correlations. The framework uses an "interrogator" device, which allows a code to perform the most general quantum process that *adaptively* interacts with the noise environment over multiple time-steps, both of which can be represented in the quantum combs formalism. Using the framework, we establish necessary and sufficient error-correction conditions in an algebraic and information-theoretic forms, which we show to be equivalent. As a corollary, we show that known conditions for static QECCs are special cases of our conditions. Lastly, we propose an optimization-theoretic approach to construct a strategic code that recovers logical information up to a desired fidelity under the most general noise model.

### T4.124 A computational test of quantum contextuality, and even simpler proofs of quantumness

Kishor Bharti* (National University of Singapore)

12:00pm – 12:15pm

Bell non-locality is a fundamental feature of quantum mechanics whereby measurements performed on "spatially separated" quantum systems can exhibit correlations that cannot be understood as revealing predetermined values. This is a special case of the more general phenomenon of "quantum contextuality", which says that such correlations can occur even when the measurements are not necessarily on separate quantum systems, but are merely "compatible" (i.e. commuting). Crucially, while any non-local game yields an experiment that demonstrates quantum advantage by leveraging the "spatial separation" of two or more devices (and in fact several such demonstrations have been conducted successfully in recent years), the same is not true for quantum contextuality: finding the contextuality analogue of such an experiment is arguably one of the central open questions in the foundations of quantum mechanics. In this work, we show that an arbitrary contextuality game can be compiled into an operational "test of contextuality" involving a single quantum device, by only making the assumption that the device is computationally bounded. Our work is inspired by the recent work of Kalai et al. (STOC '23) that converts any non-local game into a classical test of quantum advantage with a single device. The central idea in their work is to use cryptography to enforce spatial separation within subsystems of a single quantum device. Our work can be seen as using cryptography to enforce "temporal separation", i.e. to restrict communication between sequential measurements. Beyond contextuality, we employ our ideas to design a "proof of quantumness" that, to the best of our knowledge, is arguably even simpler than the ones proposed in the literature so far.

Accepted in FOCS 2024 Paper link: https://arxiv.org/pdf/2405.06787

### T4.49 Entanglement generation from athermality

Jeongrak Son*, A. de Oliveira Junior, Jakub Czartowski, Nelly H. Y. Ng (Nanyang Technological University)

12:15pm – 12:30pm

Quantum entanglement is a crucial resource for all three pillars of quantum technologies: computation, communication, and metrology. The manipulation of entanglement via restricted operations that cannot generate entanglement has been extensively studied and is now well-understood. However, the generation of entanglement and its thermodynamic cost remain less explored. We investigate the generation of entanglement within a model-independent thermodynamic framework and provide a comprehensive analysis of how the thermodynamic cost (athermality of a state) affects entanglement generation.

We define and characterise the set of states that can be entangled without investing any work. We then study the geometric properties of this set and quantify the amount of entanglement obtainable from each state. In particular, in the case of two-qubit systems, we derive a simple condition to determine whether an initial state is entanglable without work investment. Finally, we demonstrate that different energy level structures of multi-partite systems result in different classes of multi-partite entanglement.

## T5: Low dimensional Materials 2

Time: Wednesday 2 Oct, 2:00pm; Venue: LT-2; Chair: Johnson GOH, A*STAR
Time allocated for invited talks is 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.

### T5.69 2D Amorphous Carbon as a Low-K Dielectric

Ugur Karadeniz*, Konstantin Vitalievitch Iakoubovskii, Artem Grebenko*, Carlo Mendoza Orofeo, Chee Tat Toh*, Barbaros Oezyilmaz* (National University of Singapore)
2:00pm – 2:15pm

Multilayer amorphous carbon (ML-AC) has emerged as a highly promising 2D material with exceptional properties. MAC possesses a single atomic layer thickness and large area continuity over the wafer scale and allows conformal coverage over a wide range of substrates at low temperatures ($< 300\,^{\circ}$C). This study presents research on the structural characterization and electronic properties of atomically thin ML-AC films. By using Plasma and laser-assisted chemical vapor deposition (PLCVD), we successfully grew monolayer and multilayer MAC films, with precise control of the number of layers. We show, that ML-AC exhibits low-k dielectric permittivity as low as 1.4 with tunable values with respect to the growth temperatures. The absence of reactive grain boundaries gives ML-AC films exceptional chemical and mechanical stability despite their sub-5 nm thickness. We demonstrate the use of ML-AC films as ultrathin barrier films for copper interconnects in integrated circuits to impede metal ion diffusion. The findings of this study highlight the exceptional properties of atomically thin amorphous materials to overcome existing material bottlenecks. Together with its technologically relevant growth conditions, there is immense potential for enhancing device performance and addressing prevalent technological challenges.

### T5.74 Energy-momentum dispersion in 2D amorphous carbon

Artem Grebenko*, Rejaul Sk, Chee Tat Toh, Bent Weber, Barbaros Oezyilmaz* (National University of Singapore)
2:15pm – 2:30pm

The relationship between the wavenumber of electron waves and their energy, known as the band structure, is crucial for understanding electron behavior in a system. At first glance, amorphous and liquid matter, which lack long-range order, might seem unlikely to possess any band structure. However, when thinking out of the Bloch's (theorem), the existence of a band structure in disordered systems is actually expected. Despite theoretical discussions dating back to the 1950s, experimental observations of band structure in liquid and amorphous systems have been scarce over the past twenty years. Moreover, no studies have yet enabled the simultaneous investigation of macroscopic and atomic scales to directly observe that the short-range order motifs are responsible for the emergence of band structure. In this work, we analyze monolayer amorphous carbon using angle-resolved photoelectron spectroscopy (ARPES) and Fourier-transform scanning tunneling spectroscopy (FT-STS). For the first time, we provide direct observation of the band structure in this disordered material and see scattering processes at the nanoscale (short-range order scale) reminiscent of those of graphene. Monolayer amorphous carbon is especially well-suited for this investigation, given that ARPES and FT-STS are surface-sensitive techniques and MAC is a 2D non-wide band gap insulator and does not have potentially disorder-insensitive (topologically protected) surface states. Our results offer a key direct insight into the origin of band structure in disordered systems, which was often postulated but limited from the direct observation. These results position amorphous systems outside the conventional view of disorder as an absence of any electron coherence. Instead, disordered materials and their heterostructures with crystalline counterparts open new avenues for exploring emergent quantum phenomena.

### T5.46 In-situ Investigation of Lithium Plating Dynamics on 2D Carbon Surfaces

Lu Shi*, Artem Grebenko, Sergey Luchkin, Hongji Zhang, Chee Tat Toh, Barbaros Oezyilmaz
(National University of Singapore)
2:30pm – 2:45pm

Traditional understanding links macroscopic features like Nucleation Overpotential (NOP) in lithium deposition dynamics to microscopic characteristics such as nucleation density and uniformity, based on Classical Nucleation Theory. This theory considers NOP an indicator of the energy barrier for lithium nucleation. However, recent studies suggest a deviation from this interpretation, questioning the direct connection between NOP and actual nucleation dynamics. These claims, however, have not been extensively analysed in situ. Understanding the relationship between nucleation and growth dynamics and measurable macroscopic properties is crucial for designing materials capable of uniform lithium plating, which is a crucial step towards high-performance batteries. In this study, we investigated three model systems using in-situ AFM to capture lithium plating dynamics: copper (Cu) foil, graphene@Cu, and Monolayer Amorphous Carbon (MAC)@Cu. According to battery performance tests, these systems exhibited expected trends in cycling performance (MAC@Cu > graphene@Cu > Cu), with corresponding decreases in NOP. Initially, this suggests a higher nucleation density for MAC and significant differences in nucleation dynamics between Cu and graphene@Cu. Contrary to expectations, we found that Cu and graphene@Cu exhibited similar nucleation densities, while MAC had a surprisingly low nucleation density. We further analysed difference mechanical and morphological differences in SEI formation and the lateral growth rate. Our finding suggests that a possible connection between MAC's insulating property, the elasticity of the SEI, and its high lateral growth rate. We also observe a unique phenomenon in MAC: the merging of Li pillars. This behaviour highlights the lateral growth as a crucial factor for enhancing the battery performance. The disorder structure of MAC and the unique property of its SEI may facilize this process. These findings are significant because they challenge the assumed correlation between high nucleation density and superior battery performance. Our results highlight the need to reconsider the material properties that contribute to optimal battery performance in the early stages of lithium plating.

### T5.54 Ultrastrong adhesion of 2D amorphous carbon to copper

Hongji Zhang*, Artem Grebenko, Chee Tat Toh, Barbaros Ozyilmaz (National University of Singapore)

2:45pm – 3:00pm

The broad application of 2D materials and their composites requires a deep understanding of their interfacial properties for both scientific and practical purposes. Typically, 2D material adhesion to substrates is dominated by van der Waals (vdW) interactions, resulting in weak adhesion. This issue is particularly significant for copper substrates, which are widely used in various applications. High adhesion energies are crucial for application of 2D systems subjected to mechanical stress, such as structural composites and layers in microelectronic devices, as identified by the IRDS and related mechanical systems standards. To overcome the low adhesion of both 2D and 3D materials, additional layers and chemical modifications (e.g., doping) are often employed. However, these methods add complexity and may not meet application requirements. Particularly for the case of microelectronics new adhesive layers can limit device scaling. It is known, that 3D amorphous carbon systems have shown strong adhesion, usually attributed to dangling bonds and various carbon atom hybridizations. Recent studies also indicate that creating defects in graphene can enhance adhesion. The discovery of monolayer amorphous carbon (MAC) raised questions about its adhesion properties: does it adhere strongly like 3D amorphous carbon or weakly like crystalline graphene? Can it form stronger bonds with substrates? Can the disrupted $\pi$ cloud facilitate orbital interaction changes? In this study, we investigated MAC directly grown on copper. Adhesion measurements using standard techniques revealed a remarkable adhesion strength of 85 J/m$^2$, 13 times higher than that of graphene on copper. XPS and NEXAFS analysis revealed the formation of covalent Cu-C bonds, unprecedented for thin carbon films on copper, which can be a possible source of the high adhesion. Our DFT study suggests that MAC corrugation alters the local density of states and charge distribution, enabling Cu-C bonding and resulting in high adhesion. We propose that the MAC and Cu interface offers a new route for achieving high adhesion between 2D materials and other surfaces. Combined with the unique properties of amorphous materials, such as high toughness and electrical insulation, this approach holds significant potential for various applications.

### T5.39 Solid-liquid duality of two-dimensional water

Maxim Trushin*, Alexandra Carvalho, Antonio H. Castro Neto (National University of Singapore)

3:00pm – 3:15pm

Water, while being an object of human curiosity for millennia, is probably the most studied substance on Earth, with a scientific discipline — hydrodynamics — devoted solely to studying water in motion. However, the water flow in reduced dimensions (for instance, through one-dimensional (1D) or two-dimensional (2D) channels) drastically deviates from the laws of conventional hydrodynamics because reducing the dimensionality of any interacting physical system amplifies interaction effects intractable by the Hagen–Poiseuille equation. The hydrogen bonds may become stable enough to bring water molecules into an ordered state making water behave not only like a liquid but also like a solid in some aspects. In particular, the water molecules confined between two solids and squeezed down to a monolayer (2D limit) do not behave like conventional water but instead resemble 2D "ice". The quotation marks are not accidental here — such kind of "ice" exists only in the presence of narrow confinement, as water forms a droplet otherwise, which is essentially a 3D object. The particular order acquired by water also depends on specific interactions between the water molecules and confining materials forming a channel. In this talk, we demonstrate a solution of a non-linear hydrodynamic equation describing 2D water flow with viscosity parameters deduced from molecular dynamic simulations. We show that the very ability of 2D water to flow in short channels is governed by the second (dilatational) viscosity coefficient, leading to flow compression and velocity saturation in the high-pressure limit. The viscosity parameter values depend strongly on whether graphene or hexagonal boron nitride layers are used to confine 2D water, which offers an interesting opportunity to obtain various nanofluids out of the same water molecules just by using alternate materials to fabricate the 2D channels.

### T5.95 Valleytronics with Charged Excitons: Electrical Control and Polarization Switching

Sarthak Das*, Kuan Eng Johnson Goh*, Ding Huang, Ivan Verzhbitskiy, Chit Siong Lau (IMRE, A*STAR)
3:15pm – 3:30pm

Monolayer transition metal dichalcogenides (TMDs) offer a unique platform for exploring valleytronics due to their valley-contrasting spin splitting [1]. This property allows for precise control of exciton valley polarization, a key requirement for valley information processing. However, the delicate nature of excitons, coupled with the challenges of electrical manipulation, has hindered progress in this field. Our research focuses on charged excitonic species, such as trions and quintons, as potential solutions to these challenges. By investigating the electrical control of their valley polarization, we discovered a novel mechanism for protecting valley information. This mechanism involves a combination of intervalley exchange interaction and spatial dispersion of charged energy states, which effectively shields the system from environmental noise. By altering the electrical bias, we can effectively switch between high and low-polarized states of charged excitonic emission over several cycles. Our findings demonstrate the feasibility of deterministic control over valley polarization in charged excitonic species. This breakthrough opens new avenues for the development of valleytronic devices [2,3] and advances our understanding towards using valley states for quantum information processing. Acknowledgement: This work was supported by the Agency for Science, Technology, and Research #21709 and C230917006. References [1] Jones et al., Nature Nanotechnology, 8, 634-638 (2013) [2] Bussolotti et al., Nano Futures, 2, 032001 (2018) [3] Goh et al., Advanced Quantum Technologies 3, 1900123 (2020).

### T5.41 Engineering 2D Semiconductors for Nanoelectronics and Quantum Applications

Chit Siong Aaron Lau* (Institute of Materials Research and Engineering)
3:30pm – 3:45pm

Quantum materials, e.g., 2D transition metal dichalcogenides, exhibit fascinating intrinsic quantum effects with no bulk counterparts arising from their unique geometry. However, progress is severely hindered by fundamental material science and device engineering challenges. I will introduce discuss our group's efforts to establish high-quality contacts at cryogenic temperatures where we revealed new transport insights into the nature of metal/2D semiconductor interface.[1] 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 WS2 quantum dot.[2] Finally, we will share some of our latest work on integrating ultrathin metal oxides printed from liquid metals with 2D materials,[3,5,6] the use of thermal scanning probe based techniques for interface and contact engineering of 2D materials,[4] and how these can potentially address crucial challenges in engineering 2D materials towards quantum applications.[4]

References 1. C.S. Lau, J.Y. Chee et al., 'Quantum Transport in Two-Dimensional WS2 with High-Efficiency Carrier Injection through Indium Alloy Contacts', ACS Nano, 14 (10), 13700-13708 (2020) 2. C.S. Lau, J.Y. Chee et al., 'Gate-Defined Quantum Confinement in CVD 2D WS2, Advanced Materials, 2103907 (2021) 3. Y. Zhang, D. Venkatakrishnarao et al., 'Liquid-Metal-Printed Ultrathin Oxides for Atomically Smooth 2D Material Heterostructures', ACS Nano, 17, 8, 7929-7939 (2023) 4. Talha-Dean, T., Tarn, Y., Mukherjee, S., John, J. W., Huang, D., Verzhbitskiy, I. A., Venkatakrishnarao, D., Das, S., Lee, R., Mishra, A., Wang, S., Ang, Y. S., Goh, K. E. J. & Lau, C. S. Nano-ironing van der Waals Heterostructures Towards Electrically Controlled Quantum Dots. ACS Applied Materials & Interfaces 2024 16 (24), 31738-31746 DOI: 10.1021/acsami.4c03639 5. C.S. Lau et al., 'Dielectrics for Two-Dimensional Transition-Metal Dichalcogenide Applications', ACS Nano, 17, 11, 9870-9905 (2023) 6. C.S. Lau et al., 'Liquid Metal Oxide-assisted Integration of High-k Dielectrics and Metal Contacts for Two-Dimensional Electronics', under review at ACS Nano.

## T6: Material Physics

Time: Wednesday 2 Oct, 2:00pm; Venue: LT-4; Chair: (TBD)
Time allocated for invited talks is 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.

### T6.190 Light-Driven Structural Change from Quasi-2D to Stable and Luminescent 3D Perovskite

Maria Lunina*, Benny Febriansyah, Yulia Lekina, Ze Xiang Shen* (Division of Physics and Applied Physics, SPMS, NTU, Singapore)
2:00pm – 2:15pm

Hybrid organic-inorganic lead halide perovskites have gained significant attention recently due to their exceptional optoelectronic properties. Beyond their use in photovoltaics, these materials have shown great promise for applications in light-emitting diodes, X-ray detectors, and photodetectors. Traditional 3D perovskites, however, are often limited by their poor stability when exposed to light and moisture. The latest advancements in perovskite-based devices have focused on using a combination of 2D and 3D perovskites to improve performance. Despite this, the high ion mobility in these materials can lead to the formation of mixed-phase quasi-2D structures at the interfaces, whose behaviors under external conditions remain poorly understood. Previous studies indicate that quasi-2D perovskites are generally less stable under illumination and can decompose or convert to 3D structures upon light exposure, although the specific mechanisms driving these changes are still unclear. Additionally, the stability and luminescence efficiency of quasi-2D perovskites after light treatment, which are vital for applications in solar cells and LEDs, have not been thoroughly investigated.

This study explores the photo-induced transformation of a quasi-2D perovskite to a 3D phase in a 2D/3D mixed-dimensional $PEA_2Cs_{n-1}Pb_nBr_{n+1}$ perovskite under ambient conditions. The proposed mechanism suggests that photoexcited electrons and holes participate in redox reactions with $H_2O$ and $O_2$ molecules on the perovskite surface, generating free radicals. These radicals react with the organic ligands, leading to their degradation and the overall decomposition of the lower-dimensional phases in the system. The treated material transitions to a 3D $CsPbBr_3$ perovskite, which shows enhanced stability compared to directly synthesized bulk perovskites. Furthermore, this new material exhibits higher luminescence efficiency, likely due to the formation of PbO and $Pb(OH)_2$, which effectively passivate defects on the surface of the resulting 3D $CsPbBr_3$ perovskite. These findings provide new opportunities to improve the properties of 3D perovskites in perovskite-based devices, potentially boosting their performance in solar cells, light-emitting applications, and sensors.

### T6.155 Strong electron-phonon coupling and bipolarons in $Sb_2S_3$

Yun Liu*, Julia Wiktor, Bartomeu Monserrat (Institute of High Performance Computing (IHPC), Agency for Science Technology and Research (A*STAR))
2:15pm – 2:30pm

$Sb_2S_3$ is an Earth-abundant and non-toxic material that is under investigation for solar energy conversion applications. However, it still suffers from poor power conversion efficiency and a large open circuit voltage loss that have usually been attributed to point or interfacial defects. More recently, there has been some discussion in the literature about the role of carrier trapping in the optical properties of $Sb_2S_3$, with some reporting self-trapped exciton as the microscopic origin for the performance loss, while others have found no evidence of carrier trapping with only large polarons existing in $Sb_2S_3$. By using first-principles methods, we demonstrate that $Sb_2S_3$ exhibits strong electron-phonon coupling, a prerequisite for carrier self-trapping in semiconductors, which results in a large renormalization of 200 meV of the absorption edge for the temperature range of 10 K to 300 K. When two electrons or holes are added to the system, corresponding to a carrier density of $1.6 \times 10^{20}\,\mathrm{cm}^{-3}$, we find wavefunction localization consistent with the presence of bipolarons accompanying a significant lattice distortion with the formation of Sb and S dimers. The formation energies of the electron and hole bipolarons are -330 meV and -280 meV per carrier, respectively. Our results reconcile some of the controversy in the literature regarding carrier trapping in $Sb_2S_3$ , and demonstrate the existence of large electron-phonon coupling and carrier self-trapping that might place a fundamental limit on the open circuit voltage and consequently the maximum efficiency of the photovoltaic cells. (Phy. Rev. Materials, 7, 085401 (2023))

### T6.163 Dynamical Layer Symmetry Breaking: Layer Electric phases

Ying Xiong*, Mark S. Rudner, Justin C.W. Song* (Nanyang Technological University)
2:30pm – 2:45pm

Electric screening plays a fundamental role in determining the phase structure of materials, and is typically constrained by the properties of electrons in thermodynamic equilibrium. Here, we show that photoexcitation enables access to multiple new types of screening behaviours with no analogue in equilibrium. In particular, by tuning the non-equilibrium carrier densities, multilayer graphene can exhibit anomalous screening properties such as anti-screening (amplification of electric fields) and overscreening (reversing of electric fields). Strikingly, at moderate continuous wave photoexcitation, the steady state nonequilibrium layer polarisation becomes multistable, sustaining a non-vanishing out-of-plane polarisation and band gap even in the absence of externally applied displacement field. Such light-induced ferroelectric-like state spontaneously breaks inversion symmetry of the system, providing a paradigm for creating and controlling new dynamical phases in non-equilibrium quantum matters.

### T6.118 Anisotropic optical properties and emergent phenomena in van der Waals $As_2S_3$

Davit Ghazaryan*, Kirill Voronin, Aleksandr Slavich, Georgy Ermolaev, Aleksey Arsenin, Valentyn Volkov, Kostya Novoselov* (Institute for Functional Intelligent Materials, National University of Singapore)
2:45pm – 3:00pm

The growing family of van der Waals crystals has been recognized as a promising platform for the investigation of novel effects and their implementation in a variety of functional devices. The nature of their out-of-plane bonds, i. e., their explicit layered structure, instantly suggests the emergence of anisotropic mechanical, optical, and electronic properties at z direction. Furthermore, the families of van der Waals crystals that also naturally possess in-plane anisotropic properties (xy plane), appear more interesting as they significantly enrich the research scope. Though the nature of in-plane bonds in constituent 2D layers of those van der Waals crystals is covalent, their unique crystal structures still stand as one of the major factors behind the anisotropy. Here, we will present our recent findings in orthorhombic van der Waals crystals (and heterostructures) of arsenic trisulphide that exhibit outstanding anisotropic optical properties and may be of great use for the creation of next-generation optical and nanophotonic devices [1-2].

1. A. Slavich, et al., Exploring van der Waals materials with high anisotropy: geometrical and optical approaches. Light: Science & Applications, Volume 13, Article number: 68 (2024). https://doi.org /10.1038/s41377-024-01407-3. 2. K. Voronin, et al., Chiral photonic super crystals based on helical van der Waals homostructures. Laser & Photonics Reviews, Volume 18, Issue 7, 2301113 (2024). https://doi.org/10.1002/lpor.2023 01113.

### T6.85 Universal Collective Spin-Charge Oscillations in High-Tc Cuprate Superconductors

Sai Prashanth Josyula*, Muhammad Avicenna Naradipa, Bin Leong Ong, Xiao Chi, Anjali Jain, Eng Soon Tok, Andrivo Rusydi* (Singapore Synchrotron Light Source, 5 Research Link, Singapore 117603)

3:00pm – 3:15pm

The strongly correlated Ba-La-Cu-O (or cuprate) system has shown rich exotic phenomena from high-critical-temperature (high-Tc) superconductivity to ferromagnetism across its phase diagram and is a model system to understand such competing phases. In this work, we report novel, universal collective spin-charge oscillations of doped-hole in the optical loss function of the high-Tc copper-oxides (cuprates) using high-resolution spectroscopic ellipsometry which is coupled with high-energy reflectance up to 35 eV. Notably, a new loss function peak at 1.8 eV is observed in both superconducting and ferromagnetic samples but with very different characteristics. The peak shows greater intensity for superconductors with higher Tc and is absent for the non-superconducting samples revealing its intimate connection with superconductivity. In contrast, this loss function peak occurs even in ultrathin films of a few unit cell thickness in ferromagnetic cuprates. Spin density functional theory calculations support that these collective spin-charge oscillation are due to a strong mixture of spin singlet-and-triplet (MST) state in the $CuO_2$-plane which further get enhanced through inter-$CuO_2$-plane Coulomb interaction and hybridizations of spin-polarized O-2p and Cu-3d orbitals. Coherently, the spin singlet state of MST plays important role for superconductivity, while the spin triplet state of MST determines ferromagnetism. Our result shows the universality of the spin-charge oscillations of MST in determining the exotic phase diagram in the high-Tc cuprates.

### T6.198 $MAPbI_3$ Perovskite Multiple-Quantum Wells via Thermal Evaporation for Enhanced Optoelectronics.

Luke R. W. White, Felix U. Kosasih, Ke Ma, Jianhui Fu, Minjun Feng, Matthew P. Sherburne, Mark Asta, Tze Chien Sum, Subodh G. Mhaisalkar*, Annalisa Bruno* (Nanyang Technological University)

3:15pm – 3:30pm

Metal halide perovskites have delivered rapid advances in emissive and absorbing functionalities in a short period of time, demonstrating enhanced properties such as increased carrier mobilities, and improved luminescent device performances.1 Two-dimensional confinement has demonstrated advantageous optoelectronic properties and facilitated fundamental studies in a variety of materials. Sequential stacking of a semiconducting material with a layer thickness below its Bohr diameter with another material of a different bandgap produces a meta-structure known as a multi-quantum well (MQW), providing advantageous optoelectronic properties such as bandgap tunability and increased exciton binding energy.2,3 Quantum wells have previously shown wide and prosperous use in III-V semiconductor materials, both for photovoltaics and light emission.4,5 Thermal evaporation provides a method to produce highly uniform, large area depositions with a high degree of thickness accuracy.6 This method has allowed fully inorganic perovskite MQWs to be produced, demonstrating the viability and optoelectronic advantages of the structure over bulk counterparts.2,7,8,9,10,11 Here we present our work on the first type-I co-evaporated hybrid organic-inorganic perovskite MQWs, demonstrating enhanced luminescent properties and increased hot carrier temperatures. Study of sequentially decreasing thicknesses of $MAPbI_3$ from bulk to ultrathin layers shows a persistent composition, with morphological analysis displaying continuous films at ultrathin thicknesses. Using bathocuproine (BCP) as the barrier material to produce a type-I bandgap alignment, single quantum wells (SQWs) exhibited a 50x increase in integrated PL intensity. Ultrafast spectroscopy was used to uncover the mechanisms behind this enhancement, finding a significant increase in radiative recombination. In addition, through Maxwell-Boltzmann distribution fitting, this examination exposed a significant increase in hot carrier temperature as the $MAPbI_3$ well thickness is reduced, opening the possibility for further study and utilisation of hot carriers in thermally evaporated organic-inorganic perovskite MQWs. A secondary material, lead phthalocyanine (PbPC), was used to generate a type-II band alignment with the $MAPbI_3$ so as to further study the charge dynamics between the well and barrier materials. Both type-I and type-II MQWs were integrated into lateral photodetector devices, with minimal increase from the type-I, and a significant increase from the type-II structures, when comparing both to $MAPbI_3$ only layers of the same thickness. This exhibits the advantage of using type-II aligned MQWs for absorbing devices, where the charges separate into the well and barrier individually, reducing recombination. [1] Advanced Materials 34, 21, https://doi.org/10.1002/adma.202108132 [2] Nano Letters, 19, 6, https://doi.org/10.1021/acs.nanolett.9b00384 [3] Journal of Applied Physics, 91, 3, https://doi.org/10.1063/1.1445280 [4] Optics Express, 26, 25, https://doi.org/10.1364/oe.26.033108 [5] Joule, 6, 5, https://doi.org/10.1016/j.joule.2022.04.024 [6] Nanoscale, 11, 30, https://doi.org/10.1039/c9nr04104d [7] Advanced Materials, 33, 17, https://doi.org/10.1002/adma.202005166 [8] ACS Energy Letters, 6, https://doi.org/10.1021/acsenergylett.1c01142 [9] Nano Letters, 22, 19, https://doi.org/10.1021/acs.nanolett.2c

[10] Advanced Science, 9, 24, https://doi.org/10.1002/advs.202200379 [11] Advanced Optical Materials, 12, 13, https://doi.org/10.1002/adom.202302701

## T7: Photonics 2

Time: Wednesday 2 Oct, 2:00pm; Venue: LT-3; Chair: Daniel Leykam, SUTD
Time allocated for invited talks is 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.

### T7.120 (INVITED) Bilayer high-Q metasurfaces for chiral emission and all-to-circular polarization upconversion

Dmitrii Gromyko*, Cheng-Wei Qiu, Lin Wu (Singapore University of Technology and Design)
2:00pm – 2:20pm

In the field of optical technology, small-scale sources that produce circularly polarized light are essential for various applications, ranging from material analysis to optical communication systems. Recent studies have focused on the development of metasurfaces featuring chiral resonances capable of differentiating between right- and left-handed circularly polarized waves [1,2]. We propose a bilayer metasurface with broken rotational symmetry that exhibits a non-degenerate quasi-BIC resonance of absolute chirality leading to unitary circular dichroism (CD) in linear and nonlinear regimes. The structure consists of top and bottom metasurfaces of thin dielectric discs with rectangular notches. With a dedicated design of twist angle between the top and bottom notches and the interlayer distance, the proposed metasurface functions as a perfect chiral mirror. We develop a comprehensive theoretical description of the resonant modes coupling in the system [3]. Then, we extend our studies to the chiral bilayer metasurfaces with high (three-fold and four-fold) rotational symmetry. While these metasurfaces selectively amplify a specific circularly polarized pump component, their rotational symmetry facilitates the conversion of this pump component into a circularly polarized nonlinear signal. The fusion of resonant chiral response and rotational symmetry defines a novel class of metasurfaces capable of transforming any linear pump into a circularly polarized nonlinear signal. We show that in this case, degenerate quasi-BIC resonant modes play the primary role in the efficient second and third harmonic generation of circularly polarized signals. Furthermore, we extend our coupling theory to describe these modes and derive the conditions of absolute chirality [4].

1. Zhang, X., Liu, Y., Han, J., Kivshar, Y. & Song, Q. Chiral emission from resonant metasurfaces. Science 377, 1215-1218 (2022). 2. Chen, Y. et al. Observation of intrinsic chiral bound states in the continuum. Nature 613, 474-478 (2023). 3. Gromyko, D. et al. Unidirectional Chiral Emission via Twisted Bi-layer Metasurfaces. arXiv preprint arXiv:2406.16003 (2024). 4. Gromyko, D., Loh, J. S., Feng, J., Qiu, C.-W. & Wu, L. Enabling all-to-circular polarization upconversion by nonlinear chiral metasurfaces with rotational symmetry. arXiv preprint arXiv:2407.19293 (2024).

### T7.183 Unlocking second harmonic generation in graphene through strain-induced sublattice polarization

Kunze Lu*, Manlin Luo, Weibo Gao, Qi Jie Wang, Hao Sun, Donguk Nam (School of Physical and Mathematical Sciences, Nanyang Technological University)
2:20pm – 2:35pm

Graphene is renowned for its exceptional optical and electronic properties. However, its inherent centrosymmetric nature has constrained its capacity to exhibit second harmonic generation (SHG). Various prior efforts have explored the possibility of disrupting graphene's spatial inversion symmetry using external stimuli, but these methods have fallen short of fundamentally altering the lattice structure of graphene. To address this limitation, we introduce a novel approach by applying non-uniform strain to graphene. This technique effectively creates sublattice polarization, thereby breaking the lattice inversion symmetry and enabling the generation of SHG. Remarkably, this strain-induced SHG is significantly enhanced, reaching approximately 50-fold higher values at low temperatures due to resonant transitions between strain-induced pseudo-Landau levels. Notably, the second-order nonlinear susceptibility of strained graphene surpasses that of hexagonal boron nitride, a material with intrinsic broken inversion symmetry. Our results demonstrate new possibilities in engineering graphene's symmetry properties, providing a practical and scalable means to achieve second-order nonlinear optical effects.

### T7.53 Interfacing rare earth ions with integrated optics

Kah Jen Wo*, Karthik Dasigi, Pavel Dmitriev, Steven Touzard (Centre for Quantum Technologies)
2:35pm – 2:50pm

A critical component in the realisation of a global quantum network is the coupling between photons at the optical and microwave frequencies. A well-known and promising candidate for building key quantum light-matter devices are rare earth ions (REIs). However, to achieve efficient optical interface with REIs, a tunable high quality factor (Q factor) cavity is required to leverage Purcell enhancement. Here, we focus on the application of thin film lithium niobate (LN) photonic integrated chips, incorporating micro-ring resonators, to interface with an erbium-doped calcium tungstate ($CaWO_4$) host crystal. In particular, we have achieved and can reproduce $\approx 3 \times 10^6$ internal Q factor micro-ring resonators on LN chips at telecom wavelengths from in-house fabrication, that are capable of being tuned through the Pockels effect, as well as robust room temperature chip bonding between the erbium-doped $CaWO_4$ crystal and our photonic integrated LN chips.

### T7.161 Fourier tomography of quantum states of light

Pierre Brosseau*, Mohammed Alqedra, Anton Vetlugin, Val Zwiller, Cesare Soci* (Nanyang Technological University)
2:50pm – 3:05pm

We report the first experimental demonstration of Fourier tomography of polarization states of single photons and entangled photon pairs. Unlike conventional tomography, which relies on discrete measurement settings, Fourier tomography employs a continuous scan through the measurement space. This method requires fewer components, potentially enhancing measurement speed and simplifying alignment. For polarization state measurements, we utilize a single rotating quarter-wave plate, a linear polarizer, and a superconducting nanowire single-photon detector per photon. The Fourier components of the single-photon counting rate (for single photon states) and coincidence rate (for entangled photons) enable accurate reconstruction of the state's density matrix. We explore the implications of this method for practical quantum state characterization and its potential applications in quantum technologies

### T7.106 Heterogenous quantum interfaces over metropolitan distances; Quantum Frequency Conversion

Isa Ahmadalidokht*, Ankush Sharma*, Alexander Ling* (National University of Singapore)
3:05pm – 3:20pm

Currently, entanglement between different stationary qubits is mostly restricted to qubits of the same type and in close proximity. While this simplifies the interconnection substantially and allowed to implement more complex quantum information processing protocols, it can not bridge the larger distances, which requires photons with a wavelength matched to the transparency windows of optical fibers, namely around 1300nm (O band) or 1550nm (C band). First demonstrations of such transfers have been reported, but the interconnection of different species is still outstanding. One part of the challenge here is to not only match the wavelengths of photons emitted by different systems, but also to adapt their coherence time or bandwidth. In this approach, we aim to transfer of quantum information between three distinct stationary qubits: (a) color centers in a solid, specifically silicon vacancy (SiV) centers emitting at 737.204 nm, (b) neutral Rubidium atoms trapped in an optical dipole trap, emitting at 780.24 nm, and (c) Barium ions trapped in an ion trap emitting at 493 nm. The initial step in this transfer process involves a spontaneous emission process, which entangles a photon with the respective stationary systems. Consequently, a wavelength conversion process is required to convert the visible-range wavelengths to the telecom band, enabling frequency match between the different systems.

In this study, we utilized Periodically Poled Lithium Niobate (PPLN) waveguides to develop efficient quantum frequency converters. We achieved a conversion efficiency of 37% at a pump power of 514 mW (1929.4 nm) for the conversion of 780.24 nm to 1310 nm, and 30% conversion efficiency at a pump power of 550 mW (1686.0 nm) for the conversion of 737.204 nm to 1310 nm. Additionally, we maintained a low noise count of 5-6 kCounts/s, detected by an Indium Gallium Arsenide Avalanche Photodiode (InGaAs APD), using a filtering system with a measured efficiency of 44%.

### T7.166 Ultrafast and efficient waveguide-integrated SNSPD

Filippo Martinelli*, Shuyu Dong, Maria Sidorova, Pierre Brosseau, Anton Vetlugin, Cesare Soci (NTU)
3:20pm – 3:35pm

One of the critical factors for large scale deployment of quantum computing and quantum networks is the availability of fast and efficient single-photon detectors. While fiber-coupled Superconducting nanowire single-photon detectors (SNSPDs) show outstanding detection performance, their macroscopic size and individual packaging significantly limit their scalability. Integration of SNSPDs with photonic waveguides is a promising approach for increasing the integration density, offering a way to scale the number of channels, as well as the possibility to combine detectors with other integrated components for additional functionalities [1]. However, standard integration approaches show limited flexibility in the geometry of the wire and prevent more complex schemes to achieve, for example, photon number resolution [2]. In this talk, we present the development of SNSPDs integrated in a novel platform based on etchless polymer waveguides. We achieve on-chip detection efficiency higher than 44 % and timing jitter of less than 93 ps. Additionally, our nanowires exhibit an exceptionally fast recovery ¡ 2 ns, making them ten times faster than standard commercial solutions. We will also discuss the potential of this new integration approach for realizing advanced detection schemes, including integrated photon number resolving detectors.

1. Ferrari, S., C. Schuck, and W. Pernice, Waveguide-integrated superconducting nanowire single-photon detectors. Nanophotonics, 2018. 7(11): p. 1725-1758. 2. Vetlugin, A.N., et al., Photon number resolution without optical mode multiplication. Nanophotonics, 2023. 12(3): p. 505-519.

## T8: Quantum Optics

Time: Wednesday 2 Oct, 2:00pm; Venue: LT-5; Chair: Christian Kurtsiefer, NUS
Time allocated for invited talks is 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.

### T8.170 Mitigating single-photon losses in optical networks via quantum Zeno effect

Anton Vetlugin*, Mariia Sidorova, Ruixiang Guo, Cesare Soci, Nikolay I Zheludev (NTU)
2:00pm – 2:15pm

Losses in optical networks fade the benefits of quantum communication and photonic quantum computing, where the fragile quantum states are prone to rapid degradation. Consequently, significant efforts are devoted to minimizing optical scattering and dissipation. Here, we present a counterintuitive approach: increasing the level of dissipation in an optical network can actually reduce overall losses. By leveraging the quantum Zeno effect, we experimentally demonstrate that the loss rate of quantum light in complex optical networks can be significantly mitigated by intentionally introducing additional dissipative elements. These results suggest a novel strategy for enhancing the performance of quantum photonic systems, potentially paving the way for more robust quantum communication and computing technologies.

### T8.38 On-demand transposition across light-matter interaction regimes in bosonic cQED

Fernando Valadares*, Ni-Ni Huang*, Kyle Timothy Ng Chu, Aleksandr Dorogov, Weipin Chua, Lingda Kong, Pengtao Song, Yvonne Y. Gao (Centre for Quantum Technologies, National University of Singapore, Singapore)
2:15pm – 2:30pm

The diverse applications of light-matter interactions in science and technology stem from the qualitatively distinct ways these interactions manifest, prompting the development of physical platforms that can interchange between regimes on demand. Bosonic cQED employs the light field of high-Q superconducting cavities coupled to nonlinear circuit elements, harnessing the rich dynamics of their interaction for quantum information processing. However, implementing fast switching of the interaction regime without deteriorating the cavity coherence is a significant challenge. We present an experiment that achieves this feat, combining nanosecond-scale frequency tunability of a transmon coupled to a cavity with lifetime of hundreds of microseconds. Our implementation affords a range of useful capabilities for quantum information processing; from fast creation of cavity Fock states using resonant interaction and interchanging tomography techniques at qualitatively distinct interaction regimes on the fly, to the suppression of unwanted cavity-transmon dynamics during idle evolution. By bringing flux tunability into the bosonic cQED toolkit, our work opens up the possibility to probe the full range of light-matter interaction dynamics within a single platform and provides valuable pathways towards robust and versatile quantum information processing.

### T8.51 Quantum Dynamic Programming

Jeongrak Son*, Marek Gluza, Ryuji Takagi, Nelly H. Y. Ng (Nanyang Technological University)

2:30pm – 2:45pm

In the quantum realm, memory utilisation becomes much subtler compared to classical cases. Measurements of memory generally disturb the memory state, while the no-cloning theorem fundamentally forbids generating additional copies of the memory from given ones. Hence, many memory-utilising protocols in classical computing could not be translated into quantum computation to date.

One prominent example of such a memory-utilising protocol is dynamic programming. Classical dynamic programming efficiently solves recursive problems by first solving smaller problems (previous steps of the recursion), storing the answers in the memory, and finally using the memory for the later steps of the recursion.

However, quantum recursion consists of steps that are quantum operations dependent on the results of previous steps, which are quantum states themselves. The straightforward application of dynamic programming into the quantum realm is difficult as i) retrieving complete information about the resulting states from earlier steps is impossible, and ii) without fully knowing the resulting state information, it is unclear whether one can compile the next recursion step.

In our work, we construct a framework for quantum dynamic programming. We overcome the memory utilisation problem by generating multiple copies of the resulting states in parallel, while the compilation problem is solved by using those memory states as instruction states for the quantum circuit, without knowing the states themselves. Our strategy achieves an exponential reduction of the circuit depth needed to solve a certain class of quantum recursions, compared to approaches that do not utilise memory.

### T8.14 Second Law of Entanglement Manipulation with Entanglement Battery

Ray Ganardi*, Tulja Varun Kondra, Nelly H.Y. Ng, Alexander Streltsov (Nanyang Technological University)

2:45pm – 3:00pm

A central question since the beginning of quantum information science is how two distant parties can convert one entangled state into another. Answers to these questions enable us to optimize the performance of tasks such as quantum key distribution and quantum teleportation, since certain entangled states are more useful than others for these applications. It has been conjectured that entangled state transformations could be executed reversibly in an asymptotic regime, mirroring the reversible nature of Carnot cycles in classical thermodynamics. While a conclusive proof of this conjecture has been missing so far, earlier studies excluded reversible entanglement manipulation in various settings. In this work, we investigate the concept of an entanglement battery, an auxiliary quantum system that facilitates quantum state transformations without a net loss of entanglement. We establish that reversible manipulation of entangled states is achievable through local operations when augmented with an entanglement battery. In this setting, two distant parties can convert any entangled state into another of equivalent entanglement. The rate of asymptotic transformation is quantitatively expressed as a ratio of the entanglement present within the quantum states involved. Different entanglement quantifiers give rise to unique principles governing state transformations, effectively constituting diverse manifestations of a ”second law” of entanglement manipulation. Our methods provide a solution to the long-standing open question regarding the reversible manipulation of entangled states and are also applicable to entangled systems involving more than two parties, and to other quantum resource theories, including quantum thermodynamics.

### T8.7 Accurate prime density produced through resonant tunnelling across a double barrier system

Charli Chinmayee Pal*, Prasanta Kumar Mahapatra (Siksha ’O’ Anusandhan Deemed to be University)
3:00pm – 3:15pm

To replicate the natural numbers and prime numbers as resonant tunneling energies in a double barrier system (DBS), a solid-state experiment based on quantum tunneling is suggested. The well potential is defined as the superposition of a weak local fluctuation potential and a smooth potential that is calculated using a semi-classical approach in order to obtain the prime numbers as eigenvalues. We derive resonant energies that precisely duplicate the local average prime density and the local average prime gap by using the transfer matrix approach and the finite element method, taking only the smooth part of the potential. The approach yields entire integers as eigenvalues for the well’s quadratic potential, with the exception of a constant zero-point energy, or the energy levels of a basic harmonic oscillator.

## T9: Low-dimensional Materials 3

Time: Wednesday 2 Oct, 4:00pm; Venue: LT-2; Chair: Justin Song, NTU
Time allocated for invited talks is 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.

### T9.12 (INVITED) Phase Engineering using 2D Heterostructures & 2D MOF formation

Andrew Wee* (NUS)
4:00pm – 4:20pm

I will talk about two of our current projects on 2D materials. In the first current project, we report a phase-selective in-plane heteroepitaxial method to grow semiconducting H-phase $CrSe_2$ (Nat. Comm. 2024). The lattice-matched $MoSe_2$ nanoribbons are utilized as the in-plane heteroepitaxial template to seed the growth of H-phase $CrSe_2$ with the formation of $MoSe_2$- $CrSe_2$ heterostructures. Scanning tunneling microscopy and non-contact atomic force microscopy studies reveal the atomically sharp heterostructure interfaces and the characteristic defects of mirror twin boundaries emerging in the H-phase $CrSe_2$ monolayers. Second, I will report a study of a conformationally flexible precursor 2,4,6-tris(3-bromophenyl)-1,3,5-triazine (mTBPT) on Cu(111) comprising a random phase of C3h and Cs conformers (Nat. Comm. 2024). At low coverage (0.01 ML) selenium (Se) doping, we achieved the selectivity of the C3h conformer and improved the nanopore structural homogeneity. Through the combination of high-resolution scanning tunneling microscopy, non-contact atomic force microscopy and density functional theory calculations, we explored the formation of the conformationally flexible mTBPT on Cu(111).

### T9.158 Efficient Emission of Highly Polarized Thermal Radiation from a Suspended Aligned Carbon Nanotube Film

Andrea Zacheo* (Nanyang Technological University)
4:20pm – 4:35pm

A polarized light source covering a wide wavelength range is required in applications across diverse fields, including optical communication, photonics, spectroscopy, and imaging. For practical applications, high degrees of polarization and thermal performance are needed to ensure the stability of the radiation intensity and low energy consumption. Here, we achieved efficient emission of highly polarized and broadband thermal radiation from a suspended aligned carbon nanotube film. The anisotropic nature of the film, combined with the suspension, led to a high degree of linear polarization ($\approx$0.9) and great thermal performance. Furthermore, we performed time-resolved measurements of thermal emission from the film, revealing a fast time response of approximately a few microseconds. We also obtained visible light emission from the device and analyzed the film's mechanical breakdown behavior to improve the emission intensity. Finally, we demonstrated that suspended devices with a constriction geometry can enhance the heating performance. These results show that carbon nanotube film-based devices, as electrically driven thermal emitters of polarized radiation, can play an important role for future development in optoelectronics and spectroscopy.

### T9.145 Impact of chalcogen vacancies on the electrical transport and oxygen-degradation of transition metal dichalcogenides

Fabio Bussolotti*, Kuan Eng Johnson Goh (Institute of Materials Research and Engineering)
4:35pm – 4:50pm

Two-dimensional (2D) semiconductor transition metal dichalcogenides (TMDs) have received considerable scientific attention as promising materials for novel optoelectronics and quantum computing applications [1]. Even in their purest pristine form, the residual presence of structural and chemical defects such as atomic vacancies, grain boundaries, and impurity dopants [1] have been reported to impact on the TMDs' electrical transport [1] and their chemical stability upon atmospheric oxygen exposure [2], thus potentially affecting the performance stability and reproducibility of real TMD-based devices. We have performed a series of experiments to understand these defect-mediated phenomena. Here, we report the influence of chalcogen (S)-vacancies on the electronic properties and oxidation degradation of TMDs where the chalcogen vacancies are selectively introduced by ion-beam sputtering [3,4]. Our research, backed by photoemission spectroscopy measurements and theoretical computations, indicates that the gap states of chalcogen vacancies and the associated Fermi level pinning could account for the significant electron injection barrier ($\geq 0.5$ eV observed at the TMD/metal interface, while no significant barrier is expected for the hole injection. In addition, we found that air oxidation of TMDs becomes significant at defect concentrations $\geq 10\%$, while TMDs with lower 10% defect concentrations tend to remain stable. Theoretical calculations revealed that single S-vacancies do not spontaneously oxidize, while the defect pairing at high vacancy concentrations facilitates the interaction with atmospheric oxygen and the subsequent oxide formation. These findings offer a possible explanation for our observations. Our work highlights the importance of managing the concentration of chalcogen-vacancies for TMDs used for the fabrication of electronics.

References [1] Goh, K. E. J., et al., Adv. Quant. Mat. 2020, 3, 1900123 [2] Lin, Z., et al., 2D Mater. 2016, 3, 022002 [3] Bussolotti, F., et al., ACS Nano 2021, 15, 2686 [4] Bussolotti, F., et al. ACS Nano 2024, 18, 8706

### T9.48 Probing twist-controlled moire structures using terahertz excitation.

Artur Shilov*, Mikhail Kashchenko, Pierre Pantaleon, Mikhail Kravtsov, Yibo Wang, Andrei Kudriashov, Zhen Zhan, Takashi Taniguchi, Kenji Watanabe, Sergey Slizovskiy, Kostya Novoselov, Vladimir Fal'Ko, Francisco Guinea, Denis Bandurin* (Department of Materials Science and Engineering, National University of Singapore, Singapore 117575, Singapore)
4:50pm – 5:05pm

Twist-controlled Moiré superlattices (MS) have emerged as a versatile platform in which to realize artificial systems with complex electronic spectra. Bernal-stacked bilayer graphene (BLG) and hexagonal boron nitride (hBN) form an interesting example of the MS that has recently featured a set of unexpected behaviors, such as unconventional ferroelectricity, electronic ratchet effect and magnetic breakdown, to name a few. The ongoing research of BLG/hBN MS has invoked a variety of sophisticated techniques to explore these effects as the insights offered by standard magnetotransport measurements remain fairly limited. In our recent work, we developed a multi-messenger approach employing terahertz (THz) excitation to probe electronic band structure of BLG/hBN MS. Leveraging the acute sensitivity of electronic temperature in graphene-based structures to low-power THz signal, we obtained a fine-structured quantum oscillations pattern resulting from the MS at high magnetic fields. By measuring the THz-driven Nernst effect in remote bands at low magnetic fields, we observed valley splitting, pointing to an orbital magnetization characterized by a strongly enhanced effective g-factor of 340. Using THz photoresistance measurements, we showed that the high-temperature conductivity of the BLG/hBN MS is limited by electron-electron umklapp processes. The same approach, applied to the twisted bilayer graphene (TBG) MS, revealed a sharp change of resistivity of TBG devices exposed to THZ, alluding to the paramount role of electronic interactions in limiting conductivity of this system at high temperatures. Last, we showed that BLG/hBN lattice alignment results in the emergence of compensated semimetals at some integer fillings of the Moiré bands separated by van Hove singularities where Lifshitz transition occurs. A particularly pronounced semimetal develops when 8 electrons reside in the Moiré unit cell, where coexisting high-mobility electron and hole systems feature a strong magnetoresistance reaching 2350% already at B = 0.25 T. Our multi-faceted analysis introduces THz-driven magnetotransport as a convenient tool to probe the band structure and interaction effects in van Der Waals materials.

### T9.113 From 2D materials to 2D optics

Zeng Wang* (IMRE, A*STAR)
5:05pm – 5:20pm

Our research delves into the potential of excitons in two-dimensional TMDCs for applications in 2D optics. We emphasize the advancements in exciton-enabled 2D optics and the electrically tunable conversion between excitons and trions at room temperature. These findings underscore the promise of TMDCs in optoelectronics, paving the way for enhanced performance in next-generation imaging and sensing technologies.

## T10: Plasma & Fusion Physics

Time: Wednesday 2 Oct, 4:00pm; Venue: LT-4; Chair: Valerian H. Hall-Chen, A*STAR
Time allocated for invited talks is 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.

### T10.202 (INVITED) Synthetic Doppler-backscattering diagnostic based on reduced models of plasma-wave interactions: recent progress and next steps

Valerian H. Hall-Chen*, Kshitish Barada, Viet Phuong Bui, Yvette Chow, Satyajit Chowdhury, Neil A. Crocker, Julius Damba, K.R. Fong, Maurizio Giacomin, Peter Hill, Jon Hillesheim, Matthew Liang, Tanmay Macwan, Lewin Marsh, Clive Michael, Ray Ng, Ruben Otin, Et al (IHPC, Agency for Science, Technology and Research (A*STAR), Singapore)
4:00pm – 4:20pm

Turbulent transport limits the performance of modern fusion devices. Understanding this turbulence is key to designing and optimising the next generation of fusion energy systems. However, measuring turbulent fluctuations is difficult due to the spatial and temporal resolutions required. Doppler backscattering (DBS) is one of the few diagnostics capable of measuring turbulent density fluctuations. Direct quantitative comparison between such measurements and gyrokinetic simulations of the same is challenging. Such comparison requires a model of plasma-wave interactions, acting as a synthetic diagnostic. Full-wave synthetic diagnostics are computationally intensive while ray tracing is unable to quantitatively account for instrumentation effects such as beam focusing and mismatch attenuation.

In this talk, we present an overview of our synthetic DBS diagnostic, which is based on beam tracing and the reciprocity theorem, and implemented in the Scotty code platform. Scotty is capable of predictively and quantitatively calculating DBS instrumentation effects in tokamak and stellarator geometries, and runs in under ten seconds. We will summarise our recent work on the validation of Scotty on DIII-D and MAST-U, followed by its use as a bridge between gyrokinetic simulations and DBS in these two tokamaks. We will then cross-compare Scotty with beam-tracing code TORBEAM and finite-element frequency-domain full-wave code ERMES. Finally, we will show preliminary comparisons of beam tracing with full-wave simulations.

### T10.137 Surrogate data-driven modeling of turbulent plasmas

Robin Varennes*, Zhisong Qu, Youngwoo Cho (Nanyang Technological University)
4:20pm – 4:35pm

A critical challenge in the development of nuclear fusion reactors is the confinement of energy, as extreme thermodynamic gradients lead to turbulent transport of heat and particles out of the vessel. The main parameters controlling this turbulent transport are still not fully understood. To address this, a data-driven approach is being explored to develop surrogate models that can better predict turbulent transport. In this work, machine learning algorithms are applied to simulation data generated with the TOKAM2D code [1, 2], which solves the Hasegawa-Wakatani equations [3]. These equations provide the simplest non-trivial model of drift-wave turbulence in a 2D plane at the plasma edge. In this study, the equations are modified to include the interchange instability caused by plasma curvature in toroidal fusion devices. Datasets are obtained by scanning across a broad range of simulation parameters. Using a machine learning regression algorithm, a model is obtained that connects the output turbulent flux and Reynolds stress to an arbitrary number of quantities of interest, e.g. density and vorticity gradients, turbulent intensity etc . . . Using a similar approach, the previous study of Heinonen et al. [4] obtained a surrogate model highlighting some evidence of physical mechanisms that are currently debated, i.e. a contribution of the vorticity gradient to the particle flux and the antiviscous behavior of the Reynolds stress. This work emphasizes the modifications induced by the symmetry breaking stemming from the interchange instability. In particular, the confidence and limits of such data-driven surrogate model are discussed. Such work is meant as a pioneering study to be extended to higher dimensional applications.

[1] P. Ghendrih, Y. Asahi, E. Caschera, G. Dif-Pradalier, P. Donnel, X. Garbet, C. Gillot, V. Grandgirard, G. Latu, Y. Sarazin, S. Baschetti, H. Bufferand, T. Cartier-Michaud, G. Ciraolo, P. Tamain, R. Tatali, and E. Serre, Generation and dynamics of SOL corrugated profiles, J. Phys.: Conf. Ser. 1125, 10.1088/1742-6596/1125/1/012011 (2018). [2] P. Ghendrih, G. Dif-Pradalier, O. Panico, Y. Sarazin, H. Bufferand, G. Ciraolo, P. Donnel, N. Fedorczak, X. Garbet, V. Grandgirard, P. Hennequin, E. Serre, and P. Tamain, Role of avalanche transport in competing drift wave and interchange turbulence, J. Phys.: Conf. Ser. 2397, 10.1088/1742-6596/2397/1/012018 (2022). [3] A. Hasegawa and M. Wakatani, Plasma Edge Turbulence, Phys. Rev. Lett. 50, 10.1103/Phys-RevLett.50.682 (1983). [4] R. A. Heinonen and P. H. Diamond, Turbulence model reduction by deep learning, Phys. Rev. E 101, 10.1103/PhysRevE.101.061201 (2020).

### T10.184 Surrogate mode of 2D turbulence with physics-informed neural networks

Jingcheng Huang* (NTU)
4:35pm – 4:50pm

Surrogate models are becoming increasingly pivotal in contemporary physics, particularly in domains where numerical solutions are challenging due to the complexity of non-linear effects, such as fluid dynamics, plasma physics, and chaos theory [1]. These models alleviate computational burdens by capturing the relationships between inputs and outputs, often by simplifying the system through observational data. [2,3] Deep learning, in particular, has proven to be an effective tool for this purpose, demonstrating significant potential in learning high-dimensional non-linear effects, even though successful examples of its application to complex nonlinear functions are still relatively few.

As a first step in developing fast and accurate surrogate models of turbulence transport, our objective is to utilize Physics-Informed Neural Networks (PINNs) to develop a forward solver for the Hasegawa-Wakatani (HW) equations [4]. By providing the model solely with the equations and the initial conditions in the linear stage, we aim to predict the turbulent electric field and plasma density. Reference data are produced by the direct numerical solver TOKAM2D, a 2D spectral code capable of simulating edge fluid turbulence including the HW equations.

In this work, multiple new variants of PINN are tested, including Fourier embedding layer [2], Fourier special penalty, causal time stepping [5], etc. Although some of these methods boost convergence during training, they fail to capture the nonlinear evolution of turbulent vortices.

Moreover, the performance of PINN degrades in fitting high-order derivatives. These results provide valuable clues to further improve learning the complex nonlinear dynamics.

References [1] Zhu, Y., Zabaras, N., 2018. Bayesian deep convolutional encoder–decoder networks for surrogate modeling and uncertainty quantification. J.Comput.Phys.366,415–447. https://doi.org/10.1016/j.jcp.2018.04.018 [2] Wang, S., Wang, H., Seidman, J.H., Perdikaris, P.,2022b. Random Weight Factorization Improves the Training of Continuous Neural Representations [WWW Document]. arXiv.org. URL https://arxiv.org/abs/2210.01274v2 (accessed 5.9.24). [3] Sun, L., Gao, H., Pan, S., Wang, J.-X., 2020. Surrogate modeling for fluid flows based on physics-constrained deep learning without simulation data. Comput. Methods Appl. Mech. Eng. 361, 112732. https://doi.org/10.1016/j.cma.2019.112732 [4] Wakatani, M., Hasegawa, A., 1984. A collisionaldrift wave description of plasma edge turbulence. Phys. Fluids 27, 611–618. https://doi.org/10.1063/1.864660 [5] Sifan Wang, Shyam Sankaran, and Paris Perdikaris. Respecting causality is all you need for training physics informed neural networks. arXiv preprint arXiv:2203.07404, 2022.

### T10.188 Quantum-Classical Hybrid Approach for Solving Nonlinear Differential Equations in Fusion Energy Research

Ameir Shaa*, Claude Guet* (NTU)
4:50pm – 5:05pm

We present a novel hybrid approach integrating quantum computing with classical projection techniques to address the computational challenges inherent in solving differential equations relevant to fusion energy science. This method was validated using a toy model, specifically the 2D Navier-Stokes equations under certain boundary conditions. Our work explores the potential of quantum algorithms, particularly the Koopman-von Neumann (KvN) and Carleman embedding methods, to enhance the efficiency and accuracy of simulations for complex nonlinear dynamical systems, including ordinary differential equations (ODEs) and stochastic partial differential equations (SPDEs). These advancements could significantly accelerate progress in fusion energy research by improving the scalability and precision of critical simulations.

### T10.139 Effect of modulated heat source on diffusive and avalanche-like transport

Youngwoo Cho*, Robin Varennes, Xavier Garbet (Nanyang Technological University)
5:05pm – 5:20pm

We utilize the global full-F gyrokinetic code GYSELA to analyze the nonlocal transport in the presence of modulated heat source, the period of which is in the range of a transport timescale. In near marginal stable case, it is observed that a localized and time-modulated heat source can trigger both diffusive and avalanche-like transport. When heat source-stimulated nonlocal transport occurs, propagation of turbulence is faster than that of heat pulse. In addition, the propagation speed is correlated with both turbulence intensity and period of modulated source. This correlation is also identified from the analytic expression derived from two-field critical gradient model.

## T11: Photonics 3

Time: Wednesday 2 Oct, 4:00pm; Venue: LT-3; Chair: Cesare Soci, NTU
Time allocated for invited talks is 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.

### T11.128 (INVITED) Linear momentum and frequency conversion in a nonlocal optical metasurface under spatially selective ultrafast modulation

Daniil Shilkin*, Son Tung Ha, Ramon Paniagua-Dominguez, Arseniy Kuznetsov (Institute of Materials Research and Engineering (IMRE), Agency for Science, Technology and Research (A*STAR))
4:00pm – 4:20pm

The interaction of light with time-variant media allows for the observation of effects not possible in static systems, including linear frequency conversion. Nonlocal optical metasurfaces, which support spatially extended optical modes, can be modulated simultaneously in both the temporal and spatial domains, potentially opening a new class of effects.

In this study, we examine the interaction of light with a nonlocal GaAs metasurface subjected to spatially structured femtosecond pumping. Using angle-resolved pump-probe spectroscopy, we trace the transient transmission spectrum near a quasi-bound state in the continuum (BIC) resonance supported by the metasurface. We begin with uniform pumping and observe behaviour resembling that of a single-mode time-variant resonator. Then, we apply spatially selective pumping, and the measurements reveal frequency conversion in the pumped regions and momentum conversion at the introduced spatial boundaries. These results demonstrate new opportunities for ultrafast beam steering and spectrum control in semiconductor metasurfaces.

### T11.89 Seismic Sensing with Optical Fibres

Thormund Tay*, Fabio Joel Auccapuclla*, Seth Poh*, Christian Kurtsiefer* (Centre for Quantum Technologies, NUS, and Department of Physics, NUS)
4:20pm – 4:35pm

Widespread deployed optical fibre networks form a large part of modern-day telecommunication infrastructure. Through ambient vibrations, such as those of seismic and human activity, strain is induced into these fibres, inducing phase shifts in the light traveling through them.

In this work, we implemented a fibre phasemeter based on the Michelson interferometer. The laser light that is retro-reflected from the deployed fibre is then interfered with frequency-shifted light from the same source. After demodulation, the integral phase strains experienced by the fibre is then determined, which allows for detection of seimsmic events. We present preliminary phase sensing results from 1 km to 20 km fiber sensors over the period of several days, with sensitivity of approximately $1 \times 10^{-9}/\sqrt{\text{Hz}}$.

### T11.169 Label-free subwavelength imaging of arbitrary shape and size objects

Benquan Wang*, Eng Aik Chan, Giorgio Adamo, Jin-Kyu So, Yewen Li, Ruyi An, Bo An, Zexiang Shen, Nikolay Zheludev (NTU)
4:35pm – 4:50pm

We demonstrate a new universal super-resolution technique for far-field label-free imaging of arbitrary shape and size objects. We present the object as an array of super-pixels each of which is resolved with resolution far beyond the diffraction limit. The high resolution of the limited size individual super-pixels is achieved by the deep learning analyzing the diffraction patterns of light scattered on them using a deep learning-process. The proof of principle experiments demonstrate that resolution of the technique depends on the size and design of the training set and easily exceeds the resolution of conventional confocal microscopy.

### T11.126 Neural Network-Based Multimode Fiber Imaging and Characterization Under Thermal Perturbations

Changyan Zhu* (Nanyang Technological University)
4:50pm – 5:05pm

Multimode fiber (MMF) imaging aided by machine learning holds promise for numerous applications, including medical endoscopy. A key challenge for this technology is the sensitivity of modal transmission characteristics to environmental perturbations. Here, we show experimentally that an MMF imaging scheme based on a neural network (NN) can achieve results that are significantly robust to thermal perturbations. For example, natural images are successfully reconstructed as the MMF's temperature is varied by up to 50 degrees Celsius relative to the training scenario, despite substantial variations in the speckle patterns caused by thermal changes. A dense NN with a single hidden layer is found to outperform a convolutional NN suitable for standard computer vision tasks. In addition, we demonstrate that NN parameters can be used to understand the MMF properties by reconstructing the approximate transmission matrices, and we show that the image reconstruction accuracy is directly related to the temperature dependence of the MMF's transmission characteristics.

### T11.102 Optical Mode Control, Switching and Shaping In Few Mode Fiber Using a Fiber Piano

Wu Shuin Jian, Anindya Banerji*, Ankush Sharma, Zohar Finkelstein, Ronen Shekel, Yaron Bromberg (Centre for Quantum Technologies)
5:05pm – 5:20pm

This work investigates the use of a fiber piano in controlling spatial modes in few mode fibers. It has been found that together with sub-optimal coupling into SMF-28 fibre and half and quarter waveplates, the fiber piano is capable of producing and reproducing desired spatial modes up to LP11 when using 808 nm light and up to LP21 when using 632.8 nm light. The control of spatial mode profile extends down to the single photon level. This is demonstrated with the help of correlated photon pairs generated via spontaneous parametric down conversion.

## T12: Astrophysics

Time: Wednesday 2 Oct, 4:00pm; Venue: LT-5; Chair:
Time allocated for invited talks is 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.

### T12.52 (INVITED) Multiband Gravitational Wave Data Analysis of Eccentric Black Hole Binaries using the DECIGO space detector

Ayush Anand*, Soichiro Isoyama*, Alvin Chua* (NUS physics (PI))
4:00pm – 4:20pm

This is a preliminary exploration into the efficacy of the multiband method of data analysis for gravitational waves emitted from non-spinning eccentric binaries using the DECIGO space detector. The hope is that multiband data analysis would allow more precise measurements of a binary's initial eccentricity, which is an important parameter because it allows us to understand the formation channel of the binary (ie, the method by which it could have formed). During multiband data analysis, data from multiple detectors is combined. This improves not just the Signal-to-noise ratio and overall parameter uncertainties, but also allows us to study the time evolution of binaries since their emitted gravitational wave frequency increases over time. DECIGO is a proposed space detector that operates in the deci-Hz frequency band not covered by other gravitational wave detectors. As such, it is a perfect candidate for multiband observations. We use a Fisher information matrix method to estimate the covariance matrix (and thus the uncertainties) of the given parameter set for a 'restricted' 2PN (post-Newtonian) eccentric waveform for a small-mass and an intermediate-mass Black hole Binary .

The main conclusion of out study is that multiband measurements are indeed superior than individual detectors in measuring all parameters. Another conclusion is that space detectors (LISA and DECIGO) are good at measuring eccentricity (ie the uncertainties for eccentricity are low), while ground based detectors (LIGO and ET) are terrible at measuring it. This could be due to possible systematic error due to the simplified nature of the post-Newtonian waveform. Whether this poor performance of LIGO and ET suggested by my results is valid or just due to systematic error is a question that demands further investigation using more accurate waveform models, especially those that, unlike post-Newtonian models, do not break down in the high frequency (ground detector) band.

### T12.16 Black Hole Formation in Gravitational Collapse

Xinliang An* (National University of Singapore)
4:20pm – 4:35pm

In this talk, I will present several mathematical results toward proving black hole formation in gravitational collapse.

### T12.15 Angular Momentum Memory Effect

Taoran He* (Department of Mathematics, National University of Singapore)
4:35pm – 4:50pm

In this talk, we will report and propose a new angular momentum memory effect of gravitational waves along null infinity based on recent progress in proving stability of Minkowski spacetime with minimal decays and nonlinear stability of Kerr black holes with small angular momentum. This accompanies Christodoulou's nonlinear displacement memory effect and the spin memory effect. The connections and differences to these effects are also addressed. This is a joint work with Xinliang An and Dawei Shen.

### T12.97 Seed sampling: A weighted stochastic sampling method for high-dimensional multimodal distributions in Gravitational Wave Analysis

Miaoxin Liu*, Alvin Chua* (Department of Physics/Department of Mathematics, National University of Singapore, Singapore, Singapore)
4:50pm – 5:05pm

The analysis of gravitational waves (GWs) requires sophisticated computational methods capable of handling the complex, high-dimensional, multimodal distributions generated by sources such as extreme mass-ratio inspirals (EMRIs) and galactic binaries. Traditional methods like dynamic nested sampling and Reversible-jump Markov chain Monte Carlo (RJMCMC) often struggle with computational efficiency and the demand for extensive computational resources. In response, this ongoing project introduces a novel weighted stochastic sampling method, ”Seed Sampling,” which leverages Latin Hypercube Sampling for initial space exploration and an adaptive weighting mechanism to efficiently target high likelihood regions. This method aims to better utlize the prior knowledge of multi-modal distribution, improve the exploration efficiency and reduce the computational costs associated with GW analysis. Preliminary results, derived from both toy models and applied scenarios in gravitational wave analysis, show promising enhancements in sampling efficiency and accuracy, suggesting this method's potential applicability in broader fields that require robust handling of complex distributions, such as cosmology and astrophysics. We will discuss the theoretical framework, algorithmic development, and future directions for this innovative approach.

### T12.59 Modelling spin precession for gravitational wave astronomy

Xiao-Ming Porter* (National University of Singapore)
5:05pm – 5:20pm

General relativity predicts the precession of vectors, such as angular momentum, transported along trajectories in curved spacetime. This effect has been key in testing predictions of general relativity against observations from our Solar System, notably with the perihelion advance of Mercury and the geodetic effect. To infer parameters from gravitational wave signals of binary systems observed by modern detectors, models must accurately account for the effects of spin precession. In this talk, I will outline a perturbation theory approach to examine spin precession in the relativistic two-body problem. I will describe the case of a spinning secondary body orbiting a massive black hole described by the Kerr metric and highlight the latest results of our exploration of features of spin precession across the parameter space.

## T13: Electronic Materials and Devices 1

Time: Thursday 3 Oct, 11:00am; Venue: LT-2; Chair: (TBD)
Time allocated for invited talks is 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.

### T13.104 (INVITED) Enhancing Graphene's Electronic Quality using Tunable Screening

Ian Babich* (NUS, Institute for Functional Intelligent Materials (IFIM))
11:00am – 11:20am

Since the discovery of graphene there has been extensive interest in understanding limits of relativistic dispersion very close to charge neutrality point (CNP), where screening length diverges, and electron-electron interactions start to play significant role[1]. Among theoretical scenarios, there are many-body gap opening at CNP and change of the spectrum[2]. However, it is extremely challenging to approach CNP close enough to study such effects, due to extrinsic inhomogeneities such as electron-hole puddles[3]. So far, only suspended graphene devices have provided some insights into this system, showing diverging Fermi velocity when approaching CNP[4]. In our work, we assembled a dual-gated high-angle twisted bilayer graphene, in which one can independently tune charge densities on each layer. We find that when doping of one of the layers increases, we completely suppress inhomogeneities in the other layer, as evident from the onset of Landau quantization already at 4 mT at 2 Kelvin. Surprisingly, our measurements reveal a bandgap at the neutrality point of such ultraclean graphene, with a gap size of 4 meV. Increased homogeneity and gap observation are reproducible across multiple devices. We investigate the origin of this bandgap and discuss various scenarios for its formation.

References:
[1] Kotov, Valeri N., et al. Reviews of modern physics 84.3 (2012): 1067.
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### T13.99 Theory of Magnetoresistance due to Edge Orbital Moment Accumulation

Hao Sun*, Giovanni Vignale (I-FIM, NUS)
11:20am – 11:35am

The orbital Hall effect, resulting from non-trivial quantum geometry of 2D materials, causes the accumulation of orbital magnetic moment near the system edges. This accumulation contributes to an electric current that flows parallel to the edges, causing a slight decrease in resistance. The accumulation of orbital moment and the resulting change in resistance can be modulated by an in-plane magnetic field. In this work, we investigate this effect in multilayered 2D materials where electrons can move between layers providing a handle through which the resistance can be controlled. The orbital moment dynamics differs from conventional spin dynamics, being governed by an anisotropic effective inverse mass tensor, for which we provide a microscopic expression. We derive phenomenological equations that describe both generation and control of orbital moment accumulations.

### T13.96 Engineering a controlled-phase gate between two superconducting cavities

Adrian Copetudo*, Amon Kasper (CQT - NUS)
11:35am – 11:50am

Superconducting cavities are a promising platform for hardware-efficient and error-correctable quantum information processing due to their infinite Hilbert space. However, to achieve universal control, these harmonic oscillators are coupled to an auxiliary superconducting qubit, whose energy levels are used to perform single- and multiple-cavity gates, ultimately limiting the gate fidelity due to the shorter qubit coherence times. Here, we present an experimental demonstration of a controlled-phase gate for several rotationally-symmetric codes that relies on the non-linearity provided by the Josephson junction without actively populating the excited energy levels of the qubit. This gate can be applied in error-correction schemes to detect photon losses in a superconducting cavity, which translates into a phase rotation of the state of a second cavity.

### T13.93 Magnetic nanodrums in motion under extreme conditions: theoretical approach

Timofei Savilov*, Makars Šiškins, Konstantin Novoselov (NUS IFIM, NUS MSE)
11:50am – 12:05pm

Magnetic nanodrums made of 2D materials, such as CrI3, FePS3, and CrGeTe3, are promising for the development of new magnetic NEMS device concepts. Can we predict the dynamics of their motion even in extreme conditions, like hard pulling with the electrostatic force or high magnetic fields? Here, we use Landau theory of phase transitions coupled with continuum mechanics theory to investigate the influence of magnetic ordering on the mechanical properties of nanodrums, and vice versa – the influence of nanomechanical strain on the formation of magnetic order. In contrast to the conventional purely analytical approach, we utilize cyclic calculations based on these analytical equations. Together with Abrikosov's interpretation of the Ornstein–Zernike theory, our model provides a detailed picture of the (anti)ferromagnetic to paramagnetic phase transition and its modulation under an external magnetic field. This approach allows to avoid low-deflection function limits that are unrealistic for a variety of extreme conditions. Despite the higher calculation complexity, our optimized computational algorithm allows for close to real-time output, rendering the model applicable for quick fitting of experimental data and partition of the contributions from different magneto-mechanical effects. Looking forward, we anticipate the development of magnetic NEMS sensors with properties, unavailable for conventional CMOS materials.

**T13.156 Probing Charge Transport in the One-Dimensional Layered Semiconductor $TiS_3$**

Ivan Verzhbitskiy*, Kuan Eng Johnson Goh* (Agency for Science, Technology and Research (A*STAR))

12:05pm – 12:20pm

The advancement of quantum technologies in sensing and fault-tolerant computation hinges on the ongoing evolution of material platforms and the creation of scalable device architectures. The quantum leap has largely benefited from the maturity of silicon technology, but certain challenges remain, prompting exploration into novel materials and concepts. Unique properties of layered materials have already revolutionized electronic concepts, circumventing many challenges of conventional silicon-based technologies. However, many aspects of 2D materials remain unexplored. Among these, intrinsic in-plane anisotropy remains largely underutilized. For example, theoretical predictions [1, 2] suggest that the natural carrier confinement in transition metal trichalcogenide $TiS_3$ along the long in-plane crystallographic axis produces an order-of-magnitude higher electron mobility compared to the carrier mobility in the perpendicular direction. Moreover, the crystalline anisotropy in $TiS_3$ promotes anisotropic crystal growth, yielding quasi-1D nanoribbons that can be exfoliated down to a few-layered narrow crystals. With the ribbon width well below 100 nm, semiconducting $TiS_3$ presents a natural platform to engineer quantum confinement for quantum dots and solid-state spin qubits. In this talk, I will present our efforts toward implementing a quantum dot device based on semiconducting quasi-1D crystals like $TiS_3$. To this end, we engineered ohmic electrical contacts for $TiS_3$ at temperatures down to a few kelvins. We demonstrated a contact resistance below 3 k$\Omega$ at 5 K, the lowest value reported for $TiS_3$ to date. This allowed us to gain insights into the semiconducting behaviour of $TiS_3$ at low temperatures and observe the Coulomb blockade effect in short-channel field-effect transistors [3]. At the end of the talk, I will discuss the feasibility of quasi-1D layered materials for quantum applications, their advantages, and important steps toward their rapid implementation.

Acknowledgements This work was supported by the Agency for Science, Technology, and Research (#21709) and K.E.J.G. acknowledges a Singapore National Research Foundation Grant (CRP21-2018-0001).

References [1] Dai, J. and Zeng, X.C., Angew. Chem. Int. Ed. 54, 7572-7576 (2015). [2] Kang, J. et al., Phys. Rev. B 92, 075413 (2015) [3] Verzhbitskiy, I. et al. (submitted)

## T14: Many Body Physics 1

Time: Thursday 3 Oct, 11:00am; Venue: LT-4; Chair: Berthold-Georg Englert, CQT
Time allocated for invited talks is 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.

### T14.92 (INVITED) Interaction-Driven Instabilities in the Random-Field XXZ Chain

Jeanne Colbois* (National University of Singapore)
11:00am – 11:20am

Despite a solid understanding of single-particle Anderson localization in one-dimensional (1D) disordered systems [1], many-body effects remain highly surprising. A famous example is the debated interaction-driven many-body localization (MBL) problem [2].

This talk will provide a brief introduction to Anderson and many-body localization in random spin chains through the lens of simple observables such as extreme magnetization (corresponding to the local density in cold atomic systems) [3] and spin-spin correlations (density-density correlations) [4,5]. Our recent advanced exact diagonalization results [5] reveal that below a certain disorder threshold, weak interactions necessarily lead to an ergodic instability of the ”many-body” Anderson insulator, whereas at strong disorder the AL insulator directly turns into MBL. Taking advantage of the total magnetization conservation, our results further unveil the remarkable behavior of the spin-spin correlation functions: in the regime indicated as MBL by standard observables, their exponential decay undergoes a unique inversion of orientation. The longitudinal correlations seem to be a key quantity to capture instabilities, in sharp contrast with the transverse correlations.

[1] P. W. Anderson, Phys. Rev. 109, 1492 (1958). [2] See e.g. the recent review P. Sierant, M- Lewenstein, A. Scardicchio, L. Vidmar, J. Zakrewski, arXiv:2403.07111 [3] V. Khemani, F. Pollmann, and S. L. Sondhi, Phys. Rev. Lett. 116, 247204 (2016); N. Laflorencie, G. Lemarié, N. Macé, Phys. Rev. Research 2, 042033 (2020); J. Colbois and N. Laflorencie, Phys. Rev. B 108, 144206 (2023) [4] A. Pal and D. A. Huse, Phys. Rev. B 82, 174411 (2010); L. Colmenarez, P A. McClarty, M.Haque, D. J. Luitz SciPost Phys. 7, 064 (2019) [5] J. Colbois, F. Alet, N. Laflorencie, arXiv:2403.09608 (accepted in PRL)

### T14.180 Corrections to central charge at BKT transitions

Jon Spalding* (NTU)
11:20am – 11:35am

The central charge is a key property of conformal field theories for critical 1D spin chains that also applies to 2D classical fields. In this talk we present an aesthetically appealing derivation of logarithmic corrections to the central charge at BKT transitions, and then provide first steps at verifying this derivation with matrix product state calculations for the Heisenberg spin chain in 1D. Lastly we summarize the utility of these universal finite size effects in identifying BKT transitions in spin chains, even with open boundaries.

### T14.181 Eigenstate Thermalization in Quantum Spin Chain with Inhomogeneous Interactions

Dingzu Wang* (National University of Singapore)
11:35am – 11:50am

The eigenstate thermalization hypothesis (ETH) is a successful theory that establishes the criteria for ergodicity and thermalization in isolated quantum many-body systems. In this work, we investigate the thermalization properties of a spin-1/2 XXZ chain with linearly inhomogeneous interactions. We demonstrate that introduction of the inhomogeneous interactions leads to an onset of quantum chaos and thermalization, which, however, becomes inhibited for sufficiently strong inhomogeneity. To exhibit ETH, and to display its breakdown upon varying the strength of interactions, we probe statistics of energy levels and properties of matrix elements of local observables in eigenstates of the inhomogeneous XXZ spin chain. Moreover, we investigate the dynamics of the entanglement entropy and the survival probability which further evidence the thermalization and its breakdown in the considered model. We outline a way to experimentally realize the XXZ chain with linearly inhomogeneous interactions in systems of ultracold atoms. Our results highlight a mechanism of emergence of ETH due to insertion of inhomogeneities in an otherwise integrable system and illustrate the arrest of quantum dynamics in the presence of strong interactions.

### T14.125 Kramers Nonlinearity in PT Symmetric Magnets

Oles Matsyshyn*, Ying Xiong, Justin Song (NTU, SPMS)
11:50am – 12:05pm

Kramers degeneracies play an essential role in the spectrum of electronic materials. Here we argue that beyond spectral properties, Kramers degeneracy plays a critical role in the nonlinear response of PT symmetric magnets. In particular, we uncover a class of second-order Kramers nonlinearities that only arise in the presence of Kramers degeneracy, vanishing in non-degenerate PT symmetric materials. Kramers nonlinearties depend on a circular dichroism between PT related Kramers states and enable to trace out the quantum geometry of the degenerate band structure. We find pronounced Kramers nonlinearitites in the nonlinear polarization responses of even layer antiferromagnetic $MnBi_2Te_4$ that enable to identify its antiferromagnetic order. This provides novel means for diagnosing Kramers pairs and addressing the internal Kramers degree of freedom.

### T14.11 Quantum Skyrmion Liquid

Dhiman Bhowmick*, Andreas Haller, Deepak Kathyat, Thomas Schmidt*, Pinaki Sengupta* (Nanyang Technological University, Singapore)
12:05pm – 12:20pm

Skyrmions are topological magnetic textures, mostly treated classically, studied extensively due to their potential spintronics applications due to their topological stability. However, it remains unclear what physical phenomena differentiate a classical from a quantum skyrmion. We present numerical evidence for the existence of a quantum skyrmion liquid (SkL) phase in quasi-one-dimensional lattices which has no classical counterpart. The transition from a conventional quantum skyrmion crystal (SkX) to a field-polarized phase (FP) is found to be of second order while the analogous classical transition near zero temperature is first-order due to a missing SkL phase. As an indicator of the quantum mechanical origin of the SkL phase, we find concentrated entanglement (indicated by the concurrence) around the skyrmion center, which we attribute to the uncertainty in the skyrmion position resulting from the non-commutativity of the skyrmion coordinate operators. The latter also gives rise to a nontrivial kinetic energy in the presence of an atomic lattice. The SkL phase emerges when the kinetic energy dominates over the skyrmion-skyrmion interaction energy. It is tied to the breaking of discrete translational invariance of the skyrmion crystal and occurs when the skyrmion radius is comparable with the size of the magnetic unit cell. In contrast to the long-range order present in the SkX phase, spin-spin correlations in the SkL phase exponentially decay with distance, indicating the fluid-like behavior of uncorrelated skyrmions. The emergence of kinetic energy-induced quantum SkL phase serves as a strong indication of the possible Bose-Einstein condensation of skyrmions in higher-dimensional systems. Our findings are effectively explained by microscopic theories like collective coordinate formalism and trial wave functions, effectively enhancing our understanding of the numerical findings.

## T15: Topological Pysics

Time: Thursday 3 Oct, 11:00am; Venue: LT-3; Chair: (TBD)
Time allocated for invited talks is 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.

### T15.149 (INVITED) Exceptional Bound Bands

Mengjie Yang*, Ching Hua Lee* (Department of Physics, National University of Singapore)
11:00am – 11:20am

Exceptional bound (EB) states are a recently discovered class of robust states, protected by the defectiveness of non-Hermitian exceptional points (EPs). This defectiveness gives rise to negative entanglement entropy, which occurs generically for lattice models containing momentum-space EPs. Different from topological boundary states or the non-Hermitian skin effect, EB states are eigenstates of the occupied projector $\bar{P}$ with eigenvalues outside 0 and 1. This spectral gap ensures the robustness of EB states. In recent advancements in EB state studies, it has been proved both theoretically and experimentally that such negative entanglement can be observed. Taking this advantage, it is possible to construct lattice models with inherent EB states. In this work, we construct a lattice model with intrinsic EB states by utilizing the matrix of the truncated occupied projector $\bar{P}$ as a unit cell. We further investigate EB and non-EB states' hybridisation within such an engineered lattice. We show that the EB-induced $\text{Re}E = 0.5$ bands are particularly prominent in the lattice model. Furthermore, the EB effects also show up when there are no truncations, i.e., in the PBC model. This lattice engineering with intrinsic EB states leads to super-sensitivity in the energy spectra.

### T15.177 Versatile Braiding of Non-Hermitian Topological Edge States

Bofeng Zhu*, Yidong Chong, Qijie Wang (NTU, SPMS)
11:20am – 11:35am

Among the most intriguing features of non-Hermitian (NH) systems is the ability of complex energies to form braids under parametric variation. Several braiding behaviors, including link and knot formation, have been observed in experiments on synthetic NH systems, such as looped optical fibers. The exact conditions for these phenomena remain unsettled, but existing demonstrations have involved long-range nonreciprocal hoppings, which are hard to implement on many experimental platforms. Here, we present a route to realizing complex energy braids using 1D NH Aubry-Andre- Harper lattices. Under purely local gain and loss modulation, the eigenstates exhibit a variety of braiding behaviors, including unknots, Hopf links, trefoil knots, Solomon links and catenanes. We show how these are created by the interplay between non-Hermiticity and the lattice's bulk states and topological edge states. The transitions between different braids are marked by changes in the global Berry phase of the NH lattice.

### T15.129 Topological disclination states and charge fractionalization in a non-Hermitian lattice

Rimi Banerjee, Subhaskar Mandal, Yun Yong Terh, Shuxin Lin, Gui-Geng Liu, Baile Zhang*, Yidong Chong* (Nanyang Technological University)
11:35am – 11:50am

Topological defects (TDs), such as dislocations and disclinations, are common in crystals, protected against local perturbations, and influence material's properties [Nat. Mater 11, 759 (2012); Rev. Mod. Phys. 89, 040501 (2017)]. While on-demand TDs is difficult to design in solid-state materials, photonic/phononic metamaterials provide a better platform for exploration [Nat Rev Phys 5, 483 (2023)]. Most studies on TDs have focused on the Hermitian limit, but extending to the non-Hermitian regime is a natural progression, as these classical-wave metamaterials are often open systems. The interplay between non-Hermiticity and topological physics leads to properties with no Hermitian counterparts [Rev. Mod. Phys. 93, 015005 (2021)].

We have shown that non-Hermiticity can induce topological disclination states with a fractional charge of 0.5 and established the bulk-defect correspondence principle for such system [arXiv:2406.03455 (2024)]. Notably, in the Hermitian regime, the system lacks both a bandgap and disclination states.

### T15.135 Non-invertible symmetry for 2d topological phase

Zhian Jia* (Centre for Quantum Technologies, National University of Singapore)
11:50am – 12:05pm

Two-dimensional (2d) topological phases are characterized by a unitary modular tensor category (UMTC) along with the chiral central charge $c_-$. For non-chiral topological phases, where $c_-$ vanishes, the topological phase is fully described by a UMTC. There are two prominent classes of lattice models that realize 2d non-chiral topological phases: (i) Kitaev's quantum double models and (ii) Levin and Wen's string-net models. These two model classes are intimately related. This talk will present a generalization of Kitaev's quantum double models to weak Hopf algebras, as well as a generalization of Levin-Wen string-net models to multifusion categories. We will establish an equivalence between these two broader classes of lattice models for non-chiral 2d topological phases. From the perspective of lattice gauge theory, we introduce weak Hopf gauge and charge symmetries. In particular, we elucidate the weak Hopf symmetry underlying the multifusion string-net models. Some applications in topological quantum memory and topological quantum computation will also be stressed.

### T15.23 Interplay between Haldane and modified Haldane models in $\alpha$-T3 lattice: Band structures, phase diagrams, and edge states

Kok Wai Lee*, Pei-Hao Fu, Yee Sin Ang (Singapore University of Technology and Design (SUTD))
12:05pm – 12:20pm

We study the topological properties of the Haldane and modified Haldane models in $\alpha$-T3 lattice. The band structures and phase diagrams of the system are investigated. Individually, each model undergoes a distinct phase transition: (i) the Haldane-only model experiences a topological phase transition from the Chern insulator (C = 1) phase to the higher Chern insulator (C = 2) phase; while (ii) the modified-Haldane-only model experiences a phase transition from the topological metal phase to the higher Chern insulator phase with identical Chern number C = 2, indicating that C is insufficient to characterize this system because of the indirect band gap. By plotting the Chern number and C phase diagram, we show that in the presence of both Haldane and modified Haldane models in the $\alpha$-T3 lattice, the interplay between the two models manifests three distinct topological phases, namely the C = 1 Chern insulator (CI) phase, C = 2 higher Chern insulator (HCI) phase, and C = 2 topological metal (TM) phase. These results are further supported by the $\alpha$-T3 Hall conductance, zigzag, and armchair edge states calculations. This work elucidates the rich phase evolution of the Haldane and modified Haldane models as $\alpha$ varies continuously from 0 to 1 in an $\alpha$-T3 model, thus suggesting $\alpha$-T3 lattice as a versatile condensed matter platform for studying topological phase transitions.

## T16: Atomic, Molecular and Optical Physics

Time: Thursday 3 Oct, 11:00am; Venue: LT-5; Chair: Arseniy Kuznetsov, A*STAR
Time allocated for invited talks is 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.

### T16.162 (INVITED) Hybrid gravimetry in geophysical surveys

Kaisheng Lee* (ntu)
11:00am – 11:20am

Gravimetry is a versatile metrological approach in geophysics to accurately map subterranean mass and density anomalies. There is a broad diversification regarding the working principle of gravimeters, in particular, atomic gravimeters can monitor gravity at an absolute scale with a high-repetition without exhibiting drift. Despite its strengths, atomic gravimeters are (currently) laboratory-bound devices due to the logistical complexities. Here, we demonstrated the utility of a hybrid gravimetric survey, with an atomic gravimeter on-site is complemented with a portable relative spring gravimeter. The atomic gravimeter served as a means to map the relative data from the spring gravimeter to an absolute measurement with an effective precision of 7.7 $\mu$Gal. Absolute measurements provide a robust and feasible method to define and control gravity data taken at different sites, or a later date, which is critical to analyze underground geological units, in particular when it is combined with other geophysical approaches.

### T16.83 3D Magic Optical Lattice for Ultracold Li-K Molecules

Xiaoyu Nie*, Canming He, Victor Avalos, Anbang Yang, Jacek Klos, Svetlana Kotochigova, Kai Dieckmann* (CQT, NUS)
11:20am – 11:35am

We report on our group's progress in setting up 3-dimensional optical lattice for ultracold $^{6}$Li and $^{40}$K atoms. The lattice potential depth is calibrated by means of Kapitsa-Dirac scattering of $^{87}$Rb BECs from short lattice pulses. Confinement-induced molecules are observed, and the association efficiency reach to 50%. MW spectroscopy for the rotational excitations has been achieved, and the coherence time is around 9 us. To further increase the rotation coherence and STIRAP efficiency in the deep lattices, we colaborate with theory group and developed magic conditions for transition both situation, where the magic wavelengths are near resonant to the coupling of $\left|X^1\Sigma, \nu = 0\right\rangle$ and $\left|b^3\Pi, \nu = 0\right\rangle$. The transition has been analyzed and narrowed down to 150GHz range. The highly resolved spectroscopy is under progress.

Our next step is to explore the loading of $^{6}$Li-$^{40}$K Fermi-Fermi mixture into the 3D magic optical lattice to achieve a higher doublon fillings, which will allow near unity association efficiency for $^{6}$Li-$^{40}$K Feshbach molecules. Combined with our recent work on the efficient transfer of $^{6}$Li$^{40}$K molecules to their rovibrational ground state in the dipole trap, our work paves the way for studying dipolar physics in 3D magic optical lattices and exploring few-body physics with mass-imbalanced Fermi-Fermi mixtures in lower dimensions.

### T16.36 Generation of Atom-Photon Entanglement with an Optically Trapped Single Atom

Zifang Xu*, Chang Hoong Chow, Boon Long Ng, Vindhiya Prakash, Christian Kurtsiefer (Centre for Quantum Technologies)

11:35am – 11:50am

Realizing effective quantum interfaces between stationary qubits like atoms with photons is necessary for constructing a distributed quantum network over distant locations. Our approach is to use a high-NA lens system as the light-atom interface to prepare entanglement between a neutral atom and a single photon. Here, we discuss recent results on generating entanglement between the polarization of a photon and the internal states of an atom via spontaneous emission. On average, 120 entangled atom-photon pairs are detected per minute. Two-qubit state tomography determines the entangled state fidelity to be 79(2)%, mainly limited by the state detection process and various decoherence mechanisms.

### T16.131 Superoscillatory tweezer arrays for subwavelength trapping and manipulation of single atoms

Kelvin Lim*, Vincent Mancois*, Lee Kai Xiang*, Wu Haijun*, Shen Yijie*, David Wilkowski* (Centre for Disruptive Photonic Technologies, Nanyang Technological University)

11:50am – 12:05pm

The trapping of a single 133Cs atom in a superoscillatory hotspot smaller than the Abbe's diffraction limit has been experimentally demonstrated [1]. Using the superoscillatory technique, we plan on realizing arrays of traps in which the spot size and separation distance can be tuned below the diffraction limit. This control over the spot size and separation distance in the subwavelength range is crucial for quantum simulation and computing with arras of neutral atoms. Creating superoscillatory tweezer arrays also poses some challenges and limitations, namely the amount of power contained in the hotspot for trapping and its sensitivity to aberrations.

[1] H. M. Rivy et al, Commun Phys., 6:155, 2023.

### T16.47 Correlated photon pair and multi-photon from a cold atomic ensemble

Yifan Li*, Boon Long Ng, Chang Hoong Chow, Vindhiya Prakash, Christian Kurtsiefer* (CQT Professor)

12:05pm – 12:20pm

A cold atomic ensemble, functioning as a nonlinear medium, offers a compelling platform for generating narrowband correlated photons in the near-resonance regime through parametric processes. This study presents a bright source of correlated photons in twin modes, produced via a double-$\Lambda$ four-wave mixing in a $^{87}$Rb cold atomic ensemble. We demonstrate that, within a counter-propagating Gaussian spatial mode, characterized by a waist of approximately 175 $\mu$m and a 1-degree deviation from the pump field, the generation rate of correlated photon pairs can reach a magnitude of $10^6$ counts per second (cps). Furthermore, we investigate multi-photon states generated by this source using Hanbury Brown and Twiss (HBT) measurements on the twin modes. Our measurements reveal a photon quadruplet rate of $20.8 \pm 0.8$ cps, corresponding to an initial generation rate on the order of $10^5$ cps when accounting for practical losses in collection and detection. We further examine the auto-correlation functions of the unheralded photons, as well as the joint third-order correlation functions among twin modes. Our results are consistent with a theoretical model based on Gaussian-state field correlations. Compared to sources based on spontaneous parametric down-conversion (SPDC), our observations suggest that four-wave mixing in a cold atomic ensemble is a promising source for generating correlated photon pairs and multi-photon states.

## T17: Electronic Materials and Devices 2

Time: Friday 4 Oct, 11:00am; Venue: LT-2; Chair: Rejaul SK
Time allocated for invited talks is 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.

### T17.90 (INVITED) Tunable Magnetic Octupole Stability and Spin Transport Behavior in Mn3Pt Noncollinear Antiferromagnet

Shaohai Chen*, Bee Chun Lim, Dennis Jing Xiong Lin, Jian Rui Soh, Hui Ru Tan, Seng Kai Wong, Hnin Yu Yu Ko, Mingsheng Zhang, Robert Laskowski, Khoong Hong Khoo, Pin Ho* (Institute of Materials Research & Engineering (IMRE), Agency for Science, Technology & Research (A*STAR))
11:00am – 11:20am

Mn-based noncollinear antiferromagnetic (AF) materials, such as Mn3X (X = Pt, Ir, Sn, Ga, Ge), exhibit unexpected spin-orbit and tunnelling phenomena promising to realize robust AF-centered nanoelectronics. However, the underlying physical mechanisms for such intriguing spin transport behavior of noncollinear antiferromagnets remain unclear till date. Here, we demonstrate single-crystalline Pm$\bar{3}$ m-face centre cubic Mn3Pt (001) multilayer thin films with vanishingly small magnetization of  10 kA/m due to the fully compensated moments arising from the triangular Mn spin arrangement. Group symmetry analysis suggests the presence of two magnetic structures Γ7 and Γ10, wherein their different triangular spin orientations give rise to noncollinear magnetic octupoles with AF and ferromagnetic orders, respectively. Meanwhile, temperature dependence resonant elastic x-ray scattering reveals a discernible dip in the magnetic ordering of Mn3Pt at a critical temperature of  230 K, albeit a temperature-independent crystal structure variation. Notably, the variation in magnetic ordering at the critical temperature coincides with the reversal of polarity of the anomalous Hall effect, which can be fine-tuned by modulating the Mn composition. Additionally, density functional theory calculations suggest the coexistence of the stable Γ10 and metastable Γ7 magnetic structures with non-zero Hall conductivity, which varies in magnitude with Mn composition-induced lattice constant changes. Our findings provide a platform for tuning transport properties using the interplaying effects of magnetic order stability and crystal lattice parameters, enabling the development of next-generation AF-based memory and unconventional computing.

### T17.132 Zero-Dipole Schottky Contact:Homologous Metal Contacts to 2D Semiconductor

Che Chen Tho, Yee Sin Ang* (Singapore University of Technology and Design)
11:20am – 11:35am

Band alignment of metal contacts to 2D semiconductors often deviate from the ideal Shottky-Mott (SM) rule due to the non-ideal factors such as the formation of interface dipole and metal-induced gap states (MIGS). Although MIGS can be strongly suppressed using van der Waals contact engineering, the interface dipole is hard to eliminate due to the electronegativity difference of the two contacting materials. Here we show that interface dipole can be practically eliminated in 2D semiconducting $MoSi_2N_4$ when contacted by its homologous metallic counterpart $MoSi_2N_4(MoN)_n$ $(n = 1 - 4)$. The SiN outer sublayers, simultaneously present in both $MoSi_2N_4$ and $MoSi_2N_4$(MoN)n, creates nearly equal charge 'push-back' effect at the contact interface. The nearly symmetrical charge redistribution leads to zero net electron transfer across the interface. Such zerodipole. Intriguingly, we show that even in the extreme close-contact case where $MoSi_2N_4$(MoN) is arbitrarily pushed towards $MoSi_2N_4$ with extremely small interlayer distance, the interface dipole remains practically zero. Such zero-dipole Schottky contact represents a peculiar case where the SM rule, usually expected to occur only in the non-interacting regime, manifests in $MoSi_2N_4$/$MoSi_2N_4$(MoN) even though the constituent monolayers interacts strongly. A model for pressure sensing is then proposed based on changing the interlayer distance in $MoSi_2N_4$/$MoSi_2N_4$(MoN).

### T17.172 Symmetry Breaking and Spin-Orbit Coupling for Individual Vacancy-Induced In-Gap States in $MoS_2$ Monolayers

Thasneem Aliyar*, Hongyang Ma, Radha Krishnan, Gagandeep Singh, Bi Qi Chong, Yitao Wang, Ivan Verzhbitskiy, Calvin Pei Yu Wong, Kuan Eng Johnson Goh, Ze Xiang Shen, Teck Seng Koh, Rajib Rahman, Bent Weber* (NTU)

11:35am – 11:50am

Spins confined to point defects in atomically thin semiconductors constitute well-defined atomic-scale quantum systems that are being explored as single-photon emitters and spin qubits. Here, we investigate the in-gap electronic structure of individual sulfur vacancies in molybdenum disulfide ($MoS_2$) monolayers using resonant tunneling scanning probe spectroscopy in the Coulomb blockade regime. Spectroscopic mapping of defect wave functions reveals an interplay of local symmetry breaking by a charge-state-dependent Jahn-Teller lattice distortion that, when combined with strong ($\approx$100 meV) spin-orbit coupling, leads to a locking of an unpaired spin-1/2 magnetic moment to the lattice at low temperature, susceptible to lattice strain. Our results provide new insights into the spin and electronic structure of vacancy induced in-gap states toward their application as electrically and optically addressable quantum systems.

### T17.56 Magneto-mechanics of 2D material membranes

Makars Siskins*, Timofey Savilov, Maciej Koperski, Konstantin Novoselov (Institute for Functional Intelligent Materials, NUS)

11:50am – 12:05pm

Nanoelectromechanical systems (NEMS) made of two-dimensional (2D) crystals are promising to address challenges in creating better sensors, smaller electronic and mechanical devices due to their atomic thickness [1][2]. When NEMS utilize suspended membranes made of magnetic 2D materials, the reduced dimensionality of these results in characteristic types of magnetically ordered phases that leave a fingerprint in their mechanical response to stress. This magneto-mechanical coupling allows to modify magnetic properties of these membranes through controlled straining, and vice versa - to affect dynamics of their motion via a magnetic field [3].

Here, we investigate 2D material membranes with magnetic phase transitions using their nanomechanical motion in both linear [3] and nonlinear [4] regime. We explain the fabrication of ultrathin 2D material membranes and techniques used to probe their motion. We then discuss their notable mechanical properties and show that 2D magnetic phases can be studied by looking at anomalies in the resonant motion of these membranes [5]. Finally, we theoretically substantiate the correlation between the motion of these membranes and the magnetic ordering at the phase transition temperature, and experimentally verify it for materials of different 2D layered antiferromagnets, ferromagnets, and their heterostructures.

[1] Steeneken, P.G. et al. Dynamics of 2D material membranes. 2D Mater 8, 042001 (2021). [2] Lemme, M.C. et al. Nanoelectromechanical Sensors Based on Suspended 2D Materials. Research, 2020, 8748602 (2020). [3] Šiškins, M., Lee, M., Mañas-Valero, S. et al. Magnetic and electronic phase transitions probed by nanomechanical resonators. Nat Commun 11, 2698 (2020). [4] Šiškins, M., Keşkekler, A., Houmes, M.J.A. et al. Nonlinear dynamics and magneto-elasticity of nanodrums near the phase transition. Pre-print at arXiv:2309.09672 (2023). [5] Houmes, M.J.A., Baglioni, G., Šiškins, M. et al. Magnetic order in 2D antiferromagnets revealed by spontaneous anisotropic magnetostriction. Nat Commun 14, 8503 (2023).

### T17.91 Orbital Current Induced by Nonlinear Optical Response in Semiconductors

Yuk Lam Kwok*, Mingrui Lai, Su Ying Quek* (NUS)
12:05pm – 12:20pm

In spintronic memory devices, information is stored using the magnetization of ferromagnets. To control the magnetization, spin torque needs to be applied, mainly from spin current in existing designs. Another rapidly developing way to obtain spin torque is from the orbital current through spin-orbit torque (SOT), and it is attracting interest because of its potential to create new designs of spintronic devices. In the previous studies of SOT, the orbital current is usually generated by the orbital Hall effect. To further explore the potential of SOT, we plan to study the bulk orbital photovoltaic effect (BOPV), a less-studied mechanism generating orbital current.

BOPV is the nonlinear optical response that converts incident alternating optical field into orbital current in centrosymmetric-broken materials. The expression for orbital current response can be derived using perturbation theory. It could generate responses with orbital polarization forbidden by symmetry in the orbital Hall effect, improving the efficiency of SOT generation. This project will focus on the first-principles methods of density functional theory.

The systems we are interested in are semiconductors with structural chirality. It is an intensely studied topic due to its important role in electronic chiral structures, predicted to demonstrate the chirality-induced spin selectivity effect, which describes that charge current is spin-polarized after propagating through chiral systems. Although the underlying physics of this effect is still under debate, it is proposed to be closely related to orbital polarization. The study will begin with a relatively simple example of trigonal tellurium, potentially moving on to more complicated systems like twisted van der Waals materials at a later stage. Through studying BOPV in a chiral system, we hope to compare the responses of different chirality and gain useful insights on the role of chirality in orbital transport, exploring possibilities for further improvement in orbital current generation.

## T18: Many Body Physics 2

Time: Friday 4 Oct, 11:00am; Venue: LT-4; Chair: Nilanjan Roy
Time allocated for invited talks is 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.

### T18.9 (INVITED) Universal scaling laws for correlated decay of many-body quantum systems

Wai-Keong Mok* (California Institute of Technology)
11:00am – 11:20am

Quantum systems are open, continually exchanging energy and information with the surrounding environment. This interaction leads to decoherence and decay of quantum states. In complex systems, formed by many particles, decay can become correlated and enhanced. A fundamental question then arises: what is the maximal decay rate of a large quantum system, and how does it scale with its size? In this work, we address these issues by reformulating the problem into finding the ground state energy of a generic spin Hamiltonian. Inspired by recent work in Hamiltonian complexity theory, we establish rigorous and general upper and lower bounds on the maximal decay rate. These bounds are universal, as they hold for a broad class of Markovian many-body quantum systems. For many physically-relevant systems, the bounds are asymptotically tight, resulting in exact scaling laws with system size. Specifically, for large atomic arrays in free space, these scalings depend only on the arrays' dimensionality and are insensitive to details at short length-scales. The scaling laws establish fundamental limits on the decay rates of quantum states and offer valuable insights for research in many-body quantum dynamics, metrology, and fault tolerant quantum computation.

### T18.45 Learning finitely correlated states: stability of the spectral reconstruction

Marco Fanizza, Niklas Galke, Josep Lumbreras*, Cambyse Rouze, Andreas Winter (Center for Quantum Technologies, National University of Singapore)
11:20am – 11:35am

We present a trace distance learning algorithm for marginals of blocks of $t$ systems of finitely correlated translation invariant states with sample complexity $O(t^2)$ and computational complexity polynomial in $t$. The algorithm requires estimates of a controlled size marginal from which it reconstructs a translation invariant matrix product operator. We also obtain an analogous error bound for a class of matrix product density operators reconstructible by local marginals. This case requires estimating a linear number of marginals leading to $\tilde{O}(t^3)$ sample complexity. The algorithm applies even to states near finitely correlated ones, with potential applications for learning physical quantum systems.

### T18.154 Superlattice induced electron percolation within a single Landau level

Nilanjan Roy*, Bo Peng, Bo Yang (Division of Physics and Applied Physics, Nanyang Technological University)

11:35am – 11:50am

In this talk, I will present our recent theoretical work on the quantum Hall effect in a single Landau level in the presence of a square superlattice of $\delta$-function potentials. The interplay between the superlattice spacing ($a_s$) and the magnetic length ($l_B$) in clean system leads to three interesting characteristic regimes corresponding to $a_s < l_B$, $a_s \gg l_B$ and the intermediate one where $a_s \sim l_B$. In the intermediate regime, the continuous magnetic translation symmetry breaks down to discrete lattice symmetry. In contrast, we show that in the other two regimes, the same is hardly broken in the topological band despite the presence of the superlattice. In the presence of weak disorder (white-noise), interestingly, we obtain a large fraction of extended states throughout the intermediate regime which maximizes at the special point $a_s = \sqrt{2\pi} l_B$. We argue the superlattice induced percolation phenomenon requires both the breaking of the time reversal symmetry and the continuous magnetic translational symmetry. It could have a direct implication on the integer plateau transitions in both continuous quantum Hall systems and the lattice based anomalous quantum Hall effect which will be explained. In addition, I will also very briefly discuss our recent results on the superlattice-induced phenomena in the fractional quantum Hall effect.

Reference: arXiv:2403.17137 (2024)

### T18.94 Kardar-Parisi-Zhang universality class in few-body localized wavefunction

Sen Mu*, Jiangbin Gong, Gabriel Lemarie (CQT, NUS)

11:50am – 12:05pm

Originally associated with classical systems, Kardar-Parisi-Zhang (KPZ) universality class describes a broad range of processes, ranging from growth of rough interfaces to directed polymers. We have identified the key features of the KPZ universality class in the fluctuations of the wave density logarithm in two-dimensional Anderson localization. Our previous work shows that these fluctuations exhibit algebraic scaling with distance, characterized by an exponent of 1/3, and follow a Tracy-Widom probability distribution. In this study, we explore the conditions necessary to realize genuine Anderson localization of a few-body wave function in Fock space, thereby uncovering the KPZ universality class in (1+1)D for the two-body localized wave function. To validate the universality of our results, we draw comparisons with the well-understood directed polymer problem in the presence of competing point and columnar disorders. Additionally, we discuss the generalization of these findings to the localized wave functions of multiple particles and the emergence of the KPZ universality class in higher dimensions. Our work paves the way for new investigations into the KPZ universality class in disordered quantum systems and establishes a bridge for applying the analytic framework of KPZ physics to the study of many-body localized quantum systems.

## T19: Mathematical Physics

Time: Friday 4 Oct, 11:00am; Venue: LT-3; Chair: Koh Wee Shing, A*STAR/IHPC
Time allocated for invited talks is 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.

### T19.119 Dynamical universality in long-range quantum systems

Nicolo Defenu* (ETH Zurich)
11:00am – 11:15am

Dive into the fascinating realm of quantum systems, the seminar will offer a panoramic view of long-range interactions. Starting with a encompassing tour of critical phenomena in systems featuring power-law interactions $1/r^{\alpha}$ at $\alpha < d$, we'll unveil the intricate equilibrium scaling dependence on the power-law exponent $\alpha$. We will then take a deep dive into the dynamic world of "strong" long-range systems with $\alpha < d$, where we'll unravel the counterintuitive features of out-of-equilibrium scaling dynamics during sudden and gradual quenches.

### T19.17 Emergence of Fluctuation Relations in UNO

Peter Sidajaya*, Jovan Hsuen Khai Low, Clive Aw, Valerio Scarani* (National University of Singapore)
11:15am – 11:30am

Fluctuation theorems are generalisations of the second law that describe the relations between work, temperature, and free energy in thermodynamic processes and are used extensively in studies of irreversibility and entropy. Many experiments have verified these relations for different physical systems in the setting of thermodynamics. In this study, we observe the same behavior away from physical thermodynamics, namely for the card game UNO, by performing numerical simulations of the game. As the analog of work, we choose the number of steps one player needs to effect a transition in her deck; the other players and the remaining cards play the role of a finite, non-Markovian bath. We also compare our observation with is expected for a Markovian random walk.

### T19.123 Estimation of Hamiltonian parameters from thermal states

Kishor Bharti* (IHPC, A*STAR)
11:30am – 11:45am

We upper- and lower-bound the optimal precision with which one can estimate an unknown Hamiltonian parameter via measurements of Gibbs thermal states with a known temperature. The bounds depend on the uncertainty in the Hamiltonian term that contains the parameter and on the term's degree of noncommutativity with the full Hamiltonian: higher uncertainty and commuting operators lead to better precision. We apply the bounds to show that there exist entangled thermal states such that the parameter can be estimated with an error that decreases faster than $1/\sqrt{n}$, beating the standard quantum limit. This result governs Hamiltonians where an unknown scalar parameter (e.g. a component of a magnetic field) is coupled locally and identically to n qubit sensors. In the high-temperature regime, our bounds allow for pinpointing the optimal estimation error, up to a constant prefactor. Our bounds generalize to joint estimations of multiple parameters. In this setting, we recover the high-temperature sample scaling derived previously via techniques based on quantum state discrimination and coding theory. In an application, we show that noncommuting conserved quantities hinder the estimation of chemical potentials.

Paper link: https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.133.040802

### T19.192 Topological Newton's Method for Locating Unstable Fixed Points

Manu Magal*, Christopher Berg Smiet (National University of Singapore)

11:45am – 12:00pm

A number of numerical algorithms have been developed to find the fixed points of multi-dimensional iterated maps in the context of dynamical systems. These methods work well at finding elliptic fixed points but not hyperbolic fixed points. We present a new algorithm for locating the fixed points of iterated maps which we call the 'Topological Newton's Method' (shortened to TNM). With analysis of regions of convergence around fixed points of the Chirikov Standard Map, we show that TNM has potential to converge to fixed points quicker than Newton's Method (NM), depending on the complexity of the iterated map. With further optimisation, this method has potential to pave the way for more refined analysis of dynamical systems.

### T19.30 Phase Transitions and Hidden Geometric Orders in Directed Percolation Model

Vitalii Kapitan*, Konstantin Soldatov, Pavel Ovchinnikov, Gennady Chitov (National University of Singapore)

12:00pm – 12:15pm

The paper studies directed percolation [1] in a stochastic chain similar to cellular automata [2]. The phase diagram was plotted using direct numerical calculations and neural networks. Four new phases, characterized by different percolation patterns (order parameters), were found in the active phase. The critical properties of these phases were studied using finite-size scaling methods. In particular, the critical indices of transitions were determined. These results confirm that in the active phases of such models, there is a hierarchy of geometric orders with different percolation patterns arising at the critical points of continuous phase transitions [2,3]. These geometric transitions belong to the universality class of directed percolation. Funded by Singapore MoE Tier 1 grant entitled "MAPLE" with grant number 22-5715-P0001 and RSF grant #24-22-00075. [1] Hinrichsen, H. // Advances in physics, 49(7), 815-958 (2000). [2] Timonin, P. N., & Chitov, G. Y. // J. of Phys. A, 48(13), 135003 (2015). [3] Timonin, P. N., & Chitov, G. Y. // Phys. Rev. E, 93(1), 012102 (2016).

### T19.200 Energy-balance Modelling of Thermal Effect on Solar Potential in Tropical Urban Environments

Po-Yen Lai* (Institute of High Performance Computing (IHPC))

12:15pm – 12:30pm

Solar energy is crucial in global efforts to achieve net-zero emissions by 2050. However, rising air temperatures due to climate change, with the past nine years ranked among the warmest on record according to the World Meteorological Organization (WMO) in 2024, pose challenges to solar panel efficiency. This study adopts effective surface balance equations to estimate solar panel surface temperatures and calculate the corresponding solar potential. The interplay between radiative and convective mechanisms on the panel surface enables solar panel thermal effects analysis under various weather conditions. Utilizing Singapore's meteorological data in conjunction with the Perez sky model, the research accurately computes short-wave radiation surrounding solar panels. This approach facilitates precise estimation of solar panel temperatures and potential energy output in tropical urban settings. The findings of this study contribute to the optimization of solar energy harvesting in tropical urban environments, addressing the challenges posed by increasing temperatures and enhancing the efficiency of solar power systems in the context of climate change mitigation efforts.

## T20: Quantum Photonics

Time: Friday 4 Oct, 11:00am; Venue: LT-5; Chair: (TBD)
Time allocated for invited talks is 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.

### T20.101 Post selection based quantum repeater protocol

Angela Anna Baiju*, Ozlem Erkilic*, Lorcan Conlon*, Biveen Shajilal*, Ping Koy Lam* (Q.InC,A*STAR)

11:00am – 11:15am

Continuous variable quantum communication offers a scalable and robust approach for long-distance quantum communication. It allows for relatively easier manipulation of quantum states, detection, and integration with current infrastructure. However, both classical and quantum long-distance communications suffer from external noise, degrading the quality of information transfer. This affects the non-classical features of the shared information. Quantum repeaters can mitigate this issue in sharing quantum resources, such as entanglement, over large distances, enabling the construction of a quantum network. In this work we make use of a heralded quantum teleporter to achieve efficient entanglement sharing. Existing protocols for sharing entanglement rely on entanglement distribution, swapping, and purification. In Zhao et al., 2023 the authors proposed using a heralded teleporter for entanglement sharing and demonstrated its superior performance in sharing entanglement, even in a lossy channel. In this study, we extend the heralded teleportation technique to multiple nodes for entanglement sharing, benchmarking it against other existing protocols as an ideal platform for developing quantum repeaters. As illustrated in the figure, we employ a heralded teleporter to teleport an EPR state between subsequent parties separated by some arbitrary distance, ultimately sharing entanglement between parties A and B. We aim to evaluate the performance of our teleporter for multiple node entanglement sharing using entanglement of formation and the purity of the output state. The performance analysis would be conducted at different nodes in both pure and lossy channels to determine optimal number of nodes for a given distance.

### T20.75 On the composable security of weak coin flipping

Jiawei Wu*, Yanglin Hu*, Akshay Bansal*, Marco Tomamichel* (National University of Singapore)
11:15am – 11:30am

Weak coin flipping is a cryptographic primitive in which two mutually distrustful parties generate a shared random bit to agree on a winner via remote communication. While a stand-alone secure weak coin flipping protocol can be constructed from noiseless communication channels, its composability has not been explored. In this work, we demonstrate that no weak coin flipping protocol can be abstracted into a black box resource with composable security. Despite this, we also establish the overall stand-alone security of weak coin flipping protocols under sequential composition.

### T20.71 Quantum Multi-time Stochastic Processes in Continuous Variable Systems

Amalina Lai*, Minjeong Song, Graeme Berk, Mile Gu (Nanyang Technological University)
11:30am – 11:45am

Quantum multi-time stochastic processes are general quantum processes that occur in a span of time, and which may be interacted with at several time intervals. These processes may, in general, be non-Markovian, whereby temporal correlations arise from interaction of the system with some typically inaccessible environment. One such way to characterize these multi-time processes are quantum combs. They describe coupled unknown environment and system transformations in practical terms by characterizing these transformations in terms of initial preparations, final output and intermediate measurement outcomes at each time step — information that is typically accessible to an experimental set-up. While this framework has been developed in discrete variable systems, it lacks a continuous variable counterpart. We thus extend the framework of quantum combs to general continuous variable systems by developing an analogous description, before elucidating the characterization, key properties, and non-Markovianity measure of Gaussian quantum combs due to their potential relevance in experimental optical systems.

### T20.26 Bayesian retrodiction of quantum supermaps

Ge Bai* (National University of Singapore)
11:45am – 12:00pm

The Petz map has been established as a quantum version of the Bayes' rule. It unifies the conceptual belief update rule of a quantum state observed after a forward quantum process, and the operational reverse process that brings the final state to a recovered state equal to the updated belief, counteracting the forward process. Here, we study a higher-order generalization of the quantum Bayes' rule by considering a quantum process undergoing a quantum supermap. For a few families of initial beliefs, we show that a similar unification is possible – the rules to update the belief of quantum channels can be implemented via a "reverse" quantum supermap, which we call the retrodiction supermap, allowing for applications such as error correction in quantum cloud computing. Analytical solutions are provided for those families, while a recipe for arbitrary initial beliefs is yet to be found.

### T20.164 Dispersive readout of the donor-based flip-flop qubit

Si Yan Koh*, Mark Chiyuan Ma, Hui Khoon Ng, Teck Seng Koh (SPMS, NTU)
12:00pm – 12:15pm

Superconducting resonators coupled to qubits offer a promising route to scalability, enabling both long-range operations and fast qubit readout. A key requirement is for qubits to have tunable electric dipole moments that couple strongly to the electric field of the resonator. The donor-based flip-flop qubit is a serious candidate due to the electron-nuclear spin states that can be controlled by microwave fields. However, a theoretical estimate of its spin-photon coupling strength is about 3 MHz [1, 2], placing it on the border between weak and strong coupling for typical planar resonator quality factors. Additionally, its lifetime is reduced by 8 orders of magnitude compared to donors in bulk silicon due to enhanced spin-valley relaxation from interface states [3]. It is therefore important to investigate whether the flip-flop qubit can leverage its advantages for dispersive readout. We show that good signal-to-noise ratios (SNR) and single-shot readout fidelities are possible across a range of qubit parameters. At most working points, the qubit remains sufficiently long lived to allow readout fidelities exceeding 90% in the weak coupling regime and fidelities ¿ 99% in the strong coupling regime. Furthermore, such high fidelities are possible with fast readout times under 100 microseconds. Our results demonstrate that fast, high-fidelity dispersive readout of the flip-flop qubit using superconducting resonators is possible in both weak and strong coupling regimes.

[1] G. Tosi, F. A. Mohiyaddin, V. Schmitt et al. Nat Commun 8, 450 (2017). [2] E. N. Osika, S. Kocsis, Y. Hsueh et al. Phys Rev Applied 17, 054007 (2022). [3] P. Boross, G. Széchenyi, and A. Pályi. Nanotechnology 27, 314002 (2016).

### T20.127 Exponentially faster preparation of quantum dimers via driven-dissipative stabilization

Davit Aghamalyan*, Kian Hwee Lim, Jian Feng Kong, Jiabin You, Wai-Keong Wai-Keong (Institute of High Performance Computing, A*STAR , 1 Fusionopolis Way, #16-16 Connexis, Singapore 138632)

12:15pm – 12:30pm

We propose a novel rapid, high-fidelity, and noise-resistant scheme to generate many-body entan- glement between multiple qubits stabilized by dissipation into a 1D bath. Using a carefully designed time-dependent drive, our scheme achieves a provably exponential speedup over state-of-the-art dis- sipative stabilization schemes in 1D baths, which require a timescale that diverges as the target fidelity approaches unity and scales exponentially with the number of qubits. To prepare quantum dimer pairs, our scheme only requires local 2-qubit control Hamiltonians, with a protocol time that is independent of system size. This provides a scalable and robust protocol for generating a large number of entangled dimer pairs on-demand, serving as a fundamental resource for many quantum metrology and quantum information processing tasks.

### T20.179 Towards Qibo-Braket Integration

Matthew Ho*, Le Tan (A*STAR, IHPC)

12:30pm – 12:45pm

Qibo is an open-source full stack API for quantum simulation and quantum hardware control where the Institute of High Performance Computing (A*STAR) is a major collaborator. Amazon Web Services is a well-known cloud service offered by Amazon. Among many cloud services is Amazon Braket, a software development kit that allows users to build quantum circuits and run circuits on real devices. A recent collaboration between AWS and IHPC sought to enhance quantum computing capabilities by developing an Qibo-AWS interface to allow Qibo end-users to execute Qibo circuits on Amazon Braket devices. This is part of Qibo-cloud-backends. The efficacy of the interface was tested using Qibo's Zero Noise Extrapolation to mitigate noise in the IQM Garnet device hosted by Amazon Braket.

# 6 Committees

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