BQIT:19

BRISTOL QUANTUM INFORMATION TECHNOLOGIES WORKSHOP 2019

6th annual conference

M Shed, Bristol

1—3 April 2019

QET Labs

University of BRISTOL

CONTENTS

PROGRAMME COVER IMAGES: Indium phosphide quantum key distribution transmitter capable of multi-protocol operation at GHz speeds
PHOTO CREDIT: Richard Collins (University of Bristol)

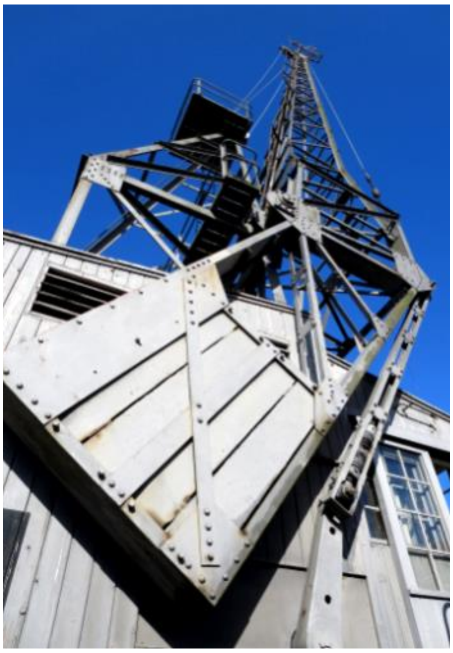


PHOTO CREDIT: Ian Caskie

WELCOME TO BQIT:19

Dear friends and colleagues,

On behalf of the BQIT:19 team, it is with great pleasure that I welcome you to Bristol for the sixth annual Bristol Quantum Information Technologies workshop.

Our goal is to build on the successes of preceding BQIT workshops. To do this we have put together a diverse and exciting technical program of research talks and posters, including a focused session on personal perspectives of working in the quantum technology industry. New to BQIT this year is a session on equality, diversity and inclusion. This will allow us to reflect where our community currently stands, to discover steps we can all take to ensure people from the broadest possible range of backgrounds thrive in academia and industry, and how we can enrich our community using the potential of diverse teams.

BQIT is organised by the University of Bristol's Quantum Engineering Technology Labs, that strives to deliver societal and economic benefit through transformative technologies and machines that harness quantum physics. QET Labs is a global centre for research, development, training and entrepreneurship in the emerging quantum technologies. It is an international node for collaborating with industry and academic world leaders, and is a leading contributor to the UK National Quantum Technologies program. BQIT forms part of our mission to help deliver transformative quantum technologies and it is our hope that you have a productive and enjoyable time while you are with us in Bristol at BQIT:19.

Yours sincerely,

Dr Jonathan Matthews (on behalf of the BQIT board)

BQIT board chair and QET Labs Senior Lecturer in Quantum Technology

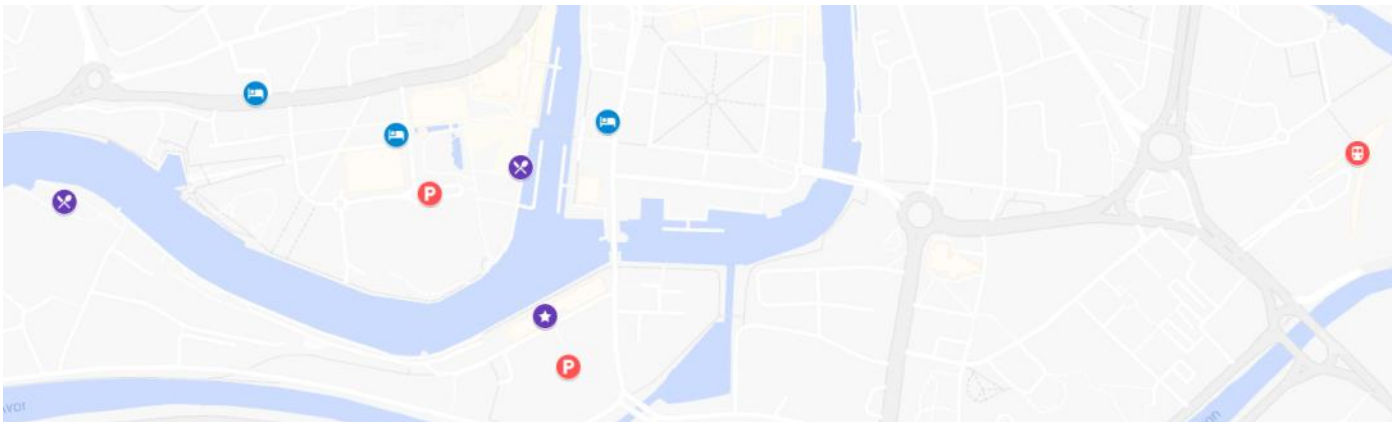
VENUE & PARKING

M Shed

Princes Wharf, Wapping Rd, Bristol BS1 4RN

BQIT:19 will be held in the M Shed event suite on the top floor, with break out space and an exhibition area in the adjoining rooms. Guests are invited to explore the museum situated within the M Shed for the duration of the conference.

Parking is available in Wapping Wharf car park behind the M Shed at a rate of £9.50 for 12 hours.



DAY ONE AGENDA
MONDAY
APRIL 1

TIME	EVENT	LENGTH
09.30	**Arrivals and registration**	**30 min**
10.00	Jonathan Matthews (Chair of BQIT board and Senior Lecturer in Quantum Technology - University of Bristol) *Welcome and opening of the workshop*	5 min
Quantum Computing (chair: Alexandra Moylett)		
10.05	Viv Kendon (University of Durham) *Continuous-time quantum computing*	40 min (+ 5 min questions)
10.50	Ben Lanyon (IQOQI Innsbruck) *Light-matter entanglement over 50km of optical fibre*	25 min (+ 5 min questions)
11.20	Juani Bermejo-Vega (Free University of Berlin) *Quantum devices outperforming classical computers*	25 min (+ 5 min questions)
11.50	**Coffee break**	**20 min**
12.10	Christophe Vuillot (Delft University of Technology) *Quantum error correction with the Toric-GKP code*	25 min (+ 5 min questions)
12.40	Valentina Parigi (Sorbonne University) *Quantum optical frequency comb and implementation of quantum complex networks*	25 min (+ 5 min questions)
13.10	**Lunch**	**60 min**

Integrated Photonics (chair: Jorge Monroy Ruz)

14.10	Gregory Goltsman (MSPU) *Superconducting nanowire single-photon detector as a key element for quantum photonic integrated circuits*	40 min (+ 5 min questions)
14.55	Christophe Galland (EPFL) *Quantum phononics at room temperature*	25 min (+ 5 min questions)
15.25	Benjamin Brecht (Paderborn University) *Quantum optics and information science in multi-dimensional photonic networks*	25 min (+ 5 min questions)
15.55	**Coffee break**	**20 min**
16.15	Elizabeth Goldschmidt (US Army Research Laboratory) *Topological quantum photonics*	25 min (+ 5 min questions)
16.45	Callum Littlejohns (Cornerstone) *CORNERSTONE: UK silicon photonics rapid prototyping capability*	25 min (+ 5 min questions)
17.15	Alex Jones (University of Oxford/Imperial College London) *Interfering photons in orthogonal states*	10 min
17.25	**Thanks & close**	**5 min**

DRINKS RECEPTION AND DINNER AT THE SS GREAT BRITAIN

SS Great Britain

Our drinks reception and dinner will be served on board the SS Great Britain, one of the most important historic ships in the world.

Guests will have access to the entire ship during their visit, with the option to attend a guided tour. Access to the museum and dry dock from 5pm.

Drinks will be served at 6pm and dinner at 7pm.

Great Western Dockyard, Gas Ferry Road, Bristol BS1 6TY

DAY ONE ABSTRACTS

Viv Kendon

University of Durham

Continuous-time quantum computing

Computing using the Hamiltonian of a system of qubits has no direct classical analogue, yet it is a natural way to exploit the computational properties of a quantum system.

I will explain how this encompasses adiabatic quantum computing, computation by quantum walk, quantum annealing and special purpose quantum simulation.

I will give examples using quantum walks that are suitable for near future noisy quantum devices.

Ben Lanyon

IQOQI Innsbruck

Light-matter entanglement over 50 km of optical fibre

When shared between remote locations, entanglement opens up fundamentally new capabilities for science and technology. Envisioned quantum networks use light to distribute entanglement between their remote matter-based quantum nodes. Here we report on the observation of entanglement between matter (a trapped ion) and light (a photon) over 50 km of optical fibre: two orders of magnitude further than the state of the art and a practical distance to start building large-scale quantum networks.

Our methods include an efficient source of ion-photon entanglement via cavity-QED techniques (0.5 probability on-demand fibre-coupled photon from the ion) and a single photon quantum frequency converter to the 1550 nm telecom C band (0.25 fibre-coupled device efficiency). Modestly optimising and duplicating our system would already allow for 100 km-spaced ion-ion entanglement at rates over 1 Hz.

Our results therefore show a direct path to entangling remote registers of quantum-logic capable trapped-ion qubits, and the optical atomic clock transitions that they contain, spaced by hundreds of kilometres.

Juani Bermejo-Vega

Free University of Berlin

Quantum devices outperforming classical computers

A near-term goal in quantum computation and simulation is to realize a quantum device showing a computational advantage. The goal here is to perform a quantum experiment whose outcome cannot be efficiently predicted on a classical computer. A hope of this program is that performing such an experiment may be simpler than building an universal quantum computer. Candidate quantum devices for this task include boson samplers and Google-AI's random quantum circuits.

In this talk, we will review the current approaches towards demonstrating superior quantum computational power, as well as associated challenges concerning scalability, verifiability and complexity theoretic soundness. We will introduce a new proposal based on short-time evolutions of 2D Ising models [1-2]. Our proposal has the benign features of being hard to simulate classically (assuming plausible complexity theoretic conjectures) while being reasonably close to cold-atomic quantum implementations, and admitting an efficient simple quantum verification protocol. This provides an alternative path towards demonstrating a reliable quantum advantages with realistic quantum simulators.

[1] J. Bermejo-Vega, D. Hangleiter, M. Schwarz, R. Raussendorf, and J. Eisert, Architectures for quantum simulation showing a quantum speedup, Phys. Rev. X 8, 021010, https://arxiv.org/abs/1703.00466

[2] D. Hangleiter, J. Bermejo-Vega, M. Schwarz, and J. Eisert, Anticoncentration theorems for schemes showing a quantum speedup, Quantum 2, 65 (2018), https://arxiv.org/bs/1706.03786

Christophe Vuillot

Delft University of Technology

Quantum error correction with the toric-GKP code

We examine the performance of the single-mode Gottesman-Kitaev-Preskill (GKP) code and its concatenation with the toric code for a noise model of Gaussian shifts, or displacement errors.

We first show how to optimally perform error correction for a single GKP qubit, in the presence of measurement errors. Then, we analyze and numerically assess the concatenation of the GKP code with the toric code when all error information is noisy.

We show how to represent the maximum likelihood decoding problem for the toric-GKP code as a 3D compact QED model in the presence of a quenched random gauge field, an extension of the random-plaquette gauge model for the toric code.

We then present and simulate an efficient decoder for this problem which shows the existence of a noise threshold.

Valentina Parigi

Sorbonne University

Quantum optical frequency comb and implementation of quantum complex networks

We show experimental procedures based on optical frequency combs and parametric processes able to produce quantum states of light involving large number of modes in the frequency and time domain. The protocols, along with mode selective and multimode homodyne measurements, allow for the implementation of reconfigurable entanglement structures with regular geometry as cluster states [1] but also graphs with more complex topology [2]. In fact, quantum complex networks, mimicking real-world structures, can be explored to study quantum transport and tailored quantum communication and information protocols. Additional non-Gaussian operations have been recently demonstrated in our setup. When applied to the graph structure a special entanglement [3] properties appear, and the non-Gaussian features are spread out with particular geometrical properties [4].

[1]Y. Cai, J. Roslund, G. Ferrini, F. Arzani, X. Xu, C Fabre and N. Treps, Nature Communications 8, 15645 (2017)

[2] J. Nokkala, F. Arzani, F. Galve, R. Zambrini, S. Maniscalco, J. Piilo, N. Treps and V. Parigi, New Journal of Physics 20, 053024 (2018).

[3] M. Walschaers, C. Fabre, V. Parigi and N. Treps, Physical Review Letters 119, 183601 (2017).

[4] M. Walschaers, S. Sarkar, V. Parigi, and N. Treps, Phys. Rev. Lett. 121, 220501(2018).

Gregory Goltsman

MSPU

Superconducting nanowire single-photon detector as a key element for quantum photonic integrated circuits

Currently, many physical systems are studied for the realization of qubits including superconducting circuits, trapped ions and atoms, quantum dots, color centers in a solid and photons. Here we focus only on the last item in the list - photons. Fortunately, Knill, Laflamme and Milburn (KLM) proposed the concept of linear optical quantum computing (LOQC), allowing one to create non-deterministic gates using photons, linear optical elements and detectors.

Despite the fact that the implementation of the KLM-protocol is possible in free space, the need for a large number of optical components and their precise configuration requires more complex solutions. Owing to a number of advantages, such as scalability, a small footprint, a low weight, no need for optical alignment as well as power consumption and CMOS-compatibility, quantum photonic integrated circuits (QPICs) can successfully solve this problem. The most popular material platforms for QPICs realization are silicon, gallium arsenide, and polycrystalline diamond. All of these platforms have the fundamental blocks that require combining on-chip, such as single photon source, linear optical elements and single-photon detectors.

In our presentation we talk about operation principles, the history of development as well as the latest success of the most promising approach for QPICs realization based on hybrid nanophotonic-superconductor devices. In this case, an NbN nanowire is placed on top of a Si_3N_4 nanophotonic waveguide, thus increasing the effective interaction length. For this reason it is possible to achieve almost complete absorption of photons and reduce the detector footprint. This reduces the dead time of the device and increases the detection efficiency. Our approach is fully scalable and, along with a large number of devices integrated on a single chip, can be adapted to the mid-IR range where photon-counting measurement may be beneficial as well. The realization of large scale QPICs can have a profound impact on science and technology, material engineering, as well as quantum information processing including quantum computing, simulation and metrology.

Christophe Galland

EPFL

Quantum phononics at room temperature

Santiago Tarrago Velez[1], Kilian Seibold[1], Nicolas Sangouard[2], Vivishek Sudhir[3], Christophe Galland[1]*

1 Ecole Polytechnique Fédérale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland

2 Universität Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland

3 LIGO Laboratory, Massachusetts Institute of Technology, Cambridge, MA 02139, USA

The ability to create and detect single photons and to reveal non-local correlations between them was a cornerstone in the development of quantum optics. It is now becoming an essential feature underlying first commercial quantum technologies such as quantum key distribution. Here, we extend these concepts to mechanical degrees of freedom and present experimental results where single quanta of vibrations (THz phonons) are created and detected at room temperature with a time resolution of 200 fs.

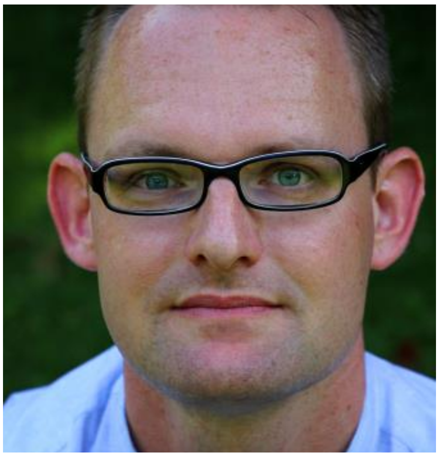
In a first experiment, we prepare a 'heralded' single phonon Fock state and prove the sub-Poissonian statistics of the resulting phonon distribution, using an optomechanical Hanbury Brown Twiss measurement [1]. In a second and ongoing experiment, we perform the first room-temperature optomechanical Bell test to test local realism on vibrational degrees of freedom.

Both experiments are enabled by a new setup in which pulsed Raman scattering and single photon detection are combined so as to excite phonons and perform projective measurements on the inelastically scattered photons [2].

References:

[1] Santiago Tarrago Velez, Kilian Seibold, Nils Kipfer, Mitchell D. Anderson, Vivishek Sudhir, Christophe Galland, under review arXiv:1811.03038 [quant-ph] https://arxiv.org/abs/1811.03038 (2018)

[2] Mitchell D. Anderson, Santiago Tarrago Velez, Kilian Seibold, Hugo Flayac, Vincenzo Savona, Nicolas Sangouard, Christophe Galland, Phys. Rev. Lett. 120, 233601 (2018)



Benjamin Brecht

Paderborn University

Quantum optics and information science in multi-dimensional photonic networks

Multi-dimensional photonic networks will play a pivotal role in future quantum technologies. The practical realisation of these networks, however, requires several ingredients: the ability to build large-scale integrated structures; methods for the efficient use of resources; and a high-dimensional alphabet for information encoding. We address these requirements by using lithium niobate waveguide chips, time-multiplexing, and temporal modes.

I will talk about three recent results that highlight our current capabilities in these areas.

First, an on-chip version of the original Hong-Ou-Mandel interference, where we realised all necessary components – including a variable time delay – on a single lithium niobate waveguide chip.

Then, a fully reconfigurable time-multiplexed quantum walk, where we can address each position of every step; different measurement strategies fundamentally change the evolution of the walk.

Finally, the controlled generation and manipulation of temporal modes using dispersion engineered parametric down-conversion and sum-frequency generation, respectively. Within this framework, we have recently demonstrated time- and frequency-metrology beyond the classical limit.

Elizabeth Goldschmidt

US Army Research Laboratory

Topological quantum photonics

Systems with topological order have proven of great interest, the best-known being electronic systems that exhibit quantum Hall effects.

A primary feature of these systems is the existence of global properties, not discernable locally, that provide robustness against local defects and variations. Such robustness is of particular interest for quantum optics in integrated photonics where fabrication defects and disorder can be a major impediment to practical and scalable quantum devices.

I will discuss how topological physics has been recently extended into the realm of photonics, allowing simulation of quantum Hall effects in optical systems. We realize topological edge states in a two dimensional array of ring resonators fabricated with standard silicon photonics techniques. We generate non-classical light via spontaneous four-wave mixing in the topologically protected modes and show enhanced spectral robustness over a topologically trivial system.

Callum Littlejohns

Cornerstone

UK silicon photonics rapid prototyping capability

The field of silicon photonics has expanded rapidly over the past several decades. This has led to a degree of standardisation in the commercial device fabrication foundries that are available for universities and fabless companies alike. Whilst this is advantageous in terms of yield, repeatability etc., it is not conducive for researchers to develop new and novel devices for future systems. CORNERSTONE offers researchers a flexible device prototyping capability that can support photonics research around the world. The CORNERSTONE project (Capability for OptoelectRoNics, mEtamateRialS, nanoTechnOlogy, aNd sEnsing) is a UK Engineering and Physical Sciences Research Council (EPSRC) funded project between 3 UK universities: University of Southampton, University of Glasgow and University of Surrey. The project is based on deep-ultraviolet (DUV) photolithography equipment, installed at the University of Southampton, centred around a 248 nm Scanner, the first of its kind in a UK university. Utilising these facilities, CORNERSTONE will offer a multi-project wafer (MPW) service on several silicon-on-insulator (SOI) platforms (220 nm, 340 nm & 500 nm) for both passive and active silicon photonic devices. This talk will give an overview of the CORNERSTONE project, present some of its early data, and summarise future MPW offerings.

Alex Jones

University of Oxford/Imperial College London

Interfering photons in orthogonal states

One of the central principles of quantum mechanics is that the interference of probability amplitudes for indistinguishable paths, not just probabilities alone, determines measurement outcomes [1]. Information that in principle allows discrimination between paths is normally assumed to result in the disappearance of interference. For example, in Young's double slit experiment, knowledge of which slit a quantum particle took results in the disappearance of interference fringes at a detection screen [1]. Similarly, the Hong-Ou-Mandel (HOM) interference of two photons vanishes if their quantum states are different [2]. Is this true for larger systems? Remarkably interference is possible despite distinguishability: here we demonstrate the multiparticle interference of four photons in a balanced four port interferometer, even though pairs of their quantum states are orthogonal [3].

[1] R P Feynman, The Feynman Lectures on Physics, Volume III (1963)

[2] C K Hong, Z Y Ou and L Mandel, Physical Review Letters 59, 2044 (1987)

[3] V S Shchesnovich and M E O Bezerra, Physical Review A 98, 033805 (2018)

NOTES

DAY TWO AGENDA
TUESDAY APRIL 2

TIME	EVENT	LENGTH
09.00	**Tea and coffee**	**30 min**
Quantum Sensing & Metrology (chair: Sabine Wollmann)		
09.30	Ulrik Lund Andersen (DTU) *Continuous variable quantum sensing*	40 min (+ 5 min questions)
10.15	Zixin Huang (University of Sheffield) *Loss-tolerant and ancilla-assisted Gaussian state quantum metrology*	25 min (+ 5 min questions)
10.45	Animesh Datta (University of Warwick) *Next generation quantum sensing – multiple parameters and fault tolerance*	25 min (+ 5 min questions)
11.15	**Coffee break**	**20 min**
11.35	Paul-Antoine Moreau (University of Glasgow) *Detection and use of quantum correlations with cameras*	25 min (+ 5 min questions)
EDI Panel (chairs: Sabine Wollmann, Euan Allen & Will McCutcheon)		
12.05	Havi Carel (University of Bristol) *What is implicit bias and what can we do about it?* Panel: Juani Bermejo-Vega (Free University of Berlin) Lara Lalemi (University of Bristol) Jonas Rademacker (University of Bristol) Ying Lia Li (UCL)	60 min (15 min introductory talk & 45 min panel session)
13.05	**Lunch**	**60 min**

Quantum Foundations (chair: Paul Skrzypczyk)

14.05	Yuhao Deng (UST China) *Toward quantum computational supremacy with photons*	40 min (+ 5 min questions)
14.50	Gustavo Lima (University de Concepcion) *High-quality multiport beamsplitters based on multicore fibers for QIP in higher dimensions*	25 min (+ 5 min questions)
15.20	Giulia Rubino (University of Vienna) *Secure communication by quantum-superimposing insecure channels*	25 min (+ 5 min questions)
15.50	Andrew White (University of Queensland) *Communicating via ignorance & imaging via counting*	25 min (+ 5 min questions)

Poster session

16.20	Poster session with teas and coffees	60 min
17.20	**Thanks & close**	**5 min**

BRISTOL PACKET BOAT TOUR AND DINNER AT REVOLUCION DE CUBA

Bristol Packet boat tour and dinner at Revolucion de Cuba

Our drinks reception will take place aboard the Tower Belle, as we tour the Bristol harbour.

Pick up from the Arnolfini at 5.50pm, depart at 6pm.

We will disembark at the Revolucion de Cuba, situated on Bristol's historic floating harbour, for our evening dinner.

Dinner will be served at 7pm.

Canon's Road, Bristol BS1 5UH

DAY TWO ABSTRACTS

Ulrik Lund Andersen

DTU

Continuous variable quantum sensing

Quantum sensing, communication and computation can be conceptually described by two different models: A discrete-variable model implementing qubit-based protocols or a continuous-variable (CV) model realizing qumode-based schemes. While the discrete variable schemes have received most attention in the quantum community, the CV systems have in recent years gained increasing interest due to technical advances and developments of new CV schemes.

In this talk, I will discuss our efforts in generating squeezed and entangled states of CV optical systems, and I will present different sensing applications of squeezed light with main focus on our recent demonstration of distributed quantum sensing. We have shown that CV entanglement between nodes in a network is able to enhance the sensitivity in measuring a collective phase shift.

Zixin Huang

University of Sheffield

Loss-tolerant and ancilla-assisted Gaussian state quantum metrology

We study interferometry with Gaussian states and show that an ancilla-assisted scheme outperforms the coherent state for all levels of loss.

In the high noise regime, we find that the ancilla-assisted strategy beats most other non-classical states.

We also find that, combined with the appropriate measurement, the achievable precision of the proposal by Caves [Phys. Rev. D 23, 1693] is larger than the value quoted in all current literature, and is less vulnerable to losses than previously thought.

arXiv:1811.10554

Animesh Datta

University of Warwick

Next generation quantum sensing – multiple parameters and fault tolerance

Quantum sensing of a single parameter is not fully quantum. It is only with the simultaneous estimation of multiple parameters at the quantum limit that we enter the realm of fully-quantum sensing. This is due to the non-commutativity involving in measuring multiple quantities simultaneously. Estimating multiple parameters simultaneously is also central to most advanced application of quantum sensing including imaging, spectroscopy, 3D magnetometry, accelerometry and gravimetry. I will discuss recent progress in multiparameter quantum sensing, focussing on imaging and 3D magnetometry.

Combating noise through improved sensor engineering is crucial to the long-term prospects of quantum sensing. I will introduce the notion of fault-tolerant quantum sensing and present our results on how better devices can enable combating larger noise in the signals being sensed.

Paul-Antoine Moreau

University of Glasgow

Detection and use of quantum correlations with cameras

The recent progresses in camera technologies have enabled the use of cameras to detect spatially resolved quantum correlations in an efficient manner. This has led to new possibilities and new schemes harnessing spatially resolved quantum correlations.

In this talk different use of such correlations detected by cameras will be presented. We will focus in particular on the use of the so-called heralded imaging scheme and will show that such a scheme can be used to perform fundamental demonstrations as well as to implement new type of quantum imaging schemes.

Havi Carel

University of Bristol

What is implicit bias and what can we do about it?

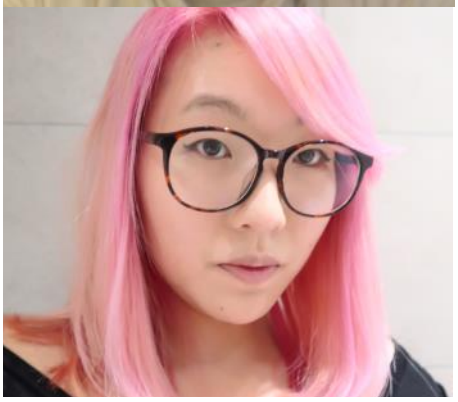
The aim of the talk is to make participants aware of the problems caused by implicit bias and stereotype threat.

It will also explain the causes of 'chilly climates' within academia, caused by these factors, as well as microaggressions.

Havi is Professor of Philosophy at the University of Bristol, and examines the embodied experience of illness and wellbeing within illness. She is the University of Bristol's academic staff point of contact for issues concerning climate, equality and diversity.

EDI Panel

(Right from top)

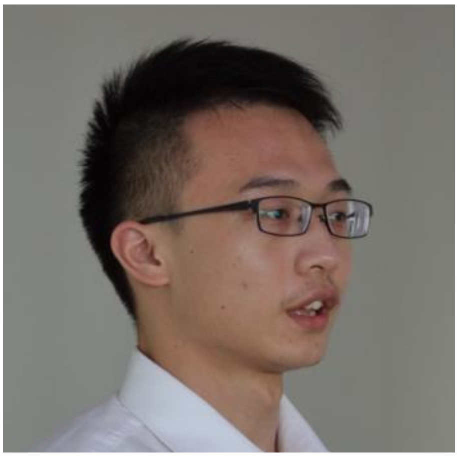


Juani Bermejo-Vega *(Free University of Berlin)* - Co-founder and co-organizer of the Quantum Excellence in Diversity (QuEDiver) seminar at the Free University of Berlin.

Lara Lalemi *(University of Bristol)* - organiser of the first BME (Black and Minority Ethnic) LGBT+ event and was the BME LGBT+ rep for the BME network at the University of Bristol. Lara was on Bristol's BME Powerlist in 2018, which showcases the city's 100 most inspiring, successful and influential black and minority ethnic people.

Jonas Rademacker *(University of Bristol)* - Chair of the Athena Swan committee at the School of Physics at the University of Bristol, Jonas led on creating a dedicated office for Early Career, Gender and Diversity (ECGD) at the LHC.

Ying Lia Li *(UCL)* - EPSRC Doctoral Prize fellow and emerging entrepreneur, Lia promotes women in STEM and is part of Prof. Oliver's `My Science Inquiry' team.



Yuhao Deng

UST China

Toward quantum computational supremacy with photons

The experimental challenge for realizing a large-scale boson sampling mainly lies in the lack of a perfect single-photon sources. In this talk, I will report two routes towards building boson sampling machines with many photons, which is also a first, necessary toward photonic quantum computing. In the first path, we developed SPDC two-photon source with simultaneously a collection efficiency of 97% and an indistinguishability of 96% between independent photons. With this, we demonstrate genuine entanglement of 12 photons.

In the second path, using a quantum dot-micropillar, we produced single photons with high purity (>99%), near-unity indistinguishability for >1000 photons, and high extraction efficiency—all combined in a single device compatibly and simultaneously. Recently, we also produced on-demand entangled photons from biexciton cascaded transition with high fidelity, efficiency and indistinguishability [arXiv.1903.06071]. Relevant papers can be found at http://staff.ustc.edu.cn/~cylu.

Gustavo Lima

University de Concepcion

High-quality multiport beamsplitters based on multicore fibers for QIP in higher dimensions

Multi-port beamsplitters (MBS) are cornerstone devices for high-dimensional (HD) quantum information processing (QIP) tasks, which have increased performance over the bi-dimensional case.

Nonetheless, the implementation of such devices has been proven to be challenging with most of recent progress provided by integrated photonics technology.

Here, we report on the production of high-quality MBSs based on a new scheme for manipulating commercially available multi-core fibers.

Then, by exploring their compatibility with off-the-shelf telecom technology, we implement the HD-QIP task of measurement-device-independent randomness generation with a programmable multi-arm interferometer operating at 2 MHz of clock repetition rate.

As a consequence of the almost perfect mode-matching and high-visibilities observed (>99.5%), we surpass the 1-bit limit of binary measurements and certify up to 1.23 private random bits generated per experimental round.

Giulia Rubino

University of Vienna

Secure communication by quantum-superimposing insecure channels

Traditional quantum communication protocols assume that the particles transmitted by the sender to the receiver follow a well-defined trajectory in space and time. However, quantum particles can propagate along a superposition of alternative paths, leading to counter-intuitive interference phenomena.

In this talk, I first present an experiment showing that the ability of a particle to visit two regions in a superposition of two orders enables secure communication even in extreme scenarios where each region is completely compromised. Then, I attempt to clarify the nature of the purported advantage, by comparing the superposition of orders to a class of processes that can be interpreted as a quantum superposition of processes with the same causal order. I conclude that the aforementioned advantages appears to be attributable to the ability to coherently control quantum operations.

This can be explained by noticing that, in a channel capacity activation, the noisy channels are set once and for all, and thus they are not subject to interventions by any parties. This observation provides new insights on the significance of operationally defining causality in terms of interventions.

Andrew White

University of Queensland

Communicating via ignorance & imaging via counting

Here we show that perfect information transmission is possible through a completely noisy channel [1]. We use a quantum switch [2] to place two channels in superposition so that we are ignorant of channel order. When both channels are fully-depolarising, the ideal limit is communication of 0.049 bits; experimentally we achieve 0.0341±0.0015 bits. When one channel is fully-depolarising, and the other is a known unitary, the ideal limit is communication of 1 bit, a capacity not possible with simple path superposition. We experimentally achieve 0.636±0.017 bits. Our results offer intriguing possibilities in applications ranging from communication through to imaging in turbulent media.

We implement a general imaging method by measuring the complex degree of coherence using linear optics and photon number resolving detectors [3]. We measure the size and position of a small distant source of pseudo-thermal light, and show that our method outperforms the traditional imaging method by an order of magnitude in precision. Additionally, we show that a lack of photon-number resolution in the detectors has only a modest detrimental effect on measurement precision, further highlighting the practicality of this method as a way to gain significant imaging improvements in a wide range of imaging applications.

[1]. Goswami, et al., arXiv 1807.07383 (2018).

[2]. Goswami, et al., PRL 121, 090503 (2018).

[3]. Howard, et al., arXiv 1811.02192 (2018).

Poster session

Sponsored by KETS Quantum Security

In Studios 1 & 2

- George Atkinson (University of Bristol) *Fisher Information with Continuous Variable Quantum Resource*
- Jake Biele (University of Bristol) *Integrated Silicon Photonic Squeezing Centered on 2.1μm for Applications in Sensing & Metrology*
- Jake Bulmer (University of Bristol) *Drive noise tolerant optical switching: How not to spill your tea (light) when you have shaky hands (electronics)*
- Chloe Clear (University of Bristol) *Characterising phonon interactions in single molecules for non-classical light sources*
- Andres Ducuara (University of Bristol) *Optimal Hidden Quantum Steerability and Maximum Extractable Quantum Obesity under Local Filtering Operations*
- Ross Falconer (Open University) *Quantum speedup of the Quartet Compatibility Problem for phylogenetic tree construction*
- Brian Flynn (University of Bristol) *Quantum Model Learning*
- Jonathan Frazer (University of Bristol) *Gigahertz-speed control of nonlinear interference in silicon*
- Antonio Andreas Gentile (University of Bristol) *Magnetic Field Learning*
- Jonte Hance (University of Bristol) *Demonstrating counterfactual communication*
- Rasmus Hoy Jensen (Technical University of Denmark) *Coupling of a Single GeV Center in Diamond to a Micro-Cavity*
- Zixin Huang (University of Sheffield) *Loss-tolerant and ancilla-assisted Gaussian state quantum metrology*
- Friederike Johlinger (University of Bristol) *Trojan Horse Attack on Chip Scale QKD*
- Alex Jones (University of Oxford) *Interfering photons in orthogonal states*
- Nicola Maraviglia (University of Bristol) *Quantum simulation of coupled PT symmetric systems*
- Will McCutcheon (University of Bristol) *Characterising Photon Pair Sources Beyond Joint-Spectra*
- Stefano Paesani (University of Bristol) *Large-scale silicon quantum photonics*
- David Payne (University of Bristol) *Multi-mode Kerr squeezing in silicon nano-photonics*
- Alasdair Price (University of Bristol) *Experimental Implementation of a Combined Cryptographic Ecosystem for Quantum-Safe Communications*
- Lawrence Rosenfeld (University of Bristol) *First observation of quantum correlated short-wave infrared photon pairs*
- John Scott (University of Bristol) *Feedforward in Photonic Quantum Computing*
- Joe Smith (University of Bristol) *Indistinguishable photons from an NV centre beyond cryogenic temperatures*
- Dominic Sulway (University of Bristol) *Re-engineering Silicon Quantum Photonics for Scalability*
- Oliver Thomas (University of Bristol) *Gaussian optics treatment of Hong-Ou-Mandel interference visibility: combined effects of nonseparability of JSAs and multi-photon events*
- Vladyslav Usenko (Palacky University) *Analysis and compensation of side channels in continuous-variable quantum key distribution*
- Gerardo Villarreal Garcia (University of Bristol) *An integrated electro-optic BaTiO3 modulator at cryogenic temperatures*

DAY THREE AGENDA
WEDNESDAY
APRIL 3

TIME	EVENT	LENGTH
09.00	**Tea and coffee**	**30 min**
Quantum Networks (chair: Henry Semenenko)		
09.30	David Elkouss (Delft University of Technology) *Towards a quantum internet*	45 min (+ 5 min questions)
10.15	Virginia D'Auria (Institut de Physique de Nice) *Plug-and-play synchronization for practical quantum networks*	25 min (+ 5 min questions)
10.45	**Coffee break**	**20 min**
11.05	Mikael Afzelius (University of Geneva) *Optical spin-wave memory using electronic rare earth spins in crystals*	25 min (+ 5 min questions)
11.35	Sae Woo Nam (NIST) *Single photon detection research at NIST for quantum information processing*	25 min (+ 5 min questions)
12.05	**Lunch**	**55 min**

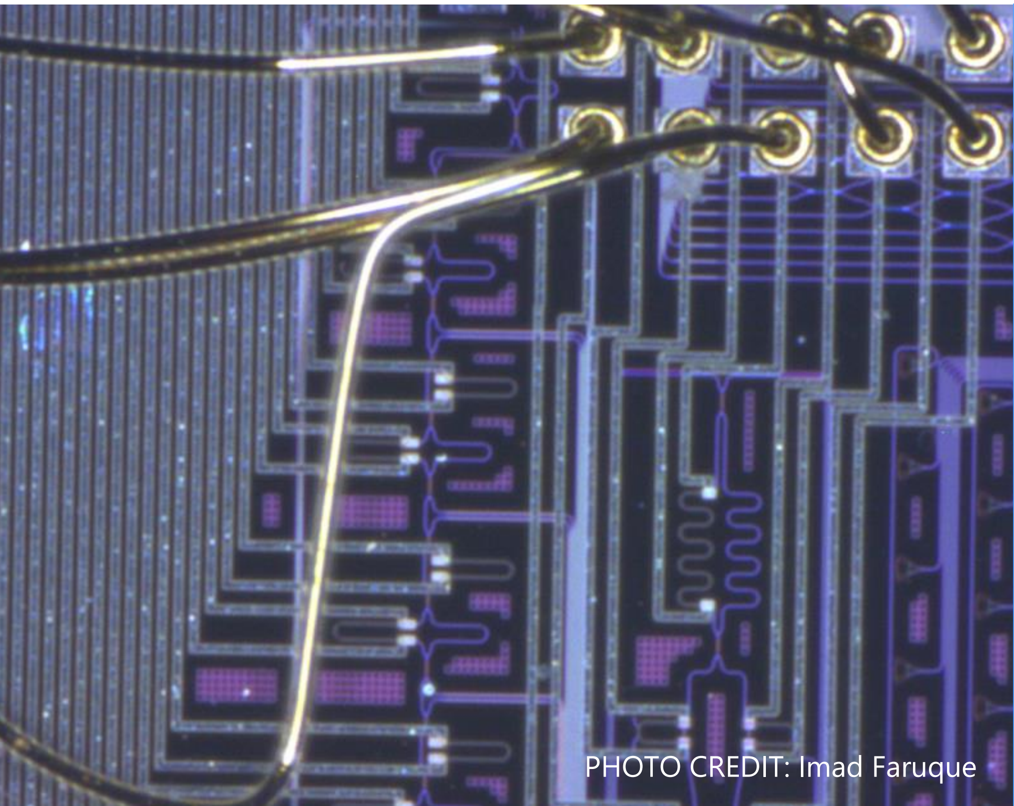
My life in the Quantum Computing Industry (chairs: Dondu Sahin & Graham Marshall) - session sponsored by QTEC

13.00	Thomas Ayral (Atos)	20 min
	Dylan Mahler (Xanadu)	20 min
	Tsung-Yeh Yang (Hitachi)	20 min
14.00	Andy Collins (QTEC) *Quantum Technology Enterprise Centre*	10 min
14.10	**Coffee break**	**20 min**

Applications of Photon Sources (chair: John Rarity)

14.30	Chloe Clear (University of Bristol) *Characterising phonon interactions in single molecules for non-classical light sources*	10 min
14.40	Nigam Samantaray (University of Bristol) *A model generating Poissonian twin beam state and the advantage of photon subtraction in loss estimations*	25 min (+ 5 min questions)
15.10	Jeremy Adcock (University of Bristol) *Programmable four-photon graph states on a silicon chip*	25 min (+ 5 min questions)
15.40	John Rarity (Director of QET Labs - University of Bristol) *Close and thanks*	10 min

15.50 CLOSE



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BQIT:20

Thank you for attending this year’s Bristol Quantum Information Technologies workshop.

BQIT will return in:

Spring 2020

DAY THREE ABSTRACTS

David Elkouss

Delft University of Technology

Towards a quantum internet

In this talk, I will present some recent efforts directed to the deployment of a quantum internet in the near future.

First, I will present stages towards the development a full blown quantum internet. Each stage is characterized by a specific increase in network functionality at the expense of a matching increase in experimental difficulty.

I will highlight some known application protocols that can be realized in each stage and discuss simple tests to certify that a particular stage as been attained.

Then, I will describe our program for designing large quantum networks. This includes a fast heuristic optimization algorithm for entanglement distribution on large networks and a quantum network simulator that we dub QNetSquid.

Finally, I will present some preliminary numerical results for a quantum network based on NV centers.

Virginia D'Auria

Institut de Physique de Nice

Plug-and-play synchronization for practical quantum networks

Quantum networks combine secure data exchanges via optical quantum communication with efficient data treatment thanks to quantum computing stages.

However, a major obstacle towards their practical realization is the lack of a universal strategy allowing to synchronize the networks' different building blocks.

We propose a plug-and-play synchronization scheme compatible with any quantum networks over fibre links and exploiting mature classical telecom technology to distribute to the different network's nodes a common, all-optical, clock signal.

Locally, the optical clock can be shaped thanks to suitable non-linear optical stages so as to be subsequently used to feed the quantum device at the specific node.

We successfully validate the quality of our scheme by testing it on the synchronization of two remote entangled photon pair sources.

Mikael Afzelius

University of Geneva

Optical spin-wave memory using electronic rare earth spins in crystals

Storage of quantum states for up to one millisecond has recently been achieve in rare-earth-doped crystals [1], by using nuclear hyperfine states that are weakly coupled to the nuclear spin bath of the crystal.

However, these nuclear states are closely spaced, which limits the memory bandwidth to a few MHz. We recently showed that the electronic hyperfine levels in 171Yb3+ behave like "clock" states, which results in optical and spin coherence times similar to nuclear states while having large energy spacings in the GHz regime typical for electronic spins [2].

This paves the way for broadband optical memories with long coherence times. In this talk I will describe the spectroscopy of this new hybrid system, and the first optical spin-wave storage using the electronic hyperfine levels in 171Yb3+.

[1] K. Kutluer, M. Mazzera, and H. de Riedmatten, Phys. Rev. Lett. 118, 210502 (2017); C. Laplane, P. Jobez, J. Etesse, N. Gisin, and M. Afzelius, Phys. Rev. Lett. 118, 210501 (2017)

[2] A. Ortu, A. Tiranov, S. Welinski, F. Fröwis, N. Gisin, A. Ferrier, P. Goldner, and M. Afzelius, Nature Materials 17, 671 (2018)

Sae Woo Nam

NIST

Single photon detection research at NIST for quantum information processing

Single-photon detectors are increasingly becoming an essential tool for a wide range of applications in physics, chemistry, biology, communications, medicine, and remote sensing.

Much of the development at NIST of superconducting devices for single photon detection has been focused on meeting the needs of information processing with photons.

I will briefly review three types of superconducting devices used to detect photon fabricated a NIST: transition-edge sensors, microwave kinetic inductance detectors, and superconducting nanowire single photon detectors.

And, I will also describe our latest work related to integration of single photon detectors with integrated photonics and trapped ion quantum computing.

Thomas Ayral

Atos

Noisy simulation of near-term, intermediate scale quantum processors

In this talk, I will be looking at the simulation of quantum programs on the Atos Quantum Learning Machine, taking into account the constraints and noise characteristics of an actual quantum processor.

Through the concrete example of the quantum Fourier transform, I will illustrate the challenges related to the compilation of this program into a quantum circuit respecting the processor's connectivity and gateset constraints.

I will discuss how hardware-specific noise models may be taken into account, how the results of the algorithm are impacted by them, and will finally hint at possible optimization strategies.

Dylan Mahler

Xanadu

My life in the Quantum Computing Industry

Xanadu is a full-stack quantum computing company located in Toronto, Canada. Focussing on implementations of continuous variable integrated photonics, Xanadu is dedicated to developing and providing access to practical quantum devices integrated with its quantum optics simulator Strawberry Fields and machine learning platform PennyLane.

In the past decade weakly driven parametric fluorescence, typically using spontaneous four-wave mixing or parametric downconversion, has emerged as the workhorse by which nonclassical light is generated on chip-based nanophotonic platforms. Much effort in this field has been directed toward optimizing the single-photon states produced by these processes, but relatively little progress has been made toward development of the nanophotonic sources of their continuous variable quantum information processing (CV-QIP) cousins: squeezed vacuum states. Typical applications in CV-QIP place stringent requirements on the properties of the source of squeezed states. Each of these properties must be carefully engineered, and chip-based nanophotonics is an ideal environment in which to do so.

I will begin by giving an introduction to Xanadu, including its motivations and goals. The bulk of my talk will report on the hardware team’s first year in operation, working toward true nanophotonic squeezed vacuum sources compatible with photon counting. I’ll end the talk with some of my own first impressions of the quantum computing industry.

Tsung-Yeh Yang

Hitachi

My life in the Quantum Computing Industry

In the era of “Big Data”, a faster and more efficient solution than the classical data processing is urgently needed. One solution is to use a quantum system, i.e., quantum information processing (QIP) together with quantum algorithms. However in order to build a quantum processor, fundamental and technical hurdles such as fast readout, long life times of the information, and large-scale quantum systems must be overcome.

The most basic cell of a quantum processor is so called a “quantum bit” or a “qubit”. Among the solutions for building qubits, semiconductors, especially silicon, is the most promising system due to its well-developed technology. Fundamentally, the spin coherence time in silicon can reach as long as milliseconds in purified silicon substrate. Technically, silicon qubits can not only be massively manufactured, but also integrated with classical semiconductor hardware by leveraging the modern VLSI technology.

With the motivations of (1) building a large-scale system and (2) fast readout, in this talk I would like to talk about the obstacles we are facing and how we resolve by using a silicon metal-oxide-semiconductor (MOS) system together with classical components, such as radio-frequency (RF) resonators, to achieve fast readout of the qubit states.

Chloe Clear

University of Bristol

Characterising phonon interactions in single molecules for non-classical light sources

Single organic molecules have recently gained attention as novel non-classical light sources with Quantum information applications. Dibenzoterrylene (DBT) encased in a nano-crystal of anthracene is an example of a single photon source which has generated research interest due to its high photostability and tunability. On this poster, simulations of the emission spectra for a single organic molecule of DBT are presented and compared against raw experimental data taken from collaborators in the Centre for Cold Matter at Imperial College London. The theoretical model utilises a polaron transformation to derive a master equation in the formalism of open quantum systems theory which describes the dynamics of the system. The model reproduces the zero-phonon line (ZPL) of the molecule which is in the infrared range (786nm) and the local vibrational modes of the DBT molecule. The local vibrational modes which appear in the spectrum have been concluded to come from the local libration of the molecule. The spectrum is broadened by the photonic environment and thermal phonon residual baths which originates from the anthracene crystal environment.

Nigam Samantaray

University of Bristol

A model generating Poissonian twin beam state and the advantage of photon subtraction in loss estimations

Absorption based measurement not only serves as base of spectroscopy and imaging, but it also finds application in all branches of science from chemistry and biology to physics and material science. However, the best sensitivity in loss estimation reached so far using classical probes is limited by shot noise. Albeit, it is known that the twin beam state (TWB) generated by spontaneous parametric down conversion (SPDC) process has thermal photon statistics in the individual modes, but its perfect photon number mode correlation allows surpassing the shot-noise limit reaching sub-shot noise sensitivity in the realistic scenario of loss estimations. In the recent years, symmetrical photon subtraction operation in the TWB has been shown to improve the individual mode photon statistics from thermal to sub-Poissonian. A question on fundamental ground naturally arises “does photon subtraction pave any advantage in noise suppression if the individual mode photon statistics of TWB becomes Poissonian instead of thermal”.

In this work, we have devised a theoretical but experimental realizable model (accounting detection losses), where changing the value of a parameter of the model changes the TWB individual mode photon statistics from thermal to Poissonian keeping the non-classical mode correlation intact. We then incorporated the symmetrical photon subtraction into the model and demonstrated advantage of it over TWB in the loss estimation accounting fixed per photon exposure to the absorbing sample. We shall present results up to two photon subtraction and for all the values of the model parameter that changes the statistics of TWB from thermal to Poisonian and in between.

References:

[1] Tapster, P., Seward, S. & Rarity, J., Physical Review A 44, 3266 (1991).

[2] Brida, G., Genovese, M. & Berchera, I. R., Nature Photonics 4, 227–230 (2010).

[3] C. C. Gerry et al., J. Opt. Soc. Am. B 29, 2581 (2012).

Jeremy Adcock

University of Bristol

Programmable four-photon graph states on a silicon chip

Quantum computers promise a paradigm shift humanity's information processing capability. Measurementbased quantum computing—built on graph states—is the prevailing architecture for large-scale quantum computation [2]. Meanwhile, silicon quantum photonics is a high-performance, scalable quantum technology platform, boasting circuits of unparalleled size [3]. However, integrated quantum photonics has so far been constrained to two on-chip generated photons. Here, we present the first device to wield four -photon entanglement, and measure state-of-the-art on-chip quantum interference.

[1] J Adcock et al., Programmable four-photon graph states on a silicon chip, arXiv preprint arXiv:1811.03023 (2018).

[2] R. Raussendorf, Measurement-based quantum computation with cluster states, International Journal of Quantum Information 7, 1053–1203 (2009).

[3] J. Wang et al., Multidimensional quantum entanglement with large-scale integrated optics, Science, eaar7053, (2018).

John Rarity

University of Bristol

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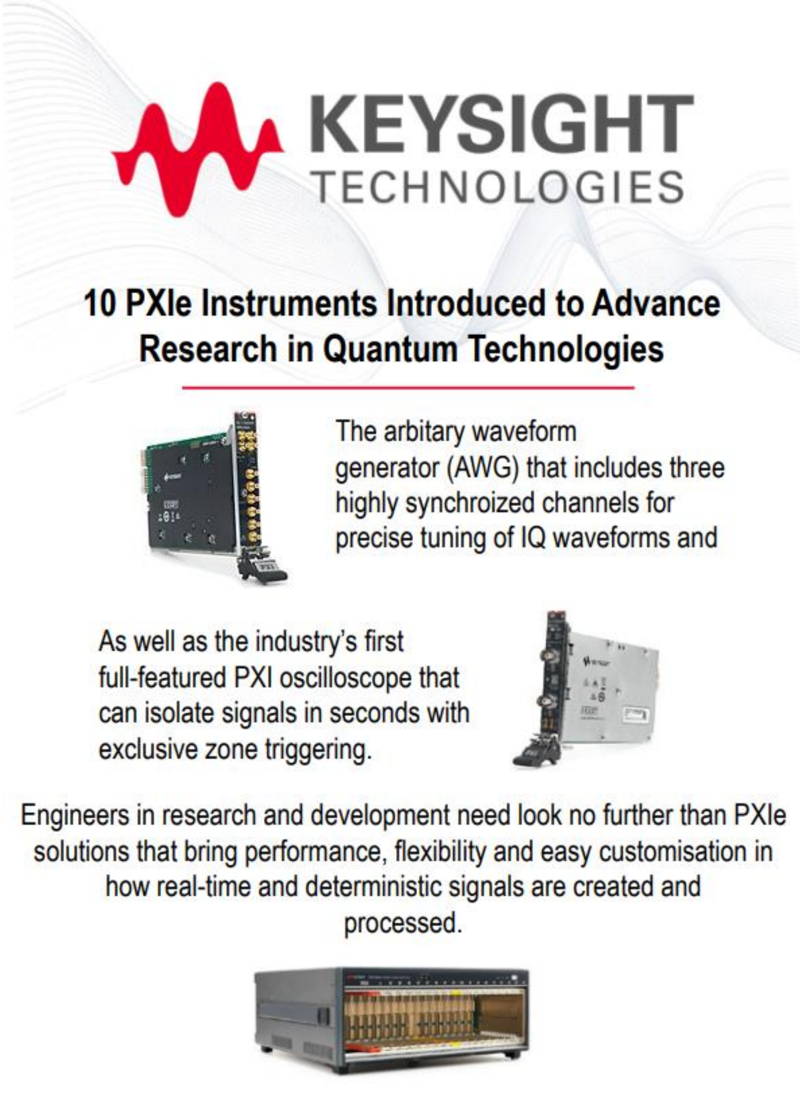

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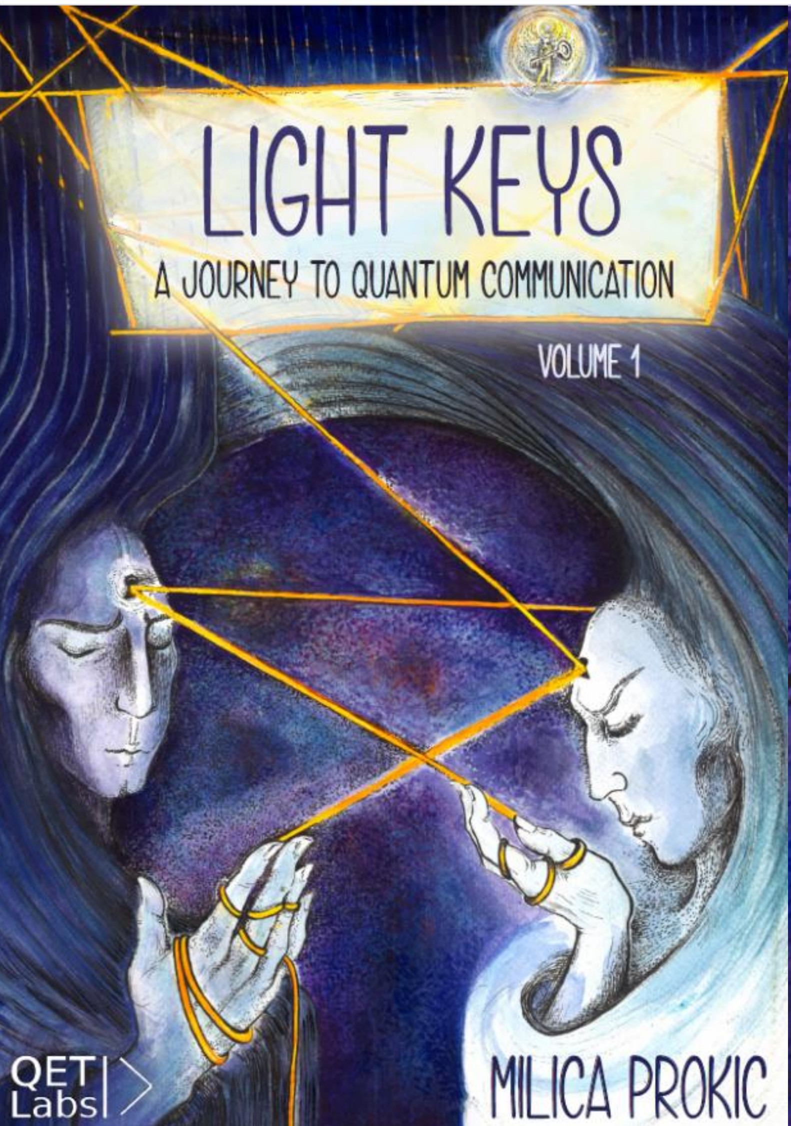

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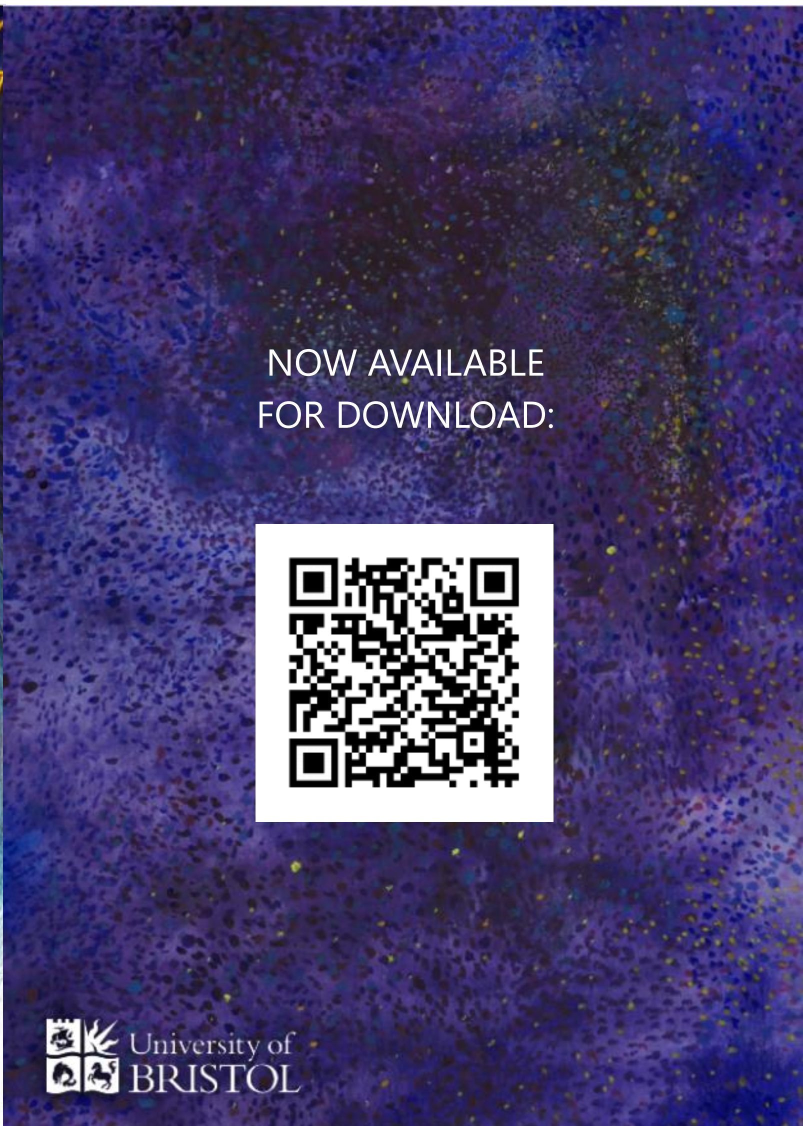

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Our 2019 speakers and panellists for sharing their work and opinions on an expansive range of topics.

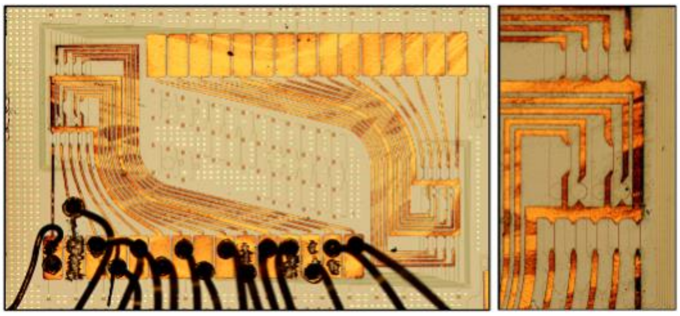
Our 2019 sponsors for supporting our event and helping to make BQIT a continued success.

The BQIT advisory board members for their innovate ideas and diligent work throughout the year.

QET Labs and Quantum Engineering CDT conference helpers: Jorge Barreto, Jake Bulmer, Lin Burden, Rachel Chadwick, Joao Fernando Doriguello, Brian Flynn, Jonathan Frazer, Becky Freshwater, Marissa Harrison, Huili Hou, Friederike Johlinger, Konstantina Koteva, Helen Mawdsley, David Payne, Emma Smith, Joe Smith, Louise Storm, Joel Tasker & Caterina Vigliar for ensuring the event ran smoothly.

Richard Collins, Ian Caskie, Imad Faruque, Josh Silverstone and Angie Diaz Barrera for providing us with photographs of Bristol and their research for use in our programme.

Finally to all of our BQIT:19 attendees for participating. We look forward to welcoming you back to Bristol again soon.



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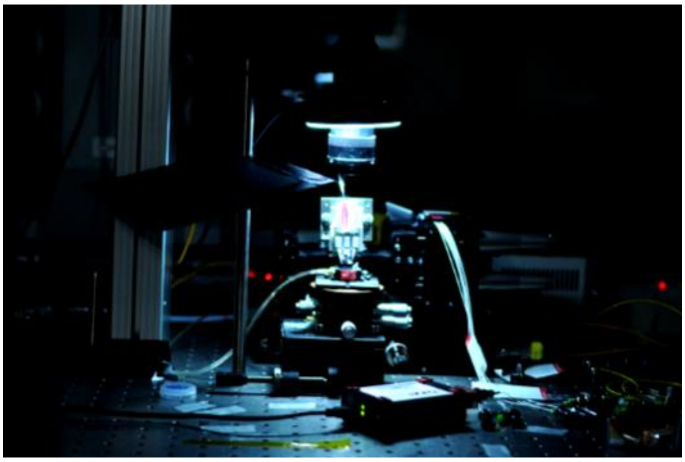

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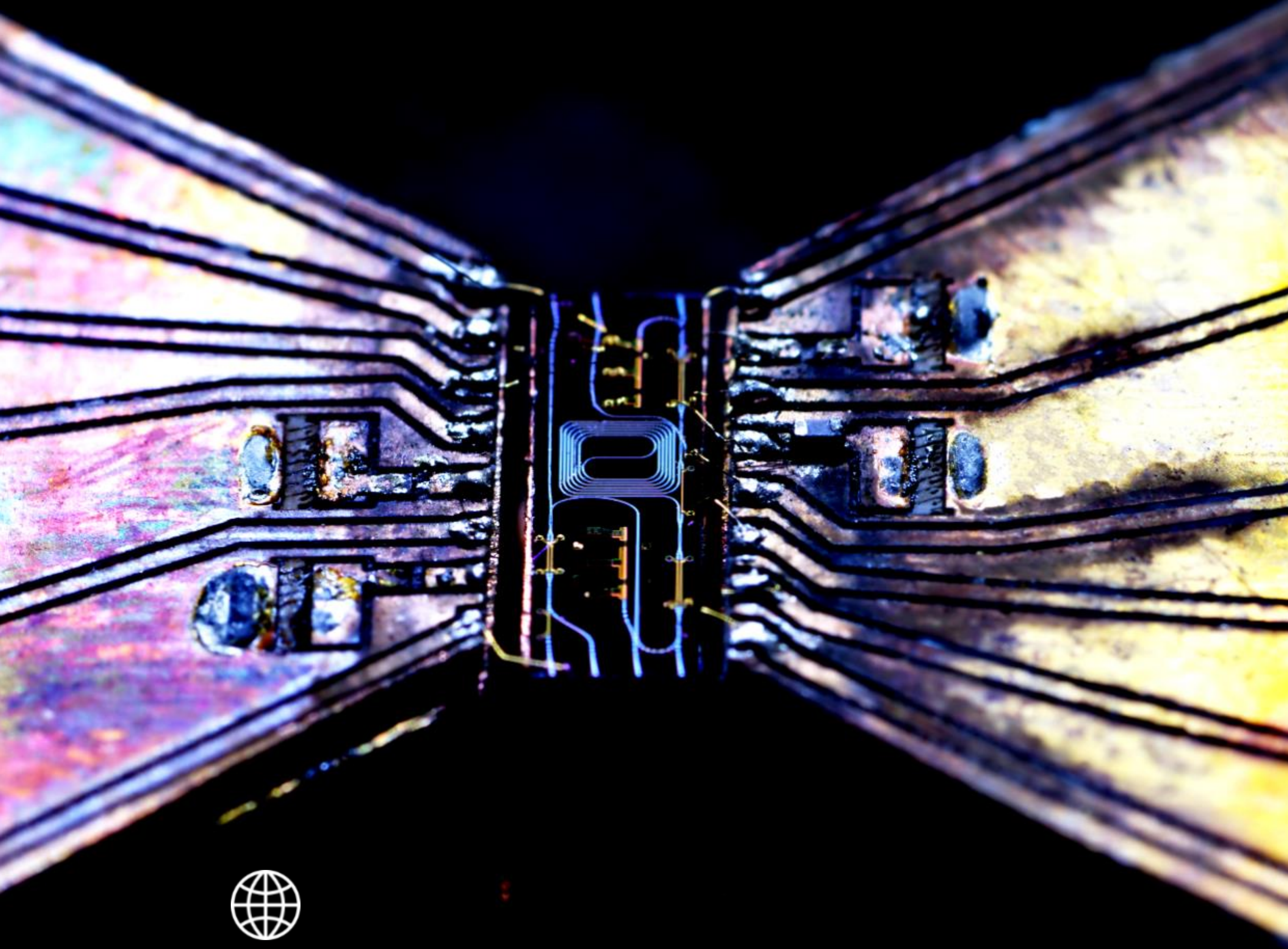

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