ABSTRACT BOOK

ANZCOP-AIP
Summer Meeting
Canberra | Dec 3-8 2023

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3rd Dec 2023

	Parallel Session 1	Parallel Session 2	Parallel Session 3	Parallel Session 4	Parallel Session 5	Parallel Session 6
17:30 - 19:30	**Welcome BBQ** Foyer (Student and ECR Networking Event 4:30-5:30 - register here: https://ANZCOP-AIPSummerNetworkingSun.eventbrite.com.au [https://ANZCOP-AIPSummerNetworkingSun.eventbrite.com.au]) Welcome BBQ 5:30-7:30 pm ANU Physics Building 60					

Monday, 4th Dec 2023

	Parallel Session 1	Parallel Session 2	Parallel Session 3	Parallel Session 4	Parallel Session 5	Parallel Session 6
07:30 - 08:30	**Morning Walk/Run/Yoga - Wellness Program** Sponsored by ANU RSPhys Equity and Diversity Committee Walk: Learn More and Register Here [https://aip-summer-meeting.com/social_events/] Run/Jog: Learn More and Register Here [https://aip-summer-meeting.com/social_events/] Yoga: Learn More and Register Here [https://aip-summer-meeting.com/social_events/]					
08:30 - 09:00						
09:00 - 10:30	**Session P1 Opening and Joint Plenary** Auditorium Jodie Bradby Plenary Speakers Welcome to Country Opening: Prof Brian Schmidt Plenary: Professor Jelena Vuckovic, Geoffrey Frew Fellow **Scalable quantum and classical photonic systems** Jelena Vuckovic					
10:30 - 11:00	**Morning Tea**					
11:00 - 12:30	**Session 1.1 AIP Quantum Science and Technology** Auditorium Maja Cassidy **11:00 - 11:15** **Non-Hermitian Quantum Geometric Tensors in an Exciton-Polariton System**		**Session 1.2 AIP Theoretical Physics** Conference Room (Lvl 4) Murray Batchelor **11:00 - 11:30** **The physical mathematics of string compactifications** Johanna Knapp	**Session 1.3 AIP Astrophysics** Board Room (Lvl 4) Gabriel Collin **11:00 - 11:30** **Nanohertz-frequency gravitational wave astronomy with the Parkes Pulsar Timing Array and beyond** Daniel Reardon		

	Yow-Ming Hu, Elena Ostrovskaya, Eliezer Estrecho **11:15 - 11:30** **Analogue quantum simulation of molecular vibronic spectra with a trapped ion** Tomas Navickas, Ryan MacDonell, Tim Wohlers-Reichel, Christophe Valahu, Arjun Rao, Maverick Millican, Michael Currington, Michael Biercuk, Ting Rei Tan, Cornelius Hempel, Ivan Kassal **11:30 - 11:45** **Femtosecond pulse laser cleaning for the preservation of Sydney Harbour Bridge** Julia Brand, Andrei V. Rode, Steve Madden, Alison Wain, Penelope L. King, Meera Mohan, Waruna Kaluarachchi, Julia Ratnayake, Ludovic Rapp **11:45 - 12:00** **Precision limits and uncertainty relations for quantum multiparameter estimation** Simon Yung, Lorcan Conlon, Ping Koy Lam, Syed Assad **12:00 - 12:15** **Tight large deviation bounds for quantum adversarial setting with applications to quantum information** Takaya Matsuura, Shinichiro Yamano, Yui Kuramochi, Toshihiko Sasaki, Masato Koashi **12:15 - 12:30** **Quantum-Mechanical Model of Asymmetry of Public Opinion Radicalisation** Ivan Maksymov, Ganna Pogrebna		**11:30 - 11:45** **Quantum field-theoretic approaches to quantum tunnelling through localised external potentials** Rosemary Zielinski, Cedric Simenel, Patrick McGlynn **11:45 - 12:15** **Entanglement entropy for scale-invariant states: universal finite-size scaling** Huan-Qiang Zhou **12:15 - 12:30** **Fractal dimension and the counting rule of the Goldstone modes** Qian-Qian Shi	**11:30 - 12:00** **The Cherenkov Telescope Array Observatory – Unveiling the Very-High-Energy Gamma-ray Sky** Sabrina Einecke **12:00 - 12:15** **Monitoring and Mitigating Radio Frequency Interference using the ASKAP radio telescope.** Liroy Lourenco **12:15 - 12:30** **Constraints on Cosmology from SPT-3G power spectra** Christian Reichardt		
12:30 - 13:30	**Lunch Break**					

13:30 - 15:30	**Session 2.1 Quantum Control Focus Session** Auditorium Jevon Longdell Sponsored by Floquet.AI **13:30 - 13:45** **Graybox quantum control** Alberto Peruzzo, <u>Akram Youssry</u> **13:45 - 14:00** **Memory Decoherence Time in Open Quantum Harmonic Oscillators and Finite Level Quantum Systems** Igor Vladimirov, <u>Ian Petersen</u> **14:00 - 14:15** **Coupled Stochastic and Quantum Master Equations for Non-Markovian Quantum Systems** <u>Hendra Nurdin</u> **14:15 - 14:30** **Optimization and robust stability of non-Hermitian quantum sensing** Liying Bao, Bo Qi, <u>Daoyi Dong</u>, Franco Nori **14:30 - 14:45** **Realising the potential of quantum technology through control** <u>Richard Taylor</u>, Pranav Mundada, Aaron Barbosa, Smarak Maity, Yulun Wang, Thomas Merkh, Tom Stace, Felicity Nielson, Andre Carvalho, Michael Hush, Michael Biercuk, Yuval Baum **14:45 - 15:00** **Sample efficient deep learning for quantum optics and quantum control** <u>Aaron Tranter</u>, Arindam Saha, Baramee Charoensombutamon, Thibault Michel, Vijey Vijendran, Lachlan Walker, Akira Furusawa, Ben Buchler, Ping Koy Lam **15:00 - 15:15**	**Session 2.2 Quantum Gravity Focus Session** Huxley Lecture Theatre Archil Kobakhidze **13:30 - 14:00** **Black holes, Hawking radiation and quantum gravity** <u>Daniel Terno</u> **14:00 - 14:30** **Searching for signatures of quantum gravity with low-energy bench-top tests** <u>Simon Haine</u>, Zain Mehdi, Joe Hope **14:30 - 15:00** **de Sitter space as coherent state of gravitons** <u>Otari Sakhelashvili</u> **15:00 - 15:15** **Hawking radiation into the electroweak instanton vacuum** <u>Elden Loomes</u> **15:15 - 15:30** **Implications of singularity regularization in black hole thermodynamics** Sebastian Murk, Fil Simovic, <u>Ioannis Soranidis</u>	**Session 2.3 AIP Education** Conference Room (Lvl 4) Ben Buchler **13:30 - 14:00** **Experiences in 'flipping' courses at higher years -- classical & quantum mechanics** <u>Adam Micolich</u>, Christine Lindstrom **14:00 - 14:30** **Bridging the Gap: Industry Mentoring of Undergraduate Physics Students to Connect First-Year Education with Career Prospects** <u>Annette Dowd</u>, Tracey Glover Chambers **14:30 - 15:00** **Can ChatGPT pass a 2nd year quantum mechanics exam?** <u>Adam Micolich</u> **15:00 - 15:30** **Panel Discussion: AI in education**	**Session 2.4 AIP Astrophysics** Board Room (Lvl 4) Sabrina Einecke **13:30 - 14:00** **2 Blast 2 Sagittarius: turning dark matter into exploding black holes in the galactic center** <u>Zachary Picker</u>, Alexander Kusenko **14:00 - 14:15** **Investigating spatial mis-modelling in point-source inference** <u>Gabriel Collin</u> **14:15 - 14:30** **Generalized Poynting-Robertson damping of relativistic lightsails: orders of magnitude improvements of stability through optical design** <u>Jadon Y. Lin</u>, C. Martijn de Sterke, Michael S. Wheatland, Alex Y. Song, Boris T. Kuhlmey **14:30 - 14:45** **Recent Approaches to Proving the Penrose Conjecture in General Relativity** <u>Thalia Greinke</u>	**Session 2.5 AIP Biophysics** Room 3.03 Building 160 Nicolas Francois **13:30 - 14:00** **Life-on-a-chip with a soundtrack: Acoustic actuation to manipulate cells and tissue** <u>Melanie Stamp</u> **14:00 - 14:30** **Biological tissues as active homeostatic materials** <u>Alpha Yap</u> **14:30 - 14:45** **Advancements in Nanoelectronic Sensing: Exploring Single-Molecule Biophysics with Solid-State Nanopores** Shankar Dutt, Lien Lai, Aarti Gautam, Anne Bruestle, Y.M. Nuwan D.Y. Bandara, <u>Buddini Karawdeniya</u>, Venkat Gopalan, Patrick Kluth **14:45 - 15:00** **High accuracy protein identification: Fusion of solid-state nanopore sensing and machine learning** <u>Shankar Dutt</u>, Hancheng Shao, Buddini Karawdeniya, Y.M. Nuwan D.Y. Bandara, Elena Daskalaki, Hanna Suominen, Patrick Kluth **15:00 - 15:30**	**Session 2.6 Anyon Focus Session** Oliphant Conference Room Sue Coppersmith, Eric Mascot **13:30 - 14:00** **Understanding and improving robustness of topological phases in nanodevices** <u>Susan Coppersmith</u> **14:00 - 14:30** **Many-body Majorana braiding without an exponential Hilbert space** <u>Eric Mascot</u>, Themba Hodge, Daniel Crawford, Jasmin Bedow, Dirk K. Morr, Stephan Rachel **14:30 - 15:00** **Tackling quasiparticle poisoning errors in Majorana qubits via quasiparticle detection** <u>Abhijeet Alase</u>, Kevin D. Stubbs, Barry C. Sanders, David L. Feder **15:00 - 15:30** **Layer Codes** <u>Dominic Williamson</u>, Nouédyn Baspin

	Software ruggedising cold-atom sensors through error-robust quantum control Stuart Szigeti, Jack Saywell, Max Carey, Phillip Light, Alistair Milne, Karandeep Gill, Matthew Goh, Viktor Perunicic, Nathanial Wilson, Calum Macrae, Alexander Rischka, Patrick Everitt, Nicholas Robins, Russell Anderson, Michael Hush, Michael Biercuk **15:15 - 15:30** **Quantum Detector Tomography: Algorithm Design and Optimization** Shuixin Xiao, Yuanlong Wang, Jun Zhang, Daoyi Dong, Ian Petersen				**A soft matter physics approach to the origins of life** Anna Wang	
15:30 - 16:00	**Afternoon Tea**					
16:00 - 18:00	**Session 3.1 Quantum Control Focus Session** Auditorium Aaron Tranter **16:00 - 16:15** **Quantum noise spectroscopy of non-Gaussian noise using arbitrary multi-axis control sequence** Kaiah Steven, Elliot Coupe, Qi Yu, Gerardo Paz Silva **16:15 - 16:30** **Imperfection Analysis for Random Telegraph Noise Mitigation using Spectator Qubit** Yanan Liu, Areeya Chantasri, Hongting Song, Howard Wiseman **16:30 - 16:45** **Efficient Optimisation of Qubit Control Pulses Using a Noise Operator Formalism and Genetic Algorithms** Chris Wise, Matt Woolley **16:45 - 17:00** **Realization of quantum autoencoders using a learning control approach**	**Session 3.2 AIP Atomic and Molecular Physics** Huxley Lecture Theatre Sean Hodgeman **16:00 - 16:30** **Searches for Dark Matter with Precision Atomic and Optical Experiments** Yevgeny Stadnik **16:30 - 16:45** **Dark matter detection via atomic interactions** Ashlee Caddell, Benjamin Roberts **16:45 - 17:00** **Variation of the Quadrupole Hyperfine Structure and Nuclear Radius due to an Interaction with Scalar and Axion Dark Matter** Victor Flambaum, Andrew Mansour	**Session 3.3 AIP Gravitational Waves** Conference Room (Lvl 4) Daniel Reardon **16:00 - 16:30** **Digitally-enhanced Suspension Platform Interferometry Sensor Test at the Gingin High Optical Power Facility** Ya Zhang, Sheon Chua, Aaron Goodwin-Jones, Carl Blair, Ammar Al-Jodah, Avanish Kulur Ramamohan, Jennifer Wright, Chunnong Zhao, Li Ju, Bram Slagmolen **16:30 - 16:45** **Commissioning of the torsion pendulum dual oscillator for low-frequency Newtonian noise detection** Avanish Kulur Ramamohan, Jennifer L. Wright, Sheon S. Y. Chua, Ya Zhang, Bram J. J. Slagmolen	**Session 3.4 Soft Matter Focus Session** Board Room (Lvl 4) Nicolas Francois **16:00 - 16:25** **Tailoring bubble surfaces for microalgae flotation** Naras Rao, Russell Yap, Tony Granville, Richard Stuetz, Christine Browne, Ray Dagustine, Mikey Whittaker, Peter Wich, William Peirson, Bruce Jefferson, Michael Holmes, Rita Henderson **16:25 - 16:50** **Sustainable and compostable plastics** Luke Connal **16:50 - 17:10** **Investigation of underscreening in electrolytes** Vincent Craig **17:10 - 17:35** **Explaining the slippery, liquid-like behaviour of nanothin grafted PDMS layers**		**Session 3.5 AIP Condensed Matter & Materials Physics** Oliphant Conference Room Eric Mascot **16:00 - 16:30** **Weak Coupling Renormalization Group Approach to Unconventional Superconductivity** Sebastian Wolf **16:30 - 16:45** **STM study of 2D Van der Waals Ferromagnetic Metal Fe3GeTe2** Mengting Zhao **16:45 - 17:00** **Atomic-scale identification of diamond surface defects using scanning tunnelling microscopy** Lachlan Oberg, Yi-Ying Sung, Rebecca Griffin, Henry Chandler, Tetiana Sergeieva, Marcus Doherty, Cedric Weber, Chris Pakes **17:00 - 17:15** **Strong light-matter coupling in tunable open microcavities**

	Hailan Ma, Daoyi Dong, Ian R. Petersen **17:00 - 17:15** **Enhanced coherent control of carrier spin states in a quantum dot using the AC Stark effect** Josiah Hsi, Tim Wohlers-Reichel, Undurti Satya Sainadh, Glenn Solomon **17:15 - 17:30** **Graybox quantum control in the strong coupling regime** Arinta Auza, Akram Youssry, Gerardo Paz Silva, Alberto Peruzzo **17:30 - 17:45** **Updated Quantum Master Equations for Simulation of Open Quantum Dynamics** Teerawat Chalermpusitarak, Gerardo Paz-Silva **17:45 - 18:00** **Simulating Digital-Analog Control of the Diamond Quantum Processor** Sophie Stearn, Marcus Doherty	**17:00 - 17:15** **Theoretical characterisation of the Ra ion for the development of atomic clocks and studies of fundamental physics** Robin Cserveny, Benjamin Roberts **17:15 - 17:30** **Extension of radiative potential for superheavy atoms** Carter Fairhall, Benjamin Roberts, Jacinda Ginges **17:30 - 17:45** **Nuclear Structure Contributions to the Hyperfine Structure in Heavy Atoms** James Vandeleur, George Sanamyan, Jacinda Ginges	**16:45 - 17:00** **Experimental demonstration of the Arm and Cavity laser frequency stabilisation for LISA** Jobin Valliyakalayil, Daniel Shaddock, Kirk McKenzie **17:00 - 17:15** **Multi-Spatial Mode Readout Of Optical Cavities For Reduced Brownian Coating Thermal Noise** Jue Zhang, Namisha Chabbra, Andrew Wade, Kirk McKenzie **17:15 - 17:30** **Measuring thermal noise in gram-scale silicon flexures at 123K** Disha Kapasi, Terry McRae, Johannes Eichholz, Paul Altin, Bram Slagmolen, David McClelland **17:30 - 17:45** **Laser Frequency Stabilisation for Mass Change Mission: Prototype Development and Performance** Emily Rose Rees, Andrew Wade, Kirk McKenzie	Issac Gresham, Seamus Lilley, Andrew Nelson, Kaloian Koynov, Chiara Neto **17:35 - 18:00** **Topological pumping of droplet time crystals** Tapio Simula, Niels Kjaergaard		Mateusz Król, Karolina Łempicka-Mirek, Katarzyna Rechcińska, Magdalena Furman, Karol Nogajewski, Rafał Mazur, Przemysław Morawiak, Wiktor Piecek, Wojciech Pacuski, Jacek Szczytko, Barbara Piętka **17:15 - 17:30** **Restructuring Matter with Laser Pulses at Ultra-Relativistic Intensity** Ludovic Rapp, Takeshi Matsuoka, Konstantin Firestein, Daisuke Sagae, Hideaki Habara, Kei-ichiro Mukai, Kazuo A. Tanaka, Eugene G. Gamaly, Ryosuke Kodama, Yusuke Seto, Takahisa Shobu, Aki Tominaga, Lachlan Smillie, Tatiana Pikuz, Bianca Haberl, Toshinori Yabuuchi, Tadashi Togashi, Yuichi Inubushi, Makina Yabashi, Saulius Juodkazis, Dmitri V. Golberg, Andrei V. Rode, Norimasa Ozaki **17:30 - 17:45** **Threshold Switching Dynamics of V3O5 Memristors and Its Application as a Leaky Integrate-and-Fire Neuron** Sujan Kumar Das, Sanjoy Kumar Nandi, Camilo Verbel Marquez, Armando Rúa, Shimul Kanti Nath, Thomas Ratcliff, Robert Glen Elliman **17:45 - 18:00** **Understanding the complex magnetic effects in a low-dimensional frustrated magnet through inelastic neutron scattering** Jackson Allen, Leonie Heinze, Richard Mole, Roger Lewis, Stefan Süllow, Kirrily Rule
18:00 - 19:00	**Public Lecture - Beyond Oppenheimer – Nuclear Science in the 21st Century** Auditorium Sponsored by HIAF Learn More and Register Here [https://www.eventbrite.com.au/e/beyond-oppenheimer-nuclear-science-in-the-21st-century-tickets-752655602167]					

Tuesday, 5th Dec 2023

	Parallel Session 1	Parallel Session 2	Parallel Session 3	Parallel Session 4	Parallel Session 5	Parallel Session 6
07:30 - 08:30	**Equity & Diversity Breakfast - Focus - Women* in Physics** Sponsored by OzGrav Learn More and Register Here [https://www.eventbrite.com.au/e/inclusion-breakfast-focus-women-in-physics-optics-and-photonics-tickets-752776904987?aff=oddtdtcreator]					
08:30 - 09:00						
09:00 - 09:45	**Session P2 AIP Plenary** Auditorium Plenary Speakers Plenary Speaker: Amelia Liu Chair: Jodie Bradby **Small-beam diffraction measurements to probe local structure and local dynamics in glasses** Amelia Liu					
09:45 - 10:15	**Morning Tea** Exhibit Open					
10:15 - 12:30	**Session 4.1 AIP Quantum Science and Technology** Auditorium Lara Gillan **10:15 - 10:45** **On-chip microwave generation with the Josephson laser** Maja Cassidy **10:45 - 11:00** **Reservoir-induced linewidth broadening of exciton-polariton laser**	**Session 4.2 AIP Theoretical Physics** Huxley Lecture Theatre Otari Sakhelashvili **10:15 - 10:45** **When energy goes missing: theoretical explanations of the excess in $B^+ \to K^+$ + invisible.** Michael Schmidt **10:45 - 11:00** **Searching for a (pseudo)scalar at 95 GeV**	**Session 4.3 Gamma-Ray and Radio Synergies Focus Session** Conference Room (Lvl 4) Sabrina Einecke **10:15 - 10:40** **CTA and Overview of its Linkages to Radio Astronomy** Gavin Rowell **10:40 - 11:05** **The SKAO and high-energy synergies, a Science Operations outlook**			**Session 4.4 AIP Condensed Matter & Materials Physics** Oliphant Conference Room Sebastian Wolf **10:15 - 10:45** **Dominance of extrinsic scattering mechanisms in the orbital Hall effect in graphene and transition metal dichalcogenides** Hong Liu, Dimitrie Culcer **10:45 - 11:00**

	Bianca Rae Fabricante, Mateusz Krol, Matthias Wurdack, Andrew Truscott, Elena Ostrovskaya, Eliezer Estrecho **11:00 - 11:15** **Optical Long Baseline Interferometry with Quantum Hard Drives.** Benjamin Field, John Bartholomew, Joss Bland-Hawthorn **11:15 - 11:30** **Photoelectrical Dynamics of an Isolated Nitrogen-Vacancy Centre in Diamond** YunHeng Chen, Marcus Doherty **11:30 - 11:45** **The Twisted Anyon Cavity Resonator as a Potential Dark Matter Detector and Sensing Device** Emma Paterson, Jeremy Bourhill, Maxim Goryachev, Michael Tobar **11:45 - 12:00** **Femtosecond laser intraoral robotic: the future of modern dentistry** Julia Brand, Ksenia Maximova, Steve Madden, Peter Woodfield, Van Dau, Dzung Dao, Laurence J. Walsh, Heiko Spallek, Omar Zuaiter, Alaa Habeb, Timothy R. Hirst, Andrei Rode, Ludovic Rapp **12:00 - 12:15** **Fabrication of highly coherent superconducting aluminium resonators on silicon** Chun-Ching Chiu, Xin He, Peter Jaconbson, Arkady Fedorov **12:15 - 12:30** **Stray magnetic field imaging of thin exfoliated iron halides flakes** Fernando Meneses, Rongrong Qi, Alexander Healey, Yi You, Islay Robertson, Sam Scholten, Ashok Keerthi, Gary Harrison, Lloyd Hollenberg, Boya Radha, Jean-Philippe Tetienne	Giorgio Arcadi, Giorgio Busoni, Navneet Krishnan, David Almeida **11:00 - 11:15** **Dark (non-)matter candidate emerging from 3-form gauge theory** Christian Canete **11:15 - 11:45** **Quantum kinetics of the orbital magnetic moment of Bloch electrons** Dimitrie Culcer **11:45 - 12:00** **The proper spin current in topological insulators** James Cullen, Hong Liu, Dimitrie Culcer **12:00 - 12:15** **Implications of Dark Photon Dark Matter for Gravitational Waves** Neil Barrie	Jimi Green **11:05 - 11:30** **Mergers of double white dwarfs and their associated transients** Ashley Ruiter **11:30 - 11:45** **Synergies between CTA and SWGO Gamma-ray Observatories to Trigger and Resolve Transient Events** Jose Bellido **11:45 - 12:00** **Dark matter searches at the Cherenkov Telescope Array and beyond** Martin White **12:00 - 12:15** **An Array of Gamma-Ray Telescopes in Australia for Transient Studies at Extreme Energies** Simon Lee, Sabrina Einecke, Gavin Rowell **12:15 - 12:30** **GammaBayes: a Bayesian pipeline for dark matter detection with the Cherenkov Telescope Array** Liam Pinchbeck, Csaba Balazs, Eric Thrane			**Photoluminescence excitation spectroscopy comparison study of multiple erbium sites in silicon** Gabriele de Boo, Alexey Lyasota, Ian Berkman, John Bartholomew, Qi Lim, Rose Ahlefeldt, Jeffrey McCallum, Matt Sellars, Chunming Yin, Sven Rogge **11:00 - 11:15** **Swift Heavy Ion Modified Materials: Applications and Characterisation using Synchrotron Small Angle X-ray Scattering** Patrick Kluth, Shankar Dutt, Alexander Kiy, Christian Notthoff, Nahid Afrin, Jessica Wierbik, Hendrik Heimes, Xue Wang, Maria Eugenia Toimil-Molares, Christina Trautmann, Nigel Kirby **11:15 - 11:30** **Ion track formation in InSb after swift heavy ion irradiation** Taleb Alwadi, Christian Notthoff, Shankar Dutt, Jessica Wierbik, Nahid Afrin, Alexander Kiy, Patrick Kluth **11:30 - 11:45** **Catalyst-free fabrication of 1D single crystal WnO3n-2 (n = 25) nano-wire bundles using low-energy He^+ ions** Maryna Bilokur, Matt Thompson, Matthew Arnold, Cormac Corr **11:45 - 12:00** **Sub-monolayer manipulation of diamond surfaces using two-photon laser method** Mojtaba Moshkani, James Downes, Richard Mildren **12:00 - 12:15** **Strain-free GaAs quantum dots with fabrication tunable radiative emission** Declan Gossink, Tim Wohlers-Reichel, Satya Undurti, Glenn Solomon **12:15 - 12:30** **The anisotropy of swift heavy ion tracks in tourmaline and fluorapatite single-crystals**

						<u>Jessica Stephanie Wierbik</u>, Hendrik Martin Heimes, Christian Notthoff, Alexander Kiy, Shankar Dutt, Nigel Kirby, Patrick Kluth
12:30 - 13:30	**Lunch Break** 13:00 - 13.30, The promise and perils of AI in academia, Dr. Lukas Wesemann, UoM, Auditorium Chair - Shankar Dutt AIP Branch Chairs Meeting - Board Room **The promise and perils of AI in academia** <u>Lukas Wesemann</u>					
13:30 - 16:00	**Session 5.1 AIP Quantum Science and Technology** Auditorium Rose Ahlefeldt **13:30 - 14:00** **Quantum imaging techniques for astronomy: how to achieve super-resolution** <u>Zixin Huang</u> **14:00 - 14:15** **Experimental Free-Space Quantum-Secured Time Transfer System for use over a Ground-to-Satellite Link** <u>Sabrina Slimani</u>, Nicole Yuen, Lula Abdirashid Ali, Fred Baynes, Ken Grant, Andre Luiten, Ben Sparkes **14:15 - 14:30** **Optical Spectroscopy of Main and Satellite Lines in Erbium Lithium Fluoride** <u>Lara Gillan</u>, Toby Hardcastle, Matthew Berrington, Matthew Sellars, Rose Ahlefeldt **14:30 - 14:45** **Spectral engineering of photon pairs from a nonlocal metasurface** <u>Jinyong Ma</u>, Shaun Lung, Jihua Zhang, Maximilian A. Weissflog, Frank Setzpfandt, Andrey A. Sukhorukov **14:45 - 15:00** **Er sites in Si for quantum applications** <u>Alexey Lyasota</u>, Ian R. Berkman, Gabriele G. de Boo, John G. Bartholomew, Shao Qi Lim, Brett C. Johnson,	**Session 5.2 AIP Theoretical Physics** Huxley Lecture Theatre Dimi Culcer, Peter Drummond **13:30 - 14:00** **Tachyonic media in analogue models of special relativity** Sundance Bilson-Thompson, Scott Todd, James Read, Valentina Baccetti, <u>Nicolas Menicucci</u> **14:00 - 14:15** **Quantum asymmetry between time and space: beyond the canonical commutator** <u>Joan Vaccaro</u> **14:15 - 14:30** **Entanglement harvesting with covariantly bandlimited fields** <u>Nicholas Funai</u> **14:30 - 14:45** **Shannon wavelets and scaled quantum field theory** <u>Dominic Lewis</u>, Nicolas Menicucci, Nicholas Funai, Achim Kempf **14:45 - 15:00** **Nonlinear Hall effect of magnetized two-dimensional spin-3/2 heavy holes**	**Session 5.3 Gamma-Ray and Radio Synergies Focus Session** Conference Room (Lvl 4) Ashley Ruiter **13:30 - 13:55** **The future is here! Diprotodon's, Potoroo's, ORC's and other new wonders of radio surveys.** <u>Miroslav Filipovic</u> **13:55 - 14:10** **Using SOFIA ionised carbon data as a probe for sub-GeV cosmic rays in young Supernova Remnants** <u>Adnaan Thakur</u>, Gavin Rowell, Ronan Higgins, Michael Burton, Yasuo Fukui, Sabrina Einecke, Hidetoshi Sano, Graeme Wong, Michael Ashley, Miroslav Filipovic, Catherine Braiding **14:10 - 14:25** **Probing Unusual and Energetic H-alpha features towards the Scutum Supershell** <u>Rami Alsulami</u> **14:25 - 14:50** **Limits on the injection energy of Galactic positrons reconsidered**	**Session 5.4 AIP Nuclear and Particle Physics** Board Room (Lvl 4) AJ Mitchell **13:30 - 14:00** **Nuclear pairing and superfluidity from a quark model** <u>Katherine Curtis</u> **14:00 - 14:30** **Coulomb excitation of ^{124}Te: persisting seniority structure in the 6^+_1 level** <u>Martha Reece</u> **14:30 - 14:45** **Aspects of nuclear structure research at the ANU** <u>Ben Coombes</u>, AJ Mitchell, Andrew Stuchbery, Greg Lane **14:45 - 15:00** **Adiabatic description of pre-fragment formation in nuclear fission**		**Session 5.5 AIP Condensed Matter & Materials Physics** Oliphant Conference Room Rich Mildren **13:30 - 13:45** **Conical Nanopores in Amorphous SiO2 Membranes** <u>Alexander Kiy</u>, Shankar Dutt, Christian Notthoff, Maria Eugenia Toimil-Molares, Nigel Kirby, Patrick Kluth **13:45 - 14:00** **Diamond-Like Carbon Thin Film Ablation, Incubation and Graphitisation in MHz Ultra-Fast Treatment Regimes** <u>Sophie Cottam</u>, Clara Tran, Marcela Bilek **14:00 - 14:15** **High-pressure phase transitions in diamondoid molecular crystals observed by in situ Raman spectroscopy** <u>Hendrik Heimes</u>, Kate Barret, Jessica Wierbik, Taylor Gluck, Dougal McCulloch, Jodie Bradby **14:15 - 14:30** **The hardness of nano- and microcrystalline lonsdaleite and diamond**

Jeffrey C. McCallum, Bin-Bin Xu, Shouyi Xie, Rose L. Ahlefeldt, Matthew J. Sellars, Chunming Yin, Sven Rogge

15:00 - 15:15
Quantum Information Processing Using an $^{167}Er^{3+}$:Y2SiO5 Quantum Memory
James Stuart, Kieran Smith, Ellen Zheng, David Pulford, Rose Ahlefeldt, Matthew Sellars

15:15 - 15:30
Development of a compact ytterbium magneto optical trap for use in precision timekeeping applications.
Ben White, Ben Sparkes, Andre Luiten, Rachel Offer, Ashby Hilton, Xiao Sun, William Rickard, Charlie Ironside

15:30 - 15:45
Quantum many-body correlations in an ultracold ^{4}He*-^{3}He* Bose-Fermi scattering halo
Yogesh Sridhar, Xintong Yan, Kannan S, Abbas Hussein, Sean Hodgman, Andrew Truscott

15:45 - 16:00
Proposed experimental demonstration of measurement-device-independent quantum security protocol using a quantum-dot photon source
Nicola Yuen, Satya Undurti, Glenn Solomon

Sina Gholizadeh, James H. Cullen, Dimitrie Culcer

15:00 - 15:15
Electrical operation of planar Ge hole spin qubits in an in-plane magnetic field
Abhikbrata sarkar, Zhanning Wang, Mathew Rendell, Nico W. Hendrickx, Menno Veldhorst, Giordano Scappucci, Mohammad Khalifa, Joe Salfi, Andre Saraiva, Andrew Dzurak, Alex R. Hamilton, Dimitrie Culcer

15:15 - 15:30
Macroscopic quantum three-box paradox
Channa Hatharasinghe, Manushan Thenabadu, Peter Drummond, Margaret Reid

Roland Crocker, Mark Krumuolz

14:50 - 15:05
Constraining cosmic ray transport with spatially- and energy-resolved observations
Mark Krumholz

15:05 - 15:20
Cosmic ray propagation in spatially intermittent magnetic fields.
Amit Seta

15:20 - 15:45
Catching the earliest radio light from TeV Gamma-ray Bursts
Gemma Anderson
15:45 - 16:00
Wrap-up discussion

Paul Tan, Cedric Simenel, Ngee-Wein Lau

15:00 - 15:15
Role of deformed shell effects in quasi-fission of compound Th-226 nucleus
Hyeonseop Lee, Cedric Simenel, Patrick McGlynn

15:15 - 15:30
The SABRE South Experiment at the Stawell Underground Physics Laboratory
Zuzana Slavkovska

15:30 - 15:45
CYGNUS-Oz: Australian R&D for a future directional dark matter detector
Victoria Bashu

15:45 - 16:00
Neutron Monitoring System at the Stawell Underground Physics Laboratory
Kyle Leaver, Gary Hill, Greg Lane, Lindsey Bignell

Xingshuo Huang, Alan Salek, Andrew Tomkins, Colin MacRae, Nick Wilson, Dougal McCulloch, Jodie Bradby

14:30 - 14:45
Giant resonant skew scattering of plasma waves
Cooper Finnigan, Dmitry Efimkin

14:45 - 15:00
Directional emission in an on-chip acoustic waveguide
Timothy Hirsch, Nicolas Mauranyapin, Erick Romero, Tina Jin, Glen Harris, Christopher Baker, Warwick Bowen

15:00 - 15:15
In-situ TEM annealing analysis of helium bubble dynamics in tungsten and its dependence on temperature during plasma exposure
Soon Han Bryan Teo, Matt Thompson, Maryna Bilokur, Dhriti Bhattacharyya, Cormac Corr

15:15 - 15:30
Development of a common tool and dataset for benchmarking of 4D-CT methods.
Stephen Catsamas, Andrew Kingston, Glenn Myers

15:30 - 15:45
Analysis of the off-focal source in transmission geometry x-ray systems
Klara Steklova, Levi Beeching, Adrian Sheppard, Andrew Kingston

16:00 - 17:30

Poster Session - AIP
Foyer

General Introduction to Inverse Anti-mass Gravitation Space Coupling Plasma By John Downes
John Downes

Disorder effects in the non-linear anomalous Hall effect of PT-symmetric Dirac fermions
Rhonald Burgos Atencia, Dimitrie Culcer

Accurate Image Multi-Class Classification Neural Network Model with Quantum Entanglement Approach
Farina Riaz, Shahab Abdulla, Hajime Suzuki, Srinjoy Ganguly, Ravinesh C. Deo, Susan Hopkins

Resolving Schrödinger's paradoxical analysis of the EPR argument.
Christopher McGuigan, Margaret Reid, Peter Drummond

Development Of An Automated Steerable Radio Telescope.
Pritam Dutta, Rushil Saraswat

Detecting Exoplanets in Multiplanetary Systems using HILine Analysis through Gaussian Fitting.
Pritam Dutta, Rushil Saraswat

Functionalization of Track Etched Amorphous SiO2 Nanopores for the Fabrication of Bioinspired Nanofluidic Devices
Nahid Afrin, Shankar Dutt, Alexander Kiy, Patrick Kluth

Characterising the Sun's open-closed magnetic flux boundary towards understanding the origin and acceleration of the slow solar wind.
Chloe Wilkins

Fundamental physics with a mass-imbalanced entangled system of ^{4}He* and ^{3}He* atoms
Kannan Suresh, Yogesh Athreya, Xintong Yan, Abbas Hussein, Sean Hodgman, Andrew Truscott

Benchmarking quantum gates for continuous-variable quantum information processing
Salini Karuvade, Andrew Doherty

Creation and storage of non-classically correlated light fields in an erbium-based quantum memory
Kieran Smith, James Stuart, Morgan Hedges, Rose Ahlefeldt, Matthew Sellars

Quantum State Stabilization via Measurement-Driven Deep Reinforcement Learning
Chunxiang Song, Yanan Liu, Daoyi Dong, Hidehiro Yonezawa

Rubidium MOT as a high-density target for Positronium formation via Positron-Rubidium scattering.
Neil Shah, Joshua Machacek, Stephen Buckman, Sean Hodgman

Polarization effects on light propagation in gravitational fields
Rama Vadapalli, Daniel Terno, Sebastian Murk

Towards understanding the effects of quantum noise in Ramsey spectroscopy
Diego Bernal-Garcia, Nattaphong Wonglakhon, Michiel Burgelman, Francisco Riberi, Lorenza Viola, Gerardo Paz-Silva

Microwave magnon and optical satellite spectroscopy on an antiferromagnetically ordered NdGaO3 crystal towards quantum transduction
Masaya Hiraishi, Gabrielle Hunter-Smith, Gavin King, Luke Trainor, Alexandra Turrini, Henrik Rønnow, Jevon Longdell

Resolution of the Quantum Clock-Time Observable
Khai Bordon, Joan Vaccaro, Fatema Tanjia

Optical Lattice for ultracold metastable Helium Bose-Einstein condensate
Y. Wath, G. Garg, X. Meng, J.W. Dai, A.H. Abbas, A.G. Truscott, S.S. Hodgman

Quenching ultra-cold He* gas across the Bose-Einstein Condensate Phase Transition
Samuel X. Meng, Joshua W. Dai, Yash Wath, Shijie Li, Gaurang Garg, Abbas H. Abbas, Andrew G. Truscott, Sean S. Hodgman

Feedback Cooling of Degenerate Quantum Gases
Kaiwen Zhu, Simon Haine, Zain Mehdi, Joseph Hope

Quantum Computer Error Structure Probed by Quantum Error Correction Syndrome Measurements
Spiro Gicev, Lloyd Hollenberg, Muhammad Usman

Classical Gaussian Boson Samplers
Peter Drummond, Ned Goodman, Alexander Dellios

High-performance liquid-metal-printed Indium oxide transistor with steep subthreshold swing
Shirui Zhang, Robert Elliman

Characterization of Local Friendliness Polytopes
Marwan Haddara, Eric Cavalcanti

Grey-box noise characterisation and control for initially correlated systems
Kaiah Steven, Elliot Coupe, Gerardo Paz-Silva

All-metal air-channel devices: nanofabrication, comparison of device geometries, and applications
Shruti Nirantar

Quantum noise spectroscopy for simultaneous reconstructions of generalised quantum environments
Elliot Coupe, Qi Yu, Kaiah Steven, Gerardo Paz-Silva

Automated quantum circuit design with nested Monte Carlo tree search
Peiyong Wang, Muhammad Usman, Udaya Parampalli, Lloyd C.L. Hollenberg, Casey R. Myers

Quantum Chaos in Open System Digital Quantum Simulation
Angsar Manatuly, Cahit Kargi, Peter Zoller, Lukas Sieberer, Nathan Langford

Constraints on the Dark Sector Through Electroweak Precision Variables
Bill Loizos

Optimising State Preparation in an Erbium Orthosilicate Quantum Memory
Raiden Lemon, James Stuart, Aaron Tranter, Matthew Sellars

Yttrium Spin Bath Dynamics in $^{167}Er^{3+}:Y^2SiO^5$
Jack Lang, Rose Ahlefeldt, Matthew Sellars

Impact of Data Augmentation on QCNNs, Compared to Classical CNNs
Leting Zhouli, Peiyong Wang, Udaya Parampalli

Highly ^{28}Si enriched silicon by localised focused ion beam implantation
Ravi Acharya, Maddison Coke, Mason Adshead, Kexue Li, Barat Achinuq, Rongsheng Cai, A.Baset Gholizadeh, Janet Jacobs, Jessica Boland, Sarah Haigh, Katie Moore, David Jamieson, Richard Curry

Quantum Variational Circuits for Document Classification
Shengxin Zhuang, John Tanner, Wei Liu, Du Huynh, Jingbo Wang

Exploring Barren Plateau Phenomenon in Quantum Data Re-uploading
Matthaus Zering, Yusen Wu, Du Huynh, Wei Liu, Jingbo Wang

Microstructural studies of carbon phases in ureilite meteorites
Alan Salek, Brock Nicholas, Andrew Tomkins, Colin MacRae, Nick Wilson, Dougal McCulloch

Cathode Spot Dynamics in Magnetic Fields
Jiongyu Liang, Kostadinos Tsoutas, Marcela Bilek

Phase Transformation of Silicon Originates from Slip Along the {111} Planes
Sean Butler, Jeffrey Partridge, Nigel Marks, Dougal McCulloch, Jodie Bradby

Non-adiabatic transport of charged particle beams
Joshua Machacek, Zhongtao Xu

Parametric Study of Nozzle Throat Dimensions on Plasma Properties of a Bidirectional Gas Injected Radio-Frequency Inductively Coupled Plasma Torch.
Ashley Pascale, Trevor Lafleur, Cormac Corr

Optical power requirements for inter-satellite laser links
Callum Sambridge, Jobin Valliyakalayil, Kirk McKenzie

Estimating ground state properties of spin models using quantum computed moments
Harish Vallury, Michael Jones, Lloyd Hollenberg

The proton-proton correlation from two-proton transfer reaction in $^{16}O + {}^{28}Si$
Caroline da Costa Seabra, Roberto Linares, Vinicius Zagatto, Jesus Lubian, Jonas Ferreira, Francesco Cappuzzello, Manuela Cavallaro, Diana Carbone, Clementina Agodi

An Ultra-Thin Film Chemiresistive Sensor for Acetone Sensing Applications
Annalise Lennon, Zhe Li, Shiyu Wei, Tuomas Haggren, Antonio Tricoli, Hark Hoe Tan, Chennupati Jagadish, Lan Fu

EMU discovery of a young X-ray binary associated with a new Galactic SNR G289.6+5.8
Sanja Lazarević, Miroslav Filipović, Shi Dai, Chandreyee Maitra, Gavin Rowell, Phil Edwards, Adeel Ahmad, Roland Kothes

Resource Estimation for Fault-Tolerant Quantum Supremacy via Algorithm-Specific Graph Execution
Jason Gavriel, Simon Devitt, Michael Bremner

Gates for protected superconducting qubits via their internal modes
Thomas Smith, Andrew Doherty

Revealing the spin-texture in the surface states of the topological insulator Ta2Ni3Te5
Johnathon Maniatis, Qile Li, James Blyth, Alexei Federov, Weiyao Zhao, Mark Edmonds

An interaction-driven quantum engine fuelled by particle transfer
Raymon Watson

Quantum Entanglement Distribution via Entanglement Swapping through Uplink Satellite Transmission
Srikara Shankara, Hudson Leone, Peter Rohde, Thinh Le, Alexander Solnstev, Simon Devitt

17:30 - 18:00						
18:00 - 19:30	**Australian Academy of Science - New Australian Science Priorities Panel Discussion** Shine Dome					

Wednesday, 6th Dec 2023

	Parallel Session 1	Parallel Session 2	Parallel Session 3	Parallel Session 4	Parallel Session 5	Parallel Session 6
07:30 - 08:30	**Morning Walk/Run/Yoga - Wellness Program** Sponsored by ANU RSPhys Equity and Diversity Committee Walk: Learn More and Register Here [https://aip-summer-meeting.com/social_events/] Run/Jog: Learn More and Register Here [https://aip-summer-meeting.com/social_events/] Yoga: Learn More and Register Here [https://aip-summer-meeting.com/social_events/]					
08:30 - 08:50						
08:50 - 09:35	**Session P3 AIP Plenary** Auditorium Plenary Speakers Plenary Speaker: Mark Chueng Chair: Nicole Bell **Testing Plasma Physics with multi-wavelength observations of the Sun and other stars** Mark Cheung					
09:35 - 10:00	**Morning Tea**					
10:00 - 12:30	**Session 6.1 AIP Quantum Science and Technology** Auditorium Simon Haine **10:00 - 10:30** **Direct observation of geometric phase interference in dynamics around a conical intersection** Christophe Valahu, Vanessa Olaya-Agudelo, Ryan MacDonell, Tomas Navickas, Arjun Rao, Maverick	**Session 6.2 Joint AIP/ANZCOP Spectroscopy and Imaging I** Huxley Lecture Theatre Frédérique Vanholsbeeck **10:00 - 10:30** **From relativity to respiration: How ideas from Einstein's general theory enable respiratory motion modelling during image-guided radiotherapy** Nicholas Hindley	**Session 6.3 ANZCOP Others** Conference Room (Lvl 4) Jevon Longdell **10:00 - 10:30** **Speckle Metrology: new levels of precision measurement** Kishan Dholakia **10:30 - 11:00** **Metasurface Microparticles Driven by Optical Forces and Torques**	**Session 6.4 ANZCOP Quantum Optics** Board Room (Lvl 4) Jacquiline Romero **10:00 - 10:30** **Dynamics of many-body photon bound states in waveguide and cavity QED** Sahand Mahmoodian **10:30 - 10:45**		**Session 6.5 AIP Nuclear and Particle Physics** Oliphant Conference Room Katherine Curtis **10:00 - 10:30** **The eighth row: the international race to discover new elements and extend the periodic table** Edward Simpson

Millican, Juan Pérez-Sánchez, Joel Yuen-Zhou, Michael Biercuk, Cornelius Hempel, Ting Rei Tan, Ivan Kassal

10:30 - 10:45
Towards gravity and force gradient sensing on compact devices: A readout free scheme for measuring phase shifts and differential phase shifts with overlapped spatial fringes matter-wave interferometry
Yosri BEN AICHA, Ryan Thomas, Zain Mehdi, Simon Haine, Paul Wigley, Kyle Hardman, John Close

10:45 - 11:00
Defining discrete Wigner functions from the Gottesman-Kitaev-Preskill code
Lucky Antonopoulos

11:00 - 11:15
Asymptotic Non-utility of Collective Quantum Measurements for Qudit Tomography
Aritra Das, Lorcan Conlon, Jun Suzuki, Simon Yung, Ping Lam, Syed Assad

11:15 - 11:30
Threshold Behaviours and Higher-order Trotterisations effects in Quantum Simulation
Treerat Srivipat, Adrien Di Lonardo, Angsar Manatuly, Cahit Kargi, Giorge Gemisis, Dominic Berry, Nathan Langford

11:30 - 11:45
Bouncing Gaussian unitary operations off of a two-mode squeezed state
Ben Baragiola, Nicolas Menicucci

11:45 - 12:00
Quantifying the difference in logical quantum error suppression

10:30 - 10:45
Hyperspectral holographic microscopy
Georgy Kalenkov

10:45 - 11:00
Optical detection of VOCs using Quasi BIC metasurface with phase read-outs
Shridhar Manjunath, Justin Wong, Alishba John, Marius Graml, Buddini Karawdeniya, Krishnana Murugappan, Antonio Tricoli, Chathura Bandutunga, Dragomir Neshev

11:00 - 11:15
Inverse-designed metasurfaces for flexible optical image processing
Neuton Li, Niken Priscilla, Lukas Wesemann, Ann Roberts, Andrey Sukhorukov

11:15 - 11:30
Optical nonlinearity enabled super-resolved multiplexing microscopy
Lei Ding, Chaohao Chen, Fan Wang, Xiaoxue Xu, Lan Fu

11:30 - 11:45
Characterizing hazardous biological and chemical materials with stand-off Laser-induced Fluorescence
Lize Coetzee, Esa Jaatinen

12:15 - 12:30
Extended frequency tuning coverage for MgO:LiNbO3 intracavity terahertz polariton lasers
Ameera Jose, Ondrej Kitzler, Helen Pask, David Spence

Mikael Käll

11:00 - 11:15
Contact Resistance Study of Graphene-based Devices for Next-generation Electronic Device Applications.
Md Arifuzzaman, Tom Ratcliff, Sanjoy Nandi, Robert Elliman

11:15 - 11:30
Biostable and compatible waveguides for chronic peripheral nervous system stimulation applications
Jeffery Low, Daniel McCormick, Poul Nielsen, Neil Broderick

11:30 - 11:45
Ultra-Fast High-Contrast Optical Modulation in Silicon Metasurfaces
Khosro Zangeneh Kamali, Anton Trifonov, Lyuben Sashov Petrov, Kaloyan Georgiev, Lei Xu, Giulia Crotti, Unai Arregui Leon, Mohsen Rahmani, Giuseppe Della Valle, Ivan Buchvarov, Dragomir Neshev

11:45 - 12:00
Orb-web Spider Viscid Webs in Natural Light – Optics and Colour
Deb Kane

12:00 - 12:15
Biomedisa AI: Automated Segmentation of Micro-CT Image Data using the Biomedisa Online Platform
Philipp Lösel, Aleese Barron, Nicolas Francois, Peter Kopittke, Mathieu Lihoreau, Enzo Lombi, Coline Monchanin, Beat Schmutz, Yulai Zhang, Andrew Kingston

Molecular optomechanics in the anharmonic regime: from nonclassical mechanical states to mechanical lasing
Mikolaj Schmidt, Michael Steel

10:45 - 11:00
Enhanced Photon Pair Generation from a Metasurface Cavity
Tongmiao Fan, Jihua Zhang, Andrey Sukhorukov

11:00 - 11:15
Improved construction of graph states in linear quantum optics
Darcy QC Morgan, Samuel J. Elman, Seok-Hyung Lee, Simon J. Devitt

11:15 - 11:30
Biased Gottesman-Kitaev-Preskill repetition code
Matthew Stafford, Nicolas Menicucci

11:30 - 11:45
Nonlinear metasurface for broad-angle photon-pair generation
Yuxin Jiang, Jihua Zhang, John Scott, Otto Cranwell Schaeper, Jinyong Ma, Milos Toth, Igor Aharonovich, Dragomir N. Neshev, Andrey A. Sukhorukov

11:45 - 12:00
Quantum Imaging Using Entangled Photon Pairs from Nonlinear Metasurfaces
Jinliang Ren, Jinyong Ma, Jihua Zhang, Jiajun Meng, Kenneth Crozier, Andrey Sukhorukov

12:00 - 12:15
Microwave to Optical Frequency Conversion in Rare Earth Ions

10:30 - 10:45
Modelling of nuclear fission with an exact time-dependent generator coordinate method
Ngee-Wein Lau, Rémi Bernard, Cédric Simenel

10:45 - 11:00
Resolving Anomalous Collectivity in ^{58}Fe through Coulomb Excitation
Jack Woodside, Ben Coombes, Gregory Lane, AJ Mitchell, Andrew Stuchbery, Lachlan McKie, Martha Reece, Nathan Spinks

11:00 - 11:15
Repurposing the ANU Enge Spectrometer for Nuclear Structure Studies
Aditya Babu, Ben Coombes, A.J. Mitchell, Daniel Tempra, Thomas Kitchen

11:15 - 11:30
Spectroscopy of neutron-rich radioisotopes towards the edge of nuclear landscape
AJ Mitchell

11:30 - 11:45
Investigation of shape coexistence and triaxiality from fast-timing measurements in Pt-188 and Pt-190
Hanaa Alshammari

11:45 - 12:00
Imaging the transverse distribution of forces in the proton with lattice QCD
Joshua Crawford, Ross Young, James Zanotti

12:00 - 12:15

	between the rotated and unrotated surface code. Anthony O'Rourke, Simon Devitt **11:45 - 12:15** **Calculating metrological potential from quantum phase-space methods** Thakur Giriraj Hiranandani **12:15 - 12:30** **design and efficiency in a graph state compiler** greg bowen, madhav vijayan			Gavin King, Luke Trainor, Jevon Longdell **12:15 - 12:30** **Inverse Designed Multimode Photonic Devices for Classical and Quantum Information Processing** Daniel Peace, Jamika Roque, Jacquiline Romero		**Impact of nuclear structure on nuclear responses to WIMP elastic scattering** Raghda Abdel Khaleq, Giorgio Busoni, Cedric Simenel, Andrew Stuchbery **12:15 - 12:30** **Cosmogenic radioisotope production in NaI:Tl** Lindsey Bignell
12:30 - 13:30	**Lunch Break** Equity Panel. Chaired by Michael Steel - Auditorium					
13:30 - 14:15	**Session P4 AIP Plenary** Auditorium Plenary Speakers Plenary Speaker: Yuerui (Larry) Lu Chair: Halina Rubenstein Dunlop **2D Quantum Materials for Next-generation Photonic and Quantum Devices** Yuerui Lu					
14:15 - 14:30	**Physics ANU Lab Tours** Foyer Registration for this event will be done using sign-up sheets located at the registration desk.					
14:30 - 15:30		**Session 7.1 Joint AIP/ANZCOP Spectroscopy and Imaging II** Huxley Lecture Theatre Danka Sampson **14:30 - 15:00** **Looking below the surface with spatially offset low frequency Raman spectroscopy** Sara Miller **15:00 - 15:15** **Dispersion Spectroscopy using a Code Division Multiplexed Optical Frequency Comb**	**Session 7.2 ANZCOP Optoacoustics & Optomechanics** Conference Room (Lvl 4) Mikolaj Schmidt **14:30 - 15:00** **Nonlinear waves and solitons in superfluid helium** Christopher Baker **15:00 - 15:15** **Longitudinal-shear hybrid acoustic wave Brillouin scattering in tailored chalcogenide waveguides**	**Australian Army Quantum Technology Workshop** Board Room (Lvl 4) The session will cover Army's current and future activities as laid out in the Army Quantum Technology Roadmap. Speakers: MAJ Wes Bartlett, Australian Army—Quantum Technology, Robotic & Autonomous		

		Anika Chan, Justin Wong, Malcolm Gray, Chathura Bandutunga **15:15 - 15:30** **Vibrational Spectroscopy for the Imaging of Art** Carlie Watt, Camilla Baskcomb, Michel Nieuwoudt	Moritz Merklein, Govert Neijts, Choon Kong Lai, Maren Kramer Riseng, Duk-Yong Choi, Kunlun Yan, David Marpaung, Stephen Madden, Benjamin Eggleton **15:15 - 15:30** **Coupled Non-degenerate Photonic Resonators for Enhanced Optomechanical Sensing** Benjamin Carey	Systems Implementation & Coordination Office (RICO) LTCOL Marcus Doherty, Australian Army—Quantum Technology		
15:30 - 16:00	**Afternoon Tea**					
16:00 - 18:00	**Session 8.1 AIP Quantum Science and Technology** Auditorium Jie Zhao **16:00 - 16:15** **Low Depth Virtual Distillation of Quantum Circuits by Deterministic Circuit Decomposition** Akib Karim, Shaobo Zhang, Muhammad Usman **16:15 - 16:30** **Photon-Number Encoded Measurement-Device-Independent Quantum Key Distribution Protocol** Ozlem Erkilic, Lorcan Conlon, Biveen Shajilal, Sebastian Kish, Spyros Tserkis, Yong-Su Kim, Ping Koy Lam, Syed Assad **16:30 - 16:45** **Topological signal processing on quantum computers for higher-order network analysis** Caesnan Leditto, Angus Southwell, Behnam Tonekaboni, Gregory White, Muhammad Usman, Kavan Modi **16:45 - 17:00** **Quantum algorithm co-design for field-testing the path to advantage**	**Session 8.2 Joint AIP/ANZCOP Spectroscopy and Imaging III** Huxley Lecture Theatre Danka Sampson **16:00 - 16:30** **Hyperfine Spectroscopy of Rubidium with a Speckle Spectrometer** Chris Perrella, Gabriel Britto Monteiro, Erik Schartner, Sarah Scholten, Morgan Facchin, Andre Luiten, Graham Bruce, Kishan Dholakia **16:30 - 17:00** **A Portable Dual-Wavelength Optical Atomic Rubidium Clock** Sarah Scholten, Clayton Locke, Nicolas Bourbeau Hébert, Emily Ahern, Ben White, Christopher Billington, Ashby Hilton, Montana Nelligan, Jack Allison, Rachel Offer, Elizaveta Klantsataya, Sebastian Ng, Jordan Scarabel, Martin O'Connor, Christopher Perrella, Andre Luiten **17:00 - 17:15** **Optical Tomographic Reconstruction of Objects within Diffuse Media.** Catherine Merx, Michael Suzzi, Matthew Randall, Galiya Sharafutdinova, Renee Goreham, John Holdsworth **17:15 - 17:30** **Improved detection of blood vessels with OCT angiography using deep learning**	**Session 8.3 Joint AIP/ANZCOP session on Astrophysics/Astronomy Optics & Instrumentation** Conference Room (Lvl 4) Barnaby Norris **16:00 - 16:15** **FPGA Based Atmospheric Correction Algorithm for Ground to Space Optical Phased Array Links** Noah Baldwin, Paul Sibley, Michael Ireland, Chathura Bandutunga **16:15 - 16:30** **Inverse Design of Aperiodic Multi-notch Bragg Gratings Using Neural Networks** Qingshan Yu, Barnaby Norris, Göran Edvell, Liguo Luo, Sergio Leon-Saval **16:30 - 16:45** **Meta-Lenslet Array Wavefront Sensor for Laser Guide Star Adaptive Optics** Sarah Dean, Josephine Munro, Israel Vaughn, Andrew Kruse, Tony Travouillon, Dragomir Neshev, Rob Sharp, Andrey Sukhorukov	**Session 8.4 AIP Theoretical Physics** Board Room (Lvl 4) Michael Schmidt, Daniel Terno **16:00 - 16:30** **Validating GBS quantum computers in phase-space** Peter Drummond, Margaret Reid, Alex Dellios, Ned Goldman **16:30 - 16:45** **Euclidean and Hamiltonian formulations of black hole thermodynamics in cosmological settings** Fil Simovic, Ioannis Soranidis **16:45 - 17:00** **Properties of Ultra-Compact Objects Near the Trapped Regions** Pravin Dahal **17:00 - 17:15** **New approaches for searching for ultralight scalar and pseudoscalar dark matter in a lab** Igor Samsonov, Victor Flambaum **17:15 - 17:30**		**Session 8.5 AIP Nuclear** Oliphant Conference Room Ben Coombes **16:00 - 16:30** **Directional Dark Matter Detection and the CYGNUS Collaboration** Alasdair McLean **16:30** **Trigger and data acquisition systems for SABRE South** Lachlan McKie **16:45 - 17:00** **Gravitational Wave Signals From Early Matter Domination: Interpolating Between Fast and Slow Transitions** Matthew Pearce, Lauren Pearce, Graham White, Csaba Balazs **17:00 - 17:15** **Charged pion decay rates with QED corrections** Rose Smail **17:15 - 17:30** **Using elastic electron scattering experiments in the development of finite**

	Christopher Bentley, Samuel Marsh, Andre Carvalho **17:00 - 17:15** **A Pauli tracking library and optimizations in MBQC** Jannis Ruh, Simon Devitt **17:15 - 17:30** **Maximal Quantum Information Leakage** Farhad Farokhi **17:30 - 17:45** **What was the state of an incoherently pumped two-level atom just prior to photo-emission? Answers from quantum state smoothing.** Kiarn Laverick, Prahlad Warszawski, Areeya Chantasri, Howard Wiseman **17:45 - 18:00** **Taming the errors in nonlinear quantum optics** James Bainbridge, Michael Steel, Mikolaj Schmidt	Mohammad Rashidi, Robert McLaughlin		**Chiral and electroweak phase transitions with hidden scale invariance** Joshua Cesca **17:30 - 17:45** **On physics of the θ-vacua** Otari Sakhelashvili **17:45 - 18:00** **Extending Global Fits of 4D Composite Higgs Models with Partially Composite Leptons** Kenn Goh, Ethan Carragher, Anthony Williams, Martin White, Wei Su		**nuclear magnetisation models for high-precision tests of the standard model.** Zachary Stevens-Hough, George Sanamyan, Jacinda Ginges **17:30 - 17:45** **Searching for Displaced Leptons at the ATLAS detector** Hitarthi Pandya **17:45 - 18:00** **Induced bias due to background modeling in SABRE and related NaI(Tl) experiments** Kieran Rule
18:00 - 19:00						
19:00 - 23:00	**Conference Dinner - Old Parliament House** Old Parliament House https://maps.app.goo.gl/awtouFHvYAC3ynWc6					

Thursday, 7th Dec 2023

<table>
<tr><th></th><th>Parallel Session 1</th><th>Parallel Session 2</th><th>Parallel Session 3</th><th>Parallel Session 4</th><th>Parallel Session 5</th><th>Parallel Session 6</th></tr>
<tr><td>07:30 - 08:30</td><td colspan="6">Equity & Diversity Breakfast: Focus on Linguistic and Cultural Inclusion
Sponsored by CQC2T

[https://anzcop-aip_summerculture.eventbrite.com.au/]

Learn More and Register Here [https://anzcop-aip_summerculture.eventbrite.com.au/]</td></tr>
<tr><td>08:30 - 09:00</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>09:00 - 09:45</td><td colspan="6">Session P5 ANZCOP Plenary
Auditorium
Plenary Speakers
Plenary Speaker: Michal Lipson

Chair: Frédérique Vanholsbeeck</td></tr>
<tr><td>09:45 - 10:15</td><td colspan="6">Morning Tea</td></tr>
<tr><td>10:15 - 12:00</td><td>Session 9.1 ANZCOP Nonlinear photonics
Auditorium
Martijn de Sterke

10:15 - 10:45
Ultralow-Noise Microwave Generation via with a Single Laser
Alexander Gaeta

10:45 - 11:00
Period-two polarization dynamics in a Kerr resonator for an enhanced coherent Ising Machine
Liam Quinn, Yiqing Xu, Julien Fatome, Stuart Murdoch, Miro Erkintalo, Stephane Coen

11:00 - 11:15</td><td>Session 9.2 ANZCOP Focus Session Quantum and Non-Conventional Metaoptics I
Huxley Lecture Theatre
Yana Izdebskaya, Jinyong Ma, Litty Thekkekara

10:15 - 10:45
Shedding New Light on Image Processing with Metasurfaces
Ann Roberts

10:45 - 11:15
Algorithm-Designed Plasmonic Nanotweezers
Kenneth Crozier

11:15 - 11:45
Two-Colour Spatially Resolved Tuning of Polymer Coated Metasurfaces</td><td>Session 9.3 ANZCOP-AIP Focus Session Coherences and Correlations in Australia: Celebrating 60 years of modern quantum optics I
Conference Room (Lvl 4)
Mikolaj Schmidt

10:15 - 10:45
Einstein-Podolsky-Rosen correlations, an objective-field Q model, and hidden causal loops.
Margaret Reid

10:45 - 11:00
The Power of Einstein-Podolsky-Rosen Steering</td><td>Session 9.4 SPIE I
Finkel - JCSMR
Link to SPIE Pacific Rim Security + Defence Workshop [https://spie.org/conferences-and-exhibitions/pacific-rim-security--defence/programme?SSO=1]

10:15 - 10:20 - Welcome and opening remarks

10:20 - 10:45 - Progress in the Australian Army Quantum TechnologyRoadmap (Wes Bartlett)

10:45 - 11:10 - AFOSR Australian Office(Geoff Andersen)

11:10 - 11:35 - ONR Global missions and collaborations (Weilin Hou)</td><td>Session 9.5 Quantum Machine Learning Focus Session
Board Room (Lvl 4)
Muhammad Usman

10:15 - 10:45
Opportunities and Challenges for Quantum Advantage in Quantum Machine Learning
Muhammad Usman

10:45 - 11:15
Quantum data science
Barry Sanders

11:15 - 11:30
Less Fidelity, More Fidelity: Approximate State Preparation for Efficient and Robust Quantum Machine Learning</td><td>Session 9.6 ANZCOP Focus Session Structured light: recent advancement and perspectives I
Oliphant Conference Room
Mickael Mounaix, Haoran Ren

10:15 - 10:45
Arbitrary structuring of single photons with a multifunctional metalens
Chi Li, Jaehyuck Jang, Trevon Badloe, Tieshan Yang, Joohoon Kim, Jaekyung Kim, Minh Nguyen, Stefan Maier, Junsuk Rho, Haoran Ren, Igor Aharonovich

10:45 - 11:15</td></tr>
</table>

	Giant all-optical reflectivity modulation of nonlocal resonances in silicon metasurfaces Andrea Tognazzi, Paolo Franceschini, Olga Sergaeva, Luca Carletti, Ivano Alessandri, Giovanni Finco, Osamu Takayama, Radu Malureanu, Andrei Lavrinenko, Alfonso Carmelo Cino, Domenico de Ceglia, Costantino De Angelis **11:15 - 11:30** **Phase-locked and Drifting Multicolour Solitons** Justin Widjaja, Antoine F. J. Runge, C. Martijn de Sterke **11:30 - 11:45** **Complex switching dynamics in Kerr ring resonator with coupled light** Rodrigues Bitha, Andrus Giraldo, Bernd Krauskopf, Neil G. R. Broderick **11:45 - 12:00** **Dual comb source with adjustable line-spacing in a single MgF2 Kerr microresonator** Pierce Qureshi, Vincent Ng, Farhan Azeem, Luke Trainor, Harald Schwefel, Stéphane Coen, Miro Erkintalo, Stuart Murdoch **12:00 - 12:15** **Ultra-fast Q-boosting in Nonlocal Semiconductor Metasurfaces** Ziwei Yang, Mingkai Liu, Daria Smirnova, Andrei Komar, Maxim Shcherbakov, Thomas Pertsch, Dragomir Neshev **12:15 - 12:30** **Domain Visualization of Periodically Poled Lithium Niobate Thin Films**	Sarah Walden, Purushottam Poudel, Chengjun Zou, Katsuya Tanaka, Thomas Pertsch, Felix Schacher, Isabelle Staude **11:45 - 12:00** **Optimizing Laser-Induced Periodic Surface Structures: A New Approach to Nanostructuring Control** Vlalden Shvedov, Yana Izdebskaya, Ilya Shadrivov **12:00 - 12:30** **Image processing with nonlocal nonlinear metasurfaces** Costantino De Angelis, Domenico de Ceglia	Qiucheng Song, Travis Baker, Howard Wiseman **11:00 - 11:15** **Certifying photon Fock states using second-order nonlinearity** Dat Thanh Le, Marcelo P. Almeida, Nguyen Ba An **11:15 - 11:30** **High-Order Fermionic Correlations in a Degenerate Fermi Gas of ^{3}He*** Shijie Li, Kieran Thomas, Abbas Hussein, Sean Hodgman, Andrew Truscott **11:30 - 11:45** **Collective pumping superradiant laser with coherence scaling beyond the Schawlow-Townes limit.** Ori Somech, Howard Wiseman **11:45 - 12:00** **Enhancing quantum teleportation efficacy with noiseless linear amplification** Jie Zhao **12:00 - 12:30** **Single photons: from the Hanbury-Brown Twiss experiment to photonic learning machines.** Gerard Milburn	11:35 – 12:00 - Defence research and innovation ecosystem in Australia: where to from here (Giacinta Parish)	Maxwell West, Azar Nakhl, Jamie Heredge, Floyd Creevey, Lloyd Hollenberg, Martin Sevior, Muhammad Usman **11:30 - 11:45** **Ansatz-Agnostic Exponential Resource Saving in Variational Quantum Algorithms Using Shallow Shadows** Afrad Muhamed Basheer, Yuan Feng, Christopher Ferrie, Sanjiang Li **11:45 - 12:00** **Kernel Alignment for Quantum Support Vector Machines Using Genetic Algorithms** Floyd Creevey, Jamie Heredge, Martin Sevior, Lloyd Hollenberg **12:00 - 12:15** **Quantum machine learning via Kerr non-linearity** Carolyn E. Wood, Gerard J. Milburn, Sally Shrapnel **12:15 - 12:30** **Explaining and evaluating quantum machine learning models** Samuel Wilkinson, Michael Hartmann, Muhammad Usman	**Characterising light in space, time, spectrum and polarisation** Martin Ploschner, Marcos Morote, Daniel Dahl, Mickael Mounaix, Greta Light, Aleksandar Rakic, Joel Carpenter **11:15 - 11:45** **Generation of Vortex Beams with Metaphotonic Structures** Yuri Kivshar **11:45 - 12:15** **Structured Light in nano and microsystems** Halina Rubinsztein-Dunlop, T. Neely, G. Gauthier, S. Simianovski, Z. Kerr, M. Davis, I. Favre-Bulle, M. Watson, P. Grant, T. Nieminen, A. Stilgoe **12:15 - 12:30** **Proof-of-concept of a 90-port arbitrary spatiotemporal vector beam shaper over 90nm bandwidth and two planes of phase manipulation** Mickael Mounaix, Nicolas Fontaine, David Neilson, Joel Carpenter
12:00 - 12:30						

	Aditya Dubey, Andreas Boes, Blanca del Rosal, Guanghui Ren, Thach Nguyen, Sumeet Walia, Brant Gibson, Arnan Mitchell					
12:30 - 13:30	**Lunch Break** ANZOS Annual General Meeting - Conference Room					
13:30 - 15:00	**Session 10.1 ANZCOP Integrated and topological photonics** Auditorium Andy Boes **13:30 - 14:00** **Exceptional points in momentum space and non-Hermitian topology of exciton-polaritons** Eliezer Estrecho **14:00 - 14:30** **Novel topological phenomena in photonic structures** Zhigang Chen **14:30 - 14:45** **Synthetic frequency dimension photonics with modulated LNOI ring devices** Hiep Dinh, Armandas Balcytis, Tomoki Ozawa, Yasutomo Ota, Toshihiko Baba, Satoshi Iwamoto, Arnan Mitchell, Thach Nguyen **14:45 - 15:00** **Efficient optical frequency doubling in SiN loaded LNOI waveguides by mitigating lateral leakage through operating near a bound state in the continuum** Jackson Jacob Chakkoria, Rifat Ahmmed Aoni, Aditya Dubey, Guanghui Ren, Thach G. Nguyen, Andreas Boes,	**Session 10.2 ANZCOP Focus Session Quantum and Non-Conventional Metaoptics II** Huxley Lecture Theatre Yana Izdebskaya, Jinyong Ma, Litty Thekkekara **13:30 - 14:00** **Localised states trapped by topological defects in photonic and hybrid metasurfaces** Daria Smirnova **14:00 - 14:15** **Rainbow metasurfaces for spectrally tunable high-harmonic generation** Piyush Jangid, Felix Ulrich Richter, Ming Lun Tseng, Ivan Sinev, Sergey Kruk, Hatice Altug, Yuri Kivshar **14:15 - 14:30** **Optimisation of Non-Linear Processes in Metasurfaces with Inverse Design** Neuton Li, Jihua Zhang, Marcus Cai, Dragomir Neshev, Andrey Sukhorukov **14:30 - 14:45** **Multi-functional Tuning of Liquid Crystals Metasurfaces** Yana Izdebskaya, Ziwei Yang, Vladlen Shvedov, Dragomir Neshev, Ilya Shadrivov	**Session 10.3 SPIE II** Conference Room (Lvl 4) Link to SPIE Pacific Rim Security + Defence Workshop [https://spie.org/conferences-and-exhibitions/pacific-rim-security--defence/programme?SSO=1] 13:30 – 13:55 - Photonic radar for high-performance sensing and imaging (Benjamin Eggleton) 13:55 – 14:20 - Infrared spectral sensing and imaging technologies for aerospace and defence (Lorenzo Faraone) 14:20 – 14:45 - Integrated molecular optoelectronics and quantum sensing (Ajay Pandey) 14:45 – 15:10 - Nanophotonics for light-weight night vision and sensor devices (Rocio Camacho Morales) 15:10 – 15:30 - Next-generation clocks for timing in GNSS-denied environments (Andre Luiten)	**Session 10.4 Quantum Machine Learning Focus Session** Board Room (Lvl 4) Barry Sanders **13:30 - 13:45** **Holomorphic Quantum Kernels for Continuous Variable Quantum Machine Learning** Rishi Goel, Laura Henderson, Sally Shrapnel **13:45 - 14:00** **Quantum Phase Recognition via Quantum Kernel Methods** Yusen Wu, Bujiao Wu, Jingbo Wang, Xiao Yuan **14:00 - 14:15** **Quantum Transfer Learning for Adversarially Robust Machine Learning on High-Resolution Datasets** Amena Khatun, Muhammad Usman **14:15 - 14:30** **Learning out-of-time-ordered correlators with quantum kernel methods** John Tanner, Jason Pye, Yusen Wu, Shengxin Zhuang, Jingbo Wang, Lyle Noakes, Wei Liu, Du Huynh **14:30 - 14:45** **Quantum Adversarial Machine Learning for Radio Signal Classification** Yanqiu Wu, Eromanga Adermann, Chandra Thapa, Seyit Camtepe, Hajime Suzuki, Muhammad Usman		**Session 10.5 ANZCOP Focus Session Structured light: recent advancement and perspectives II** Oliphant Conference Room Mickael Mounaix, Haoran Ren **13:30 - 14:00** **Planar polarization optics from camera to emission enhancement** Xiangping Li **14:00 - 14:30** **Quantum metasurfaces for single-photon structured light generation at room temperature** FEI DING **14:30 - 15:00** **Harnessing structured light for observational astronomy with Photonic Lanterns** Sergio Leon-Saval **15:00 - 15:30** **Rotational levitated optomechanics with structured light** Kishan Dholakia, Y. Arita, S. H. Simpson, G. D. Bruce, E. M. Wright, P. Zemánek

	Shankar K. Selvaraja, Arnan Mitchell	**14:45 - 15:00** **Metasurfaces Based Polarimetry with Redundancy for Satellite Imaging** Sarah Dean, Neuton Li, Josephine Munro, Robert Sharp, Dragomir Neshev, Andrey Sukhorukov		**14:45 - 15:00** **Calibrating the role of entanglement in variational quantum circuits** Azar Nakhl, Thomas Quella, Muhammad Usman		
15:00 - 15:30		**15:00 - 15:30** **Photon-pair generation and quantum measurements with metasurfaces** Andrey Sukhorukov		**15:00 - 15:15** **Complexity analysis of weakly noisy quantum states** Yusen Wu **15:15 - 15:30** **Quantum-Inspired Machine Learning: a Survey** Larry Huynh, Jin Hong, Ajmal Mian, Hajime Suzuki, Yanqiu Wu, Seyit Camtepe		
15:30 - 16:00	**Afternoon Tea** Exhibit Close					
16:00 - 17:30	**Poster Session - ANZCOP (Foyer) and Session: SPIE III (Conference Room Lvl 4)** The ANZCOP poster session is proudly supported byRaymax [https://www.raymax.com.au/] Link to SPIE Pacific Rim Security + Defence Workshop [https://spie.org/conferences-and-exhibitions/pacific-rim-security--defence/programme?SSO=1] **Enhanced generation of optical harmonics from resonant silicon metasurfaces** Pavel Tonkaev, Kirill Koshelev, Sergey Kruk, Yuri Kivshar **Nonlinear properties of femtosecond-laser inscribed waveguides into Gallium Lanthanum Sulfide glass** Trong Thuy Ha, Thomas Gretzinger, Alex Fuerbach **Temporal characteristics of stationary switching waves in a normal dispersion pulsed-pump fiber cavity** Matthew Macnaughtan, Miro Erkintalo, Stéphane Coen, Stuart Murdoch, Yiqing Xu **Nonlinear Up-Conversion Imaging Using Lithium Niobate Metasurfaces** Laura Valencia, Rocio Camacho Morales, Jihua Zhang, Isabelle Staude, Andrey Sukhorukov, Dragomir Neshev **Size Dependent Two-photon Absorption in Au and Ag Nanospheres** Callum McArthur, Sarah Walden, Esa Jaatinen **Enhanced Second Harmonic Generation in freeform dielectric metasurfaces** Rocio Camacho Morales, Neuton Li, Tuomas Haggren, Samantha Williams, Hark Hoe Tan, Chennupati Jagadish, Andrey Sukhorukov, Dragomir Neshev **A general analytic method for finding soliton solutions** Long Qiang, Neil Broderick, Martijn de Sterke **Scattering from a temporal medium** Sarvesh Kumar, Venkatachalam Subramanian					

Resonance-driven optical torques at the nanoscale
Ivan Toftul, Yuri Kivshar

Integrated Silicon-on-Insulator Optomechanical Magnetometers.
Benjamin Carey

Enhancing Efficiency of High-Powered AlGaAs Edge-Emitting Laser Through Coupled Waveguides at 793nm
Jacob Charvetto, Jamie McInnes, Glenn Solomon

Brillouin laser at 1064 nm with Cascade-Control Using an Etalon Input Coupler
Adam Sharp, David Spence, Rich Mildren

Isolator-Free 40 W Diamond Raman Laser at 607 nm
Adam Sharp, Hadiya Jasbeer, Richard Pahlavani, David Spence, Rich Mildren

Frequency Stabilised Diamond Raman Laser
Richard Pahlavani, Hadiya Jasbeer, Adam Sharp, Rich Mildren

Gap-surface plasmon-induced Indium selenide photoluminescence enhancement
Ha Young Lee, Damian Nelson, Wei Yan, Kenneth B Crozier, James Bullock, Sejeong Kim

Optical coupling in lasing semiconductor nanowires
Lukas Raam Jaeger, Francesco Vitale, Wei Wen Wong, Hoe Tan, Carsten Ronning

Quantum-enhanced multispectral Raman imaging
Alex Terrasson, Nicolas Maraunyapin, Warwick Bowen

Single-photon source for rare-earth doped crystal quantum memories
Luke Trainor, Helen Chrzanowski, Xavier Barcons Planas, Janik Wolters, Jevon Longdell

Detecting single photon events with superconducting thin film Niobium Nitrate
Samantha Summerford, Declan Gossink, Jamie McInnes, Glenn Solomon

Gradient Order Effect in the Gradient Echo Memory: Revisiting the 3-level Atom
Jesse Everett, Ankit Papneja, Arindam Saha, Cameron Trainor, Aaron Tranter, Ben Buchler

III-V Nanowire Quantum Well Infrared Photodetectors
Yue Bian, Lan Fu

Optical Fibre Environmental Sensors for use in Sewers
Lachlan Anderson, Martin Ams, Peter Dekker, Thomas Kuen, Louisa Vorreiter, Heri Bustamante, Michael Withford

Characterising cartilage degeneration using polarisation-sensitive optical coherence tomography
Darven Murali Tharan, Matthew Goodwin, Daniel Everett, Cushla McGoverin, Sue McGlashan, Ashvin Thambyah, Marco Bonesi, Frédérique Vanholsbeeck

Experimental observation of linear pulse evolution with high-order dispersion
Dhruv Hariharan, Martijn de Sterke, Antoine Runge

Free Space Optical Transceiver: Mechanical design review
aaesha alteneiji, Asma Al Ahmadi, Layla Alshehhi, karim Elayoubi, Juan coronel

Wavefront Beam Characterization Through Turbulence Emulator
Karim Elayoubi, Juan Coronel, Asma Al Ahmadi, Aaesha Alteneiji, Reem Al Ameri, Abdellatif Bouchalkha, Safa Al Hosani

Designing a Microstructured Optical Fiber Hydrophone
Harry Schutz, Stephen Warren-Smith, Wen Qi Zhang

Polarization and spectral tuning using VO2 nano-fins
Caleb Estherby, Matthew Tai, Matthew Arnold, Angus Gentle, Michael Cortie

Flexible metasurface-nanowire LED integrated device for optical sensing
Dawei Liu, Shridhar Manjunath, Duk Choi, Yue Bian, Angela Barreda, Buddini Karawdeniya, Isabelle Staude, Hoe Tan, Dragomir Neshev, Chennupati Jagadish, Lan Fu

Formation and growth of photodeposited Ag microstructures on ZnO thin films.
David Sutton, Esa Jaatinen

Metasurface-nanowire photodetectors for polarization sensitive infrared photon detection and imaging
Longsibo Huang, Yang Yu, Li Li, Chaohao Chen, Songqing Zhang, Han Wang, Wenwu Pan, Wen Lei, Lorenzo Faraone, Chennupati Jagadish, Ziyuan Li, Lan Fu

A Frequency Measurement Method for the MEMS Infrared Resonance Sensor
XIA ZHANG, HANWEI ZHOU, DACHENG ZHANG

Quantitative Polychromatic Dual Energy X-ray Imaging and Tomography
Yiyue Huang, Andrew Kingston, Adrian Sheppard

Analysis on Optical Coherence Tomography Scans to Detect Irregularities and Restoration Work on Paper-Based Artwork
Hendrik Nieuwboer, Camilla Baskcomb, Marco Bonesi, Matthew Goodwin, Abi Thampi, Frederique Vanholsbeeck

Measuring water temperature and salinity simultaneously with a laser.
Carolyn Taylor, Ondrej Kitzler, Simon Curtis, Brad Neimann, Judith Dawes, James Downes, David Spence, Helen Pask

Comparison of lidar sensing methods for oceanic temperature measurement
Brad R. Neimann, David J. Spence

Ultra Lightweight Handheld Optical Coherence Tomography Probe for Tissue Imaging
Alok K Kushwaha, Sneha Sethi, Minqi Ji, Lisa Jamieson, Robert A. Mclaughlin, Jiawen Li

Selective Area Epitaxy of Multi GaAs/AlGaAs Radial Quantum well Nanowire Lasers
Anha Bhat, Ziyuan Li, Olivier Lee Cheong Lem, Naiyin Wang, Li Li, Felipe Kremer, Wei Wen Wong, Mykhaylo Lysevych, Chennupati Jagadish, Hark Hoe Tan, Lan Fu

Ultrafast All-Optical Valleytronics in WSe2 Monolayers
Sebastian Klimmer, Paul Herrmann, Thomas Lettau, Mohammad Monfared, Isabelle Staude, Ioannis Paradisanos, Ulf Peschel, Giancarlo Soavi

Thermal Phase-only Tuning of Huygens Metasurfaces
Khosro Zangeneh Kamali, Dragomir Neshev

	Highly Directional and Long-Propagating Ghost Phonon Polaritons through Selective Mode Excitation Manuka Suriyage, Yuerui Lu **InAs/InAsP/InP core-shell nanowire arrays for SWIR photodetector applications** Yang Yu, Wei Wen Wong, Zhe Li, Chaudhary Deepanshu Sheetla Prasad, Kosala Dhanawansha, Hark Hoe Tan, Chennupati Jagadish, Ziyuan Li, Lan Fu **2D Quantum Materials for Next-generation Photonic and Quantum Devices** Yuerui Lu **Switchable Edge Detection with Multilayered Thin Film Structures** Jia Le Lai, Rocio Camacho-Morales, Dragomir Neshev **Spatial and polarisation characterisation of photonic lanterns** Adam Taras, Barnaby Norris, Sergio Leon-Saval **Short-timescale laser frequency stabilisation at the 0.1 Hz/√Hz level** Ya Zhang, Chathura Bandutunga, Terry McRae, Malcolm Gray, Jong Chow **Enhanced absorption in two-dimensional materials via inverse-designed metasurface** Jaegang Jo, Haejun Chung, Sejeong Kim **Modelling mid-spatial frequency manufacturing errors for aspherical optics** Israel Vaughn, Andrew Kruse **Cranial Car Key Communication: Human Heads as Microwave Antennas** Adem Ozer, James Bainbridge, Michael Steel, Mikolaj Schmidt **Extraordinary second harmonic generation modulated by divergent strain field in pressurized monolayer domes** Boqing Liu **Addressing Optomechanical Drift in a Spatiotemporal Beam Shaping System** Andrew Komonen, Daniel Dahl, Martin Plöschner, Marcos Morote, Nicolas Fontaine, Joel Carpenter, Mickael Mounaix **Photon transport in two-dimensional atom arrays** Alexander Johnston, Sahand Mahmoodian **Strong-field nanophotonics with wide-bandgap semiconductors.** Albert Mathew, Sergey Kruk, Kazuhiro Yabana, Shunsuke Yamada, Anatoli Kheifets
17:30 - 18:00	
18:00 - 19:30	**Industry Networking Event** Foyer Sponsored by Momentum, Physics ANU

Friday, 8th Dec 2023

	Parallel Session 1	Parallel Session 2	Parallel Session 3	Parallel Session 4	Parallel Session 5	Parallel Session 6
07:30 - 08:30	**Morning Walk/Run/Yoga - Wellness Program** Sponsored by ANU RSPhys Equity and Diversity Committee Walk: Learn More and Register Here [https://aip-summer-meeting.com/social_events/] Run/Jog: Learn More and Register Here [https://aip-summer-meeting.com/social_events/] Yoga: Learn More and Register Here [https://aip-summer-meeting.com/social_events/]					
08:30 - 09:15	**Session P6 ANZCOP Plenary** Auditorium Plenary Speakers Plenary Speaker: Jennifer Kehlet Barton **Optical Imaging with miniature endoscopes for early cancer detection** Chair: Jiawen Li					
09:15 - 09:45	**Morning Tea**					
09:45 - 11:45	**Session 11.1 ANZCOP Nanophotonics & Nanoplasmonics I** Auditorium Andrey Miroshnichenko Dr. Kirill Koshelev's invited talk celebrates his achievement of winning the Bragg Gold Medal for Excellence in Physics by the Australian Institute of Physics. For more information about this honor, please visit:Bragg Medal Information [https://www.aip.org.au/bragg-medal]. **09:45 - 10:15** **Passive and tunable metasurfaces based on dielectric nanoantennas** Arseniy Kuznetsov **10:15 - 10:30**	**Session 11.2 ANZCOP Biophotonics & Optical Sensors I** Huxley Lecture Theatre Frédérique Vanholsbeeck **09:45 - 10:15** **What did Theranos get right? The race to desk-top diagnostics ...** Cather Simpson **10:15 - 10:30** **Sensing rotational inertia for fast viscometry measurements** Mark Watson, Alexander Stilgoe, Itia Favre-Bulle, Halina Rubinsztein-Dunlop	**Session 11.3 ANZCOP Focus Session Structured light: recent advancement and perspectives III** Conference Room (Lvl 4) Mickael Mounaix, Haoran Ren **09:45 - 10:15** **Tailoring nonlinear optical pulses with structured light** Antoine Runge **10:15 - 10:45** **Mitigating nonlinear effects in multimode fibers with focused output via wavefront shaping** Stephen Warren-Smith, Chun-Wei Chun, Linh Nguyen, Kabish Wisal, Shuen Wei, Ori Henderson-Sapir, Erik Schartner, Peyman	**Session 11.4 ANZCOP Memorial session for Prof. Jim Piper I** Oliphant Conference Room David Lancaster Sponsored by MQ Photonics and ANZOS **10:15 - 10:45** **My Mate Jim Piper** Brian Orr **10:45 - 11:15** **In memory of Jim Piper: Biophotonics** Jin Dayong		

	Near infrared color center integratednanophotonics in an integrated sample and singlephoton detector cryogenic system Victoria Norman, Sridhar Majety, Pranta Saha, Alex Rubin, Marina Radulaski **10:30 - 10:45** **Large Area Two Wavelength Colour Routing via Multilayer Huygens' Metasurfaces** Joshua Jordaan, Alexander Minovich, Dragomir Neshev, Isabelle Staude **10:45 - 11:00** **Molecular strong coupling: an exploration employing open, half- and full planar cavities** Kishan Menghrajani, Adarsh Vasista, Wai Jue Tan, Stefan Maier, William Barnes **11:00 - 11:15** **Manipulation of Electric and Magnetic Dipolar Emission from Lanthanides Using Nanoscopic Structures for Polarization-Controlled Light Emission** Marijn Rikers, Ayesheh Bashiri, Aleksandr Vaskin, Angela Barreda, Michael Steinert, Duk-Yong Choi, Thomas Pertsch, Isabelle Staude **11:15 - 11:45** **Advanced Light Trapping in Resonant Dielectric Metastructures for Nonlinear Optics** Kirill Koshelev **11:45 - 12:00** **Beyond the Purcell Effect: Modifying Spontaneous Emission via Plasmonic Doping** Mohsin Ijaz, Boyang Ding, Richard Blaikie	**10:30 - 10:45** **High Sensitivity Measurement of Refractive Index Using the Orbital Angular Momentum of Light** Anastasiia Zalogina, Aman Punse, Crispin Szydzik, Chris Perrella, Andy Boes, Arnan Mitchell, Kishan Dholakia **10:45 - 11:00** **Optical Tweezers for Microrheology of the Cumulus Matrix in a Microlitre Volume** Chris Perrella, Carl Campugan, Tania Mendonca, Cheow Yuen Tan, Erik Schartner, Yoshihiko Arita, Graham Bruce, Amanda Wright, Kishan Dholakia, Kylie Dunning **11:00 - 11:15** **Biohydrodynamics of bacterial-based active matter** Patrick Grant, Mark Watson, Timo Nieminen, Alexander Stilgoe, Halina Rubinsztein-Dunlop **11:15 - 11:30** **Fast detection of single proteins with integrated plasmonic-photonic hybrid cavities** Igor Marinkovic, Larnii Booth, Warwick Bowen **11:30 - 11:45** **Laser-based trace-level sensing of molecules in agricultural and environmental air** Yabai He, Julian Hill, Brian Orr	Ahmadi, Heike Ebendorff-Heidepriem, A. Douglas Stone, David Ottaway, Hui Cao **10:45 - 11:15** **Colored Structured Light with Incoherent White Light Illumination** Hongtao Wang, Joel Yang **11:15 - 11:45** **Spatiotemporal optical beam shaping and measurement** Joel Carpenter	**11:15 - 11:45** **In memory of Jim Piper: Raman lasers and beyond** Helen Pask **11:45 - 12:15** **From pilot project to a world leading National laser microfabrication facility** Michael Withford		
11:45 - 12:00						
12:00 - 13:00	**Lunch Break**					
13:00 - 13:45	**Session P7 ANZCOP Plenary** Auditorium Plenary Speakers Plenary Speaker: Tomoki Ozawa Chair: Daria Smirnova					

	Recent developments in synthetic-dimension photonics Tomoki Ozawa					
13:45 - 13:50						
13:50 - 14:50	**Session 12.1 ANZCOP Nanophotonics & Nanoplasmonics II** Auditorium Alexander Solntsev **13:50 - 14:05** **Towards a Dynamic and Switchable All-Optical Image Processing Device** Dominik Ludescher, Lukas Wesemann, Lincoln Clark, Mario Hentschel, Harald Gießen, A Roberts **14:05 - 14:20** **Trapping Light in Air with Dielectric Mie Voids** Kirill Koshelev, Mario Hentschel, Florian Sterl, Steffen Both, Julian Karst, Lida Shamsafar, Thomas Weiss, Yuri Kivshar, Harald Giessen **14:20 - 14:35** **Fragility of edge states in topological photonic structures** Yecheng Hu, Alex Y. Song **14:35 - 14:50** **Optimisation Of Lasing Metasurfaces With Symmetry Constraints On The Modes** Matthew Parry, Kenneth Crozier, Andrey Sukhorukov, Dragomir Neshev	**Session 12.2 ANZCOP Biophotonics & Optical Sensors II** Huxley Lecture Theatre Lukas Wesemann **13:50 - 14:20** **Advances in functional optical coherence tomography: translation of F-OCT technology from bench to bedside** Zhongping Chen **14:20 - 14:35** **Diagnostic accuracy of stereoscopic optical palpation for tumour margin assessment in breast-conserving surgery** Qi Fang, Rowan Sanderson, Renate Zilkens, Imogen Boman, Ken Foo, Devina Lakhiani, Benjamin Dessauvagie, Christobel Saunders, Brendan Kennedy **14:35 - 14:50** **The development of structured phantoms to investigate surface roughness in optical coherence elastography** Rowan Sanderson, Harrison Caddy, Hina Ismail, Ken Foo, Lachlan Kelsey, Devina Lakhiani, Peijun Gong, Chris Yeomans, Benjamin Dessauvagie, Christobel Saunders, Barry Doyle, Brendan Kennedy	**Session 12.3 ANZCOP Fiber Optics & Communications** Conference Room (Lvl 4) Simon Fleming **13:50 - 14:20** **Distributed Acoustic Sensing in observational seismology – a case study for characterising the Alpine Fault at Haast (South Westland, New Zealand)** Meghan Miller, Voon Hui Lai, John Townend **14:20 - 14:35** **High-sensitivity measurement of optical absorption at 2µm in ZBLAN glass** Sophie Muusse, Nutsinee Kijbunchoo, Sebastian Ng, Huy Tuong Cao, Alson Ng, Erik Schartner, Alexander Hemming, Heike Ebendorff-Heidepriem, Peter Veitch **14:35 - 14:50** **Development of a Fibre-Coupled Erbium Based Quantum Memory** Paul McMahon, Matthew Sellars	**Session 12.4 ANZCOP Memorial session for Prof. Jim Piper II** Oliphant Conference Room David Lancaster Sponsored by MQ Photonics and ANZOS **13:50 - 14:20** **In memory of Jim Piper: Self-frequency-doubling crystal lasers and strong collaborative works with Shandong University, China** Pu Wang **14:20 - 14:50** **Arcs, Sparks, Colours … Jim Piper's world-leading contributions to Metal Vapour Laser Innovation, Applications and Training** Daniel Brown		
14:50 - 15:05		**Session 13.2 ANZCOP Biophotonics & Optical Sensors III** Huxley Lecture Theatre Robert McLaughlin **14:50 - 15:05**	**Session 13.3 ANZCOP Novel photonic materials & Fabrication** Conference Room (Lvl 4) Mikael Kall **14:50 - 15:05** **Robustness of optical skyrmions** Haoran Ren			
15:05 - 15:50	**Session 13.1 ANZCOP Laser physics & Active photonics** Auditorium Alexander Solntsev			**Session 13.4 ANZCOP THz & Microwave photonics** Board Room (Lvl 4)		

	15:05 - 15:20 **Development of ytterbium-fibre amplifier system producing 72fs pulses for coherent supercontinuum generation** Naveed Abbas, Claude Aguergaray, Neil G. R. Broderick **15:20 - 15:35** **Thulium-doped silicate fiber lasers between 1900 and 2050 nm for next-generation Gravitational wave detectors** Georgia Bolingbroke, Michael Oermann, Sebastian Ng, Alex Hemming, Dmitrii Stepanov, Jesper Munch, Peter Veitch **15:35 - 15:50** **Development of an ocean LiDAR for sensing of water column properties** Ondrej Kitzler, Carolyn Taylor, Simon Curtis, Brad Neimann, James Downes, Judith Dawes, Helen Pask, David Spence	**Event-Based Imaging for Biophotonics: Optimising the Tracking of Passive & Active Matter** Gabriel Britto Monteiro, Megan Lim, Tiffany Cheow Yuen Tan, Avinash Upadhya, Zhuo Liang, Tomonori Hu, Benjamin J. Eggleton, Chris Perrella, Kylie Dunning, Kishan Dholakia **15:05 - 15:35** **Lasers, Milk, Blood and Sperm – Making Light Work** Cather Simpson	**15:05 - 15:20** **Hybrid Integration of Chalcogenide Waveguides with Silica Template for Infrared Nonlinear Applications** Duk-Yong Choi, Hansuek Lee **15:20 - 15:35** **3D Graphitised Stretchable and Wearable Devices** Litty Varghese Thekkekara **15:35 - 15:50** **Multiwavelength InGaAs/InP quantum well nanowire array micro-LEDs for high-speed optical communications** Zhe Li, Fanlu Zhang, Zhicheng Su, Yi Zhu, Nikita Gagrani, Mark Lockrey, Li Li, Igor Aharonovich, Yuerui Lu, Hoe Tan, Chennupati Jagadish, Lan Fu	Ilya Shadrivov **15:05 - 15:20** **Active control of bound states in the continuum in toroidal metasurfaces with vanadium dioxide** Fedor Kovalev, Andrey Miroshnichenko, Alexey Basharin, Ilya Shadrivov **15:20 - 15:35** **Enhancement of chiroptical response in high-quality metallic metasurfaces** Yiyuan Wang, Jinhui Shi **15:35 - 15:50** **Photonic Radar with Millimetre Resolution for UAV and Vital Sign Detection** Ziqian Zhang, Yang Liu, Eric Magi, Benjamin Eggleton		
15:50 - 16:20	**Awards and Closing Ceremony** Auditorium					

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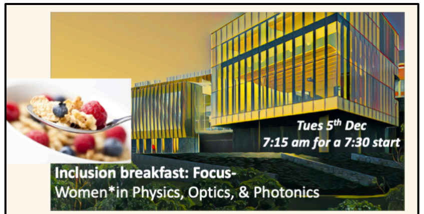

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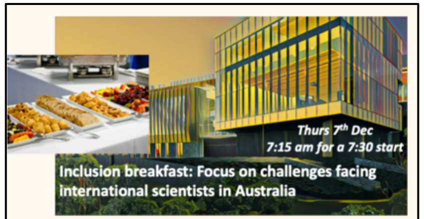

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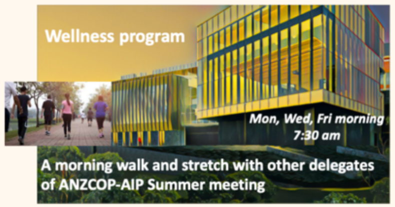

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INVITED TALKS

37

Testing Plasma Physics with multi-wavelength observations of the Sun and other stars

Mark Cheung
CSIRO, Marsfield, Australia

Abstract

Stellar interiors and atmospheres span a wide range of plasma regimes, and are natural laboratories for plasma physics. In particular, remote sensing of the Sun across the electromagnetic spectrum provides important constraints on a range of (astro)physical phenomena, including magnetic reconnection, magnetised shocks, dynamo action, magnetohydrodynamic turbulence, particle acceleration, conservation of topological invariants (e.g. magnetic helicity), solar/stellar flares, and more. In this talk, we will illustrate a few of these topics with data from spaceborne and ground-based observatories, using them to evaluate state-of-the-art numerical models.

Generation of Vortex Beams with Metaphotonic Structures

Yuri Kivshar
Australian National University, Canberra, Australia

Abstract

Optical vortices provide one of the promising solutions for enhancing the capacity of data multiplexing to meet an unprecedented growth in big data and internet traffic information [1]. The optical vortex possesses a phase singularity—an undefined phase in the beam center—and has attracted special attention for carrying the orbital angular momentum (OAM). Although several coherent light sources with OAMs have been developed thus far, there are limitations to the rational design of ultra-small, high-quality optical cavities supporting vortex modes. Here, we discuss several approaches to generate optical vortex beams at the nanoscale.

First, we demonstrate wavelength-scale, low-threshold, vortex, and anti-vortex nanolasers with OAMs of ±1, using symmetric optical cavities designed via topological disclination, see Figs. 1(a,b). Various photonic disclination cavities were designed using the similarities between tight-binding models and numerical simulations. These unprecedented optical nanocavities exhibit strong confinement of resonant modes with OAMs by retaining the angular momentum observed in disclination geometries. In the experiment, the OAM lasing modes were clearly identified by measuring polarization-resolved images and self-interference patterns.

Next, we suggest and demonstrate a new strategy for the vortex generation at the nanoscale that surpasses single-pixel phase control. We reveal that interaction between the neighboring nanopillars of the metaphotonic quadrumer (metamolecule) can tailor both intensity and phase of transmitted light. Consequently, a subwavelength nanopillar quadrumer is sufficient to cover $2l\pi$ phase change, thereby efficiently converting incident light into high-purity optical vortices with different topological charges l. Benefiting from the nanoscale footprint of metaphotonic quadrumers, we demonstrate high-density vortex beam arrays and high-dimensional information encryption, bringing a new degree of freedom to many designs of metadevices.

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Distributed Acoustic Sensing in observational seismology – a case study for characterising the Alpine Fault at Haast (South Westland, New Zealand)

Meghan Miller[1], Voon Hui Lai[1], John Townend[2]
[1]Australian National Univeristy, Canberra, Australia. [2]Victoria University of Wellington, Wellington, New Zealand

Abstract

Distributed acoustic sensing (DAS), a new type of passive seismic sensor, is positioned to revolutionise seismology by providing dense spatial sampling and temporal resolution. DAS repurposes long sections (1-10s of kilometres) of fibre optic cable into thousands of individual sensors ("large-N") at meter spacing and uses light to measure the ground motion as seismic waves pass through the fibre. We introduce a new DAS array deployed for nearly 3 months between late-February and mid-May 2023 near Haast in the South Island of New Zealand. This experiment utilises ~25 km-long telecommunication fibers running roughly parallel and perpendicular to the Alpine Fault, which marks the boundary between the Australian Plate and the Pacific Plate. The Alpine Fault produces large (~M8) earthquakes every 200-400 years, with the last large earthquake occurring in 1717 AD.

A key goal of this DAS deployment and planned further work is to improve characterization of natural hazards in southern New Zealand including Alpine Fault seismicity and rockfalls, and to demonstrate the feasibility of DAS studies using dark commercial telecommunications fibers in New Zealand. Due to the high temporal (1 kHz) and spatial resolution (4-metre), DAS can improve the detection of weak seismic sources, including low-magnitude earthquakes diagnostic of fault activity, rockfalls and avalanches in remote mountainous region. The dense sensor deployment across the Alpine Fault further allows us to make high-resolution images of the fault zone including the near-surface fault geometry and structure where it crosses the sole highway in the area. The DAS acquisition coincided with the operation of the ~450 km-long Southern Alps Long Skinny Array (SALSA), which includes 45 seismometers installed 10–12 km apart within ~3 km of the fault trace, to provide new opportunities for interpreting DAS and conventional seismometer data to study seismicity and fault geometry.

63

Biological tissues as active homeostatic materials

Alpha Yap
IMB, University of Queensland, Brisbane, Australia

Abstract

My talk will consider the mechanobiology of epithelia. Epithelia are a fundamental mode of tissue organization in multicellular animals, where sheets of cells are connected together by cell-cell adhesion systems. The result is to create communities of cells with potential emergent properties. It is now apparent that epithelia behave as active mechanical materials. In particular, cell-cell adhesion junctions not only couple cells together, but allow cytoskeletal forces to generate tension at those junctions themselves. Further, those adhesion junctions possess mechanotransduction mechanisms to sense changes in mechanical force. Thus cell-cell adhesions can support mechanical homeostasis in epithelial tissues: detecting force imbalances and eliciting proportionate responses. I will discuss the cellular processes responsible for mechanical homeostasis. Finally, I will consider the hypothesis that such mechanical homeostasis can be utilized by epithelia for biological homeostasis: as a quick response mechanism to challenges to tissue integrity, such as cell injury and apoptosis.

64

Tailoring nonlinear optical pulses with structured light

Antoine Runge
University of Sydney, Sydney, Australia

Abstract

Chromatic dispersion plays a key role in numerous modern applications, ranging from telecommunication to supercontinuum and ultrashort pulse generations. For example, optical solitons balance self-phase modulation (SPM) and negative quadratic dispersion ($\beta_2 < 0$). On the other hand, higher orders of dispersion are commonly seen as perturbations of this conventional soliton model, either limiting the pulse duration or the stability of the propagating pulse. Recently, a new type of shape-maintaining pulses, known as pure-quartic solitons (PQSs), and arising from the balance between SPM and negative quadratic dispersion ($\beta_4 < 0$), was identified in a photonic crystal waveguide. This showed that higher order dispersion effects can be leveraged for optical pulse control and enable innovations in nonlinear optics. However, the fabrication of waveguides with dominant high order dispersion remains challenging, limiting the experimental generation of these new pulses.

I review our recent work on the generation of new optical solitons arising from hybrid high-order dispersion. By using a mode-locked fiber laser, incorporating a spectral pulse-shaper which allows for the precise tailoring of the net-cavity dispersion, we access a wide range of new operating regimes corresponding to previously unobserved soliton pulses. We demonstrate the generation of solitons arising between SPM and any pure, negative even order of dispersion.

Using this dispersion engineering technique, we also demonstrated a novel technique in which nonlinear effects can be enhanced through the tailoring of the linear dispersion so as to exhibit J identical maxima that are periodically spaced in frequency. This leads to the formation of J coincident optical pulses co-propagating at the same group velocity, so that they mutually interfere. In the time domain, this corresponds to a highly non-uniform carrier that leads to the enhancement of the effective nonlinearity.

65

Ultralow-Noise Microwave Generation via with a Single Laser

Alexander Gaeta
Columbia University, New York, USA

Abstract

We demonstrate optical frequency division on a single photonic chip driven by a single continuous-wave laser using the principle of all-optical harmonic synchronization. This is accomplished by synchronizing two distinct dynamical states of Kerr cavities and transferring the stability of a high-frequency reference waveform to a low-repetition-rate Kerr comb. The reference state is the beat frequency of the signal and idler fields from a microresonator-based optical parametric oscillator (OPO), which achieves high phase stability due to the inherently strong signal-idler frequency correlations. The Kerr comb is synchronized to the OPO via a coupling waveguide, where harmonic factors of 34 and 468 are achieved for 227-GHz and 16-GHz soliton combs, respectively. We achieve a 630-fold phase-noise reduction and a 16-GHz microwave signal is generated via photodetection, which demonstrates the lowest microwave noise achieved on the silicon-nitride platform. This work offers a simple, effective approach for performing OFD and provides a pathway toward chip-scale devices that can generate microwave frequencies comparable to the purest tones produced in metrological laboratories.

66

Arbitrary structuring of single photons with a multifunctional metalens

Chi Li[1,2], Jaehyuck Jang[3], Trevon Badloe[4,5], Tieshan Yang[2], Joohoon Kim[4], Jaekyung Kim[4], Minh Nguyen[2], Stefan Maier[1,6], Junsuk Rho[3,7,8,9], Haoran Ren[1], Igor Aharonovich[2,10]
[1]School of Physics and Astronomy, Monash University, Melbourne, Australia. [2]School of Mathematical and Physical Sciences, University of Technology Sydney, Sydney, Australia. [3]Department of Chemical Engineering, Pohang University of Science and Technology, Pohang, Korea, Republic of. [4]Department of Mechanical Engineering, Pohang University of Science and Technology, Pohang, Korea, Republic of. [5]Graduate School of Artificial Intelligence, Pohang University of Science and Technology, Pohang, Korea, Republic of. [6]Department of Physics, Imperial College London, London, United Kingdom. [7]Department of Mechanical Engineering, Pohang University of Science and Technolog, Pohang, Korea, Republic of. [8]POSCO-POSTECH-RIST Convergence Research Centre for Flat Optics and Metaphotonics, Pohang, Korea, Republic of. [9]National Institute of Nanomaterials Technology (NINT), Pohang, Korea, Republic of. [10]ARC Centre of Excellence for Transformative Meta-Optical Systems, University of Technology Sydney, Sydney, Australia

Abstract

Structuring light emission from single-photon emitters (SPEs) in multiple degrees of freedom is of a great importance for quantum information processing towards higher dimensions [1]. However, traditional control of emission from quantum light sources relies on the use of multiple bulky optical elements or nanostructured resonators with limited functionalities, constraining the potential of multi-dimensional tailoring [2]. Here we introduce the use of an ultrathin polarisation-beam-splitting metalens for the arbitrary structuring of quantum emission at room temperature [3]. Including, directionality, polarisation, and orbital angular momentum (OAM) simultaneously (Fig. 1A).

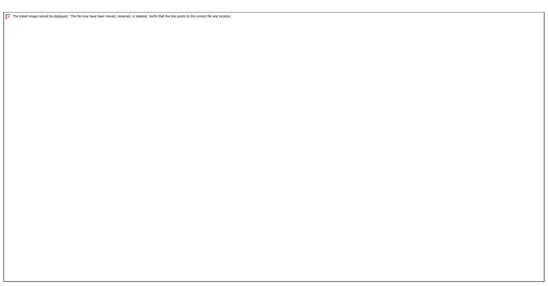

Fig. 1. Schematics of multidimensional manipulation of hBN quantum emission using a multifunctional metalens. (A) Directional photon splitting, polarisation control and subsequent OAM encoding. (B, C) Enlarged views of each encoding concept where grating and vortex grating are adapted to structure the photons in extra dimensions. In addition, the directionality of orthogonal linear polarisations is well inherited and projected as the red and blue spots in the momentum (k) space.

We demonstrate arbitrary shaping of the directionality of quantum emission by adding phase gratings selective to orthogonal polarisations onto the metalens profile, which are represented by different spots in the momentum space of the metalens (Fig. 1B). In addition, we show that different

helical wavefronts can be further added onto the metalens profile, leading to the generation of distinctive OAM modes in orthogonal polarisations of SPEs, which are represented by doughnut-shaped spots with different sizes in momentum space (Fig. 1C).

We proposed and implemented a multifunctional metalens to arbitrarily structure quantum light sources at room temperature. And further experimentally demonstrated with bright and linearly polarised SPEs in hBN. The demonstrated arbitrary wavefront shaping of quantum emission in multiple degrees of freedom could unleash the full potential of solid-state SPEs to be used as high-dimensional quantum sources for advanced quantum photonic applications.

76

Mitigating nonlinear effects in multimode fibers with focused output via wavefront shaping

Stephen Warren-Smith[1], Chun-Wei Chun[2], Linh Nguyen[1], Kabish Wisal[2], Shuen Wei[3], Ori Henderson-Sapir[3], Erik Schartner[3], Peyman Ahmadi[4], Heike Ebendorff-Heidepriem[3], A. Douglas Stone[2], David Ottaway[3], Hui Cao[2]
[1]University of South Australia, Mawson Lakes, Australia. [2]Yale University, New Haven, USA. [3]The University of Adelaide, Adelaide, Australia. [4]Coherent, Bloomfield, USA

Abstract

A paradigm shift in optical fiber laser technology requires fundamentally new strategies for overcoming intrinsic limitations of operating in the single transverse mode regime while maintaining high beam quality output. We are investigating novel techniques based on mode control in multimode optical fiber amplifiers that allow for suppression of nonlinear effects, such as stimulated Brillouin scattering, while maintaining high beam quality. We show experimentally that wavefront-shaping of coherent input light that is incident on a highly multimode fiber can increase the power threshold for stimulated Brillouin scattering (SBS) by an order of magnitude, whilst simultaneously controlling the output beam profile. Our theoretical model reveals that the suppression of SBS is due to the relative weakness of intermodal scattering compared to intramodal scattering, and to an effective broadening of the Brillouin spectrum under multimode excitation. Our method is efficient, robust, and applicable to continuous waves and pulses. This work points toward a promising route for suppressing detrimental nonlinear effects in optical fibers, which will enable further power scaling of high-power fiber systems for applications to directed energy, remote sensing, and gravitational-wave detection.

77

Shedding New Light on Image Processing with Metasurfaces

Ann Roberts
The University of Melbourne, Melbourne, Australia

Abstract

The modification of optical images is ubiquitous in contemporary technology and the widespread availability of digital cameras means that this is most often performed using computational methods. With increasing concerns over energy consumption and the rise of applications where time is critical, there is renewed interest in all-optical or hybrid approaches to image processing. The use of optical systems to perform image processing in the Fourier plane was first demonstrated in the 1940s and has the significant benefits of real-time operation with no additional energy required. Such methods can also be extended to the visualization of the phase of an optical field as implemented in Zernike phase contrast microscopy. This permits imaging samples with weak absorption that include many biological cells that are typically imaged following staining which precludes investigation of cellular and subcellular dynamics. Microscopic phase information has typically been obtained using interferometric methods including digital holographic and Differential Interference Contrast (DIC) microscopy. These conventional optical approaches to phase contrast imaging typically require relatively bulky, and sometimes expensive, optics. More recently, there have been demonstrations of sophisticated computational strategies for extracting phase from intensity, but these can be relatively slow, limiting throughput. The increasing availability of meta-optical approaches for image processing and optical analogue computing, more generally, provides a new avenue for extracting information from optical fields, including using an image (rather than Fourier) plane spatial filtering approach. Although techniques such as edge enhancement have attracted widespread attention, phase visualization and wavefront recovery are also compelling applications of this paradigm.

This presentation will discuss recent developments in nanophotonic approaches to all-optical image processing and wavefront recovery. The introduction of tunability of the device using polarization or thermally controllable phase change materials to permit different imaging modalities (such as conventional bright field or phase contrast) will be highlighted.

81

Colored Structured Light with Incoherent White Light Illumination

Hongtao Wang, Joel Yang
Singapore University of Technology and Design, Singapore, Singapore

Abstract

Recent advances in nanofabrication techniques have opened new avenues for controlling light, including polarization, phase, and orbital angular momentum (OAM). OAM beams have various applications from classical optics to quantum, but typically relies on coherent laser sources, unlike ambient incoherent light source. To bridge this gap, our research enhanced the spatio-temporal coherence of incident white light and generated colored OAM beams to operate under incoherent white light conditions. Empowered by two-photon polymerization lithography, we designed and fabricated colored vortex beam (CVB) units with 3D nanoscale features. Based on these CVB units, we develop photonic tallies encoding color, spatial position, and OAM information. When combined with photonic tally "keys," distinct patterns of colored rings emerged, forming an encrypted optical code that could be machine-readable and verified against a database. Detection of CVB only requires an ordinary optical microscope with reduced aperture illumination, making it a straightforward process. This method offers a robust optical anti-counterfeiting solution with cross-pair verification capabilities.

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Sub-10-nm Nanofabrication of Optical Antennas for Manipulating Light-Matter Interactions

Zhaogang Dong
Institute of Materials Research and Engineering, A*STAR, Singapore, Singapore. Department of Materials Science and Engineering, National University of Singapore, Singapore, Singapore

Abstract

Nanostructural optical antennas have enabled the strong light-matter interactions, where the structural resonances are either based on plasmonics or dielectric Mie resonances. In this talk, we present our recent work on the sub-10-nm nanofabrication of optical antennas for manipulating light-matter interactions [1], imaging of the inaccessible bound-states-in-the-continuum (BIC) mode [2], quasi-BIC resonance for enhancing cathodoluminescence (CL) emission [2], the highly saturated red color pixels [3], color-sensitive miniaturized detectors [4], tunable color pixels [5, 6], the plasmonic resonances of Si nanostructures at ultra-violet (UV) [7], and engineering/controlling of perovskite emission wavelength [8].

90

Novel topological phenomena in photonic structures

<u>Zhigang Chen</u>
Nankai University, Tianjin, China

Abstract

Graphene has attracted immense attention due to its fundamental interest and highly exploited applications. Apart from carbon-based graphene materials, various synthetic honeycomb structures ("artificial graphene") have been established. In particular, photonic graphene has been proposed and demonstrated as an ideal platform for investigation of unconventional edge states and pseudospin angular momentum, among other intriguing phenomena. In this talk, I will present a few examples of our recent demonstrations in laser-written photonic structures, including a new generic type of graphene edge states exhibiting topological flat band, a universal mapping of topological singularity that leads to ladder-type generation of angular momentum beams, as well as robust vortex transport via topological disclinations.

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Recent developments in synthetic-dimension photonics

Tomoki Ozawa
Tohoku University, Sendai, Japan

Abstract

The concept of synthetic dimensions is to use non-spatial degrees of freedom as spatial dimensions to simulate higher-dimensional models using lower dimensional platforms. Originally proposed in ultracold atomic gases to use hyperfine spin degrees of freedom as a dimension, the concept of synthetic dimensions has then been actively explored in photonics. Various non-spatial degrees of freedom, such as polarizations, frequency modes, and time, have been employed as synthetic dimensions. Of particular interest in the study of synthetic dimensions is to realize topologically nontrivial photonic bands and study topological photonics in such synthetic lattices.

From the viewpoint of fundamental science, synthetic dimensions provide an unprecedented method to realize four or higher dimensional physical models in experimentally relevant setups. From the application viewpoint, topological photonics, whose effects are often sensitive to spatial dimensionality, combined with synthetic dimensions can lead to unique ways to exploit topological phenomena. For example, one may utilize chiral edge states of two-dimensional photonic lattices in one-dimensional physical setups.

In this talk, I will give an overview of this exciting field of synthetic-dimension photonics. I start from introducing the idea of photonic synthetic dimensions with an emphasis on how topological models can be realized and probed in models involving synthetic dimensions. I will then discuss recent progress in the study of synthetic dimensions in photonics, with a particular emphasis on frequency modes used as a synthetic dimension.

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Characterising light in space, time, spectrum and polarisation

Martin Ploschner[1], Marcos Morote[1], Daniel Dahl[1], Mickael Mounaix[1], Greta Light[2], Aleksandar Rakic[1], Joel Carpenter[1]
[1]The University of Queensland, Brisbane, Australia. [2]Coherent, Fremont, USA

Abstract

The ability to measure polarisation, spectrum, temporal dynamics, and complex spatial wavefront of light is essential to study fundamental phenomena in laser dynamics, nonlinear optics and telecommunications. For example, spatial and spectral beam profiles of lasers determine the maximum bitrate at which computers can talk to each other in data centres, thus affecting the bandwidth of cloud services everyone uses. Current characterisation techniques only apply in limited contexts, bringing challenges in investigating such commercially relevant lasers. Non-interferometric methods typically lack access to spatial phase, while phase-sensitive approaches necessitate an auxiliary reference source or an adequate self-reference, neither of which is universally available. Irrespective of reference availability, deciphering complex wavefronts of beams evolving at picosecond timescales remains particularly challenging, which forms a substantial roadblock in developing next-generation lasers with higher telecom speeds and increased reliability. Here, we harness the principles of spatial state tomography to circumvent these limitations. A full description of an unknown beam is retrieved by measuring its spatial state density matrices at unique spectral and temporal slices for both polarisations, using a spatial light modulator to display projective holograms and a single-mode fibre to guide the collected signal to a high-speed photodiode and a spectrometer. We demonstrate the method by characterising the rich spatiotemporal and spectral output of a vertical-cavity surface-emitting laser diode that has so far resisted comprehensive analysis using existing techniques and which forms the backbone of communication frameworks in data centres.

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Metasurface Microparticles Driven by Optical Forces and Torques

Mikael Käll
Chalmers University of Technology, Gothenburg, Sweden

Abstract

High-index dielectric metasurfaces that deflect light or alter its polarization state experience photon recoil forces and torques due to conservation of linear and angular momentum. We utilized this effect to construct miniature "metavehicles" able to navigate across a surface in water under plane-wave illumination while being steered through the incident polarization [1]. The control scheme does not involve gradient forces, in contrast to the vast majority of previous optical manipulation studies, yet the forces generated are strong enough to let the metavehicles work as transporters of microscopic cargo, such as biological cells. Depending on how the metasurface is constructed, metavehicles can be optimized for different behaviors and functionalities, thereby opening the door to novel fundamental studies and applications in fields like microrobotics, micromachines, and active matter.

[1] Andrén et al, Nature Nanotechnology 16, 970-974 (2021).

Mikael Käll is an experimental physicist focusing on fundamental and applied nanooptics. His current research projects mainly deal with the physics and applications of optical metasurfaces and optical forces. He has previously worked with topics like surface-enhanced Raman scattering, plasmonic biosensors, optical antennas, biophotonics, and strongly correlated electron systems. He has co-authored more than 200 journal papers that have been cited more than 29000 times to date.

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Advanced Light Trapping in Resonant Dielectric Metastructures for Nonlinear Optics

Kirill Koshelev
Nonlinear Physics Center, Research School of Physics, Australian National University, Canberra, Australia

Abstract

We review the physics of photonic bound states in the continuum (BICs) and their applications in meta-optics, including enhancement of nonlinear response, light-matter interaction and development of active nanophotonic devices. For metasurfaces composed of subwavelength meta-atoms with broken in-plane symmetry, we show that quality factor of BICs can be unambiguously controlled by variation of meta-atom asymmetry parameter. We show that control of the unit cell asymmetry allows to achieve the optimal coupling condition that maximizes the fields inside the metasurface. We apply smart engineering of resonances of asymmetric dielectric metasurfaces to design multi-functional metadevices for applications in nanophotonics. In particular, we employ BIC-empowered silicon metasurfaces to generate efficiently high-order optical harmonics up to the 11th order and explore transition between the perturbative and non-perturbative nonlinear regimes. We demonstrate how silicon asymmetric metasurfaces integrated with two-dimensional flakes of transition metal dichalcogenides (TMDs) can be used to boost the intrinsic second-order nonlinearity of monolayers. We further explore TMD resonators composed of structured dielectric arrays and individual nanoparticles for strong light-matter coupling phenomena. We discuss the extension of metasurface functionalities for biosensing applications in biomarker detection and quantum information processing with entangled photons. We finally discuss the strategies to shape the wavefront of the nonlinear signal including applications to self-action and nonlinear chiroptical response.

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Quantum metasurfaces for single-photon structured light generation at room temperature

FEI DING
University of Southern Denmark, Odense, Denmark

Abstract

Metasurfaces, i.e., ultrathin arrays of engineered meta-atoms, have attracted increasing attention due to their unprecedented capabilities of molding classical light [1,2]. As metasurfaces revolutionize optical designs by replacing bulky optical components with ultrathin planar elements, numerous compact devices have been demonstrated. Besides controlling classical light, metasurfaces have the potential to emerge as essential components for nonclassical optical fields at the single-photon level. In this talk, I will talk about a conceptually new approach of quantum metasurfaces to the room-temperature generation of single-photon structured light entailing quantum emitters non-radiative coupling to surface plasmons that are transformed, by interacting with an optical metasurface, into a collimated stream of single-photon sources with the designed handedness [3], orbit angular momentum [4], and polarizations [5].

F. Ding, A. Pors, and S. I. Bozhevolnyi, "Gradient metasurfaces: a review of fundamentals and applications," Rep Prog Phys. 81,026401 (2018).

1. **F. Ding, Y. Yang, R. Deshpande, and S. Bozhevolnyi, "A review of gap-surface plasmon metasurfaces: fundamentals and applications," Nanophotonics 7, 1129 (2018).**
2. **Y. Kan, S. K. H. Andersen, F. Ding, S. Kumar, C. Zhao, S. I. Bozhevolnyi, "Metasurface-enabled generation of circularly polarized single photons," Adv. Mater. 32, 1907832 (2020).**
3. **C. Wu, S. Kumar, Y. Kan, D. Komisar, Z. Wang, S. I. Bozhevolnyi, and F Ding, "Room-temperature on-chip orbital angular momentum single-photon sources," Sci. Adv. 8, eabk3075 (2022).**
4. **S. im Sande, Y. Kan, S. Kumar, S. I. Bozhevolnyi, and F Ding, "Versatile single-photon generating using quantum metasurfaces," In Preparation.**

164

Algorithm-Designed Plasmonic Nanotweezers

Kenneth Crozier
University of Melbourne, University of Melbourne, Australia

Abstract

Plasmonic apertures permit optical fields to be concentrated into subwavelength regions. This enhances the optical gradient force, enabling the precise trapping of nanomaterials such as quantum dots, proteins, and DNA molecules at modest laser powers. Double nanoholes, coaxial apertures, bowtie apertures, and other structures have been studied as plasmonic nanotweezers, with the design process generally comprising intuition followed by electromagnetic simulations with parameter sweeps. Here, instead, a computational algorithm is used to design plasmonic apertures for nanoparticle trapping. The resultant apertures have highly irregular shapes that, in combination with ring couplers also optimized by algorithm, are predicted to generate trapping forces more than an order of magnitude greater than those from the double nanohole design used as the optimization starting point. The designs are realized by fabricating precision apertures with a helium/neon ion microscope and are studied them by cathodoluminescence and optical trapping. It is shown that, at every laser intensity, the algorithm-designed apertures can trap particles more tightly than the double nanohole. This work was published in Advanced Optical Materials (2021, 2100758). We will furthermore show recent work (unpublished at the time of submission) on which we use inverse design, namely the gradient descent method with adjoint sensitivity analysis, to design plasmonic nanotweezers.

200

Spatiotemporal optical beam shaping and measurement

Joel Carpenter
The University of Queensland, St Lucia, Australia

Abstract

This presentation will focus on new techniques for arbitrary spatiotemporal beamshaping, where the amplitude, phase, and polarisation can be specified arbitrarily for every point in space and time (or frequency). All discussed will be technology such as multi-plane light conversion (MPLC) for implementing arbitrary spatial NxN unitary transformations, as well as techniques for measuring spatial optical fields using off-axis digital holography and high-dimensional spatial state tomography.

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Planar polarization optics from camera to emission enhancement

Xiangping Li
Jinan Unviersity, Guangzhou, China

Abstract

Metasurfaces [1], composed of arrays of subwavelength artificial atoms, have demonstrated capability of powerful wavefront manipulation. The ultra-thin thickness of metasurfaces offers a new platform for development of integrated planar optics with multifarious functionalities. In this talk, I will present our recent research progress focused on polarization manipulation. By leveraging the inverse design methods, we design and fabricate vectorial meta-gratings that can distribute full Poincare sphere polarization into different diffraction orders. By integrating vectorial meta-grating with the phase of a metalens, we demonstrate a planar polarization camera which is able to capture not only the intensity image of an object but also the full polarization characteristics simultaneous [2]. In addition, resonant metasurfaces can offer exotic platforms for light-matter interactions such as bound states in the continuum (BIC)[3]. We demonstrate a resonant metasurface composed of double nanobricks with judicious design can support BIC with ultra-high Q factors. Moreover, the high-Q resonance can be polarization controlled for selective enhancement of upconversion emissions. We demonstrate dual-band polarized upconversion enhancement by incorporate rare earth nanoparticles into such resonant metasurfaces[4].

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A multimodal microscopy toolkit to assess brain autofluorescence

Blanca del Rosal, Mary Slayo, Hasan Ul Banna, Ying Zhi Cheong, Philipp Reineck, Brant C. Gibson, Sarah J. Spencer
RMIT University, Melbourne, Australia

Abstract

Although tissue autofluorescence is generally treated as background noise to be minimised when imaging fluorescent labels of interests, it is emerging as a powerful diagnostic marker in a variety of applications. In the brain, autofluorescence is directly related to immune cells, and is therefore likely impacted by neuroinflammation. Here, we have used a combination of confocal microscopy, time-resolved imaging (fluorescence lifetime microscopy, FLIM) and photoluminescence spectroscopy to assess the impact of neuroinflammation in brain autofluorescence; and coherent Raman techniques to analyse its molecular origin. We will discuss our more recent results and the challenges related to identifying changes across sample groups, particularly in the context of FLIM data.

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Localised states trapped by topological defects in photonic and hybrid metasurfaces

Daria Smirnova
Australian National University, Canberra, Australia

Abstract

We report novel phonon-polariton states trapped by topological defects in a patterned silicon metasurface integrated with hexagonal boron nitride (hBN). The topological defects, created by stitching domains with different choices of unit cells in the distorted hexagonal pattern, support spatially localised hybrid modes, originating from coupling of the electromagnetic field with phonons in hBN. The topological defect modes of the designed mid-IR-operating structure were imaged in both real- and Fourier-space, revealing their singular radiation profiles, spiral polarization texture and selective excitation though coupling to spin-polarised edge waves at heterogeneous topological interfaces.

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2D Materials for Integrated Photonics

Sejeong Kim
University of Melbourne, Melbourne, Australia

Abstract

Two-dimensional (2D) materials are extensively used in almost all scientific research areas, from

fundamental research to applications. Initially, 2D materials were integrated with conventional non-2D

materials having well-established manufacturing methods. Recently, the concept of constructing

photonic devices exclusively from 2D materials has emerged. Various devices developed to date have

been demonstrated based on monolithic or hetero 2D materials. In this talk, photonic devices that

solely consist of 2D materials are introduced, including photonic waveguides, lenses, and optical cavities.

Exploring photonic devices that are made entirely of 2D materials could open interesting prospects as

they enable the thinnest devices possible because of their extraordinarily high refractive index. In

addition, unique characteristics of 2D materials, such as high optical anisotropy and spin orbit coupling,

might provide intriguing applications.This talk will also discuss recent work on Valleytronics and deep learning for photonics.

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Small-beam diffraction measurements to probe local structure and local dynamics in glasses

Amelia Liu
Monash University, Clayton, Australia

Abstract

Traditional broad-beam diffraction cannot solve the structures of amorphous materials and glasses uniquely, which is a significant roadblock to further development and discovery [1]. Recent technological advances in a) beam definition to collect diffraction from small volumes, b) fast, full-field counting detectors and c) automated acquisition have enabled the collection of ensembles and scanned arrays of small-beam, "speckle" diffraction patterns from disordered materials. These patterns exhibit strong fluctuations in the diffracted intensity with position, angle, and time, reflecting variations in the local order and promising new ways to obtain interesting, statistical and local structural information [1]. In this presentation, I will discuss how we have used the fluctuations in these "speckle" patterns to quantify local order in glasses [2] and spatially-resolve the local stability and local structure to understand phenomena like ageing and shear banding [3].

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Acknowledgements

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My Mate Jim Piper

Brian Orr
Macquarie University, Sydney, Australia

Abstract

Professor Jim Piper made many notable contributions to optical physics and engineering and to their real-world applications. My reminiscences of Jim go back to 1975, when he arrived at Macquarie University and I was at UNSW. I recall our various early collaborations, such as the Centre for Lasers and Applications (an ARC Special Research Centre awarded in 1988, soon after I became Professor of Chemistry at Macquarie) and the 1996 International Quantum Electronics Conference in Sydney (with Jim as its Chair). His infectious 'can-do' approach has been inspirational to many in local and international science, technology and academia.

401

In memory of Jim Piper: Biophotonics

Jin Dayong
UTS, Sydney, Australia

Abstract

I will present my research journey with Jim Piper as my PhD supervisor, career mentor, and my 'academic father' from 2003 onwards. Jim Piper has been instrumental in shaping my academic career over the past 20 years. This journey encompasses the inception of my research career as an international PhD student, the completion of my thesis focusing on time-resolved flow cytometry, followed by postdoctoral work on time-domain multiplexing techniques. Subsequently, it led to a series of intensive research endeavours involving upconversion nanoparticles and super-resolution nanoscopy imaging. In 2013, we successfully established the ARC Centre of Excellence for Nanoscale Biophotonics (Macquarie node). Since my relocation to UTS in 2015, I have maintained regular visits to Jim for career advice. During the pandemic and throughout the period when Jim was battling illness, we continued to have frequent catchups till my last coffee with him in Dec. He has been always positive, patient, and encouraging.

402

In memory of Jim Piper: Raman lasers and beyond

Helen Pask
Macquarie University, Sydney, Australia

Abstract

Here I pay tribute to Prof. Jim Piper, my PhD supervisor, colleague and mentor. Our work on crystalline Raman lasers commenced in 1995, and seeded streams of research at Macquarie University that continue to this day, delivering a steady stream of publications, patents, PhD graduates, industry partnerships, awards and recognition. Jim was particularly active in this research field at the time he was awarded the 2006 Carnegie Centenary Professorship by the Carnegie Trust of the Universities of Scotland, and an Honorary DSc by Heriot-Watt University.

I will highlight some of the scientific insights, research achievements and innovative thinking that led to the recognition of Macquarie University as a world leader in the field of crystalline Raman lasers. I will also show how several key research directions at Macquarie today have direct connections back to Jim's research.

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From pilot project to a world leading National laser microfabrication facility

Michael Withford
Macquarie University, Sydney, Australia

Abstract

Circa 1993 Jim Piper initiated a modest laser micromachining initiative addressing the emerging manufacturing needs of local medical companies. At that time the laser micromachining was undertaken using lab-built visible nanosecond pulsed lasers. In 2003 Jim built on that platform by leading a LIEF grant, with colleagues from the University of Sydney, to establish a Femtosecond Laser Micromachining Facility in Australia. Jim's prose in that application stated "this facility, unique in Australia, will be comparable to the best such facilities in the world" and will have outcomes that include "demonstration and development of novel photonic / optoelectronic devices and of new techniques crucial to cost-effective manufacture of photonic components". His vision expressed in that grant flourished and evolved into the Optofab Node of the Australian National Fabrication Facility, a facility that continues to support a wide range of Australian med-tech and photonics companies. In this presentation I will touch on the pivotal role Jim played in establishing this crucial manufacturing capability in Australia.

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In memory of Jim Piper: Self-frequency-doubling crystal lasers and strong collaborative works with Shandong University, China

Pu Wang
Beijing University of Technology, Beijing, China

Abstract

I met Prof. Jim Piper for the first time on the campus of Tsinghua University during his visiting to Prof Yujing Huo in the autumn of 1995. Jim told me that he would like to sponsor me to come to Australia to pursue my Ph.D study under his supervision and worked on a project of self-frequency-doubling crystal and lasers, which Jim proposed with wisdom of combination of my research background in Shandong University and the perspective of the cutting-edge diode-pumped ytterbium-doped crystal laser technology at that time. The project finished with fruitful results, including several influential research publications and research funding. This was the true start of my scientific research career, I attribute a lot to Jim for his vision, his willing to guiding me and his friendship. In this presentation I will concentrate on my Ph.D work of self-frequency doubling crystal Yb:YAB lasers proposed by Jim and the strong collaborations he developed with Shandong university for more than 20 years.

408

Looking below the surface with spatially offset low frequency Raman spectroscopy

Sara Miller
University of Otago, Otago, New Zealand

Abstract

Oral delivery is the most commonly used route to administer pharmaceutics. The ability for the drug to dissolve in the GI tract and then permeate across the gut mucosa are two key limiting factors for bioavailability and hence pharmaceutical performance.1 Formulation strategies to overcome these limitations, such as altering the solid state form, need to be utilised during product development. The solid state form present during production and its stability during its shelf life is important to detect and track. Changes to the solid state of the active pharmaceutical ingrident during sorage can alter the bioavaliability of the formulation and potentially cause patent infringements. The ability to non-destructively detect the internal composition of pharmaceutical formulations is highly desirable.

Light based methods that detect how a molecule vibrates (vibrational spectroscopy) are able to non-destructively "chemically fingerprint" a sample's composition. Raman spectroscopy is one such technique and has many demonstrated applications including assessing medicines. Spatially offset Raman spectroscopy (SORS, also called deep Raman) is a form of Raman spectroscopy2 which enables non-destructive detection of subsurface layers. Low frequency Raman spectroscopy (LFR) ($\tilde{\nu}$ ~ 10 to 300 cm-1) is sensitive to the crystallinity of materials, with many demonstrated applications for characterizing the solid-state forms present in different pharmaceutical systems.3 Coupling SORS with LFR yields spatially offset low frequency Raman spectroscopy, a method for subsurface detection of composition that is particularly sensitive to the solid-state form of the solids present. This talk will highlight some pharmaceutical applications for coupling these techniques, including tracking the dehydration through a tablet over time and detecting the subsurface composition of a tablet through a thick, colored coating.4-6

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2. **Applied Spectroscopy 2005, 59, 393.**

3. **International Jou. Pharmaceutics 2021, 592.**

4. **Analytical Chemistry 2020, 93.**

5. **Analytical Chemistry 2021, 93.**

6. **Molecular Pharmaceutics 2022.**

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Image processing with nonlocal nonlinear metasurfaces

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Abstract

Flat-optics has been recently unveiled as a powerful platform to perform data processing in real-time, and with small footprint [1, 2, 3]. So far, these explorations have been limited to linear optics, while arguably the most impactful operations stem from nonlinear processing of the incoming signals. In this context, here we add a new twist and depth to analog optical computing: we demonstrate that nonlinear phenomena combined with engineered nonlocality in flat-optics devices can be leveraged to synthesize Volterra kernels able to perform complex operations on incoming images in real-time.

Metasurfaces have already introduced a paradigm shift for nonlinear optics enabling stronger nonlinearities in thin films and manipulation of the nonlinearly-generated wavefront [4, 5]. In this framework, here we show that it is possible to exploit nonlocal nonlinearities as a powerful tool for analog computing with light waves. We show that using nonlinear nonlocality in flat optics we can realize analog image processing with previously not accessible functionalities. By exploring the simple scenario of a uniform thin sheet with second order nonlinearity, we demonstrate edge detection operation with exciting potential. In our proposed nonlinear flat-optics solution, the non-resonant nature of the nonlinear interaction involved in image processing allows edge detection over a broadband spectrum with ultra–high contrast and superior resilience to noise.

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Photon-pair generation and quantum measurements with metasurfaces

Andrey Sukhorukov
Australian National University, Canberra, Australia

Abstract

We present the theoretical and experimental advances on quantum photon-pair generation through spontaneous parametric down-conversion in nonlinear metasurfaces, underpinning quantum entanglement engineering at a sub-wavelength scale for photon shaping with tailored polarization and spatial correlations. We also outline the applications of metasurfaces for the manipulation and measurement of multi-photon quantum states for free-space quantum imaging and communications.

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2D Quantum Materials for Next-generation Photonic and Quantum Devices

Yuerui Lu
School of Engineering, Canberra, Australia

Abstract

Two-dimensional (2D) van der Waals quantum materials have become important building blocks for future electronic, photonic, phononic and quantum devices1-5. The highly enhanced Coulomb interactions in the atomically thin quantum 2D materials, arising from the reduced dimensionality and weak dielectric screening, allows the formation of tightly bound excitons, biexcitons and interlayer biexcitons. These tightly bound quasi-particles have been of keen interest for both fundamental studies and novel device applications, such as entangled photon sources, quantum logic gates, etc. Because of their ultra-light weight, defect-less surface and low intrinsic losses, atomically thin 2D materials are also perfect candidate materials for ultra-sensitive transducers for sensing and communication applications. In this talk, I would like to talk about how to tailor the van der Waals interactions and engineer the light-matter interactions in ultrathin quantum materials, for next-generation nano-photonic and quantum devices. I will highlight our recent work on 1) discovery of interlayer biexcitons in atomically thin heterolayers6; and 2) the generation of quantum light sources using ultra-thin quantum materials.

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What did Theranos get right? The race to desk-top diagnostics …

Cather Simpson
The University of Auckland, Auckland, New Zealand

Abstract

Imagine a world in which you go to the doctor, give a finger-prick of blood when you walk in the door, and have the results of your blood text in your hands before you walk into your appointment. Or you feel terrible but can't get an appointment with your primary care physician for 3 weeks, so you pop into a pharmacy and within 15 minutes know whether you've got something serious or just need more sleep. This is the vision that Orbis Diagnostics, one of our start-up companies out of the University of Auckland's Photon Factory, is trying to realise. It's also the vision that Theranos CEO Elizabeth Holmes sold, and it's a very compelling one. Within 10 years of coming out of "stealth mode" Theranos was worth $9B USD! But it's actually a lot harder than it sounds to achieve putting a panel of blood tests on a single platform that can be used point of care. Orbis is using centrifugal microfluidics and cleverly adapted ELISA approaches to achieve this goal. In this talk, I will present our results on measurements of anti-SARS-CoV-2 RBD (receptor binding domain) in vaccinated people, and our progress towards creating a truly multiplexed, 3-test panel for Hepatitis B. I will also highlight the pitfalls that took down Theranos, and how we are avoiding these on our path to success.

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Advances in functional optical coherence tomography: translation of F-OCT technology from bench to bedside

Zhongping Chen
University of California, Irvine, Irvine, USA

Abstract

Functional optical coherence tomography (OCT), a technology that we developed 25 years ago, is one of the fastest-growing areas of biomedical optics with numerous potential clinical applications. In this presentation, I will describe the latest advancements in functional OCT (F-OCT), which encompass Doppler OCT, OCT angiography, and optical coherence elastography. Furthermore, I will report on the development of acoustic radiation force optical coherence elastography (ARF-OCE) technology, aimed at characterizing the biomechanical properties of tissues using Doppler OCT. Understanding tissue mechanical properties offers valuable medical insights for disease diagnosis and prognosis. The ARF-OCE technology will have a broad range of clinical applications, including imaging and diagnosing of ophthalmic diseases, cancer, and cardiovascular diseases. I will review recent advancements in F-OCT and discuss several research projects conducted in my laboratory, focusing on technology development and the translation of F-OCT into clinical practice. Lastly, I will discuss the challenges and opportunities associated with translational research.

427

Nonlinear waves and solitons in superfluid helium

Christopher Baker
The University of Queensland, Brisbane, Australia

Abstract

Nonlinear waves and solitons in superfluid helium

428

Passive and tunable metasurfaces based on dielectric nanoantennas

Arseniy Kuznetsov
Institute of Materials Research and Engineering, A*STAR, Singapore, Singapore

Abstract

Dielectric metasurfaces have recently emerged as a new platform for precisely manipulating light beams at nanoscale. Metasurface-based flat optical components can be more compact and cheaper compared to conventional bulk optics and demonstrate unique, previously inaccessible functionalities. In the first part of my talk, I will show several metasurface-based flat optical devices developed by our group including (i) extra-large NA metalenses, (ii) extra-large-field-of-view metalenses with white-light imaging capabilities, and (iii) compact hyperspectral imaging system for space applications. Then I will show how integrating dielectric nanoantennas inside liquid crystal cells allows us to achieve tunable metasurfaces with 2π phase variation either in reflection or transmission. I will also demonstrate how integrating this tunable metasurfaces with CMOS pixels leads to single pixel tunability in both 1D and 2D configurations with a pixel size going down to 1 µm level. The developed single-pixel tunable metasurafce devices pave the way to multiple applications including LiDAR for autonomous vehicles and 3D holographic displays.

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Exceptional points in momentum space and non-Hermitian topology of exciton-polaritons

Eliezer Estrecho
Australian National University, Canberra, Australia

Abstract

Exceptional points in momentum space and non-Hermitian topology of exciton-polaritons

430

Speckle Metrology: new levels of precision measurement

Kishan Dholakia
The University of Adelaide, Adelaide, Australia

Abstract

Speckle is rich in information and can form the basis for ultra-high precision measurements. In this talk, I will describe how we can generate and analyse speckle patterns for studying changes in wavelength, refractive index and displacement. The measurement of wavelength can reach attometre resolution in either multimode fibres or integrating spheres. Separately, there is an increasing demand for sub-nanometric displacement and position sensing for both fundamental and applied science. Our speckle patterns created by multiple reflections of light inside an integrating sphere provide an exceptionally sensitive probe of displacement. The particular sphere geometry we use is one split into two independent hemispheres, one of which is free to move in any given direction. The relative motion of the two hemispheres produces a change in the speckle pattern from which we can analytically infer the amplitude of the displacement. The method enables a measurement of approximately 17 pm amplitude (l/50,000) with a signal to noise ratio of 3. The future prospects for these areas will be discussed.

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A Portable Dual-Wavelength Optical Atomic Rubidium Clock

<u>Sarah Scholten</u>[1], Clayton Locke[2], Nicolas Bourbeau Hébert[1], Emily Ahern[1], Ben White[1], Christopher Billington[1], Ashby Hilton[1], Montana Nelligan[1], Jack Allison[1], Rachel Offer[1], Elizaveta Klantsataya[1], Sebastian Ng[2], Jordan Scarabel[2], Martin O'Connor[2], Christopher Perrella[1], Andre Luiten[1,2]

[1]University of Adelaide, Adelaide, Australia. [2]QuantX Labs, Adelaide, Australia

Abstract

Modern society is critically dependent upon stable timing signals typically disseminated by global navigation systems such as GPS, but the highest degree of timing accuracy is afforded by laboratory-based primary frequency standards. The trade-off between clock frequency stability and Size, Weight and Power (SWaP) is the subject of intense research, with high-performance portable clock systems a necessity for a large array of real-world applications and in GPS-denied environments.

We report progress on the development and out-of-lab demonstrations of a next-generation optical timing reference based on the dual-wavelength excitation of the $5S_{1/2} \rightarrow 5D_{5/2}$ two-photon transition of rubidium-87. This work aims to develop a commercial portable frequency reference that has greatly improved frequency stability over the best commercially available technologies. We make use of the robustness of mature laser telecommunications technologies, FPGA-based control systems and automation, and a compact optical frequency comb to generate stable clock outputs in the optical (778nm, 385THz) and radio frequency (1GHz) domains for interfacing with both optical systems and conventional electronics. We have measured fractional frequency instability of the rubidium clock of 1.5×10^{-13} at 1s, integrating down at $1/\sqrt{t}$ to 3×10^{-15} at 8,000s.

Variants of this clock architecture have operated successfully in harsh out-of-lab environments including onboard a moving van and for several weeks operating autonomously on the deck of a large maritime vessel during active sea trials. The clock is currently being developed for space operations.

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Figure caption: Left to right: 19" rack mounted portable Rb clock held within 11 rack units (11U); readout of clock during operation in vehicle; Clock performance of 1.5×10^{-13} at τ = 1s, integrating down at $1/\sqrt{\tau}$ to 3×10^{-15} at 8,000s, clock loading onto HMNZS Aotearoa (within shipping container, circled) prior to naval exercises.

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Dynamics of many-body photon bound states in waveguide and cavity QED

__Sahand Mahmoodian__
The University of Sydney, Sydney, Australia

Abstract

Two-level atoms provide an ultimate nonlinearity as they can only absorb a single excitation at a given time. If two-level atoms are coupled to an optical waveguide incoming photons can deterministically interact with the atoms and probe their nonlinearity. Here we explore the quantum nonlinear optics of a waveguide QED system with atoms unidirectionally coupled to a waveguide. This system has previously been explored within the mean-field limit and produces the well known self-induced transparency bright soliton. We extend this treatment to the quantum many-body limit and show that a class of scattering eigenstates called photon bound states govern the quantum many-body physics in this system. This class of eigenstates gives rise to a simple description of the complex many-body dynamics of this system and allows us to calculate quantum corrections to the soliton solution obtained from mean-field theory. An experimental demonstration in a cavity QED platform showing the propagation of one-, two- and three-photon bound states is also presented.

442

Harnessing structured light for observational astronomy with Photonic Lanterns

Sergio Leon-Saval
The University of Sydney, Sydney, Australia

Abstract

Photonic lanterns are a relatively new waveguide technology that, by its intrinsic working mechanism, can give significant information of the structure of light at its input based on its optical transmission properties. This technology forms a low-loss interface between a multimode waveguide and a set of few-mode and/or single-mode waveguides. I will present some of the new proposed uses of photonic lantern technology for observational astronomy using the information embedded in the light structure.

445

Arcs, Sparks, Colours … Jim Piper's world-leading contributions to Metal Vapour Laser Innovation, Applications and Training

Daniel Brown
ASML, San Diego, USA

Abstract

Between 1975 - 2000, pulsed Metal Vapor Lasers (MVLs) were one of the few laser types capable of delivering high average power with multi-kilohertz repetition rate and wide spectral coverage using different lasant metals. During this "golden age" of MVLs, Jim Piper and his colleagues significantly advanced the fundamental physical understanding of these systems, developing radical and effective power scaling approaches (including significant improvements in beam quality), and pathfinding a wide array of new laser applications in materials processing and other disciplines. Although MVLs have now been superseded by newer solid-state-based laser technologies, Jim's legacy in this space lives on. The knowledge derived from MVL-based sources remains relevant today; and Jim's training and mentoring in MVL systems launched a generation of researchers into a broad array of impactful R&D areas.

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Scalable quantum and classical photonic systems

Jelena Vuckovic
Standford University, Palo Alto, USA

Abstract

Recent breakthroughs in photonics design, along with new nanofabrication approaches and heterogeneous integration play crucial roles in building photonics for applications including optical interconnects and quantum technologies. The implementation of scalable quantum systems is the most dramatic example of this effort, as it requires new photonic materials and device functionalities, together with stringent device performances. Recently it has been shown that the platforms based on optically interfaced spin qubits in diamond and in silicon carbide can be used to build systems for quantum networking, and possibly even for quantum simulation and computing. However, truly scalable systems require integration of all passive and active photonic devices on the same chip, including sources. Following the same advances in design, fabrication, and heterogenous integration, even Titanium:sapphire laser, the workhorse of optics laboratories, can be miniaturized into sub-cubic centimeter volume together with its pump, and without any loss of performance.

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Rotational levitated optomechanics with structured light

Kishan Dholakia[1], **Y. Arita**[2,1], **S. H. Simpson**[3], **G. D. Bruce**[2], **E. M. Wright**[4,2], **P. Zemánek**[3]
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Abstract

Rotational levitated optomechanics with structured light

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Structured Light in nano and microsystems

Halina Rubinsztein-Dunlop[1], T. Neely[1], G. Gauthier[1], S. Simianovski[1], Z. Kerr[1], M. Davis[1], I. Favre-Bulle[1], M. Watson[1], P. Grant[1], T. Nieminen[2], A. Stilgoe[3]
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Abstract

Structured Light in nano and microsystems

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Lasers, Milk, Blood and Sperm – Making Light Work

Cather Simpson
The University of Auckland, Auckland, New Zealand

Abstract

What is a University for? 50 years ago, the answer would have been two-fold – to teach the next generation and to create new knowledge through novel, curiosity-driven research. Research commercialisation occurred, but it was not the rule. Today's universities, governments and funding bodies add a third purpose: helping drive positive economic impact upon the region, country and world through return on R&D investment, a concept taken from the business world.

One way to create value and economic impact from research funding is to spin technology out of the university lab and into the marketplace. In this talk, I will explore this rise of the academic entrepreneur, with particular emphasis upon what it means for the ivory tower and the technology landscape. I will scaffold this discussion around the three photonics companies that have spun out of our laboratory at the Photon Factory at the University of Auckland, and the next two that are in the works. I am particularly keen to explore whether the rise of the academic entrepreneur is a positive development or a cautionary tale.

460

The promise and perils of AI in academia

Lukas Wesemann
ARC Centre of Excellence for Transformative Meta-Optical Systems, Melbourne, Australia. University of Melbourne, Melbourne, Australia

Abstract

The recent rise of generative artificial intelligence has created unprecedented opportunities and challenges for academics. Driven by economic incentives, the pace at which artificial intelligence is evolving is staggering, with transformative changes in education and research to be expected. Recent data from a Nature survey involving postdoctoral researchers highlights academia's growing awareness of AI tools such as chatGPT and its analogs. However, perceptions about their value and risks span a wide spectrum. While preliminary guidelines have been set forth by universities, the swift progress in the field of artificial intelligence will require ongoing evaluation. While most universities support careful use of those tools, the University of Hong Kong recently surprised the academic world when it announced that it would fully embrace the use of generative AI. We now have to ask ourselves important questions, including: "How do we want to integrate AI in our education?"; "What is a researcher's fundamental contribution to science?". This talk aims to provide an introduction to the question "How will AI transform academia and how should we use it?". Furthermore, this presentation aims to discuss practical use cases and the corresponding risks of AI in academia, including its role in hyper-personalised learning, literature reviews, coding, laboratory setups, academic writing, assisting non-native English speakers, grant proposals, AI-assisted peer-review and publication, and its capability to support the development of new research hypotheses. Finally, the purpose of this talk is to inspire discussions on a safe and productive use of AI in academia.

ORAL TALKS

4

Dominance of extrinsic scattering mechanisms in the orbital Hall effect in graphene and transition metal dichalcogenides

Hong Liu, Dimitrie Culcer
University of New South Wales, Sydney, Australia

Abstract

The theory of the orbital Hall effect (OHE), a transverse flow of orbital angular momentum in response to an electric field, has concentrated overwhelmingly on intrinsic mechanisms. Here, using a quantum kinetic formulation, we determined the disorder contribution to the OHE of 2D massive Dirac fermions and shown that it exceeds the intrinsic contribution by an order of magnitude, using graphene, transition metal dichalcogenides and topological antiferromagnets as prototypes. We find that, in doped systems, extrinsic effects associated with the Fermi surface (skew scattering and side jump) provide ≈95% of the OHE. This suggests that, at experimentally relevant transport densities, the OHE is primarily extrinsic. The calculation offers an approach to tuning and maximizing the orbital torque and can be extended to other classes of materials, such as Weyl and Dirac semimetals, topological insulators, and van der Waals heterostructures, as well as opening future perspectives on graphene-based orbitronics and twistronics, since magic-angle twisted bilayer graphene is the first material with purely orbital-based magnetism.

5

Quantum kinetics of the orbital magnetic moment of Bloch electrons

Dimitrie Culcer
UNSW, Sydney, Australia

Abstract

The fact that Bloch electrons possess an orbital magnetic moment has been known for half a century and has come under renewed scrutiny recently as part of a general effort to understand angular momentum dynamics in systems in which spin-orbit interactions are absent or negligible. These include the valley-dependent g-factors of graphene structures, the orbital Edelstein effect, the orbital Hall effect, and the orbital torque in magnetic systems including topological antiferromagnets.

Despite intense interest in the OMM of Bloch electrons its fundamental properties are poorly understood. At present, there is no systematic quantum theory of the OMM and orbitasl torque. Part of the problem is that dealing with the position operator between Bloch states is non-trivial. A multitude of fundamental aspects need to be clarified, for example: (i) What are the mechanisms leading to a nonzero orbital angular momentum? (ii) When is it conserved? (iii) What happens to it out of equilibrium?

In this talk I will present a quantum mechanical theory of the OMM and its rate of change due to intrinsic mechanisms focussing on the intrinsic homogeneous non-degenerate case. Because the position operator couples states separated by infinitesimal wave vectors the calculation involves two covariant derivatives – one each for the sum and difference wave-vectors. I will show that the torque comes exclusively from the force moment acting on the Bloch electrons. By developing a quantum kinetic equation I will show that, in an electric field, the force moment produces three contributions to the torque, which can all be related to Zitterbewegung. Two contributions cancel identically, while the remaining contribution vanishes in two-band systems with particle-hole symmetry but is nonzero in general. I discuss the torque in various Dirac fermion systems, as well as strategies for experimental verification and strategies for experimental verification.

6

Electrical operation of planar Ge hole spin qubits in an in-plane magnetic field

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Abstract

Hole spin qubits in group-IV semiconductors, especially Ge and Si, are actively investigated as platforms for ultrafast electrical spin manipulation thanks to their strong spin-orbit coupling. Nevertheless, the theoretical understanding of spin dynamics in these systems is in the early stage of development, particularly for in-plane magnetic fields as used in the vast majority of experiments. In this work we present a comprehensive theory of spin physics in planar Ge hole quantum dots in an in-plane magnetic field and provide a brief comparison with experimental measurements of the angular dependence of electrically driven spin resonance. We focus the theoretical analysis on electrical spin operation, phonon-induced relaxation, and the existence of coherence sweet spots. We find that the choice of magnetic field orientation makes a substantial difference for the properties of hole spin qubits. Furthermore, although the Schrieffer-Wolff approximation can describe electron dipole spin resonance (EDSR), it does not capture the fundamental spin dynamics underlying qubit coherence. Specifically, we find that: (i) EDSR is non-linear in the in-plane B-field strength and weaker than for perpendicular magnetic fields; (ii) The Rabi ratio T_1/T_π i.e. the number of EDSR gate operation per unit relaxation time, is expected to be as large as $5{\times}10^5$ at the magnetic fields used experimentally; (iii) The orbital magnetic field terms make the in-plane g-factor strongly anisotropic in a squeezed dot, in excellent agreement with experimental measurements; (iv) Focusing on random telegraph noise, we show that coherence sweet spots do not exist in an in-plane magnetic field, as the orbital magnetic field terms expose the qubit to all components of the defect electric field. These findings will provide a guideline for experiments to design ultrafast, highly coherent hole spin qubits in Ge.

7

The proper spin current in topological insulators

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Abstract

This last decade has seen a staggering amount of research into topological insulator spin torques. While the mechanisms behind these spin torques are well known, the relative size of each competing spin torque mechanism remains unsettled. While the topological insulator surface states can give rise to a massive Rashba Edelstein effect, spin torques due to the bulk states cannot be simply dismissed without a proper analysis. Here we calculate one such bulk mechanism for spin orbit torques; the spin Hall effect. Spin Hall effect calculations are notoriously controversial due to the unphysical conventional definition of the spin current. However, we have addressed this by employing our recently developed fully quantum mechanical formula for the calculation of the proper conserved spin current. This method allows us to straightforwardly calculate both intrinsic and extrinsic proper spin currents and is applicable to a wide range of materials. By calculating the magnitude of the proper spin currents and spin conductivities in the bulk of topological insulators we evaluate the role of the spin Hall effect in topological insulator spin torques.

9

Searches for Dark Matter with Precision Atomic and Optical Experiments

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Abstract

Ultra-low-mass bosonic particles produced non-thermally in the early Universe may form a coherently oscillating classical field that can comprise the observed cold dark matter. The very high number density of such particles can give rise to characteristic wave-like signatures that are distinct from the traditional particle-like signatures considered in more traditional searches for WIMP dark matter. In particular, ultra-low-mass scalar dark matter may induce apparent variations of the fundamental "constants" of Nature [1,2]. I discuss the basic principles of and recent results in searches for ultra-low-mass scalar dark matter using precision low-energy experiments, including atomic spectroscopy [2,3], optical cavities [4] and interferometry [5] (see Refs. [6,7] and references therein for an overview of the most recent results). I also discuss the possibility of using spectroscopy in exotic atoms such as muonium as a novel and complementary probe of dark matter [8].

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11

Robustness of optical skyrmions

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Abstract

Skyrmions endowed with topological protection have been extensively investigated in various platforms including magnetics, ferroelectrics, and liquid crystals, stimulating applications such as memories, logic devices, and neuromorphic computing. While the optical counterpart has been proposed and realized recently, the study of optical skyrmions is still in its infancy. Among the unexplored questions, the investigation of the topology induced robustness against disorder is of substantial importance on both fundamental and practical sides but remains elusive. We managed to employ the 3D vectorial holography principle [1] to generate optical skyrmions numerically in real space with different topological features at will, providing a unique platform to investigate the robustness of various optical skyrmions [2]. Quasiparticles with different skyrmion numbers (Nsk=-1, 1/4, 1/2, 1) are achieved numerically based on the 3D electric field vectors from a vectorial hologram. More importantly, we provide a comprehensive investigation of the robustness against disorder, accounting for the imperfection of hologram devices or light propagation in a scattering medium. A disorder-induced topological state transition is observed for the first time in a family of optical skyrmions composed of six classes with different skyrmion numbers. Intriguingly, the optical skyrmions produced from a vectorial hologram are exceptionally robust against scattering from a random medium, shedding light on topological photonic devices for the generation and manipulation of robust states for applications including imaging and communication.

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12

Nonlinear Hall effect of magnetized two-dimensional spin-3/2 heavy holes

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Abstract

In this work, we probe the nonlinear response of spin-3/2 heavy holes in zincblende semiconductors through a quadruple term with an electric field enabled by T_d-symmetry, reflecting the inversion symmetry breaking. We show that in a symmetric quantum well in the presence of both in-plane and out-of-plane Zeeman field, a sizable transverse nonlinear response to the electric field exists, named the nonlinear anomalous Hall effect. The nonlinear contribution originating from Tetrahedral symmetry in hole systems until now was believed to be negligible, however, our calculations prove differently.

13

Beyond the Purcell Effect: Modifying Spontaneous Emission via Plasmonic Doping

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Abstract

Optical resonators can alter quantum emitters' local density of optical states (LDOS), thus modifying the spontaneous emission (Fig. 1a). This is known as the Purcell effect, widely regarded as the standard explanation of cavity-emitter interactions. Here we show that this effect fails to properly address the emission modified by plasmonic resonators, i.e. a special type of metal cavities, which can strongly affect the transition processes by charging the emitters along with modifying the LDOS (Fig. 1b). In particular, by integrating quantum dots (QDs) into a grating-like plasmonic resonator (Fig. 1c), we can transiently dope the QDs with a large number of hot electrons that are produced during plasmon excitation. The doping makes carriers accumulate in the conduction band of QDs, yielding high-frequency radiative emission (Fig. 1d) that cannot be enabled by the Purcell enhancement. Our finding identifies a new cavity-emitter interaction pathway that breaks the limit of LDOS modification, initiating practical opportunities for zero-threshold lasing.

16

The SABRE South Experiment at the Stawell Underground Physics Laboratory

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Abstract

The SABRE (Sodium iodide with Active Background REjection) experiment aims to detect an annual rate modulation from dark matter interactions in ultra-high purity NaI(Tl) crystals in order to provide a model independent test of the signal observed by DAMA/LIBRA. It is made up of two separate detectors; SABRE South located at the Stawell Underground Physics Laboratory (SUPL), in regional Victoria, Australia, and SABRE North at the Laboratori Nazionali del Gran Sasso (LNGS).

SABRE South is designed to disentangle seasonal or site-related effects from the dark matter-like modulated signal by using an active veto and muon detection system. Ultra-high purity NaI(Tl) crystals are immersed in a linear alkyl benzene (LAB) based liquid scintillator veto, further surrounded by passive steel and polyethylene shielding and a plastic scintillator muon veto. Significant work has been undertaken to understand and mitigate the background processes, that take into account radiation from the detector materials, from both intrinsic and cosmogenic activated processes, and to understand the performance of both the crystal and veto systems.

SUPL is a newly built facility located 1024 m underground (~2900 m water equivalent) within the Stawell Gold Mine and its construction has been completed in 2022. The laboratory will house rare event physics searches, including the upcoming SABRE dark matter experiment, as well as measurement facilities to support low background physics experiments and applications such as radiobiology and quantum computing. The SABRE South commissioning is expected to occur in 2023/2024.

This talk will report the general status of the SABRE South assembly and on the design of SUPL.

17

Non-Hermitian Quantum Geometric Tensors in an Exciton-Polariton System

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Abstract

Open dissipative systems described by non-Hermitian Hamiltonians have attracted a great amount of interests because they exhibit a wide range of effects such as directional emission, as well as novel topological invariants and edge states. A hybrid light-matter system of microcavity exciton polaritons, which arise from the strong coupling of excitons in a semiconductor and cavity photon modes, represents an accessible platform for studies of non-Hermitian effects, including the novel topology. Previous work has demonstrated that the exciton polaritons can be used to experimentally measure a quantity called the quantum geometric tensor. The quantum geometric tensor is a complex-valued tensor. Its imaginary component corresponds to a topological effective magnetic field in momentum space known as the Berry curvature, and its real part is the quantum metric tensor that defines the distance between two quantum states. Recently, this quantum geometric tensor has been generalized to non-Hermitian systems. Due to the bi-orthogonal left and right eigenvectors of the non-Hermitian systems, there exist two different ways to define components of the generalized quantum geometric tensor. One is defined using only the right eigenvector (which we denote as RR), while the other is defined using both the left and right eigenstates (which we denote as LR). However, only the components of the RR quantum geometric tensor have been experimentally measured so far. In this work, we calculate the components of the two generalized quantum geometric tensors in an exciton-polariton system. We also extend the formalism in previous work and show that the LR generalizations of the quantum geometric tensor can be experimentally measured. Our results suggest further directions for exploring non-Hermitian topology using exciton polaritons.

19

Induced bias due to background modeling in SABRE and related NaI(Tl) experiments

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Abstract

The SABRE (Sodium iodide with Active Background REjection) experiment aims to detect an annual rate modulation from dark matter interactions in ultra-high purity NaI(Tl) crystals in order to provide a model independent test of the signal observed by DAMA/LIBRA. It is made up of two separate detectors; SABRE South located at the Stawell Underground Physics Laboratory (SUPL), in regional Victoria, Australia, and SABRE North at the Laboratori Nazionali del Gran Sasso (LNGS).

The search for an annual modulating interaction rate requires a detailed understanding of the experimental background including any time dependence.Significant work has been undertaken to mitigate the background processes such as radiation from detector materials, from both intrinsic and cosmogenic activated processes. In addition to these mitigation techniques, accurate modeling of backgrounds and potential biases is crucial for the success of the SABRE experiment. Mismodelling of the experimental background has been suggested as a potential interpretation of the DAMA modulation, understanding this effect has been complicated due to the lack of a publicly available background model.

This talk will focus on methods for modeling potential biases and statistical methods of background subtraction in the SABRE South detector and related direct detection experiments. As well as the interpretation of the DAMA/LIBRA results and the potential dark matter signal(s) that could be observed using the SABRE South apparatus.

20

Fast detection of single proteins with integrated plasmonic-photonic hybrid cavities

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Abstract

Enzymes can perform catalytic reactions down to the microsecond scale. Within each reaction, much faster conformational changes occur. Time-resolved detection of these nanoscale motions can provide new insights into complex dynamics of biocatalysis. Here we experimentally demonstrate optical label-free detection of individual proteins with time resolution below a microsecond. This was achieved by developing nanofabricated plasmonic-photonic crystal resonators with a small mode volume and high quality factor. We show that nanoscopic fields in the plasmonic hotspots should enable sensitivity to nanoscale conformational motion of individual proteins. Furthermore, we discuss how our platform has a potential to enable studying vibrational modes of individual proteins as a cavity optomechanical system in a sideband resolved regime.

22

Hybrid Integration of Chalcogenide Waveguides with Silica Template for Infrared Nonlinear Applications

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Abstract

Hybrid integration involves constructing a photonic integrated circuit using two or more materials in a platform in which we can use the best material for each optical functionality. The different materials are required to be combined faultlessly, thus presenting its own design and fabrication challenges. Chalcogenide glass (ChG) has been extensively researched as one of promising photonic platforms for several decades owing to its high optical nonlinearity and wide transmission window in infrared (IR) spectral region. Monolithic ChG planar waveguides produced by semiconductor processing - photolithography and plasma etching, however possess several limitations. One critical issue is relatively high optical propagation loss compared with a few decibel per metre level of silicon nitride and thin film lithium niobite. In this study we integrated ChG films on silica pedestal and achieved ultra-low loss waveguides and resonators below 1dB/m in infrared, leveraging etch-free light guiding and noble light coupling scheme [1]. Utilising the hybrid platform we demonstrated supercontinuum generation with 1.5 octaves spectral broadening and carbon monoxide gas sensor [2], stimulated Brillouin scattering (SBS) laser with sub-mW threshold pump power in near infrared [1]. Very recently, we observed the first on-chip SBS lasing at mid-infrared wavelength at 3.3 µm where cascade Brillouin scattering was stretched to the 6th Stokes wave. We believe that this achievement could be a significant step going toward the development of a narrowband laser and Kerr comb generation in mid-IR.

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23

The development of structured phantoms to investigate surface roughness in optical coherence elastography

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Abstract

Compression optical coherence elastography (OCE) is a promising technique capable of detecting disease, such as breast cancer, based on changes in the tissue elasticity. OCE uses mechanical models which assume the tissue surface is flat, despite tissue often exhibiting variations in surface topography which can lead to inaccuracies in OCE measurements. While this discrepancy is generally known, it is challenging to study as the effects of surface roughness are coupled with mechanical heterogeneity in tissue. In this work, we propose the development of mechanically homogeneous imaging phantoms which accurately replicate the surface roughness of human breast tissue. We fabricated these phantoms by first capturing the three-dimensional (3-D) surface profile of the tissue using optical coherence tomography (OCT). Moulds were created from the negative of the surface profile and 3-D printed. Finally, the phantoms were fabricated by casting silicone into the moulds. In total, 24 phantoms were produced using this method from scans of 6 different breast tissue specimens. The accuracy of these phantoms was validated by comparing the OCT-measured surface profiles of the phantoms to those of the corresponding tissue specimens which yielded a mean correlation of 0.96 ± 0.03 ($p<0.001$). To demonstrate the impact of surface roughness on OCE, we performed quantitative micro-elastography (a compression OCE variant) on one of the surface roughness phantoms as well as a flat phantom. We noted that the surface roughness phantom resulted in a small decrease in elasticity accuracy (mean error of 11.7% compared to 8.2% for flat phantom), and a larger decrease in elasticity sensitivity (mean standard deviation of 21.2% compared to 9.4% for the flat phantom). A moderate correlation was also seen between phantom surface roughness and elasticity contrast ($r = 0.59$, $p<0.001$) which suggests that surface roughness introduces spatially-varying mechanical contrast and must be carefully considered when interpreting compression OCE measurements.

27

Maximal Quantum Information Leakage

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Abstract

A new measure of information leakage for quantum encoding of classical data is defined. An adversary can access a single copy of the state of a quantum system that encodes some classical data and is interested in correctly guessing a general randomized or deterministic function of the data (e.g., a specific feature or attribute of the data in quantum machine learning) that is unknown to the security analyst. The resulting measure of information leakage, referred to as maximal quantum leakage, is the multiplicative increase of the probability of correctly guessing any function of the data upon observing measurements of the quantum state. Maximal quantum leakage is shown to satisfy post-processing inequality (i.e., applying a quantum channel reduces information leakage) and independence property (i.e., leakage is zero if the quantum state is independent of the classical data), which are fundamental properties required for privacy and security analysis. It also bounds accessible information. Effects of global and local depolarizing noise models on the maximal quantum leakage are established.

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Two-Colour Spatially Resolved Tuning of Polymer Coated Metasurfaces

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Abstract

Optical metasurfaces have revolutionised the ability to control and manipulate EM fields. By carefully designing a 2D array of sub-wavelength nanoresonators, or meta-atoms, the light-matter interactions have been engineered to produce novel optical devices including ultrathin filters, lenses, displays and sensors. For the vast majority of fabricated metasurfaces, the constituent meta-atoms are designed for a specific application and cannot be manipulated after fabrication. In order to broaden the application of optical metasurfaces to optical switches, dynamic displays and arbitrary wavefront manipulators, the realisation of efficient, tuneable metasurfaces, in response to external stimuli, is paramount.

Most reports of tuneable metasurfaces employ a single stimulus to tune the optical resonance. Our group recently reported silicon metasurfaces, hosting quasi-BIC resonances, which when coated with multi-stimuli responsive polymers lead to active tuning of the optical resonance [1]. While each stimulus could be employed independently, using the dual stimuli of light and temperature produced resonance shifts up to 5 nm and 62% transmission modulation, that was fully recoverable.

Further to this work, we have recently demonstrated that two different photoswitches, azobenzene and spiropyran when incorporated into polymers, can be used concomitantly to add advanced functionality to metasurface resonance tuning. Both photoswitches can be switched with UV light, inducing a 15 nm redshift, and 4 nm blueshift in the metasurface resonance for polyspiropyran (pSPA) and polyazobenzene (pAZO) coated metasurfaces, respectively. The increased functionality is enabled by the fact that the two photoswitches – and hence metasurface resonance shifts – can be recovered with different visible wavelengths. Tracking of the transmission at the initial resonance wavelength, pSPA redshifted resonance wavelengths and pAZO blueshifted resonance wavelength, constitutes a three-input logic gate with potential applications in information storage.

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29

Neutron Monitoring System at the Stawell Underground Physics Laboratory

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Abstract

The newly constructed underground physics laboratory (SUPL) in the Stawell Gold Mine will host the dark matter direct detection experiment SABRE. Soon, physics measurements will begin in the mine including muon, gamma ray, and neutron background measurements. The neutron monitoring system is being developed at the University of Adelaide, based on Bonner Sphere detectors. An array of three He-3 neutron detectors, taking measurements from within 12 Bonner Spheres, will allow the neutron flux within the laboratory to be measured. The spheres, made of polyethene act as neutron moderators and range in size from 2.5 inches to 18 inches. This allows determination of the neutron flux in energies from 10-2eV through to 10^7eV. Unfolding of the count rate in each sphere, combined with the response functions, is used to calculate the neutron flux of the environment around the spheres. The system has been successfully tested using an Americium-Beryllium neutron source at the University of Adelaide and is currently being adapted for operation in the remote, limited access, environment of SUPL.

2 Blast 2 Sagittarius: turning dark matter into exploding black holes in the galactic center

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Abstract

There is a broad range of dark sectors in which small-scale structures form. These structures can be stable on short or long timescales, collapsing to black holes at any time from the early to the present-day Universe. These 'microstructure black holes' (MSBHs) can have a wide range of masses. Small MSBHs would evaporate via Hawking radiation with lifetimes shorter than the age of the Universe, but they are not subject to the usual early universe bounds on the abundance of small primordial black holes. We investigate the possible signal of such a population of exploding, late-forming black holes, constraining their abundance with observations from diffuse extragalactic gamma- and x-ray sources, the Galactic Center, and dwarf spheroidal galaxies. Additionally, the spectrum of gamma rays from these explosions can agree remarkably well with the GeV excess observed by Fermi Gamma-ray Space Telescope.

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Thulium-doped silicate fiber lasers between 1900 and 2050 nm for next-generation Gravitational wave detectors

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Abstract

LIGO Voyager proposes a cryogenically cooled Silicon detector with the use of laser technology between 1900 nm – 2100 nm, with current interest on 2050 nm [1]. Current 2µm laser technology does not reach the low noise and high-power requirements of GW detectors. We report single frequency, linearly polarised thulium-doped silica fiber (TDF) distributed Bragg reflector (DBR) fiber lasers between 1900 nm and 2050 nm with high efficiencies of up to 38.5% (w.r.t absorbed power) and output powers of up to 100 mW. Initial characterization of frequency noise and relative intensity noise demonstrates performance comparable to the free running aLIGO NPRO suitable for further stabilization to GW detector requirements. We shall present the full characterization of our TDF DBR lasers and their suitability for use in next-generation cryogenic Silicon GW detectors.

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Stray magnetic field imaging of thin exfoliated iron halides flakes

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Abstract

Magnetic van der Waals materials are often proposed for use in future spintronic devices, aiming to leverage the combination of long-range magnetic order and near-atomic thinness to produce energy-efficient components. One class of material that has been discussed in this context are the iron halides $FeCl_2$ and $FeBr_2$, which are A-type antiferromagnets with strong uniaxial magnetocrystalline anisotropy. However, despite characterization of the bulk materials, the possibility for sustaining the magnetic behaviors that would underpin such applications in thin flakes has not been investigated. In this work, we use nitrogen-vacancy (NV) center microscopy to quantitatively image magnetism in individual exfoliated flakes of these iron halides, revealing the absence of magnetic remanence, a weak induced magnetization under bias field and variable behavior versus temperature. We show that our results are consistent with the antiferromagnetic behavior of the bulk material with a soft ferromagnetic uncompensated layer, indicating that extended (>1 µm) ferromagnetic domains are not sustained even at low temperatures (down to 4 K). Finally, we find that the magnetic order is strongly affected by the sample preparation, with a surprising diamagnetic order observed in a thin, hydrated sample.

Reference: https://arxiv.org/abs/2307.10561

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Generalized Poynting-Robertson damping of relativistic lightsails: orders of magnitude improvements of stability through optical design

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Abstract

Lightsails are a promising candidate for interstellar exploration, as they are in principle able to reach relativistic speeds when propelled by ground-based high-power laser light transferring momentum onto the craft. For their launch to be successful, lightsails need to remain centered within the beam during the entire acceleration phase. Recently, a theoretical proof of concept showed that the optical reflectivity of diffraction gratings can create passive stabilization of the sail inside the beam. However, the sail's motion without damping forces means that oscillations transverse to the beam direction resulting from restoring forces leave an undesired transverse velocity component once the laser is turned off. This residual transverse velocity leads to the sail moving off-course for the rest of its flight.

Damping of these oscillations is thus crucial for the lightsail to reach its desired destination with any accuracy. Thus far, the only damping mechanism proposed in literature is an internal, damped degree of freedom, which would strain the mass budget of the sail. More recently, it has been theorised that the Doppler effect and Poynting-Robertson effect, a relativistic effect, can create damping in a simple mirror geometry. However, this mirror geometry is limited in the magnitude of damping it can achieve.

Here, we derive a generalized covariant framework for Doppler and Poynting-Robertson damping based on arbitrary angle-dependent optical cross-sections. We show that by designing the angular reflectivity profile, the damping first seen for the mirror geometry can be improved by orders of magnitude to levels indeed sufficient to ensure that the lightsail stays on path. We demonstrate implementations of suitable reflectivity profiles using optimized dielectric gratings.

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From relativity to respiration: How ideas from Einstein's general theory enable respiratory motion modelling during image-guided radiotherapy

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Abstract

Lung cancer is the most common cause of cancer-related death and 75% of lung cancer patients will receive radiation therapy. A frequently neglected challenge in lung cancer radiation therapy is real-time respiratory motion management (RRMM). As patients breathe, tumours and organs move. We have developed the first method for simultaneous tumour and organ-at-risk tracking that can be implemented on a standard treatment machine. Without real-time adaptation, margins must be added to encompass tumour position over all points in the respiratory cycle. On average these margins increase irradiated volumes by 30%, resulting in unnecessary healthy tissue damage.

A key challenge for RRMM involves estimating the 3D position of tumours and organs-at-risk from 2D images. 3D information, from CT and MRI scans, is generated by stacking 2D images together. However, during treatment, patient anatomy will have changed by the time these images are constructed. One way of overcoming this challenge is to construct models prior to treatment that capture correspondences between 2D images and 3D motion. Previous approaches modelled 3D motion by using straight lines confined to flat planes, which are easy and quick to compute. However, these models were never successfully implemented in realistic clinical scenarios as they could not adapt to the complex biomechanical changes that occur during treatment. Here we extend beyond flat planes by borrowing ideas from general relativity. Einstein's theory of general relativity holds that massive objects create curvature in the fabric of spacetime causing other objects to move along a curved paths as if they were being pulled. Repurposing the mathematics of this theory, we found that lung tumours and thoracic organs can be tracked to submillimetre accuracy by viewing respiratory motion as warping some fabric whose curvature is driven by the musculature associated with breathing.

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Many-body Majorana braiding without an exponential Hilbert space

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Abstract

Qubits built out of Majorana zero modes (MZMs) constitute the primary path towards topologically protected quantum computing. Simulating the braiding process of multiple MZMs corresponds to the quantum dynamics of a superconducting many-body system. It is crucial to study the Majorana dynamics both in the presence of all other quasiparticles and for reasonably large system sizes. We present a method to calculate arbitrary many-body wavefunctions as well as their expectation values, correlators and overlaps from time evolved single-particle states of a superconductor, allowing for significantly larger system sizes. We calculate the fidelity, transition probabilities, and joint parities of Majorana pairs to track the quality of the braiding process. We show how the braiding success depends on the speed of the braid. Moreover, we demonstrate the topological CNOT two-qubit gate as an example of two-qubit entanglement. Our work opens the path to test and analyze the many theoretical implementations of Majorana qubits. Moreover, this method can be used to study the dynamics of any non-interacting superconductor.

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Enhanced Photon Pair Generation from a Metasurface Cavity

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Abstract

The generation of photon pairs is playing an enabling role for diverse applications, including quantum sensing and quantum communication. Metasurfaces, two-dimensional arrays of nanostructures with subwavelength thickness, have extraordinary capabilities in enhancing and shaping the emission of quantum states of light. However, only periodic metasurfaces were considered in previous studies, while the potential of spatially modulated nanopatterns for ultimate enhancement remained untapped.

In this work, we show that the photon-pair generation efficiency can be strongly increased while the metasurface dimensions are reduced with a specially designed guided-mode cavity formed by two distributed Bragg reflectors (DBR) as sketched in Fig. 1(a) . We nontrivially extend the principle previously developed for classical second-harmonic generation and design the gratings made of SiO_2 on top of $LiNbO_3$ thin film which mediates quantum photon-pair generation through Spontaneous Parametric Down Conversion (SPDC). We tuned the periods (filling ratios) of central grating and DBRs to 892.6nm (0.56) and 445.88nm (0.49), respectively. The number of periods in the central grating is 20, while there are 150 periods in the DBR section. The distance between DBR and central gratings, denoted as the phase-shift lengthas sketched in Fig. 1(a), is designed to be 420nm.

We identify the cavity mode with a high quality-factor of Q ~ 939, as shown in Fig. 1(b), using the quasi-normal mode (QNM) theory. We then compute the photon pair generation rate for different pump wavelengths, see Fig. 1(c). Remarkably, our newly engineered metasurface can resonantly enhance the photon-pair generation rate by ~50 times relative to the previously analyzed simple periodic metagrating. Importantly, such a dramatic enhancement is sustained over a broad range of photon wavelengths, enabling flexible all-optical reconfigurability suited for various potential applications.

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Quantum-Mechanical Model of Asymmetry of Public Opinion Radicalisation

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Abstract

We propose a quantum-mechanical model that represents a human system of beliefs as quantised energy levels of a physical system. This model underscores a novel perspective on opinion dynamics, recreating a broad range of experimental and real-world data that exhibit an asymmetry of opinion radicalisation. In particular, the model demonstrates the phenomena of pronounced conservatism versus mild liberalism when individuals are exposed to opposing views, mirroring recent findings on opinion polarisation via social media exposure. Advancing this model, we establish a solid framework that integrates elements from physics, psychology and philosophy, and also emphasise the inherent advantages of the quantum approach over traditional classical models. Our findings enhance ongoing efforts to elucidate psychological, behavioural and decision-making phenomena using the laws of quantum mechanics. These results also lend additional support to the quantum mind hypothesis, suggesting that the most radicalised opinions may not necessarily mirror the most firmly held beliefs but are driven by strongly held opinions and exposure to dissenting views.

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Advancements in Nanoelectronic Sensing: Exploring Single-Molecule Biophysics with Solid-State Nanopores

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Abstract

Solid-state nanopores have recently gained traction as single-molecule, tag-free sensing devices that can provide physical, chemical, kinetic, and dynamic information about (bio)molecules, insights that are typically inaccessible with classical ensemble-average sensing. When a target molecule moves across the nanopore under an externally applied bias, it engenders a resistance fluctuation. These 'translocation events', specifically the magnitude of the change in current and transit time, allow inferences on molecular attributes. The size, charge, shape, and thickness of the nanopore, solution chemistry, and transport mechanisms can be optimized to explore the physicochemical properties of various target molecules at pM - nM concentrations.

Figure 1. (a) Schematic representation of a solid-state nanopore sensor with double-stranded DNA translocating through it under an applied bias. (b) A representative current trace that shows the real-time current drops as molecules pass through the pore.

Size tunability alone makes the solid-state nanopores a versatile tool for analyzing a wide range of molecules such as DNAs/RNAs, proteins, antibodies, polysaccharides, and viruses. Indeed, we have demonstrated that ultra-thin (3-10 nm) silicon nitride membranes with 4- to 20-nm diameter nanopores could be used to detect various biomolecules at low nM and pM (low ppb) ranges. Results from our recent studies of a neuron-specific transfer RNA (tRNAArg), whose C50U mutation is associated with neurodegeneration, have showcased the power of this approach to observe in real-time conformational sampling and navigation of the folding landscape by the wild-type and C50U mutant tRNAArg. We have also developed experimental and machine learning

protocols to identify biomarkers in complex samples (e.g., serum) for early diagnosis of various health conditions.

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The physical mathematics of string compactifications

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Abstract

We discuss how a physics analysis (eg vacua, quantum states, path integral) of a supersymmetric gauge theory in two dimensions can give access to the mathematics of Calabi-Yau spaces. Calabi-Yaus play a notable role in the context of string compactifications. In particular, the physics approach provides access to the moduli spaces of Calabi-Yaus. These moduli spaces encode information that is of relevance to pure mathematics and theoretical physics. They have recently received renewed interest in the context of the swampland program. This talks aims at outlining the basic concepts of applying physics methods to study mathematical structures within this setting.

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Understanding and improving robustness of topological phases in nanodevices

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Abstract

Topologically nontrivial electronic phases have the potential to enable future nanodevices with novel and useful properties. While such phases are often robust to infinitesimal amounts of disorder and other nonidealities, in practice it is challenging to make systems in which nonidealities are not dominating the device performance. This talk will discuss our work that investigates the effects of some nonidealities as well as methods to enable the design and fabrication of lithographically defined nanodevices with more robust topological phases.

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When energy goes missing: theoretical explanations of the excess in $B^+ \rightarrow K^+$ + invisible.

Michael Schmidt
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Abstract

The Belle II experiment recently announced the first measurement of the decay of a B meson to a positively charged kaon and missing energy with a branching ratio which is 2.8σ above the Standard Model expectation. In this talk I will present possible new physics explanations of this excess and discuss their implications for other measurements.

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Biased Gottesman-Kitaev-Preskill repetition code

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Abstract

Continuous-variable quantum computing architectures based upon the Gottesman-Kitaev-Preskill (GKP) encoding have emerged as a promising candidate because one can achieve fault-tolerance with a probabilistic supply of GKP states and Gaussian operations. Furthermore, by generalising to rectangular-lattice GKP states, a bias can be introduced and exploited through concatenation with qubit codes that show improved performance under biasing. However, these codes (such as the XZZX surface code) still require weight-four stabiliser measurements and have complex decoding requirements to overcome. In this work, we study the code-capacity behaviour of a rectangular-lattice GKP encoding concatenated with a repetition code under an isotropic Gaussian displacement channel. We find a numerical threshold of $\sigma = 0.599$ for the noise's standard deviation, which outperforms the biased GKP planar surface code with a trade-off of increased biasing at the GKP level. This is all achieved with only weight-two stabiliser operators and simple decoding at the qubit level. Furthermore, with moderate levels of bias (aspect ratio~ 2.4) and nine or fewer data modes, significant reductions in logical error rates can still be achieved for sigma < 0.3, opening the possibility of using GKP-biased repetition codes as a simple low-level qubit encoding for further concatenation.

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Life-on-a-chip with a soundtrack: Acoustic actuation to manipulate cells and tissue

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Abstract

Life/Disease-on-a-chip systems have emerged as powerful tools for modelling and studying various pathophysiological conditions, enabling the investigation of disease mechanisms and screening potential therapeutics with remarkable precision. Their paramount advantage is the ability to bridge the gap between in vitro and in vivo research. These microscale systems are designed to replicate human physiology, utilising human cells and tissues, providing a more relevant human-centric model for studying diseases. They offer insights that are often elusive with animal models due to human-animal-model discrepancies and ethical considerations. However, achieving precise fluid manipulation and cellular interactions has been a persistent challenge.

The integration of acoustic waves into microfluidic platforms has catalysed a paradigm shift, offering unprecedented control and versatility in mimicking the complex physiological microenvironments associated with various diseases. Acoustic actuation enables contactless and label-free manipulation of fluids, cells, and particles, reducing the risk of contamination and cellular stress while recapitulating disease-specific conditions.

In our research, we utilise this technology to develop Life-on-a-chip models to study cell and tissue response to acoustofluidic and mechanic stimuli with a degree of spatial and temporal fidelity that has hitherto been unexplored. By utilising acoustic streaming, we mimic physiological shear stress, examining the impact of fluid flow on cell adhesion and cell-cell/cell-substrate interaction. Furthermore, harnessing acousto-mechanical forces enables precisely placing and manipulating cells within a microchip, allowing contact-free patterning to create complex 3D tissue constructs. We demonstrate acoustic-stimulated enhanced cell migration and proliferation observed in real-time via fluorescence microscopy.

These efforts will significantly advance our understanding of various pathologies by developing more accurate human models. Life/Disease-on-a-chip systems, enriched with acoustic wave technology, open doors to innovative approaches in disease research and treatment, with the potential to reshape the future of medicine.

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Proposed experimental demonstration of measurement-device-independent quantum security protocol using a quantum-dot photon source

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Abstract

Secure systems facilitate essential services across many industries globally, supporting and enriching modern day human life. Many current security protocols and methods, collectively known as cryptography, that underpin these systems may be severely compromised by the development of quantum computers and algorithms [1]. Quantum key distribution (QKD) is an area of quantum cryptographic research that leverages quantum mechanical features such as superposition and entanglement to provide unconditionally secure communications. Unlike classical cryptography, QKD is theoretically invulnerable to unlimited computational power and time.

The most recent milestone demonstration is a satellite-to-ground QKD communication network functioning across a total of 4,600 km using two 1,200 km free-space links [2]. However, this impressive implementation uses non-ideal photon sources, which introduce vulnerabilities to the system that eavesdroppers can exploit. This is because the security in many QKD protocols is only guaranteed if ideal quantum light sources are used [3]. In fact, many quantum hacking methods exist and target either the source or detection [4].

Photons emitted by quantum-dots can have superior single-photon purity – i.e., suppression of multi-photon states, photon indistinguishability, brightness, and controllability, as compared to other solid-state photon sources [5]. New measurement-device-independent QKD protocols have been designed to eliminate exploitable side-channels from the detection apparatus [6]. This presentation proposes an experimental solution which combines a measurement-device-independent QKD protocol with a quantum-dot quantum light source, to reliably defend against all known and future attacks on the source or detection.

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Coupled Stochastic and Quantum Master Equations for Non-Markovian Quantum Systems

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Abstract

Quantum Markov models are employed ubiquitously in quantum physics and in quantum information theory due to their relative simplicity and analytical tractability. However, the Markov approximation is based on some strong assumptions on the system of interest and its environment, which may not be satisfied in arbitrary physical systems. Therefore, developing useful modelling tools for general non-Markovian quantum systems for which the Markov approximation is not valid is an important undertaking. This work considers non-Markovian principal quantum systems that can be embedded in a larger Markovian quantum system with one or more compound baths consisting of an auxiliary quantum system and a quantum white noise field, and presents a set of coupled stochastic and quantum master equations for embedded non-Markovian quantum systems. It includes the special case of a purely Hamiltonian coupling between the principal and auxiliary systems as a closed system without any external white noises. The results are expected to be of interest for studying (open-loop and feedback) control of continuous-time non-Markovian systems and reduced models for numerical simulation of such systems. They may also shed additional light on the general structure of continuous-time non-Markovian quantum systems.

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Shannon wavelets and scaled quantum field theory

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Abstract

The likely presence of a fundamental minimum length scale to the universe (motivated by generalised uncertainty principles and UV divergences in quantum field theory to name a few) has led to the application of information theoretic techniques such as bandlimitation to quantum field theory. For example; an ultraviolet cut-off to quantum field theory provides a natural minimum length scale and gives an isomorphism between continuous and discrete representations of a quantum field through Shannon's sampling theorem. A QFT discretised in such a way will still possess the translational symmetries and conserved Noether charges generally associated with fundamentally continuous systems.

We extend on this notion by showing that non-bandlimited quantum field theories can be decomposed into bandlimited ones using Shannon wavelets. Each scale of the wavelet decomposition gives a field theory possessing an ultraviolet cut-off and, as a result, an equivalent discrete theory. As such, one can use wavelets to decompose an N+1 dimensional continuous field theory into a 2N+1 dimensional discrete theory (where the scale of the wavelet decomposition is treated as a spatial dimension). We show that for non-interacting quantum fields (and certain engineered interacting ones) the physics of the field at one scale is entirely isolated from that of other scales, meaning that no events at one scale can have any effect on the field at any other scale. For fields that can self-interact we find that despite non-zero couplings between the scales of the field, quantities such as the Feynman propagator between scales remain zero.

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Optimisation Of Lasing Metasurfaces With Symmetry Constraints On The Modes

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Abstract

The dispersion and quality factor of the eigenmodes of a metasurface depend upon the symmetry of the modes. We may therefore wish to include the mode symmetry as an objective in optimisation routines, which in turn requires a method to quantify numerically the symmetry of vector fields obtained from simulations. Here, we propose and numerically demonstrate a novel technique to quantify the symmetry of the eigenmodes of a metasurface using projection operators.

We present, as an example, the optimisation of a metasurface for lasing that is infiltrated with up-converting nano-particles, which offers many advantages for novel lasing systems, such as high directionality and low lasing threshold. Such lasing systems require the optimisation of two metasurface modes that are resonant at the absorption and lasing wavelength bands. The absorption band also requires a weak angular dispersion to allow for a large acceptance angle for the absorption. Our technique allows us to optimise the absorption mode dispersion, as well as the directionality of the lasing emission.

By the use of our technique we are able to select only those modes with the symmetry that gives the response we required and we also excluded modes because the symmetry analysis showed an overlap of modes that would produce effects that we wished to avoid. As a result, we have designed a MS with resonances at both the absorption and lasing bands of a UCNP-based MS laser. We believe that these projector techniques will be of general use wherever symmetry considerations must be taken into account.

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Direct observation of geometric phase interference in dynamics around a conical intersection

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Abstract

Photochemical reactions that occur in molecular processes such as our vision often involve rapid and efficient reactions that occur on femtosecond timescales. These are enabled by conical intersections (CI), points where two electronic potential energy surfaces intersect. Probing the dynamics near CIs in molecular systems is notoriously difficult due to the ultrafast dynamics. Moreover, CIs can give rise to geometric phase, which can significantly alter reaction outcomes. To date, only indirect signatures of geometric phase interference have been observed experimentally.

Here, we report experimental observation of the interference caused by geometric phase in dynamics around a conical intersection in a single trapped ion [1]. Our approach relies on an analog quantum simulation framework where molecular dynamics are encoded in the ion's electronic and vibrational levels. A conical intersection is engineered in the trapped ion system using state-dependent forces enacted by laser beams. The dynamics happen on the millisecond timescale of the ion's vibration, allowing a finer resolution of the timing. We are able to reconstruct the motional wavepacket's probability density at varying times and observe clear interference due to geometric phase. These results pave the way for useful analog quantum simulations of difficult problems in chemistry using trapped ions.

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de Sitter space as coherent state of gravitons

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Abstract

Not a long ago, it was argued that the quantum gravity only tolerates de Sitter as a state on top of a valid vacuum. So, we construct the de sitter state as a coherent state of gravitons on top of the Minkowski vacuum. To make the construction consistent, we use BRST quantization. As an example, first we study such construction in QED, and then we generalize it in linear gravity. Coupling the gravity with a large number of soft scalars gives us the possibility to take double-scale, so-called species limit, in which gravity linearize and the construction is exact. In this theory, only collective quantum phenomena, like Gibbons-Hawking radiation, survive. We also double-check consistency of our construction using the above processes.

The talk is based on:

Berezhiani, Dvali, Sakhelashvili, Phys. Rev. D 105, 025022

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Optical nonlinearity enabled super-resolved multiplexing microscopy

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Abstract

Optical multiplexing for nanoscale object recognition is of great significance within the intricate domains of biology, medicine, anti-counterfeiting and microscopic imaging. Traditionally, the multiplexing dimensions of nanoscopy are limited to emission intensity, colour, lifetime, and polarization. Here we propose a novel dimension, optical nonlinearity, for super-resolved multiplexing microscopy. This optical nonlinearity is attributable to the energy transitions between multiple energy levels of the doped lanthanide ions in upconversion nanoparticles (UCNPs), resulting in unique optical fingerprints for UCNPs with different compositions. We apply a vortex beam to transport the optical nonlinearity onto the imaging point spread function (PSF), creating a robust super-resolved multiplexing imaging strategy for differentiating UCNPs with distinctive optical nonlinearities. The composition information of the nanoparticles can be retrieved with variations of the corresponding PSF in the obtained image. We demonstrate four channels multiplexed super-resolved imaging with a single scanning, applying emission colour and nonlinearity of two orthogonal imaging dimensions with a spatial resolution higher than 150 nm (1/6.5 λ). Our work provides a new and orthogonal dimension – optical nonlinearity – to existing multiplexing dimensions, which shows great potential in bioimaging, anti-counterfeiting, microarray assays, deep tissue multiplexing detection, and high-density data storage.

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Explaining the slippery, liquid-like behaviour of nanothin grafted PDMS layers

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Abstract

Over the past decade, a new class of anti-adhesive surfaces known as slippery covalently-attached liquid surfaces (SCALS) has emerged, characterized by low values of contact angle hysteresis (CAH, less than 5°) with water and most solvents.[1] Despite their nanoscale thickness (1 to 5 nm), SCALS exhibit behaviour similar to lubricant-infused surfaces, including high droplet mobility[2] and ability to prevent icing, scaling, and fouling. Their efficacy is attributed to the liquid-like mobility of the tethered chains.[3] However, the precise physico-chemical characteristics that underpin the ultra-low CAH are unknown, making rational design of these systems impossible. In this work several synthetic methods for polydimethylsiloxane (PDMS) SCALS were reproduced, and the physicochemical properties of the resulting surfaces characterized thoroughly, including using atomic force microscopy (AFM) single-molecule force spectroscopy and neutron reflectometry to obtain information on grafted chain length. The conclusion is that the water CAH of PDMS SCALS depends on both uniformity and mobility within the grafted layer, and can be satisfactorily predicted based on the reduced grafting density.[4]

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Measuring thermal noise in gram-scale silicon flexures at 123K

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Abstract

The observatories used to search for gravitational waves signals are multi-kilometre-scale laser interferometers that require a sensitivity to mirror displacement approaching 10^{-20} m/rtHz. To reduce the impact of thermal noise in mirrors and suspensions, next-generation interferometric gravitational wave observatories are expected to operate at cryogenic temperatures with crystalline silicon mirrors suspended from silicon ribbons.

Silicon has a zero coefficient of thermal expansion at 123 K, resulting in vanishing of thermo-elastic noise. Silicon ribbons resemble cantilever geometry, and therefore studying the thermal noise in the flexing region of a gram-scale silicon oscillator is analogous to the suspension thermal noise encountered in these ribbon suspensions. At the Australian National University, we designed and commissioned a cryogenic facility to directly measure the spectral shape of thermal noise in crystalline silicon using a cavity-enhanced interferometric readout at, and around temperatures of 123 K. The primary challenge of this work lies in the measurement of cryogenic low noise displacements on the order of 10^{-16} m/rtHz of a crystalline silicon mechanical oscillator. In this talk, I will present results of our cool-down runs, thermal noise measurements from the experiment, upgrades, and future plans of this facility.

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Defining discrete Wigner functions from the Gottesman-Kitaev-Preskill code

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Abstract

Wigner functions (WFs) are a useful tool in quantum mechanics to represent states and operators in phase space. For states, negativity of the WF can be a resource for quantum computing. However, unlike the uniquely defined continuous WF (CWF), for discrete systems, there are many definitions of a discrete WF (DWF), each defined over some subset of dimensions (even, odd, or prime and prime power).

In this work, we propose a straightforward and unambiguous DWF for any dimension by focusing on a 2dx2d sized unit cell for the CWF of the Gottesman-Kitaev-Preskill (GKP) encoding. Such a DWF contains redundant information, and we identify a number of inequivalent procedures including coarse graining (summing sets of four points into a new point) and reducing (ignoring the half-integer points) that can be used to remove this redundancy. Each procedure maps our 2dx2d DWF to a distinct dxd DWF. The question is whether these WFs satisfy a set properties one would like them to; for example, those set out by Wootters. We show that the above two maps indeed do reproduce Wootters' DWFs for the d=2 and prime d>2 cases, respectively.

Furthermore, we show that the above procedures are examples of a more general method that maps a single 2dx2d DWF to a class of dxd DWFs. We find that the elements of this class can be straightforwardly related to one another by coefficients that do not depend on the phase-space coordinates.

By providing a straightforward procedure from the CWF to a DWF through the GKP code, we begin to establish common ground amongst the jungle of definitions for a DWF.

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Femtosecond laser intraoral robotic: the future of modern dentistry

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Abstract

Dentistry is subject to a rapidly accelerating demand driven by the high prevalence of oral diseases and an increasingly aging population. Untreated dental caries, severe periodontitis, and tooth loss are among the ten most common conditions, globally affecting more than 3.5 billion people in 2022.

Dentists predominantly remove hard tissue using two methods:

(1) the traditional grinding drills with vibration causing pain, discomfort, and requiring constant water cooling to avoid overheating the living tissues; and

(2) the relatively newer laser ablation techniques with 100µs-pulsed Erbium lasers.

Both methods generate mechanical and thermal stress that can cause micro-cracks in the enamel and dentin. Such cracks may turn into potential initiation sites for new bacterial and chemical contamination and must be avoided for the long-term success of dental treatment. Whilst Erbium lasers employ copious water spray to reduce thermal effects, they cannot compete with high-speed dental drills' speed and cutting quality.

The combination of femtosecond lasers, intra-oral robotics, and a micro-electromechanical system (MEMS) provides practical solutions to the enduring challenges associated with the removal of the human body's hardest tissue. Femtosecond laser pulses were used to perform efficient, fast, and ultra-precise cavity-cutting of teeth without using any irrigation or cooling system. The processed surfaces were assessed with optical and scanning electron microscopy, Raman spectroscopy and optical profilometry. No structural damage nor chemical change in the composition of enamel and dentin was observed. We explored temperature variations inside the dental pulp during the laser procedure showing a maximum increase of 5.5˚C, which is within the acceptable limit of temperature increase during conventional dental treatments.

Supported by a real-time monitoring system for visualization and diagnosis with appropriate digital controls, the technology will allow dentists to perform minimally invasive and pain-free treatment with the capacity to improve overall access to oral healthcare.

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Nonlinear metasurface for broad-angle photon-pair generation

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Abstract

Entangled photons are extensively used in quantum information technologies. Recently, generation of photon pairs was reported from ultrathin nonlinear metasurfaces, where spontaneous parametric down conversion (SPDC) is resonantly enhanced [1, 2]. In quantum imaging, broad-angle SPDC emission is needed for a wide field of view and high resolution [3], however the spatial emission from previously studied metasurfaces was inherently constrained due to the angular dispersion of optical resonances.

In this work, we reveal that broad-angle SPDC can be achieved through a novel design of nanopatterns in fully etched lithium niobate metasurfaces, see Fig. 1(a). By tailoring the coupling between nonlocal resonances of different nature [4], we suppress the strong angular dispersion and obtain a flat band with bandwidth ~ 11 nm in the transverse momentum space (Fig. 1(b)). As a result, a broad-angle SPDC emission is supported when setting the pump wavelength near half of the flat-band resonance (Fig. 1(c)). The emission spectrum has a bandwidth of ~ 7 nm and the total emission rate integrated over the transverse wavevector range in Fig. 1(c) is 166 Hz/mW, which is ~ 16 times higher than the total rate achieved with previous 1D grating [2]. Following the structure fabrication (inset in Fig. 1(a)), we are progressing with experiments. Our results can open new opportunities for free-space quantum optics applications including quantum imaging and quantum communications.

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Femtosecond pulse laser cleaning for the preservation of Sydney Harbour Bridge

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Abstract

The Sydney Harbour Bridge is a heritage-listed bridge located in Sydney, Australia, and is made of a steel arch flanked by massive granite-clad pylons on each side of the shore. The maintenance of such a structure is a monumental undertaking, and the current conservation work involves sandblasting. Many restrictions and challenges make the process difficult.

Cleaning with laser light has become a popular technique for the removal of unwanted surface layers. Nanosecond pulse lasers are the most widely used, and already commercially available with portable units deployable on-site. Those lasers offer various benefits compared to more conventional cleaning methods like sandblasting, such as avoiding the use of abrasives and eliminating problems of chemical toxicity, corrosive residues, and erosion or loss of surface detail. However, ns-lasers rely on thermal mechanism of ablation, which generates heat and shock waves that result in undesirable side-effects such as surface melting, formation of cracks, and annealing/softening of thinner sections of the bulk material.

Femtosecond pulse lasers offer a remarkable alternative to nanosecond lasers and provide an effective solution to these problems. The non-linear nature of the interaction with materials results in so called 'cold ablation', meaning very limited heat transfer to the material. The range of contaminants to be removed includes spray paints (graffiti), dirt, biofilms, and rust. We explored the cleaning treatment of the steel from the bridge arch and of the Australian Moruya granite, containing quartz, plagioclase, potassium-feldspar, biotite, and hornblende minerals, used in the pylons cladding. The effects on the treated surfaces and the cleaning efficiency were assessed using multiple analytical methods including optical and scanning electron microscopy, profilometry, Raman and FTIR spectroscopy. We demonstrate efficient cleaning results in a damage-free treatment, illustrating the significant advantages of femtosecond pulse lasers for the maintenance and preservation of assets around the world.

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The eighth row: the international race to discover new elements and extend the periodic table

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Abstract

In total, humanity has discovered 118 elements. Eleven elements were known in ancient times, with the remaining 107 being discovered since 900 AD. The techniques used have varied substantially, and include boiling thousands of litres of urine (phosphorus, 1669), burning seaweed (iodine, 1811), analysis of discarded accelerator parts (technetium, 1937), and thermonuclear explosions (einsteinium, 1952). However, since 1955 all new elements have been discovered using particle accelerators and nuclear reactions.

The last six new elements (atomic numbers Z=113-118) were all discovered by bombarding heavy targets with accelerated calcium-48 beams. In calcium-48 (Z=20, N=28) the protons and neutrons are in fully filled spherical shells (analogous to Noble gases) and this stability and the relatively large number of neutrons appear to make calcium-48 particularly good for synthesising new elements. Despite this, the fusion process that leads to new element formation is exceedingly rare, and discovering element 118 (oganesson, 2002) took four months of accelerator time and 2.5×1019 beam particles to produce just four oganesson atoms.

Going beyond element 118 is a major challenge because we cannot use calcium-48 - the radioactive target elements required [einsteinium (Z=99) or fermium (Z=100)] cannot currently be created in sufficient quantity. We therefore need to use beams with more protons than calcium, but attempts using titanium, vanadium, chromium, iron and nickel have all failed. If the fusion probabilities were 100 times lower than calcium-48, discovering element 119 might take another decade. If they are 1000 times lower we may have reached the limit of discoverable elements. Fundamentally, we need to better understand the complexities of nuclear fusion to guide our attempts to discover new elements.

This talk will explain how new element discovery advances science and will discuss work undertaken at the Australian National University to forge a pathway to the eighth row of the periodic table.

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Certifying photon Fock states using second-order nonlinearity

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Abstract

Certifying whether a photon Fock state is present or not while preserving its quantum state is an important task that proves useful in optical quantum technologies. The existing methods to perform such task apply to single photons only and consume costly quantum resources. Here we propose a resource-efficient scheme for certification of an arbitrary (nonvacuum) photon Fock state by using second-order optical nonlinearity. In particular, we utilize the correlations in both photon number and polarization of a stimulated parametric downconversion process to herald the presence and the quantum state of an incoming Fock state. We then present applications of our scheme in overcoming transmission loss of photons in quantum channels as well as in preparation of NOON states and hybrid continuous-discrete entangled states.

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Restructuring Matter with Laser Pulses at Ultra-Relativistic Intensity

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Abstract

Silicon polymorphs with exotic electronic and optical properties have recently attracted significant attention due to the wide range of useful bandgap characteristics. They are typically formed by static high-pressure techniques, which put limitations on the sample volumes and even more severely limit the crystal structures made.

We present here a new approach to create unusual crystal structures deep in the bulk of a silicon by irradiating it with an ultrashort laser pulse at ultra-relativistic intensity (up to 7.5x10^19 W/cm2) [2]. Laser-generated MeV-electrons due to strong repulsion, self-generation of magnetic field, nonlinear relativistic effects and resulted branching, deposit their energy into a large volume across the whole thickness of the sample. In addition to recoil pressure from the ablated material, the high energy density conditions lead to restructuring of silicon into new crystal polymorphs. Synchrotron X-ray diffraction, Raman spectroscopy, and HRTEM studies provide unequivocal evidence of exotic Si phases formation deep in the bulk of silicon. The analysis revealed the presence of high-pressure silicon nanocrystals embedded in amorphous silicon. This is particularly encouraging for the cases of st12-Si and bt8-Si which cannot be made by static pressure techniques and where there is no any other method to scale-up their volumes.

The unexplored domain of material transformations exposed to a high flux of laser-produced MeV-electrons opens new pathways for the conversion into new crystal structures applicable to a wide range of materials in considerably larger volumes, all preserved for further studies and exploitation.

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Development of a common tool and dataset for benchmarking of 4D-CT methods.

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Abstract

Computed Tomography (CT) is a technology that calculates a digital 3D representation of a sample from its 2D projection scan data. Due to its ability to non-destructively measure the internal structure of a sample, it has found application in industry, medicine, and science. While medical CT can scan a sample in seconds, high-resolution CT at the micrometer scale (micro-CT) is limited by X-ray flux and requires minutes, or even hours, for a high-quality scan. This prohibits the 3D measurement of most dynamic processes which have shorter time-scales. The frontier of '4D-CT' (3D+time) combines static techniques with a model of sample dynamics to exploit temporal correlations and a-priori assumptions to better measure dynamic processes. Currently, these techniques are developed with a specific physical system and assumptions on the type of dynamics in mind. While this approach has demonstrated success, the restriction to a specific physical system makes adaptation to other systems and comparison between different methods difficult. To address these issues, we have developed a tool and dataset for testing 4D-CT methods. The toolset generates simulated CT-scan data of a dynamic system described via a simple scripting syntax. The toolset can also generate the system's ground-truth 3D state at arbitrary time which can be used to benchmark reconstructions of the scan data. The dataset consists of CT-scan data for a few dynamical systems. These have been chosen to exhibit a range of classes of dynamics, such as smooth and slowly varying motion, fracturing dynamics, and fluid flow. Covering a range of dynamics is critical as most current 4D-CT methods focus only on one class and may fail when tested on other dynamics. To ease adoption, use, and extension of our work, we are publishing the tool and datasets as open-source software to TomoBank, a repository for CT data.

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Diamond-Like Carbon Thin Film Ablation, Incubation and Graphitisation in MHz Ultra-Fast Treatment Regimes

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Abstract

Laser-induced graphitisation (LIG) methods yield fast-throughput and customisable fabrication of graphene electrodes requiring low-cost carbon-based precursor materials. Here the role of incubation in ultra-fast laser processing and ablation mechanisms of diamond-like carbon (DLC) nano-film precursors is outlined with a focus on film thickness influence. The underlying incubation processes in zero damage ablation studies are correlated to empirically observed graphitisation results and possible factors imposing limits on film processing dynamics are discussed. Incubation and graphitisation seeding effects within larger area ultra-fast laser treatments are showcased, highlighting the impacts of precursor nonuniformities, and providing insights into managing these phenomena with treatment parameters.

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Less Fidelity, More Fidelity: Approximate State Preparation for Efficient and Robust Quantum Machine Learning

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Abstract

Quantum machine learning (QML) is widely touted as an application of quantum computing with the potential to deliver significant advantages over classical algorithms.Its practical realisation, however, remains impeded by considerable challenges.For example, in order for a quantum computer to process classical data, it must first be encoded into a quantum state, a generically challenging and computationally expensive task with the potential to undermine any quantum speedups. Furthermore, the deep circuits needed to encode complex datasets into small numbers of qubits are not suitable to execute on near-term quantum devices with relatively high noise levels.The efficient preparation of quantum states is therefore an important line of research, but remains a comparatively understudied component of the QML pipeline. In this work, we have implemented approximate state preparation methods through genetical gorithms, variational and matrix product state based approaches. We find that such methods can approximately prepare states encoding standard image datasets (MNIST and FMNIST) to a level suitable for QML using circuits two orders of magnitude shallower than a naive implementation, obtaining drastic savings in circuit depth largely without sacrificing classification accuracy. Moreover, we find that our approximate models enjoy superior robustness against adversarial input data manipulations. The partial alleviation of adversarial vulnerability, possible due to the ``drowning out'' of adversarial perturbations while retaining the meaningful large-scale features of the data, constitutes a considerable benefit for approximate state preparation. Finally, on a simple image dataset, our approximate state preparation procedures render high performance classification on real quantum hardware possible, while exact state preparation leads to long circuits overwhelmed by noise. With all three of our proposed state preparation methods increasing the efficiency and robustness of the tested QML models, our techniques bring the possibility of NISQ-era large-scale QML closer to reality.

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A Pauli tracking library and optimizations in MBQC

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Abstract

In quantum computing, it is crucial to reduce the number of gates and qubits as much as possible. This optimization can be tackled on multiple levels, e.g., optimising the quantum algorithm on the logical circuit level or trying to develop more efficient error-correcting codes. We tackle a possible optimization on the circuit level, namely the classical tracking of Pauli operators through circuits that consist only of Clifford gates and measurements. These kind of circuit constructions appear, for example, when doing measurement-based quantum computing (MBQC) or in general whenever non-Clifford operators are realized through gate teleportation with the help of additional ancilla qubits which are entangled using only Clifford gates, e.g., as in the surface code. While the classical tracking of the Pauli operators removes the need of performing these operations on the actual quantum device, it also enables space and time optimization regarding qubit initialization and measurement scheduling: When teleporting the non-Clifford gates as above, or in general any gate as in MBQC, the non-determinism of the according measurements usually induces (tracked) Pauli corrections conditioned on the measurement outcomes. Analyzing the Pauli tracking, in connection with the required spacial graph state in the case of MBQC, gives knowledge about how the computation can be optimized in space and in time, i.e., what is the mininum number of required qubits or given a fixed number of qubits, how many steps of parallel measurements are required. We provide tools to perform the Pauli tracking and to perform the space and time optimizations on limited circuits. Specifically, we briefly present a Pauli tracking library and algorithms to optimize circuits, which we apply to specific circuits.

Active control of bound states in the continuum in toroidal metasurfaces with vanadium dioxide

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Abstract

The narrow bandwidth and exceptionally high Q-factor of toroidal resonances in metamaterials have garnered significant attention [1]. Active control of toroidal resonance characteristics represents a promising avenue for further exploration and research. In this study, we demonstrate how a thin film made of vanadium dioxide integrated into the central gap of the toroidal resonator may dramatically change the Q-factor of the toroidal resonance as the temperature changes. The proposed tunable metasurface is composed of an array of meta-atoms formed by two symmetrical gold split-ring resonators on a sapphire substrate. The phase change transition of vanadium dioxide occurs in a narrow temperature range providing a large variation in impedance. This leads to a change in the transmission at the frequency of the toroidal resonance and, accordingly, in the amplitudes of the multipole expansion components demonstrating a high sensitivity to the introduced losses. Additionally, we analyse the behavior of the toroidal resonance when introducing asymmetry in the geometry of the meta-atom. We study the resonances in such an asymmetric structure and analyse the amplitude and Q-factor dependence on the toroidal resonator's asymmetry. The amplitude of the resonance increases with the degree of asymmetry, corresponding to the excitation of symmetry-protected bound states in the continuum (BIC) [2]. The proposed tunable metasurface holds potential applications in various fields, including time-varying photonic systems, room temperature terahertz and infrared bolometers, as well as multifunctional metadevices.

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Dual comb source with adjustable line-spacing in a single MgF_2 Kerr microresonator

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Abstract

Kerr microresonators are widely recognised as a powerful platform to generate compact and efficient optical frequency combs (micro-combs). Micro-combs offer low noise stable operation when configured to generate localized dissipative structures known as temporal cavity solitons (CS). For spectroscopy, imaging, and ranging applications; the generation of two frequency combs with different comb line-spacings is highly desirable. In this configuration, the beat signals of consecutive comb line pairs can be mapped from the optical domain to the radio-frequency (RF) domain, enabling high-speed, high-resolution measurements. In this work, we realise a dual micro-comb source where two counter-propagating combs are driven by pumping the same spatial resonator mode at different azimuthal mode frequencies. We show that by changing the driven azimuthal mode, through adjusting the pump frequency used, the micro-combs' RF line-spacing can be discretely tuned. Moreover, varying the relative detuning of the two pumps provides an additional continuous nonlinear tuning due to differential self-phase-modulation (SPM). We drive an MgF_2 micro-disk resonator (FSR = 56 GHz, finesse = 30,000) with two counter-propagating pumps separated by an adjustable frequency spacing up to 80 FSRs. We demonstrate discrete tunability of the RF comb line-spacing achievable through adjusting this FSR separation. This coarse tuning provides adjustable dual-comb RF line-spacings between 100 kHz to 1 MHz in steps of ~10 kHz/mode. Additionally, by varying the relative detuning of the two soliton pumps, we demonstrate a further ~100 kHz of continuous, fine tunability through the differential SPM experienced by the two combs. These techniques yield mechanisms for both the discrete (coarse), and continuous (fine), tunability of the line-spacing of the resultant RF comb. Moreover, these methods are extended to solitons operating in different mode-families, offering access to even larger RF line-spacings. We believe these methods will find useful application in the optimisation of future microresonator dual-comb setups.

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The Twisted Anyon Cavity Resonator as a Potential Dark Matter Detector and Sensing Device

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Abstract

The minimum axion mass detectable by existing photonic dark matter searches is set by the detector's frequency and hence size, which places the lower limit around 10^{-7}eV [1], leaving the ultra-light dark matter (ULDM) parameter space relatively unexplored. In this work, a new class of electromagnetic resonator is described; the Anyon Cavity Resonator (see Fig. 1), which has the potential to couple to ULDM axions. This is possible due to the existence of a single electromagnetic mode with non-zero helicity, which is generated in vacuo through a pure photonic magneto-electric coupling of a transverse electric (TE) and transverse magnetic (TM) mode [2]. The resonator is based on twisted hollow structures that possess mirror-asymmetry. The origin of these high helicity modes is demonstrated using finite element simulation. It is predicted that these cavities will have the capability to search for dark matter down to 10^{-24} eV with a minimum coupling strength of $10^{-15.8}$ GeV^{-1} [2]; covering a completely unexplored region of parameter space. Further, the generation of a topologically protected Berry phase is successfully measured in Möbius cavities, which are formed by bending the aforementioned twisted hollow structures around on themselves to form a ring.

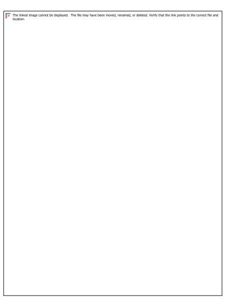

Fig.1. 3D printed twisted triangular waveguide

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Fabrication of highly coherent superconducting aluminium resonators on silicon

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Abstract

The superconducting circuit has become the most widely used platform for implementing a quantum computer and investigating circuit quantum electrodynamics. The performances of a quantum computer and the experiments are determined by the quality of individual superconducting qubit. The coherence time of a superconducting qubit can be correlated with the quality of the superconducting resonators made from the same recipe. The quality of resonators is determined by the material and fabrication procedures. We investigated and optimized the fabrication procedure of a superconducting resonator based on aluminium and silicon. Notably, we had more than five-fold increase in quality factors after the optimization. Furthermore, we show effects of post-treatment on the quality of resonators.

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High-sensitivity measurement of optical absorption at 2µm in ZBLAN glass

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Abstract

Absorption and scattering in optical components and their coatings cause signal attenuation, wavefront distortion, thermal-stress-induced birefringence, and potentially catastrophic failure of the component. We describe a high-sensitivity measurement system that could be used to measure the absorption coefficients of optical substrates and coatings at wavelengths extending from the UV to MWIR. We shall also report its application to the measurement, with unprecedented sensitivity and accuracy, of the bulk and surface optical absorption coefficients at 2 µm in low-loss ZBLAN glass. Importantly, the measurement is unaffected by scattering from microscopic or randomly distributed scattering sites and provides information that is critical to attempts to reduce the attenuation in ZBLAN optical fibres. Reduction to < 0.02 dB/km, a factor of 10 less than for 1.55 µm and fused silica single-mode fibre, would enable the next generation of long-haul communications. This measurement system could also be applied to investigate losses in components used in high power lasers and optical systems such as next-generation gravitational wave detectors where the circulating power is expected to exceed 1 MW.

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Implications of Dark Photon Dark Matter for Gravitational Waves

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Abstract

The well-studied graviton-to-photon conversion process provides an intriguing method to observe early universe gravitational wave sources. However, these effects are suppressed when considering magnetic fields present in the early universe, due to the presence of the Standard Model plasma. In contrast, a dark magnetic field would induce an analogous graviton-to-dark photon conversion process, but not be subjected to these suppression effects, greatly enhancing the probability of conversion. In the presence of a dark magnetic field, the Gravitational Waves generated in the early universe - such as from inflation, phase transitions, and topological defects - would be partially converted to dark photons. There is also possible polarisation dependent effects on the Gravitational Waves depending on the properties of the dark photon energy density. Importantly, the dark photon can play the role of dark matter if it has a small mass, with the dark photons generated from the conversion process for different gravitational wave sources leaving imprints on the dark matter power spectrum. Thus, providing a unique array of correlated observational signatures.

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Properties of Ultra-Compact Objects Near the Trapped Regions

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Abstract

Assumptions of finite-time formation of a trapped region and finiteness of curvature scalars on its boundary are sufficient to constrain a general spherically symmetric metric to correspond to two classes of solutions of the Einstein equations. Each solution can describe an expanding white hole or an evaporating black hole, also referred to as physical black (or white) holes because of their finite-time formation.

First, we focus on the general properties of these trapped (or anti-trapped) solutions, exploring how matter and forces behave in their vicinity. All the solutions are real-valued only if the null energy condition (NEC) is violated in the vicinity of the apparent horizon. Moreover, spherically symmetric black hole solutions cannot grow, but growth of axially symmetric black holes are possible. While the curvature scalars are finite on the apparent/anti-trapping horizon, it is still a weakly singular surface.

Next, we establish connections between the observed properties of ultra-compact objects and their theoretical properties, as transpired from our model. We present an exactly solvable candidate model for astrophysical black holes, which can be embedded in a cosmological background. In the leading order approximation, evaporating black hole (or accreting white hole) solution takes the form of the ingoing (or outgoing) Vaidya metric. This suggests a universal description of the near-horizon geometry of evaporating black (or accreting white) holes in terms of the Vaidya metric.

We then extract the thermodynamic properties of physical black holes by transforming the coordinates to write the near horizon of a black hole spacetime into the Rindler metric. As the Vaidya metric captures many essential features of evaporating black hole spacetimes, we demonstrate that the linear Vaidya metric can be brought into manifestly conformally static form, allowing us to determine its Hawking temperature with respect to the conformal vacuum.

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Conical Nanopores in Amorphous SiO_2 Membranes

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Abstract

When a highly energetic heavy ion passes through a target material, the damaged region left in its wake often exhibits preferential chemical etching over the undamaged material. This etch-anisotropy can be used to create pores with nanometer sizes and different shapes such as cylindrical or conical in many materials. Track-etched nanopores have been used for a wide range of applications such as ultrafiltration, bio- and medical sensing, nanofluidic and nanoelectronic devices.

We present a method for fabrication of conical nanopores in thin amorphous SiO_2 (a-SiO_2) membranes using ion track etching. 1 µm thin a-SiO_2 windows are irradiated with 2.2 GeV ^{197}Au ions at the Universal Linear Accelerator UNILAC (GSI Helmholtz Centre for Heavy Ion Research, Darmstadt, Germany). Subsequently, the windows are exposed to HF from one side leading to the formation of conical nanopores.

A 55 × 66 μm^2 membrane is irradiated with $4.4 \cdot 10^5$ ions cm^{-2} and etched with 2.5% HF for 14.5 min, leading to the formation of 16 pores. Atomic force microscopy and scanning electron microscopy enables to image the pore base radius, which is determined to (158.3 ± 2.6) nm. Using small-angle x-ray scattering the half-cone angle can be precisely determined to be (12.6 ± 0.1)°.

The transport characteristics and surface properties are measured by performing conductometric measurements, where the ionic current of a KCl solution is monitored across the membrane. This technique also provides an accurate estimate of the pore tip radius of (5.7 ± 0.1) nm. We find that at neutral pH the surface is negatively charged due to SiO^- groups present at the pore surface. The geometrical asymmetry of conical pores combined with a strongly charged surface that can be tuned by adjusting the pH and electrolyte concentration causes a large ionic current rectification (ICR) of up to 10. This indicates a very high selectivity towards cations.

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3D Graphitised Stretchable and Wearable Devices

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Abstract

The development of smart skins as an integral laminated wearable platform holds great promise for various applications in healthcare monitoring and soft robotics [1]. These artificial skins are designed to respond directly to physical and mechanical stimuli from the environment or the spotted targets, allowing for real-time observations and interactions [2]. The advantage of laminated thin films is their conformability and smoothness, reducing the stress and discomfort typically associated with wearables. One critical challenge in developing these smart skins is balancing durability with functionality due to the drawbacks of existing lamination technologies that might limit their long-term use and effectiveness.

We report the development of vital stretchable electronic and photonic components like stretchable electrodes and varifocal lenses to address this challenge using graphene oxide (GO)-polydimethylsiloxane (PDMS) thin film and 3D laser printing technology [3]. These components can contribute to achieving compact, highly sensitive sensing and imaging systems, which are crucial for the successful functioning of smart skins. The thickness of these devices is around 1/20th of the epidermis layer thickness of human skin. The process responsible for creating these structures within the GO-PDMS thin film involves graphitisation. The graphitisation process occurs due to the interaction of the material with a spatially controllable, tightly focused femtosecond (fs) laser beam in the confined region within the GO-PDMS thin films. This process is responsible for forming stretchable electrodes and varifocal lenses within the thin film, making them an integral part of the smart skin's functionality.

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Analogue quantum simulation of molecular vibronic spectra with a trapped ion

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Abstract

Simulating quantum chemical systems on classical computers can be challenging, particularly in strong vibronic (vibrational and electronic) coupling regimes where the Born-Oppenheimer approximation breaks down. Moreover, the dynamics on these chemical systems are on ultrafast femtosecond timescales, which is experimentally challenging to access through conventional spectroscopy. Alternatively, vibronic coupling can be efficiently simulated in an analogue fashion on quantum systems with coupled internal states and bosonic modes \cite{first_ref}. We use this encoding to map molecular dynamics onto our 171Yb+ trapped ion system where the ion's motional harmonic oscillator states represent the vibrational modes of the molecule, while the vibronic interactions are implemented by coherently driving multi-tone Raman transitions.

We experimentally reconstruct the vibronic Franck-Condon spectra of a SO2 molecule with good agreement with spectroscopic data \cite{sec_ref}. This experiment is made possible by recent improvement in the trapped ion's motional coherence time by a factor of $\approx$50, enabled by amplitude noise filtering and active feedback. The results demonstrate accuracy of our simulator. The low noise of the simulator allows for more complex simulations of chemical dynamics.

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Role of deformed shell effects in quasi-fission of compound Th-226 nucleus

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Abstract

Quasi-fission is the process at which the nucleus re-separates before complete fusion,thereby competing with the fusion process. As the name suggests, this process is superficially like the fission process. However, there are a few significant differences in the two mechanisms, such as the timescale involved in the processes and the dependence of the final fragments on the entrance channels. The hindrance to the super-heavy element formation process and the fission-like properties of the quasi-fission fragments motivate theoretical investigations of quasi-fission.

Recent observations comparing the final fragments resulting from fission and quasi-fission of various nuclei suggest evidence for similar shell effects present in the two mechanisms, opening new possibilities to probe some properties of fission in the region of the nuclear chart inaccessible via experiments, through the quasi-fission process.

To compare the shell effects present in fission and quasi-fission, quasi-fission trajectories are calculated using the time-dependent Hartree-Fock code Sky3D. Collisions that form compound nucleus of Th-226 were simulated near the fusion barrier at various energies and angular momenta, then compared to the topography of the potential energy surface of Th-226 to interpret their behaviours.

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Monitoring and Mitigating Radio Frequency Interference using the ASKAP radio telescope.

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Abstract

I will present research that encompasses a multifaceted approach to address Radio Frequency Interference (RFI) challenges using the Australian Square Kilometre Array Pathfinder (ASKAP) telescope. The talk will comprise two main components: an analysis of flagged data (data that is discarded) trends and RFI mitigation using subspace projection.

Firstly, I will present statistics of flagged data patterns based on antenna orientation, frequency, and time since 2019. Monitoring RFI, using the telescope itself as an RFI monitor, provides insights into how RFI varies throughout the day and year-on-year. Furthermore, this technique identifies RFI sources, such as mobile communications and GPS, to understand their impact on science survey projects. Furthermore, historical data analysis aids in predicting the typical amount of flagged data, facilitating optimized scheduling of observations to minimize RFI effects. Additionally, the research supports spectrum management to ensure compliance with RFI regulations in designated radio-quiet zones.

The second aspect centres on mitigating RFI using spatial filtering using subspace projection methods, a technique that adjusts beamformer weights to eliminate the unwanted signal. I will demonstrate RFI suppression to the noise floor and present the effects of this technique on sensitivity and beam pattern.

In conclusion, this research offers a comprehensive strategy for monitoring and mitigating RFI using the ASKAP telescope. It provides valuable tools and insights to optimize telescope operations in an increasingly polluted radio spectrum. Moreover, it highlights the effectiveness of oblique projection spatial nulling as a promising approach for countering RFI, laying the groundwork for its practical application in real-time RFI mitigation for ASKAP and similar radio telescopes.

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Enhancement of chiroptical response in high-quality metallic metasurfaces

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Abstract

In the recent years, many breakthroughs have been achieved in resonant nanophotonics. Manipulation and control of light properties are enabled by nanoscale resonant structures supporting plasmonic and Mie resonances [1]. Bound states in the continuum (BICs) with infinite quality factor has attracted much attention duo to unique properties including suppressed radiative losses and strong local field enhancement [2]. Realistic structures can exhibit quasi-BICs with a high yet finite Q factor due to material and radiative losses. Very recently, it has been shown that quasi-BIC in dielectric metasurfaces can realize strong chiroptical response [3]. Here, we extend this concept to metallic metasurfaces with extrinsic chirality enhancement.

We design a metasurface composed of perfectly conducting metal immersed in a dielectric with $\epsilon = 2.2$. The meta-atom is characterized with C_3 and in-plane mirror symmetries. The structure supports a BIC mode at the frequency of 18.7GHz and topological charge of 1, which are confirmed by the far-field and Q factor evolution in the vicinity of Γ point. We explore how the BIC transforms into a high-quality mode at oblique incidence in the range of 0-15°, with the incidence plane parallel to the hexagon side. The Q factor change and linearly polarized transmission evolution is studied further. For the angle of 7°, we calculate the transmission and circular dichroism (CD) confirming the formation of a quasi-BIC with Fano-type line-shape.

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In-situ TEM annealing analysis of helium bubble dynamics in tungsten and its dependence on temperature during plasma exposure

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Abstract

The International Thermonuclear Experimental Reactor's (ITER) decision to operate with a full tungsten (W) divertor has spurred further interest in the material's prospects[1, 2]. W is the favoured plasma-facing material in fusion reactors such as ITER due to its high melting point and low tritium retention. The harsh conditions in a reactor actively degrade the material. Thus, assessing a plasma-facing component's material lifetime remains a crucial aspect of the study to minimize interruption to tokamak operations[3, 4].

In-situ TEM annealing up to 998 K was performed on polycrystalline bulk W samples pre-exposed at either 573 K or 1013 K to a pure helium (He) plasma to a fluence of 1025 m-2 to investigate the annealing behaviour of He bubbles. Annealing had little effect on the bubble structure for the lower temperature exposure of 573 K. Bubbles trapped in snake-like structures remained throughout annealing. There were minimal observed changes in the average bubble size and number density. Annealing had a significant effect on the higher temperature exposure of 1013 K where bubbles were found to be trapped in clusters. Increasing the annealing temperature caused a significant increase in the average bubble size accompanied by a decrease in bubble number density. There was no observed migration of bubbles during the annealing process in either sample. These trends in the bubble dynamics with annealing temperature suggest that Ostwald ripening dominates annealing bubble growth at annealing temperatures up to 998 K, whereby bubble growth is determined by the different pressures of different bubble sizes rather than through bubble migration and coalescence.

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Modelling of nuclear fission with an exact time-dependent generator coordinate method

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Abstract

As practical uses and experimental observations of nuclear fission continue to develop in the modern world, there is an increasing demand for theoretical models to accurately describe and predict the outcomes of this complex process. Our research explores a pathway to such models using the Time-Dependent Generator Coordinate Method (TDGCM), with the goal of extracting fission yields, probability distributions of obtaining fission fragments with different mass and charge numbers, for comparison with experiment. The TDGCM simulates time evolution of a nucleus across a potential energy surface (PES) describing how the total energy of the nucleus varies with its collective shape. Successful applications of this formalism have so far relied on the Gaussian Overlap Approximation (GOA) to simplify computations, but at the cost of accuracy and physical relevance.

We briefly explain the problem of discontinuities, unphysical artefacts arising during PES generation which prohibit time evolution, and present methods we have developed to effectively remove them. Next, we introduce the basic theory of TDGCM in the context of nuclear fission, as well as the problems that have so far hindered its exact implementation without the GOA. We explain the techniques we have designed to overcome some of the key obstacles, then showcase and evaluate some preliminary results from our implemented model. We conclude with an outlook for our work in the near future, and consider its overall contribution towards predictive models of nuclear fission.

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FPGA Based Atmospheric Correction Algorithm for Ground to Space Optical Phased Array Links

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Abstract

Optical Phased Arrays (OPA) offer a compelling solution to the challenge of optically accessing Earth orbit from the ground for communications, energy delivery and interstellar propulsion. An OPA, consisting of an array of coherently combined optical beams, with sufficient size and order of sub-apertures, can provide heightened power transmission compared to that achieved through individual laser operation.

One application where these technologies are required at scale is the Breakthrough Starshot project [1]. This endeavour aims to use a ground based OPA to propel a sail-based spacecraft (sailcraft) to the Alpha Centauri and travel at approximately 0.2 lightspeed. A critical component of this system is the real-time measurement and correction of atmospheric wavefront distortion at the sub-aperture level. This project demonstrates the hardware implementation of the proposed correction algorithm running in real-time on a field programmable gate array (FPGA).

We present the key findings from the FPGA implementation of the atmospheric correction algorithm, including results from hardware-in-loop validation of the real-time signal processing. We obtain measurements of the algorithm's phase detection resolution and validate quantization and latency limits showing suitability for usage in OPA systems. This presents a critical step towards implementing a full optical test towards high-speed, electro-optic wavefront correction for ground-to-space optical links.

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Repurposing the ANU Enge Spectrometer for Nuclear Structure Studies

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Abstract

Light-ion transfer reactions represent an underutilized tool to examine single-particle behavior. While the use of split-pole magnetic spectrographs to study nuclear reactions with light ions [1] has ebbed in the past decades, recent advances in reaction theory, detector & electronics development and, digital signal processing capabilities has necessitated a comeback. To that end, the ANU Enge Spectrometer [2] is being upgraded with the newly developed Light-ion Focal Plane Detector (L-ion FPD) to enable (d,p) and (d,t) transfer reaction studies. Additionally, concurrent experiments using overseas facilities like HELIOS (Helical Orbit Spectrometer) at Argonne National Laboratory and SOLARIS at FRIB (Facility for Rare Isotope Beams) will leverage the ability to perform experiments in inverse kinematics, getting around the inability to make high quality targets when confronted by low natural abundances [3][4]. Initial experiments involve studying Calcium isotopes around N = 28 which are excellent candidates for probing shell-model theories. Fragmentation of fpg orbital strengths near the doubly-magic ^{48}Ca is poorly understood and the reliability of previously determined spectroscopic strengths are questionable [5]. This presentation will outline the development and capabilities of the new L-ion FPD, results and findings of finite-range Distorted Wave Born Approximation (DWBA) calculations will be discussed, and details of the broader experimental campaign shared.

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Collective pumping superradiant laser with coherence scaling beyond the Schawlow-Townes limit.

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Abstract

For more than 60 years, the Schawlow-Townes limit was thought to limit the laser coherence $\mathfrak{C}$ — the number of photons emitted from the laser into the beam in one coherence time — to a scaling $\theta(\mu^2)$, where μ is the mean number of optical-frequency excitations stored inside the laser. However, recently, it has been shown [Baker et al., Nat. Phys. \textbf{17}, 179 (2021)] that this is just a standard quantum limit (SQL). The Heisenberg limit — an achievable ultimate limit set by quantum mechanics for the task of producing a beam with the standard properties of a laser beam — is $\mathfrak{C} = O(\mu^4)$, a quadratic enhancement. So far, proposals to demonstrate beyond-SQL scaling of $\mathfrak{C}$ have been limited to circuit QED, at microwave frequencies (i.e.~a maser). Here, we propose an optical-frequency laser platform that can surpass the Schawlow-Townes scaling: a superradiant laser in the bad-cavity limit with feedback-controlled collective pumping. We show that the coherence can exhibit a scaling as large as $\mathfrak{C} =O(\mu^{8/3})$. Here, in the bad-cavity limit, $\mu \approx N/2$, where N is the number of superradiant atoms.

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Nanofabrication and spectroscopy of two-dimensional boron nitride (hBN), black phosphorus (BP) and GaN.

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Abstract

Background and aims

There are very few techniques that permit both nanofabrication and spectroscopy of devices composed of two-dimensional materials at the required sub-nanometre resolution. Here, we discuss the development of successful strategies employing charged particle beams for in-situ functionalization, nanofabrication and cathodoluminescence spectroscopy of two-dimensional semiconductors including hBN, BP and GaN.

Methods

Environmental SEM (ESEM) experiments were conducted using a variable pressure FEI Sirion SEM. Room temperature photoluminescence (PL) measurements were performed on a custom-built confocal PL setup under 532 nm continuous laser excitation. Cathodoluminescence (CL) spectra were collected using a Delmic SPARC system with a 13 mm parabolic mirror.

Results

High resolution electron beam etching of hexagonal boron nitride is demonstrated under 8 Pa water vapour in an ESEM. The hBN undergoes denitrogenation under electron beam induced etching in H2O, forming volatile NO and NO2 and leaving behind boron nanoparticles. Under continued irradiation, the dissociated H2O molecules react with NO and NO2 species to produce nitric acid, resulting in highly localized, clean etching of the hBN. We also study the stability of another two-dimensional material, few-layer BP in H2O, O2, NF3 and NH3 environments using ESEM and in situ electrical conductance measurements. The electron beam is used both for ESEM imaging, and also to generate reactive species such as *O, *OH, *F and *H that can drive spatially-localized chemical reactions at the sample surface. Finally, focused electron beam irradiation is used to generate cathodoluminescence from ultra-thin GaN nanosheets (~1.4 nm), demonstrating a broadband photoelectrical spectral response from UV (280 nm) to NIR (1050 nm) (Fig.1).

Figure 1. (a) Tauc plot analysis from UV-Vis measurements of 2D GaN nanosheets with an estimated band gap energy of 3.6 eV. (b) Photoluminescence (PL) spectroscopy and (c) Cathodoluminescence (CL) Spectroscopy measurements of the 2D GaN nanosheets.

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Extended frequency tuning coverage for $MgO{:}LiNbO_3$ intracavity terahertz polariton lasers

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Abstract

Terahertz (THz) lasers based on stimulated polariton scattering (SPS) are a promising source of THz radiation with tunable and narrowband emission. The generation process involves the interaction of fundamental, Stokes, and THz fields in non-centrosymmetric crystals. For the most commonly used SPS crystal: $MgO{:}LiNbO_3$ (MLN), early models predict continuous THz frequency output from ~1-6 THz, with peak gain between 2-3 THz. This is not the case in experiments as most MLN intracavity lasers stop working past 3 THz. Our previous work attributed this lack of full-range THz generation to the presence of a 3.15 THz low-frequency (LF) mode. The LF mode causes unexpected absorption, and therefore, a decrease in gain, and an increase in laser threshold at the mode frequency. In this study, we developed a gain model that accounts for the right THz absorption in the crystal and determines the laser threshold at a range of THz frequencies. Shown in Fig. 1 are the calculated (colored, solid) and measured (dotted) curves for the fundamental field intensity at the SPS threshold as a function of THz frequency. The agreement of the measured values to the calculated curve with the LF mode (orange) confirmed the effect of the 3.15 THz LF mode and the gain recovery past the mode frequency. Here, we show continuous THz generation that extends up to 5.4 THz (so far, the widest achieved by a nonlinear crystal via intracavity SPS). The observed tuning at high THz frequencies extends the overall frequency coverage of MLN-based SPS THz lasers and was only achieved after careful understanding and consideration of the theory that underpins the SPS behavior.

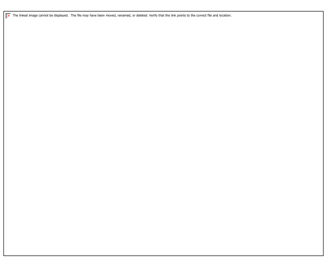

Figure 1 Comparison between the measured (blue dots) and modeled curves (colored lines) for fundamental field intensity at the SPS threshold.

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Photoelectrical Dynamics of an Isolated Nitrogen-Vacancy Centre in Diamond

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Abstract

Nitrogen-vacancy (NV) centres in diamond is a promising architecture for quantum sensing/ microscopy, quantum communications and quantum computing. While this defect has been extensively studied, the charge dynamics of the NV centre are one of the few aspects of this defect that are not yet fully understood. Resolving this remaining issue is key to improving the performance of the centre in its various quantum technologies.

In this work, we aim to present the latest advancements in simulating the photoelectric dynamics of an isolated NV centre. The intricate nature of these dynamics poses a substantial challenge for simulations, primarily due to the complex photophysical processes inherent in isolated NV centres, which have remained incompletely understood until now. Leveraging recent breakthroughs that shed light on the intricate photoionisation mechanisms within the NV centre, we construct a comprehensive photoelectrical model for an isolated NV centre. This model will be built by integrating drift-diffusion and rate equation modeling techniques as well as recent measurements of carrier capture cross-sections. The insights generated by this model are expected to significantly enhance the efficiency of the photoelectric readout mechanism. This enhancement is particularly crucial as it stands as the only scalable approach for achieving efficient readout to increase the deployability and functionality of diamond quantum sensors, as well as for the realisation of large-scale diamond quantum computers.

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Implications of singularity regularization in black hole thermodynamics

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Abstract

Regular black holes have become a popular alternative to the singular mathematical black holes predicted by general relativity as they circumvent mathematical pathologies associated with the singularity while preserving crucial black hole features such as the trapping of light. Here, we will analyze how to generate these geometries and study their thermodynamic properties within the framework of general relativity. Our study reveals that the regularization of the singularity, through the introduction of a minimal length scale, has a plethora of implications, one of which is the absence of a Hawking-Page phase transition. We extend our study to the dynamical case, showing that supplemental terms are required in the dynamical first law of black hole thermodynamics to maintain its essence. The additional terms manifest in the dynamical first law as work terms, while the notion of internal energy is captured by the Misner-Sharp mass. Furthermore, we explicitly demonstrate that the linear coefficient of the Misner-Sharp mass expansion near the outer apparent horizon suffices for a complete thermodynamic description.

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Quantum algorithm co-design for field-testing the path to advantage

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Abstract

To help end users to appreciate both the current status and the potential future impact of quantum computing, providing practical-scale solutions that leverage quantum resources is a powerful demonstration. These demonstrations ideally satisfy three criteria: (1) a current quantum computation at non-trivial scale, (2) a smooth scaling approach such that the quantum computation can measurably scale towards a target threshold for potential quantum advantage, and (3) algorithm design that minimises the most challenging resources for a given hardware. We illustrate this approach using a scheduling and routing scenario for the Australian Army: our hybrid quantum algorithm provides solutions for full-scale use-cases and features (1) a current quantum routing sub-routine for ~6 vehicles on several available routes, (2) a problem decomposition method that allows scaling of the number of vehicles towards the classically-challenging threshold at ~100 vehicles, and (3) resource requirements of only sparse two-qubit connectivity outside local qubit clusters and circuit duration less than 1ms for classically-challenging problems (within challenging but achievable T1 limits) on superconducting devices. We highlight the impact of Q-CTRL's error-reducing infrastructure software, which increases current high-quality solution size (2X larger than direct hardware deployment), provides >6X improvement in time-to-solution, and reduces the device T1 limit required for large scale problems by ~20%.

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Multi-functional Tuning of Liquid Crystals Metasurfaces

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Abstract

Optical metasurfaces present remarkable opportunities for manipulating wave propagation in unconventional ways, surpassing the capabilities of traditional optical devices, such as flat lenses, beam converters, deflectors and holograms. To date, most functional dielectric metasurfaces are based on static structures defined by geometric parameters such as the shape and size of meta-atoms and their arrangement. However, the apparent limitation of such metasurfaces is the lack of flexibility for their optical properties after they have been fabricated. Integrating optical metasurfaces into liquid crystal (LC) cells has proven to be a successful strategy for realizing pronounced metasurface resonance tuning. Due to the anisotropy of LCs, the positions of the resonances can be dynamically controlled by an external stimulus, such as temperature [1], voltage [2] or magnetic field [3].

Here, we introduce the novel concept of multi-functional metasurface tuning by LCs, where the application of an external magnetic field effectively controls the molecular reorientation. To illustrate this concept, we present an experimental and theoretical study where the magnetic field in such bulk configuration provides fully controllable 3D molecular orientation, entailing extra flexibility for spectral tuning of electric and magnetic resonances of dielectric metasurfaces. Moreover, we suggest a multi-stimuli-responsive system where we combine magnetic and thermal tunability of LC-integrated dielectric metasurfaces. By applying both stimuli simultaneously, we are able to enter tuning regimes, which are inaccessible by the application of a single stimulus only. This is possible because the magnetic-field tuning approach does not require pre-alignment of LC through special surface treatment, such as surface rubbing, which is commonly used for other liquid crystal tuning methods. Our results open important opportunities for realizing dynamically reconfigurable metadevices for a wide range of applications, including sensing, imaging, and communication technologies.

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Spectral engineering of photon pairs from a nonlocal metasurface

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Abstract

Quantum photon pairs from spontaneous parametric down-conversion (SPDC) are the building blocks of many quantum technologies. Ultrathin nonlinear metasurfaces have recently shown outstanding potential for miniaturising this quantum light source, demonstrating the enhanced generation of spatially [1] and polarization [2] entangled photons. While frequency-entangled photons were generated from metasurfaces [3], the photon spectra were fixed at the wavelengths determined by local metasurface resonances, limiting the potential to generate on-demand quantum states in the spectral degree of freedom.

Here, we suggest and confirm experimentally that nonlocal metasurfaces enable continuous tuning of the generated photon-pair spectra simply by adjusting the pump incident angle θ_p, as sketched in Fig. 1a. Our metasurface supports nonlocal resonances with specific angular dispersion shown in Fig. 1b. Because of the energy conservation and transverse phase matching condition in SPDC process, the emitted photon pairs have degenerate wavelengths for θ_p= 0° (blue dots), while the non-degenerate regime is realised for θ_p= 0.3° (red dots). We experimentally measure the spectra (Fig. 1c) of the photon pairs by a procedure similar to Ref. [3] and observe a characteristic change from a degenerate single peak to non-degenerate double peaks when tilting the metasurface. This can facilitate the flexible preparation of frequency-encoded quantum states from ultra-thin metasurfaces, opening new opportunities for applications.

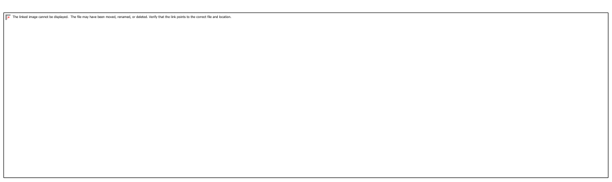

Fig 1: a Sketch of photon spectrum shaping by tilting the metasurface. A pump laser is injected onto the metasurface at an angle θ_p along the y-direction. b Optical resonances vs. transverse wavenumber. Two times the pump wavelength is equal to 1556 nm (orange dashed line).
c Experimental measurement of photon spectra at different pump angles. The inset shows an SEM image of the fabricated metasurface.

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Experimental Free-Space Quantum-Secured Time Transfer System for use over a Ground-to-Satellite Link

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Abstract

The reliance on Global Navigation Satellite Systems (GNSS) such as the Global Positioning System (GPS) in providing accurate time and positioning information is essential for navigation, communication networks and electricity grids. However, GPS signals can be easily spoofed whereby false time and location information is sent to a GPS receiver.

Quantum clock synchronisation protocols using pairs of entangled photons have been proposed as a means of providing unspoofable and precise time transfer [1]. The most well-known experiment to date involved the transmission of an optical quantum time transfer signal between the Micius quantum satellite and a ground station in China in 2020 [2]. However, questions remain regarding operational performance of this technique as true single photons were not employed in this demonstration. In 2023, one-way time transfer was achieved using pairs of time correlated single photons over a free-space link [3]. Long distance quantum-secured time transfer will require ground-to-satellite links. We therefore need to consider the effects of loss, turbulence and noise on the quantum time transfer signals being transmitted via ground-to-satellite links.

Here we will present our latest results investigating effects such as loss, turbulence and noise on a two-way quantum time transfer link using correlated photon pairs. To date we have demonstrated the potential performance of free-space time transfer using time correlated single photons with picosecond resolution. We will present our latest work towards using polarisation-entangled photons to demonstrate quantum-secured time transfer over a ground-to-satellite link - where the confirmation of entanglement guarantees the authenticity of the signals.

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The anisotropy of swift heavy ion tracks in tourmaline and fluorapatite single-crystals

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Abstract

When swift heavy ions (SHIs) with kinetic energies in the MeV to GeV range penetrate a crystalline solid, they interact with the materials' target electrons through inelastic collisions. The resulting electronic excitations yield a thermal spike, which can create amorphous defect structures resembling narrow straight damage trails [1,2]. These ion tracks with radii of only a few nanometers and lengths of up to tens of micrometers are well-suited as a proxy for naturally created fission tracks in minerals interesting for geo- and thermochronology, as well as the degradation mechanisms and radiation resistance of materials that are exposed to this kind of radiation, for instance, in radioactive waste. Previous work has shown that synchrotron-based small-angle X-ray scattering (SAXS) is highly suited to investigate ion track damage in natural minerals. SAXS is capable of resolving the track morphology with high precision and sufficient time resolution. This precision allows us to determine the anisotropy in the damage profile produced by SHIs and its dependence on the crystallographic orientation of the track.

We present a comprehensive SAXS study of ion tracks created with ^{197}Au ions in natural tourmaline single crystals (R3m) and the structurally related fluorapatite ($P6_3/m$). The ion track radii were investigated as a function of the fluence and the crystallographic orientation of the tracks. For the first time, the complete ion track cross-section was determined revealing a deviation from the ideal cylindrical damage profile for tracks created perpendicular to the [001] direction in both crystals. In addition, the average track radii show a slight anisotropy of tracks created in different crystallographic directions. This study helps to understand the fundamental solid-state processes involved when irradiating natural single-crystals with SHIs.

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Biostable and compatible waveguides for chronic peripheral nervous system stimulation applications

Jeffery Low, Daniel McCormick, Poul Nielsen, Neil Broderick
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Abstract

Biostable and compatible waveguides for chronic peripheral nervous system stimulation applications

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Advancements in the field of optogenetics have led to studies that have shown the ability to stimulate subsections of the vagus nerve in rats and sheep optically, once the relevant light sensitive ion channels are expressed in the nerve via delivery by viral vectors [1]. The viral vectors can be designed to preferentially express light sensitive channels based on function. This enables selective activation of functions within complex nerves like the vagus, allowing new targeted treatments for conditions such as heart arrhythmia, urinary incontinence or dyspnoea to be explored.

However, before new devices that leverage this ability can be implanted with the intention of providing long term optical stimulation, a new method of delivering light to the nerve is needed. Optical fibres are too rigid to implant safely into a mobile area of the body and existing devices that utilise microLEDs mounted near the nerve are not designed for chronic usage [2].

We aim to create waveguides that are compliant and inert enough to exist inside the body perpetually without causing damage, while still maintaining their light guiding ability so that the power of optical nervous system stimulation can be used in new medical treatments.

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2. **Jiayu Wang and Jianfei Dong. "Optical waveguides and integrated optical devices for medical diagnosis, health monitoring and light therapies". In: Sensors 20.14 (2020), p. 3981.**

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Molecular optomechanics in the anharmonic regime: from nonclassical mechanical states to mechanical lasing

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Abstract

Recently, several groups suggested that Raman scattering of light from molecules in a plasmonic cavity can be seen as an optomechanical process [1,2] – similar to that governing the inelastic scattering of light in Brillouin waveguides, on particles trapped in an optical tweezer, or a cloud of atoms in a trap. This realization brought the vast set of tools developed for canonical optomechanics to the field of Surface- or Tip-Enhanced Raman Scattering (SERS and TERS). Simultaneously, it stretched the landscape of cavity optomechanics towards the ultra-high THz mechanical frequencies characteristic of molecular vibrations, and closer to the elusive limit of the strong single-photon coupling.

In this presentation, we briefly introduce the formalism of molecular optomechanics as a quantum optics picture of the molecular Raman scattering. We then discuss how this formalism can be used to predict, and explain unexpected features of SERS, such as the sub-nanometer resolution of TERS [3], nonlinearities in SERS intensity [4, 5], or the strong intensity correlations between Stokes and anti Stokes emission.

Finally, we how how the extension of this formalism towards explicitly treating the anharmonic potentials of molecular systems offers a pathway towards engineering nonclassical states of the molecular vibrations and antibunched THz emission, and enabling the implementation of a new type of optical phonon laser [6].

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High-pressure phase transitions in diamondoid molecular crystals observed by in situ Raman spectroscopy

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Abstract

Due to their structural similarities with diamond (C), diamondoids are promising candidates for high-pressure, high-temperature synthesis of cubic and hexagonal nanodiamonds [1]. Functionalised diamondoids can be used as a precursor material for the synthesis of nanodiamonds with desirable physical properties such as fluorescence [2].

Four types of diamondoids, adamantane ($C_{10}H_{16}$), diamantane ($C_{14}H_{20}$), triamantane ($C_{18}H_{24}$), and tetramantane ($C_{22}H_{28}$) were studied with Raman spectroscopy using 533 nm unpolarised laser radiation. Experiments under high-pressure conditions up to extreme pressures of 50 GPa were carried out in diamond anvil cells (DACs). Raman spectra at ambient conditions were compared with calculated spectra. The calculation was performed with density functional theory (DFT), using a DEF2-SVP basis set and the B3LYP hybrid functional. Although all investigated samples are crystalline, the simulation of Raman modes based on a single molecule yields accurate representations of Raman spectra.

The samples undergo phase transformations under elevated pressure, associated with changes in their Raman spectra as several new Raman modes emerge under compression, associated with a symmetry reduction of the molecule. These phase transformations are fully reversible and the samples possess a sponge-like rebound after decompression.

Future work will include in situ high-pressure neutron-diffraction methods to determine the precise crystal structures of the compounds. Furthermore, the samples will be studied with in situ Raman spectroscopy at high-pressures and high-temperatures using heated DACs to investigate the reaction to pure carbon phases such as cubic or hexagonal diamond.

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Inverse-designed metasurfaces for flexible optical image processing

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Abstract

Nanostructured metasurfaces offer unprecedented flexibility in transforming optical fields in ways that are challenging with traditional optics. In particular, they can facilitate analogue optical processing in a compact system, without the bulk or computational post-processing in conventional approaches. Of significant practical importance is an opportunity to perform real-time phase imaging with metasurfaces. Recent demonstrations were based on the conversion of phase modulations imparted by a phase object onto incoming light into corresponding intensity modulations. In this work, we present novel metasurface patterns optimised with inverse-design for performing large numerical aperture phase imaging with an asymmetrical optical transfer function (OTF), overcoming the limitations of previous metasurface demonstrations.

In addition, we design a metasurface whose OTF exhibits a Gaussian function. Commonly, a Gaussian kernel is applied to images to denoise scenes through computational convolutions. Here, we propose an all-optical analogue of this operation. We can recover a denoised intensity image from an input noisy amplitude object using our specially designed metasurface that filters out all the high spatial frequency components. Under current investigation is the multiplexing of different OTFs onto a single metasurface device. We anticipate that such inverse-design of metasurfaces will have a variety of applications in all-optical phase differentiation, edge detection and signal processing simultaneously.

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Optimisation of Non-Linear Processes in Metasurfaces with Inverse Design

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Abstract

Sum-frequency generation (SFG) is a fundamentally important second-order nonlinear process with many applications spanning from optical frequency conversion to spectroscopy. Recent advances in nanotechnologies facilitated the development of ultra-thin metasurfaces where optical resonators can enhance and tailor nonlinear interactions with functionalities beyond the capabilities of traditional bulky crystals. We develop a novel optimisation framework that can simultaneously enhance the efficiency, tailor the polarisation transformation matrix and increase directionality of the SFG process from a metasurface. Our inverse-design method nontrivially generalises the previous studies of second-harmonic generation.

Additionally, we apply the inverse-design scheme to optimise nonlinear metasurfaces for spontaneous parametric down-conversion (SPDC), facilitating enhanced efficiency of generating photon pairs and their tailored quantum polarisation entanglement. This is realised by drawing on the principle of quantum-classical correspondence between the SPDC and SFG processes

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High-Order Fermionic Correlations in a Degenerate Fermi Gas of $^3He^*$

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Abstract

A key observable in investigations into quantum systems are the n-body correlation functions, which provide a powerful tool for experimentally determining coherence and directly probing the many-body wavefunction. While the (bosonic) correlations of photonic systems are well explored, the correlations present in matter-wave systems, particularly for fermionic atoms, are still an emerging field. In this work, we use the unique single-atom detection properties of $^3He^*$ atoms to perform simultaneous measurements of the n-body quantum correlations, up to the fifth-order, of a degenerate Fermi gas. In a direct demonstration of the Pauli exclusion principle, we observe clear anti-bunching at all orders and good agreement with predicted correlation volumes. Our results pave the way for using correlation functions to probe some of the rich physics associated with fermionic systems, such as d-wave pairing in superconductors.

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An Array of Gamma-Ray Telescopes in Australia for Transient Studies at Extreme Energies

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Abstract

The nature of the most extreme astronomical phenomena is better understood through observing their GeV and TeV gamma-ray flux, in particular by quickly following up on transient events and continuously monitoring source flux variation. An Imaging Air Cherenkov Telescope (IACT) array in Australia, as part of a worldwide network of IACTs complementing the upcoming Cherenkov Telescope Array (CTA), would be a crucial part in achieving 24-hour all-sky coverage at these energies. Small arrays of telescopes were thus simulated to study the performance of an Australia-sited array with varying altitude, number of telescopes, layout, and telescope design. Additionally, methods were studied to optimise such an array for detecting TeV transients, and their performance for observations of active galactic nuclei (AGN), gamma-ray bursts, and galactic transients was modelled. For instance, an array of four CTA Medium-Sized Telescopes in Australia was estimated to detect ~25 AGN flares at $>5\sigma$ per year, up to a maximum of 40 per year, and up to a redshift of $z\approx1.5$. This talk will include an overview of this telescope network idea and further results from the performance studies.

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Improved detection of blood vessels with OCT angiography using deep learning

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Abstract

Optical coherence tomography angiography (OCTA) is an optical imaging method that can image small blood vessels. This is particularly useful in diseases such as diabetes, where blood vessels degrade with disease progression. OCTA achieves this by acquiring multiple OCT measurements at each location and quantifying the rate of decorrelation of the speckle noise. In OCT, speckle is temporally invariant for stationary tissues. However, in blood vessels, the blood flow changes the configuration of sub-resolution scatterers and hence the speckle signal, with faster flow giving rise to more rapid change (or decorrelation) in the speckle. Accurate measurement of the rate of speckle decorrelation requires multiple OCT acquisitions, which is time-consuming and computationally demanding when acquiring data over a 3D volume of tissue.

Deep learning methods provide a framework to extract optimal information from the signal, with the potential to generate accurate estimates of speckle decorrelation whilst significantly reducing the number of OCT scans required. Because the diameter of the blood vessels being examined is typically 30-100 microns, whilst the density of OCT sampling is 10 microns, adjacent OCT measurements are not independent. We have exploited this by implementing an artificial neural network (ANN) architecture that combines information from multiple OCT measurements at each location and augments these with measurements from adjacent locations. As shown in Fig.1:(left), the labelled data for training is automatically generated using N=10 OCT acquisitions at each location, and the network is trained to generate decorrelation estimates using a reduced number of OCT acquisitions. Using in vivo data acquired on human subjects, we demonstrate that the ANN could generate accurate estimates of speckle decorrelation as the number of OCT acquisitions is reduced, with greater accuracy than estimates generated without the ANN. These results demonstrate that deep learning methods could more efficiently utilize reduced data in OCTA.

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Commissioning of the torsion pendulum dual oscillator for low-frequency Newtonian noise detection

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Abstract

Next-generation gravitational-wave detectors will aim to extend their sensitivity range towards lower Fourier frequencies. However, the local gravity perturbations known as Newtonian noise will likely limit the detectors at these frequencies. The Torsion Pendulum Dual-Oscillator, or TorPeDO, is a novel experiment designed to directly detect Newtonian noise, which can then be used for both noise subtraction in next-generation gravitational wave detectors and potentially utilized in early warning systems for earthquakes. Currently, efforts are underway to commission the TorPeDO sensor at the Australian National University.

This sensor comprises of two suspended perpendicular torsion bars that differentially rotate in response to Newtonian noise. The torsion bars will be suspended from a Seismic Isolation Chain, a custom-designed quadruple suspension system to isolate them from ground motion. The differential angle is optically measured via length changes of four Fabry-Perot cavities formed around the two torsion bars. The Pound-Drever-Hall technique is used to interrogate each cavity with an individual laser. However, the free-running frequency noise of the readout lasers will dominate the sensor readout. To mitigate this, each readout laser is controlled to a common reference laser with a heterodyne phase-locked loop. The TorPeDO has a sensitivity target of 3.6 × 10^−14 rad Hz^−1/2 limited by suspension thermal noise at 100 mHz and 2.2 × 10^−17 rad Hz^−1/2 limited by readout shot noise at 10 Hz [1].

Our presentation encompasses the latest developments in the commissioning and control implementation of the Seismic Isolation Chain, alongside the characterization of the four simultaneous heterodyne phase-locked loops crucial for the optical readout of the TorPeDO sensor.

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Dark (non-)matter candidate emerging from 3-form gauge theory

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Abstract

Current astrophysical observations such as the rotational curves of galaxies, galaxy structure formation, gravitational lensing and the cosmic microwave background - to name a few - have all pointed towards the existence of a new type of matter, known as dark matter (DM). DM is believed to only interact appreciably through gravity alone and makes up around 85% of the known matter in our universe. The nature of this DM is unknown and a wide variety of candidates have been proposed, ranging from new hypothetical particles (such as WIMPs, axions and dark photons), to primordial black holes and modified gravity theories.

In this work, I propose a novel approach to explaining the effects associated with DM through the implementation of so-called 3-form gauge fields. A 3-form gauge field by itself in vacuum does not actually introduce any dynamics to the Universe; rather, it behaves similarly to an electric field that is constant in spacetime. However, if we couple this 3-form gauge field to the cosmological medium, then the field generates a local propagating degree of freedom that can act as the role of DM. I present preliminary work done in the minimal construction of such a theory in a flat, expanding universe. The cosmological medium is modeled as a perfect, homogeneous fluid such that it can be described by a real scalar field. The phenomenology of this theory is investigated to see how it compares to current DM observational limits. If this theory of DM were to be realised, it would imply that many of the current searches of DM may be unfeasible and new approaches to DM detection would need to be considered.

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Quantum Imaging Using Entangled Photon Pairs from Nonlinear Metasurfaces

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Abstract

The quantum correlations of photon pairs inspired the development of quantum ghost imaging principles, offering fundamental advantages such as the operation at ultra-low photon flux and high signal-to-noise ratio. Over the last years, it was demonstrated experimentally that nonlinear metasurfaces with a thickness of only a few hundred nanometers can facilitate strongly enhanced generation of photon pairs through spontaneous parametric down-conversion (SPDC). Furthermore, the quantum photon state can be tailored to feature spatial, spectral, and polarisation entanglement. However, the potential of metasurface-based photon-pair sources for quantum imaging was not previously investigated.

We reveal the unique benefits of quantum imaging based on nonlinear metasurfaces, facilitating an efficiently combined ghost and all-optical scanning imaging protocol. The schematic setup is represented in Fig. 1a, where the metasurface incorporating a subwavelength-scale silica grating on top of a lithium niobite thin film generates spatially entangled signal and idler photons, featuring two unique properties: (i) the photon emission is narrow in y- yet broad in z-direction and (ii) the emission angle in y-direction can be all-optically scanned by simply tuning the pump beam wavelength (Fig. 1b). Using these features, we can image an object placed in the 'signal' arm. A single-photon bucket detector and a 1D array of detectors are put in the 'signal' and 'idler' arms respectively, allowing ghost imaging in the z-direction and all-optical scanning in the y-direction (Fig. 1a). As an example, we experimentally reconstructed the image of an 'S'-shape object using correlation measurement (Fig. 1c). Importantly, there is a practical potential to further increase the imaging resolution by enhancing the Q-factor and increasing the metasurface dimensions. We anticipate that our analysis will pave the way toward novel quantum imaging applications of metasurfaces-based quantum light sources.

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Figure 1

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Hyperfine Spectroscopy of Rubidium with a Speckle Spectrometer

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Abstract

Highly multi-mode media can convert a coherent input optical field's spatial profile into a granular speckle pattern. These speckle patterns are highly dependent upon properties of the medium and the input light field. One property of interest is the input light's optical spectrum, with numerous speckle spectrometers demonstrated to address this point. Precision wavelength measurements are crucial in many applications including laser spectroscopy [1], optical sensing [2], and laser locking [3]. Typically, spectrometers utilize one-to-one spectral to spatial mapping through the use of diffractive optical elements. Speckle patterns translate wavelength changes into a higher-dimensional problem, allowing for both high resolution and large bandwidth in an intrinsically compact design.

Here we explore the limits of a speckle pattern-based spectrometer, and demonstrate the ability to resolve atomic spectral features with sub-megahertz resolution. This is demonstrated using an integrating sphere spectrometer to produce speckle patterns from which wavelength measurements are extracted using a transmission matrix method. To demonstrate the precision of the wavelength measurement spectrometer, we measure the hyperfine structure of the $5S_{1/2} \rightarrow 5P_{3/2}$ transition in rubidium at 780nm. We show preliminary measurements of the transition, showing saturated absorption features of width ~10MHz with MHz frequency resolution. This is a significant improvement compared to multi-mode fibre-based transmission matrix spectrometers which are limited to ~100MHz resolution [1].

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Optical Tweezers for Microrheology of the Cumulus Matrix in a Microlitre Volume

Chris Perrella[1], Carl Campugan[1], Tania Mendonca[2], Cheow Yuen Tan[1], Erik Schartner[1], Yoshihiko Arita[3], Graham Bruce[3], Amanda Wright[2], Kishan Dholakia[1,3], Kylie Dunning[1]
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Abstract

In the field of in vitro fertilisation (IVF), there is a burgeoning need to understand how cell properties of the cumulus oocyte complex may be used to predict successful pregnancy and live birth rates post-IVF. Here we used optical tweezers [1] for the first time to measure the viscosity of the cumulus cell matrix surrounding the oocyte (egg). This study aimed to determine whether the viscosity of the cumulus cell matrix – prior to fertilisation – is reflective of subsequent embryo developmental potential and indicative of pregnancy success.

Measurements were performed using a 1µm diameter silica probe particle trapped by a focused 1064nm laser. We benchmarked the accuracy of the system by measuring the viscosity of glycerol with varying mass fractions [2]. Preliminary viscosity measurements of the cumulus cell matrix were performed in isolation from both the cumulus cells and the oocyte. This showed that the viscosity of cumulus matrix was significantly higher when sampled from oocytes with a higher developmental potential (in vivo matured) compared to those of lower quality (in vitro matured [IVM]). The use of microrheology to measure viscosity around intact cumulus oocytes complexes and its association with oocyte development potential will be reported on, with the goal of gaining an indicative assessment of their development potential whilst minimising disturbance to the oocyte.

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Ansatz-Agnostic Exponential Resource Saving in Variational Quantum Algorithms Using Shallow Shadows

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Abstract

Variational Quantum Algorithms (VQA) have been identified as a promising candidate for the demonstration of near-term quantum advantage in solving optimization tasks in chemical simulation, quantum information, and machine learning. The standard model of training requires a significant amount of quantum resources, which led us to use classical shadows to devise an alternative that consumes exponentially fewer quantum resources. However, the approach only works when the observables are local and the ansatz is the shallow Alternating Layered Ansatz (ALA), thus severely limiting its potential in solving problems such as quantum state preparation, where the ideal state might not be approximable with an ALA. In this work, we present a protocol based on shallow shadows that achieves similar levels of savings for almost any shallow ansatz studied in the literature, when combined with observables of low Frobenius norm. We show that two important applications in quantum information for which VQAs can be a powerful option, namely variational quantum state preparation and variational quantum circuit synthesis, are compatible with our protocol. We also experimentally demonstrate orders of magnitude improvement in comparison to the standard VQA model.

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Rainbow metasurfaces for spectrally tunable high-harmonic generation

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Abstract

Resonant dielectric nanostructures and metasurfaces composed of high-index subwavelength-scale Mie-resonant elements offer opportunities to enhance nonlinear light-matter interaction. In bulky media, phase-matching conditions give rise to enhanced nonlinear optical effects. On the contrary, at the subwavelength scale, nonlinearities are governed by optical resonances arising from both collective modes of metasurfaces as well as localized modes of individual resonators. However, for fixed nanostructure geometries, the spectral range of operation is restricted to the proximities of resonant frequencies. To overcome this limitation, here we introduce rainbow metasurfaces to realize spectrally tunable resonant enhancement of light-matter interaction. We design and fabricate the metasurface composed of germanium nanoresonators with varying geometrical parameters, such that the resonant frequency changes continuously along the metasurface longitudinal co-ordinate. We realise experimentally the rainbow metasurfaces hosting high-Q optical resonances in the mid-IR spectral range. The metasurfaces resonantly enhance the 3rd and 5th harmonics. The tunability of the generated high harmonics transpire on varying the excitation laser along the metasurface's co-ordinate, resulting in wide spectral coverage of multiple optical harmonics. Wide spectral coverage of resonantly enhanced generation of optical harmonics endows metasurfaces with functionality that was so far only available for bulk media.

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Quantum Transfer Learning for Adversarially Robust Machine Learning on High-Resolution Datasets

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Abstract

The integration of quantum computing and machine learning is an emerging area of research and development in the field of quantum technologies. However, evaluating large-scale quantum models remains challenging due to current limitations in reliable quantum circuit implementations and the availability of a small number of qubits. Moreover, dealing with high-resolution images on quantum computers requires a large number of qubits and leads to inefficient training. Achieving this level of scalability and stability in quantum systems is a significant challenge at this stage. To address these challenges, we propose a quantum transfer learning (QTL) approach that leverages the strengths of both domains to improve image classification performance and maximises the utilisation of small-scale quantum convolutional neural networks (QCNNs) in the era of noisy intermediate-scale quantum computers. By transferring the learned knowledge from the pre-trained classical convolutional neural networks (CNNs), which possess a comprehensive understanding of the target domain, to the small-scale QCNN, remarkable classification accuracy and significant speedup are achieved for the proposed QTL method. This hybrid model enables the extraction of meaningful features from raw image data, bridging the gap between classical and quantum paradigms. Through comprehensive experiments on diverse datasets, including Ants & Bees, CIFAR-10, and Road Sign Detection, we demonstrate the superior performance of QTL compared to classical transfer learning. Additionally, we address the vulnerability of the proposed QTL model to adversarial attacks and introduce adversarial training to enhance model robustness. Our findings demonstrate that QTL, augmented with adversarial training outperforms classical methods and exhibits resilience against adversarial perturbations.

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Biohydrodynamics of bacterial-based active matter

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Abstract

Active matter occurs quite commonly in nature, from flocks of birds to schools of fish and even human crowds. Being able to convert the energy in their surroundings into mechanical work, these far-from-equilibrium systems exhibit complex collective dynamics which are difficult to track and theoretically model. Swarms of bacteria are a popular choice for active matter studies since they use their flagella to self-organise and exhibit interesting collective behaviours. Here we apply biophotonics techniques to model the collective dynamics of bacteria to help enhance microdevice propulsion and the design of artificial microswimmers. In the current work, we pair video microscopy with DeepTrack, a machine learning software, to precisely track and record swarms of Escherichia coli (E. coli) active matter (Midtvedt et al., 2021). Performing machine vision with DeepTrack gives us valuable insight into the nuances that influence their collective behaviours as well as providing an effective basis in which current theoretical models can be critically assessed. We use optical tweezers to characterise the swimming powers of individual E. coli, and in doing that we study how the actions of multiple E. coli are influenced by single E. coli. Investigating the collective behaviours of E. coli is extended by introducing geometric constraints formed by circular ring and spiral structures created with photolithography. Using DeepTrack, we were able to accurately compute trajectories of several E. coli moving in these structures. Observations made regarding their movements within the structures could have important uses in nanotechnology. Fully understanding how these systems behave, and the laws that quantitatively describe them, has extraordinary potential in biological and physical applications.

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Giant all-optical reflectivity modulation of nonlocal resonances in silicon metasurfaces

Andrea Tognazzi[1,2], Paolo Franceschini[3,2], Olga Sergaeva[3], Luca Carletti[3,2], Ivano Alessandri[3,2], Giovanni Finco[4], Osamu Takayama[5], Radu Malureanu[5], Andrei Lavrinenko[5], Alfonso Carmelo Cino[1], Domenico de Ceglia[3,2], Costantino De Angelis[3,2]
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Abstract

Metasurfaces offer a versatile playground to tailor the electromagnetic field at subwavelength scale to control wavefront, polarization, and nonlinear processes. Reconfigurability of the optical response of these structures is challenging due to the nanoscale size of their constitutive elements. A long-sought solution to achieve tunability at the nanoscale is all-optical modulation by exploiting the ultrafast nonlinear response of materials. However, the nonlinear response of materials is inherently very small and, therefore, necessitate optical excitations with large values of energy density. Here, we present a high-contrast nonlocal metasurface based on polycrystalline silicon meta-atoms lying on silica pedestals, that exhibits a guided mode resonance in the near-infrared spectral region, and we show giant photoinduced relative reflectance variation (up to 60%) on the picoseconds timescale. We use time- and wavelength-resolved spectroscopy to investigate the out-of-equilibrium temporal dynamics of the nonlocal near infrared resonance following free-carrier injection. The analysis of the experimental data, combining a coupled rate equations model and rigorous coupled-wave analysis, allows to disentangle the contribution of the photonic structure and the modulation of the optical properties with a simple yet effective tool (due to free carriers and lattice heating effects), and reveals a decrease of the carrier recombination time with respect to bulk material. Our results have direct impact in the design of next-generation ultrafast all-optical modulators and switches with reduced energy consumption, since we demonstrate an increase of one order of magnitude in the relative reflectance variation, with energy densities below 250 uJ/cm^2, with respect to unstructured silicon.

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Quantum many-body correlations in an ultracold $^4He^*$-$^3He^*$ Bose-Fermi scattering halo

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Abstract

Please refer to the uploaded extended abstract.

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Cosmic ray propagation in spatially intermittent magnetic fields.

Amit Seta
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Abstract

Cosmic rays are a dynamically important component of the interstellar medium in star-forming galaxies and they play a crucial role in enhancing galactic winds and regulating star formation. Their primary influence stems from their interaction with magnetic fields within galaxies. The galactic magnetic field, especially at smaller scales, exhibits spatial intermittency (fields concentrated in random filaments and sheets). This presentation will discuss the role of such structures in the propagation of cosmic rays.

For this study, we conducted test-particle simulations with both intermittent and non-intermittent magnetic fields having identical power spectra. Our findings demonstrate that the cosmic ray diffusion coefficient for low-energy cosmic rays (~ GeV) is higher and the incoming direction of ultrahigh-energy cosmic rays (UHECR, ~ EeV) from the source is better preserved in the presence of such spatially intermittent structures. These results should be considered when interpreting radio, gamma-ray, and UHECR observations.

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Searching for a (pseudo)scalar at 95 GeV

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Abstract

The CMS collaboration has recently reported excesses in the production of pairs of tau-leptons and photons in the mass range of 90-100 GeV. A much older result from the LEP reports an excess of b-quark pairs at a similar energy range. Individually, each result is below the 3-sigma threshold for clear hints of BSM physics. However, considered together, these results indicate the possibility of an undiscovered particle with a mass of 95 GeV.

Models with additional Higgs doublets, such as the archetypal Two-Higgs doublet models (2HDMs), provide a possible solution to this question, introducing new spin-0 particles which could have the right mass and interactions to produce these excesses. These models are well-motivated theoretically and have the potential to resolve other open questions in the Standard Model such as neutrino masses and the nature of dark matter.

We consider a 2HDM with an additional scalar or pseudoscalar mediator, with all new bosons mixing with Standard Model fields via the Higgs sector. Such models introduce four new bosons: a heavy scalar, a pseudoscalar, a charged scalar, and an additional scalar or pseudoscalar. Fixing the mass of one of the light (pseudo)scalars to 95 GeV, we investigate the parameter space of these models to determine if they could generate the excesses seen at CMS and LEP. Additionally, these models are subject to constraints from flavour physics (such as the decays of rare B-mesons and meson mixing) and collider physics (such as resonance and missing transverse energy searches). We also apply these constraints to the parameter space of our models and determine which regions can satisfy all of these constraints as well as generating the observed excesses.

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Quantum Detector Tomography: Algorithm Design and Optimization

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Abstract

In the past decades, we have witnessed significant progress in a variety of fields of quantum science and technology, including quantum computation, quantum communication, quantum sensing, and quantum control. In these applications, a fundamental task is to develop efficient estimation and identification methods to acquire information on quantum systems. Quantum detector tomography (QDT), the task of estimating all the parameters of a set of POVM, is important for calibrating quantum measurement devices and enhancing the information extraction accuracy.

In this work, we firstly provide a brief introduction to quantum tomography and QDT. Then we investigate how to optimize the probe states in QDT. We characterize the optimal probe state sets based on minimizing the upper bound of the mean squared error (MSE) and minimizing the condition number. We can prove that SIC and MUB states are optimal. In the adaptive scenario we propose a two-step strategy to adaptively optimize the probe states, and prove that our strategy can improve the modified infidelity from $O(1/\sqrt{N})$ to $O(1/N)$ under certain conditions for N state copies \cite{xiao2021optimal}. Then using regularization, we improve the QDT accuracy with the probe states given. We employ weighted least squares estimation, discuss different regularization forms, prove the scaling of MSE under static assumptions, and characterize the best regularization \cite{xiao2022regularization}. Numerical examples are presented to demonstrate the effectiveness of our strategies. In a quantum optical experiment, our adaptive regularization with weighted least squares achieves lower MSE compared to Tikhonov regularization with least squares.

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Trapping Light in Air with Dielectric Mie Voids

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Abstract

Manipulating light on the nanoscale has become a central challenge in photonic metastructures, resonant metasurfaces, nanoscale optical sensors, and many more, and it is largely based on resonant light confinement in dispersive and lossy metals and dielectrics. Here, we experimentally implement a novel strategy for dielectric nanophotonics: Resonant subwavelength localized confinement of light in air [1].

We demonstrate that individual voids created in high-index dielectric host materials support localized Mie modes with exceptional optical properties. In striking difference to resonant dielectric nanoparticles, Mie void modes do not suffer from the loss and dispersion of the host medium and are weakly dependent on the void geometry due to the confinement in air. Moreover, Mie void modes in Si possess a large quality factor in the visible and UV, comparable or larger than that for Si resonant nanoparticles. We demonstrate the one-to-one correspondence between the properties of dielectric particles and voids, generalizing the Babinet principle developed for metallic surfaces. We experimentally realize resonant Mie voids by focused ion beam milling into bulk silicon wafers. We experimentally demonstrate resonant light confinement with individual Mie voids from visible down to the UV spectral range at 265 nm. We also experimentally demonstrate a high locality of optical properties of individual voids, which allows implementing them as non-interfering pixels while arranged densely in lattices. Using this property, we further experimentally utilize the bright, intense, and naturalistic colours for nanoscale colour printing.

The concept of Mie voids paves the way towards the operation of functional high-index metasurfaces into the blue and UV spectral range, while the combination of resonant dielectric Mie voids with dielectric nanoparticles will more than double the parameter space for the future design of metasurfaces and other micro- and nanoscale optical elements.

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Resolving Anomalous Collectivity in ^{58}Fe through Coulomb Excitation

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Abstract

Nuclei in the region around the Z = 28 magic number have long been considered to be well-described by the shell model, with strong agreement between measured properties and shell-model predictions [1]. Iron (Z = 26) isotopes, 2 protons short of the closed shell, are no exception, with most experimental observables supporting the shell-model description. However, previous lifetime measurements of one particular excited state in ^{58}Fe [2] give a transition strength that deviates markedly from shell-model predictions [1, 3]. The adopted value is high enough to suggest weak collectivity, representing a significant change in the structure of the Z = 28 region.

The CAESAR array of high-purity germanium gamma-ray detectors at the Heavy Ion Accelerator Facility, ANU, has recently been upgraded to perform Coulomb-excitation measurements. It was first used to perform target-excitation measurements, but in this work, we report the first beam-excitation measurements. Previous measurements of the nearby isotope ^{56}Fe are precise, consistent [4], and agree with shell-model predictions [1, 3]. We have therefore performed measurements on ^{56}Fe and ^{58}Fe under the same experimental conditions. Our measurement agrees with the well-known transition strengths in ^{56}Fe, providing confidence in the apparatus and methodology for performing beam-excitation measurements. A study of the neighbouring ^{58}Fe transitions yields results consistent with modern shell-model theory. This presentation will discuss the experimental methods, the results for both isotopes, and their interpretation and consequences for the nuclear shell model near the Z = 28 magic number.

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Quantum asymmetry between time and space: beyond the canonical commutator

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Abstract

The violation of time reversal symmetry (T-violation) in particle physics is evidence of time-asymmetric dynamics, and offers a new perspective for studying time. I recently introduced a new theory [1] exploring how T-violation might underlie differences between time and space. Central to the theory is a quantum virtual path (QVP) --- essentially a quantum walk through time --- which is the superposition of all paths comprising steps generated forward in time by H_F and backward in time by H_B where H_F and $H_B=TH_FT^{-1}$ are two versions of the Hamiltonian related by Wigner's time reversal operator T, and T-violation is represented by a non-zero commutator $[H_F,H_B]$. Equations of motion and conservation laws are not assumed in the theory, rather they emerge phenomenologically as a consequence of T-violation. Moreover, the theory predicts clock-time to depend on the local T-violation, and remarkably, Lorentz symmetry is shown to be a consequence of relative Doppler shifts in the T violation of a background field [2,3].

The formalism was introduced using the canonical commutator where $[H_F,H_B]$ is a c-number [1], and while this has allowed the potential of the formalism to be established without unnecessary complexity, it restricts the applicability of the results. I will present recent work extending the formalism to treat a broad range of (non-canonical) commutators using a new representation of QVPs in which the optimal fiducial path is factored out and path averages of the non-commutativity of H_F and H_B are central. I will demonstrate the results using (i) a complex quantum scalar field interacting with a classical scalar field that has a nonzero vacuum expectation value, and (ii) the collective treatment of mesons and neutrinos based on Standard-Model values.

[1] J.A.Vaccaro,Proc.R.Soc.A,472,20150670(2016) https://dx.doi.org/10.1098/rspa.2015.0670
[2] K.Bordan,F.Tanjia,J.A.Vaccaro,"Resolution of the Discrete Clock-Time Observable",submitted AIP Summer Meeting (2023).
[3] in preparation.

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Chiral and electroweak phase transitions with hidden scale invariance

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Abstract

The mass hierarchy problem is concerned with the large differences in scale present in our universe, namely between the Higgs mass (125 GeV) and the Planck mass (10^19 GeV). The Standard Model currently offers no explanation for this difference which prompts the investigation of other fundamental theories. It has been argued that scale invariance of physical laws may be a solution to hierarchy problem. In this theory, physical laws are invariant under mass, energy or length scalings and at zero temperature it is only through quantum mechanical effects that scales and the hierarchy of scales emerge. A general cosmological consequence of this theory is that electroweak symmetry breaking doesn't occur until later in the universe's evolution, at lower temperatures. Here, it is triggered by chiral symmetry breaking, when the unbound quarks of the universe cool and condense into bound hadron states. The change in conditions may result in a change in the type of phase transition that the universe undergoes during the electroweak symmetry breaking. If a first order phase transition occurred, this may have produced gravitational waves which could be detectable today in the gravitational wave background. In this work, effective field theory was used at both zero and non-zero temperatures to model the Higgs, dilaton (an effective scalar field which ensures scale invariance) and meson fields. Parameters in the model were found by matching predictions of the model at zero temperature with observables today, then these same parameters were used in the non-zero temperature model to understand the electroweak and chiral phase transitions.

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New approaches for searching for ultralight scalar and pseudoscalar dark matter in a lab

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Abstract

We consider dark matter (DM) models with DM particles represented by scalar (dilaton-like) and pseudoscalar (axion-like) fields beyond the Standard Model (SM). We assume that these fields fully saturate the local DM density near the Solar system and may be detected via feeble interactions with SM particles. If the masses of DM particles are small, typically well below 1 eV, these fields exhibit wave-like properties with oscillation frequency proportional to the mass of these particles. These oscillations can, in principle, produce observable effects through small temporal and spatial variations of fundamental constants such as the fine structure constant, electron and nucleon masses. In the case of scalar fields, we propose new experimental approaches for detection of this type of DM in the laboratory with the use of electric and magnetic fields, and cold atoms or molecules. The axion dark matter can also produce variation of the nuclear mass which is searched for with networks of atomic clocks and magnetometers. The amplitude and phase of the axion field may fluctuate due to stochastic nature of DM particles. We show that these fluctuations may manifest themselves as a specific type of noise in experiments searching for variations of frequencies of atomic clocks. Observing this type of noise could indicate the presence of the axion signal in such experiments. Non-observation of all mentioned above effects allows us to exclude previously not covered regions of parameter spaces in these models for the DM particle mass in the range from 10^-17 to 10^-6 eV.

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Quantum Adversarial Machine Learning for Radio Signal Classification

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Abstract

The development of machine learning (ML) methods has supported numerous autonomous applications. Despite the current development, ML, specifically neural network, is susceptible to adversarial perturbations. While vulnerabilities of neural networks attract enormous attention, there has been growing interest in how quantum machine learning (QML) will fare against adversarial attacks [1]. However, quantum adversarial machine learning (QAML) is still in its infancy and most research work is focused on the field of computer vision [2]. There remains a notable gap in research when it comes to crucial applications such as speech recognition and radio signal classification. These areas have demonstrated vulnerabilities to adversarial attacks in ML algorithms [3,4], yet QAML research in this context is relatively underexplored.

In this work, we study the robustness of quantum classifiers to a variety of adversarial attacks with a focus on quantum variational classifiers (QVCs) in the task of radio signal classification. In addition, we propose the application of approximate amplitude encoding (AAE) technique which greatly reduces the number of gates required to encode classical data. Our extensive simulation results clearly present that attacks generated on QVCs transfer well to classical CNN models, indicating that these adversarial examples can fool neural networks which they are not explicitly designed to attack. However, the converse is not true. QVCs largely resist the attacks generated on CNNs. Moreover, by studying the data stealthiness of the adversarial examples, adversarial attacks generated on quantum models are generally more imperceptible. Overall, with comprehensive simulations of attacks, our results shed new light on the growing field of QML by bridging knowledge gaps in QAML in radio signal classification and uncovering advantages of applying QML methods in practical applications.

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Synthetic frequency dimension photonics with modulated LNOI ring devices

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Abstract

We created a thin-film lithium niobate integrated device, containing a ring resonator and broadband travelling-wave modulator to probe higher-dimensional physics. It produces frequency modes as synthetic lattice sites spaced over 400-600GHz range. Reconfigurable modulation enables simulation of up to three-dimensional connectivity schemes.

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Adiabatic description of pre-fragment formation in nuclear fission

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Abstract

Predicting fission yields - the distribution of fragment masses and charges observed from a given fission event - is necessary for better descriptions of phenomena such as the r-process, which drives the formation of heavy elements in our universe, and for practical applications, such as nuclear energy technologies. A promising means of predicting fission yields in a quantum framework relies on Potential Energy Surfaces (PESs), which describe the energy of nuclear shapes as they become extremely elongated and eventually split into two fragments. To make PESs, constraint operators are used to force nuclei into particular shapes, and the number of constraints gives the dimension of a PES. Current two-dimensional (2D) PESs have been used to predict fission yields, but contain an artifact called the scission discontinuity, which hinders the accuracy of yields. To date, it has only been possible to remove the discontinuity by moving to 3D PESs, and no yields have been extracted from such PESs.

In our research, we demonstrate a method to create a 2D PES which does not contain the scission discontinuity. While existing 2D PES use only two constraints for a single PES, we split the fission process into three stages, and use a different combination of shape constraints at each of these stages. In particular, we are then able to probe the stage of fission where fragment identities are well established. This crucial stage of fragment formation is missing from previous 2D PESs. We will discuss the advantages of our method, the compromises we made to gain a 2D description of the full fission process, and address the avenues of work our research opens up, including the use of these PESs for predicting fission yields.

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Quantum field-theoretic approaches to quantum tunnelling through localised external potentials

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Abstract

Despite the widespread application of single-particle quantum tunnelling in technology and measurement, its theoretical foundations remain poorly understood. Notable examples include the Klein Paradox , where unitarity is violated for particles incident on large potentials, and in the still-unresolved problem of tunnelling time. The former is resolved by accounting for particle/anti-particle creation using quantum field theory (QFT). QFT is one of our most precise physical theories, accounting for beyond-QM effects such as the anomalous magnetic moment, the Stark shift, and virtual particle creation and annihilation. Presently, there is no complete single-particle description of quantum tunnelling using a QFT framework. This work attempts to develop a formalism to describe single-particle quantum tunnelling consistent with QFT, with the goal to investigate any beyond-QM corrections to quantum tunnelling.

We investigate a massive neutral scalar field, interacting with an external, localised potential (which is not quantised). Because quantum tunnelling is a fundamentally non-perturbative process, typical QFT calculations which rely on a perturbative expansion of scattering matrix elements in terms of the coupling constant, are not applicable in the tunnelling regime. Instead, an all-order dressed propagator must be found to describe tunnelling transmission and reflection probabilities. We compute this dressed propagator, and show that it recovers transmission and reflection results consistent with relativistic quantum mechanics.

We then consider QFT corrections brought about by the neutral scalar field coupling to another massive quantised neutral scalar field. We derive an all-order recursive expression for the loop-corrected scalar propagator, which contains only the class of vertex-corrected diagrams. This equation applies for general external potentials. Though there is no closed-form analytic solution, there exist methods to approximate and bound the QFT corrections in certain coupling and mass regimes. These results give an appropriate starting point to numerically model quantum tunnelling using QFT.

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design and efficiency in a graph state compiler

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Abstract

The universal quantum gate set comprising Clifford group operators and the non-Clifford T-transformation, can be realised through the measurement-based quantum computing (MBQC) model, meaning the formalism is viable as a error- corrected, fault-tolerant architecture. However, processing T-transformations introduces the possibility of errors, which require mitigation through magic state distillation. The resourcing requirements for error-correcting protocols proposed for T-transformations are a significant design consideration in quantum compiler research.

'Jabalizer' and 'Etch' are applications that adapt algorithms encoded under circuit model syntax to the MBQC model. Jabalizer outputs a graph state consistent with the fault-tolerant ICM form: an 'algorithm-specific graph' (ASG) resolves Clifford group operations on a classical computing facility, by means of the stabiliser formalism, and passes a graph of T-transformations only to the quantum computing facility. Etch follows a circuit etching protocol: the cluster state, Clifford and non-Clifford, is passed in its entirety to the quantum computing facility.

Both Etch and Jabalizer must request qbits from the kernel managing quantum resources to process their graph state output, which would suggest that in all cases Jabalizer's smaller ASG payload is superior to Etch's monolithic payload. However, it is possible that qbits requested by Etch to process Clifford transformations might be recycled to create the magic state distillation cluster for processing T-transformations. If the graph state prescribed by Etch attains or approximates an efficient ratio of pauli to non-pauli qbits then, qbits allocation under Etch becomes multi-functional as distinct from mono-functional under Jabalizer.

This talk is an overview of Etch, including the lattice specifications and the ratio of pauli to non-pauli qbits as a metric of efficiency. I will evaluate the impact of these findings upon the respective ASG and circuit etching protocols and the implications of the tests for next steps in quantum compiler research.

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Topological signal processing on quantum computers for higher-order network analysis

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Abstract

The processing and interpretation of data in complex networks have posed significant challenges owing to the complicated structure of the connections within the network. In recent years, it has become possible to represent networks with multiway connections, often referred to as higher-order networks, via the use of topological entities known as simplicial complexes. In conjunction with signal processing methodologies, the domain of topological signal processing (TSP) employs the Hodge Laplacian, a topological tool, to execute spectral filtering techniques on network data. These techniques are employed to undertake a range of network data processing and analysis tasks, including but not limited to data denoising, reconstruction, and prediction. However, when the number of interactions in the higher-order network rises, the dimension of the simplicial complex rises as well, resulting in exponential computing costs. In this research, we provide a novel quantum method designed to accelerate the filtering procedures in TSP. Furthermore, we demonstrate the practical use of this approach in extracting network data via the utilization of Hodge decomposition. We use the tools that have been provided in recent quantum algorithms for topological data analysis (QTDA) and integrate them with spectrum filtering approaches using the quantum singular value transformation (QSVT) algorithm. This approach facilitates the use of quantum computers in the realm of higher-order network analysis, thereby expanding the range of potential applications.

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Black holes, Hawking radiation and quantum gravity

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Abstract

Black hole solutions of the Einstein equations provide excellent models of astrophysical black holes as well as conceptual examples illustrating the interplay of physics and geometry. Identifying these solutions, as well as finding differences with them, is a standard part of studies on modified theories of gravity, whatever their original motivation.

Hawking radiation is the most celebrated result of quantum field theory on a curved background. It completed the formulation of black hole thermodynamics and initiated the black hole information loss debate. Candidate theories of quantum gravity are required to demonstrate their way of entropy counting, indicate modifications to gravitational collapse, and take a stance on the issue of information loss and/or its resolution.

We first review the key semiclassical black hole properties and the consistency of the underlying assumptions. Then we discuss how some candidate quantum gravity theories align with these properties

[Invited contribution to Gravity and the Quantum]

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Quantum-Inspired Machine Learning: a Survey

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Abstract

Quantum-inspired Machine Learning (QiML) is a burgeoning field, receiving global attention from researchers for its potential to leverage principles of quantum mechanics within classical computational frameworks. However, current review literature often presents a superficial exploration of QiML, focusing instead on the broader Quantum Machine Learning (QML) field. In response to this gap, this survey provides an integrated and comprehensive examination of QiML, exploring QiML's diverse research domains including tensor network simulations, dequantized algorithms, and others, showcasing recent advancements, practical applications, and illuminating potential future research avenues. Further, a concrete definition of QiML is established by analyzing various prior interpretations of the term and their inherent ambiguities. As QiML continues to evolve, we anticipate a wealth of future developments drawing from quantum mechanics, quantum computing, and classical machine learning, enriching the field further. This survey serves as a guide for researchers and practitioners alike, providing a holistic understanding of QiML's current landscape and future directions.

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Diagnostic accuracy of stereoscopic optical palpation for tumour margin assessment in breast-conserving surgery

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Abstract

Breast-conserving surgery (BCS) is one of the main treatments for early-stage breast cancer. Intraoperative cancer detection in BCS plays a pivotal role in achieving successful tumour removal while preserving optimal cosmetic results. Among all the techniques for intraoperative cancer detection, optical elastography is an emerging technique utilising an optical imaging system to measure mechanical properties of tissue. OCT-based optical elastography is one of the main techniques that has been developed and has been demonstrated to have the capability to accurately identify cancer. However, the accessibility and cost of OCT-based optical elastography can hinder its widespread adoption, especially for patients with lower income and in resource-constrained healthcare environments. In this study, we present the diagnostic accuracy of a novel camera-based optical elastography technique, stereoscopic optical palpation (SOP), for tumour margin assessment in BCS. SOP is significantly more cost-effective compared to previous optical elastography approaches, and relatively straightforward in generating images for determining margins. SOP was performed on the margins of intact, freshly excised specimens from 53 patients undergoing BCS. Stress maps of 30*30 mm^2 were acquired and generated within two minutes during the imaging. To determine the accuracy of tumour margins assessment, 53 patients were enrolled and 247 subimages (10*10 mm^2) were analysed in a cross-validation machine learning algorithm. The sensitivity and specificity of tumour margin assessment are determined to be 82.1% and 84.5% for cancer within 1 mm from the margin. These results demonstrate that SOP can be an effective tool to assist in tumour margin assessment. Due to its simplicity and affordability, SOP holds promise to be broadly used in numerous clinical applications.

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Topological pumping of droplet time crystals

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Abstract

In 2005, Couder, Protière et. al. reported on observations of walking droplets in a Floquet driven system [1]. Their findings opened a path for a flourishing field of research coined hydrodynamical quantum analogs [2]. We have identified certain class of such driven droplets as realizations of classical time crystals [3]. In this talk, I will present recent results from our experiments on the creation and observation of topological pumps for droplet time crystals. Thouless quantum pumps are quantum mechanical devices whose functioning relies on quantum tunneling that allows spatial transport of charges such as electrons at single quantum precision due to the underlying topological invariance quantified by the Chern number of the pump. In our classical droplet system, we have discovered a way to circumvent the requirement of tunneling and have realized transport of the droplets backward and forward in time lattices at single site precision in a topologically protected manner, and have measured the topological invariant characterizing these pumps.

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Development of ytterbium-fibre amplifier system producing 72fs pulses for coherent supercontinuum generation

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Abstract

We present the development of a ytterbium-fiber amplifier system capable of producing ultrafast pulses with a duration of 72fs and energy of 15.4nJ at a high repetition rate of 34.3MHz. First, we employ an all-fiber SESAM modelocked linear-cavity laser (LCL) as a seed source. This laser emits linearly chirped pulses with a duration of 2ps, average output power of 12mW, and FWHM spectral width of 10nm. These parameters correspond to the Transform-limited sech^2 profile pulse duration of 158fs. The seed pulses are fed into a bidirectionally pumped ytterbium-doped fibre amplifier (YDFA) with a gain of 21dB, resulting in an amplified average power of 530 mW. To further reduce the pulse duration to below 100fs, amplified pulses are propagated through a segment of SMF for spectral broadening. During propagation through the YDFA and SMF, the seed pulses underwent significant temporal and spectral modifications, resulting in the pulsewidth broadening to 5.1ps and spectral width increasing to 34nm. Pulse compression quality is determined by the FROG analysis at the output of SMF, which reveals the accumulation of a linear frequency chirp across the pulses, which can be mitigated by applying opposite dispersion. Subsequently, the temporally broadened 5.1ps pulses are compressed using a Treacy-type pulse compressor, resulting in pulses as short as 72fs, corresponding to a pulse compression factor exceeding 62. These ultrashort pulses, characterized by their high peak power, are launched into a 40cm-long nonlinear photonic crystal fibre, leading to the generation of a white light supercontinuum (SC) spanning over an octave. Spectral coherence is ensured by maintaining a soliton order below 10. Such a coherent and octave-spanning SC is essential for applications such as carrier-envelope offset stabilization in modelocked lasers, with potential uses in frequency metrology, ultra-stable microwave generation, and advanced optical communication

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Photonic Radar with Millimetre Resolution for UAV and Vital Sign Detection

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Abstract

Microwave photonics-enabled radar technology is gaining momentum due to its numerous advantages over conventional electronic approaches. Photonics technology's broad bandwidth and low-loss characteristics have led to a growing interest in generating, manipulating, and distributing microwave or radio-frequency (RF) signals to enhance radar sensing performance. As a result, photonic radar has the capability to achieve unprecedented sensing range resolution and precision, meeting the requirements of diverse applications, ranging from capturing ultrafine details of unmanned aerial vehicles (UAVs) to detecting the vital signs of humans and animals.

In this talk, we present a photonic stepped-frequency radar system enabled by an optical frequency-shifting loop. This addition to the photonic radar family exhibits extra promising features. The system delivers a bandwidth capacity exceeding 30 GHz (5 mm range resolution), with signal quality on par with the state-of-the-art electronic signal generators, while utilising a relatively simple to moderately complex optical system setup and relying solely on MHz-level driving electronics. Compared with other approaches, the demonstrated system achieves an optimal balance among sufficient bandwidth, system tunability, high time-frequency linearity, and avoidance of high-speed electronics. We applied this system to image a drone's propellers and to extract the vital signs of a living animal— a cane toad — which serves as a proxy for a human, demonstrating the system's efficacy in real-world scenarios. The system is further highlighted for its adaptability to radar and LiDAR sensing with an extended ambiguity range exceeding 15 metres — a tenfold extension compared to our previous demonstrations, emphasising its versatility and potential in hybrid detection and sensor fusion, leading to more reliable and accurate sensing results.

This photonic approach offers a new path toward high-resolution and cost-effective hybrid radar-LiDAR modules with reduced system complexity and the potential of using on-chip components for better size-weight-power and a wide range of sensing applications.

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Entanglement harvesting with covariantly bandlimited fields

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Abstract

In QFT UV cutoffs are often used as renormalisation or calculational tools, however as we know from condensed matter physics these cutoffs can have physical origins and relevance. The generalised uncertainty principles introduce the notion of a physical minimum length scale that should appear in QFTs, with the added requirement that any cutoff should be Lorentz covariant. The covariant cutoff introduced by Kempf and Pye acts on the spectrum of the d'Alembertian operator, whose main effects are on the Feynman propagator. Past work has focussed on the consequences of this cutoff on scattering amplitudes in phi-4 theory, however our work considers the effects of the covariant bandlimit on detector-field interactions, of which the simplest affected example is entanglement harvesting.

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Imperfection Analysis for Random Telegraph Noise Mitigation using Spectator Qubit

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Abstract

In a scenario where data-storage qubits are kept in isolation as far as possible, with minimal measurements and controls, noise mitigation can still be done using additional noise probes, with corrections applied only when needed. Motivated by the case of solid-state qubits, we consider dephasing noise arising from a two-state fluctuator, described by random telegraph process, and a noise probe which is also a qubit, a so-called spectator qubit (SQ).We construct the theoretical model assuming projective measurements on the SQ, and derive the performance of different measurement and control strategies in the regime where the noise mitigation works well. Based on an analytical construction using Bayesian maps, we design a one-parameter family of algorithms. In the asymptotic regime of high noise-sensitivity of the SQ, we show analytically that this family of algorithms reduces the data qubit decoherence rate by a divisor scaling as the square of this sensitivity. Followed by the analytical results for perfect case, we also analysed the effect of imperfections in system parameters and measurement uncertainties to the final decoherence rate. We show that for several different imperfections, we are still able to achieve the same scaling in decoherence rate deduction when the uncertainties are bounded.

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Impact of nuclear structure on nuclear responses to WIMP elastic scattering

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Abstract

Experimentalists strive to better analyse signals of dark matter direct detection at detectors. Thus, improved theoretical models are being developed to describe WIMP-nucleus elastic scattering, with one particular interest area focusing on enhanced study of the nuclear response functions associated with various target detector isotopes. We build on this by investigating the sensitivity of said nuclear responses to nuclear structure, considering a complete list of non-relativistic effective field theory (EFT) nuclear operators. We employ nuclear shell model interactions which differ from those used in previous literature, to facilitate comparison between different nuclear structure results.

We perform state-of-the-art nuclear shell model calculations for isotopes relevant to direct detection experiments: ^{19}F, ^{23}Na, $^{28-30}$Si, ^{40}Ar, ^{127}I, $^{70,72-74,76}$Ge and $^{128-132,134,136}$Xe. Our integrated nuclear response values sometimes exhibit large (up to orders-of-magnitude) factor differences compared to those in previous works for certain WIMP-nucleus interaction channels and their associated isotopes. We highlight the potential uncertainties that may arise from the nuclear components of WIMP-nucleus scattering amplitudes due to nuclear structure theory and modeling. This enables us to deduce the effect of these uncertainties on the scattering cross-section. In particular, we investigate the effect of nuclear structure on the scattering cross-sections associated with the XENON100 and LUX direct detection experiments for ^{nat}Xe isotopes.

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Low Depth Virtual Distillation of Quantum Circuits by Deterministic Circuit Decomposition

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Abstract

In order to run algorithms with quantum advantage on NISQ devices, noise mitigation techniques are required [1]. Recently, Huggins et al. [2] proposed a virtual distillation (VD) technique to correct expectation values using a projective measurement on duplicate copies of the circuit. This requires measuring the expectation value of an observable to swap circuit copies (S2). While the circuit to measure S2 and commuting observables have shown success, arbitrary observables result in circuits so deep they can add more noise than they mitigate on NISQ devices.

In our work, we demonstrate two methods of VD that give low depth circuits for all possible Pauli strings and allow application to algorithms such as the variational quantum eigensolver (VQE) [3]. Our methods deterministically decompose the projective circuit into multiple low depth measurements and provide a tradeoff between circuit depth and number of measurements. We illustrate our method by recovering the molecular dissociation curves for hydrogen chains using real noisy superconducting devices.

Furthermore, we show that VD on VQE can violate the variational principle and give unphysical results. This occurs if there is more noise in S2 than on Pauli string measurement. We illustrate how our methods can be used to bound the noise on S2 by the other observables and recover the variational principle.

Our work demonstrates a complete scheme to implement virtual distillation for VQE algorithms that ensures both low depth circuits and the conservation of the variational principle. This will be useful as a noise mitigation technique option in the optimisation layer on real devices.

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Optimization and robust stability of non-Hermitian quantum sensing

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Abstract

Non-Hermitian (NH) dynamics has been widely studied to enhance the precision of quantum sensing; and nonreciprocity can be a powerful resource for NH quantum sensing, as nonreciprocity allows to arbitrarily exceed the fundamental bound on the measurement rate of any reciprocal sensors. Here we establish fundamental limits on signal-to-noise ratio for reciprocal and nonreciprocal NH quantum sensing [1]. In particular, for two-mode linear systems with two coherent drives, an approximately attainable uniform bound on the best possible measurement rate per photon is derived for both reciprocal and nonreciprocal sensors.

Multimode NH lattice dynamics can provide exponentially enhanced quantum sensing where the quantum Fisher information (QFI) per photon increases exponentially with the lattice size. However, it has also been shown that the quintessential NH skin effect does not provide any true advantage. Here, we demonstrate the importance of optimizing the phase of the coherent drive and the position of the injection and detection in multimode NH quantum sensing [2].

The presence of noise may greatly degrade the ability to detect small parameter changes in NH quantum sensing. We analytically characterize and highlight the impact of the structure of loss and gain on the sensitivity and stability of NH quantum sensors. Counter-intuitively, we find that by only tuning the loss structure properly, the exponential sensitivity can be surprisingly regained when the sensing dynamics is stable [3].

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STM study of 2D Van der Waals Ferromagnetic Metal Fe_3GeTe_2

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Abstract

Van der Waals (vdW) ferromagnetic materials, such as CrX_3 (X= Cl, Br, I), Cr_2GeTe_3, and Fe_3GeTe_2 (FGT), with robust two-dimensional (2D) ferromagnetism even down to monolayer, have recently been extensively investigated due to their long-range magnetic ordering in the 2D limit leading to realization of future novel spintronic devices. Among many 2D ferromagnets reported previously, FGT exhibits a robust 2D ferromagnetic feature with high Tc, good air stability, and increased Tc above room temperature by ionic gate showing great application potential. In addition, lots of interesting phenomena, such as heavy Fermions (HF), topological Skyrmions, and antisymmetric magnetoresistance have been found in FGT and its heterostructures. Exploring the microscopic interaction mechanism of spin, lattice, orbital and other degrees of freedom in FGT materials will help us understand the origin of its 2D magnetism, develop effective magnetic modulation methods, analyze the origin of its HF, explore the mechanisms of magnetoelectric coupling, and provide theoretical and technical support for the application of FGT materials in spintronic devices. Here, we utilized the low-temperature scanning tunneling microscope to investigate the electronic structure of the FGT (001) single crystal. We have found that an anomalous enhancement of Kondo screening was observed at the Kondo hole of local Fe vacancies in FGT. By further analyzing the anomalous Kondo hole effect, a microscopic Kondo-Ising lattice model was proposed to understand the competition between Ising ferromagnetism and Kondo screening, revealing the origin of HF in FGT. Furthermore, a voltage-controlled negative differential conductance was realized in the FGT tunneling junction, which paves a way to design and develop applications based on 2D vdW magnets.

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Strain-free GaAs quantum dots with fabrication tunable radiative emission

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Abstract

Semiconductor quantum dots (QDs) are recognised as excellent sources of non-classical light states, and are considered a promising, scalable, source for the fields of quantum information, metrology, and computing. The growth of more ideal QDs to better realise progress in these fields remains an active area of research. In this talk, a recent technique to fabricate QDs by local nano-etching and redeposition by molecular beam epitaxy is presented. When a metal such as aluminium or gallium is deposited on an AlGaAs film, nucleation of nano-scale droplets occurs. At elevated temperatures, these droplets will etch, forming nano-scale cone-like indentations. By depositing a lower bandgap materal such as GaAs and then capping with a larger bandgap material such as AlGaAs, QDs are formed in the indentation regions. 15K photoluminescence studies using a 516nm laser show QD ensemble emission between 680nm to 800nm, where the emission wavelength varies depending on the amount of GaAs material deposited. 4K micro-photoluminescence studies reveal single QDs and their exciton structure. By comparing atomic force microscopy and the photoluminescence results we show a strong correlation and control between QD emission properties and the QD fabrication process.

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Aspects of nuclear structure research at the ANU

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Abstract

The Department of Nuclear Physics and Accelerator Applications is consistently developing, improving, and applying techniques to improve understanding of nuclear structure across the nuclear chart. Descriptions of nuclear structure are generally separated into single-particle-like and collective regions. A complementary suite of experiment stations at the Heavy Ion Accelerator Facility exist to study these two modes of behaviour, and the complex transitions that emerge between them.

Coulomb-excitation (Coulex) experiments are excellent probes of collective features of atomic nuclei. A new target chamber and silicon-photodiode particle-detector array has been developed for the Compton Suppressed Array (CAESAR) of HPGe gamma-ray detectors, allowing Coulomb-excitation measurements to be performed for target-like and beam-like stable nuclei. These measurements are sensitive to the collective enhancement of E2 matrix elements and have been essential in determining pathways for the onset of nuclear collectivity. Several complementary techniques for excited-state lifetime measurements are also available at the ANU. One of the exciting developments in the measurement of nuclear structure is LaBr3 detectors. These detectors have the excellent timing resolution characteristic of scintillator detectors while boasting energy resolution significantly better than other scintillators. This enhanced capability allows nuclear structure to be explored through measured transition rates and magnetic moments.

Different approaches are required to study their single-particle properties. A new program with nucleon-transfer reactions and particle spectroscopy is being developed at ANU. In conjunction with the existing electron-spectroscopy program, detailed investigation and critical examination of the theory behind the nuclear shell model, and core-excitation intruder states, is about to take place.

This presentation will provide an overview of the new and upgraded research capabilities at the Heavy Ion Accelerator Facility, highlighting some recent successes and future priorities for nuclear-structure research in Australia.

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Spectroscopy of neutron-rich radioisotopes towards the edge of nuclear landscape

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Abstract

Atomic nuclei positioned between the so-called 'valley of stability' and 'neutron drip-line' provide an exciting testing group in which nuclear-structure models can be examined. Gaining access to these exotic nuclei experimentally presented a long-standing challenge in the field. However, recent progress in the production of radioactive ion beams has led to significant advancement in current experimental research capabilities. Cutting-edge facilities, such as the CARIBU upgrade at Argonne National Laboratory [1], the Facility for Rare Isotope Beams, and the ILL Grenoble, offer exciting prospects for investigation into nuclear structure far from stability, origins of the elements through the rapid neutron-capture process in stars, and applied topics such as the reactor antineutrino anomaly and decay heat discrepancies.

The shape of an atomic nucleus is considered to be one of its most fundamental properties. Generally speaking, those with closed nucleon quantum shells possess spherical ground states and their properties are well described by the nuclear shell model. In open-shell regions, enhancement of proton-neutron interactions between valence nucleons drives the onset of collective behaviour and the establishment of static deformed ground states. Axially symmetric, quadrupole (L=2) deformation is by far the most common deviation from the spherical shape, with rarer instances of higher-order multipoles (L=3, octupole) having been observed.

This presentation will provide an overview of these facilities and discuss ongoing work concerning nuclear shape transitions and decay properties of neutron-rich nuclei near A=100 and A=150.

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Efficient Optimisation of Qubit Control Pulses Using a Noise Operator Formalism and Genetic Algorithms

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Abstract

Predicting qubit-environmental interactions given an arbitrary sequence of control pulses is a non-trivial problem. The high dimensionality of the space of possible control pulses further compounds this complexity. Such challenges have motivated our exploration of effective and efficient machine learning techniques to find control pulse sequences that minimise qubit decoherence.

To start addressing this problem, Youssry et al. introduced a formalism for separating ideal control dynamics from the system-environment interactions. This work introduced a noise operator, which encoded the influence of system-environment interactions. With this, the authors trained a deep learning model to predict this operator and, once sufficiently trained, used the model to efficiently find control pulses such that the noise operator was as close as possible to the identity matrix.

We start our work by showing how to deduce this system-environment interaction directly from experimental expectation values, thus mitigating the need to predict it. We then use genetic algorithms to optimise control pulses. Our method makes no assumptions about any underlying noise model or qubit implementation and uses only observable expectations. With our method, no large dataset of quantum data nor training of a deep learning model is required, thus reducing the classical and quantum experimental resource requirements.

Simulating a single qubit subject to non-stationary Gaussian coloured noise acting along the x and z axes. We can achieve a mean 98.39% (+/- 0.18%) process fidelity across quantum gates (Pauli-I, Pauli- Pauli-X, Pauli-Y, Pauli-Z, Hadamard, rotation by pi on four around the x-axis), with optimisation being bounded by GPU memory. We achieve this by implementing control along the x and y axes while requiring less than a quarter of the qubit evolution simulations as required by previous work.

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The Power of Einstein-Podolsky-Rosen Steering

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Abstract

Quantum steering is the phenomenon where one party (Alice) steers the quantum system of another party (Bob) into distinct ensembles of states by performing different measurements on her subsystem. It is known to be a type of nonlocality that is stronger than quantum entanglement, but weaker than Bell nonlocality. Here we introduce the power of one pure steered state for EPR-steering in a pair of qubit and multi-party network.

First, we consider the scenario where Alice and Bob each have a qubit and Alice performs dichotomic projective measurements. If the ensemble from Alice's first setting contains only one pure state p in quantum steering ellipsoid E, occurring with probability p_p. Using projective geometry, we derive the necessary and sufficient condition analytically for Alice to be able to demonstrate EPR-steering of Bob's state using this and some second setting, when the two ensembles from these lie in a plane. Based on this, we show that, for a given E, if the probability of Bob's pure state p_p is high enough then any distinct second setting by Alice is sufficient to demonstrate EPR-steering. Similarly we derive a necessary condition. Moreover, the criteria we derive are tight; for spherical steering ellipsoids, the bounds coincide.

Second, we investigate the power of one pure steered state in a network scenario involving n parties, who each perform local measurements on part of a global quantum state, that is produced using only a two-party entangled state, and mixing with ancillary separable states. We derive analytically the necessary and sufficient steering criteria for different sets of measurement settings. Strikingly, we find that one party can steer every one of the n-1 other parties, for arbitrarily large n, using only two measurements. Furthermore, we experimentally demonstrate this type of steering between three parties with the detection loophole closed.

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Molecular strong coupling: an exploration employing open, half- and full planar cavities

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Abstract

Open cavities have been put forward as a convenient platform with which to undertake molecular strong coupling. Whilst a number of demonstrations of Rabi- splitting in open cavities have been reported by monitoring reflectivity and/or transmission, it remains unclear whether such structures really drive a molecular resonance into the strong coupling regime [1, 2, 3]. Here we explore a more stringent monitor of strong coupling, the modification of photoluminescence. We examine the emission from a range of dye-doped open, half and full optical microcavities. For each configuration an analysis of the reflectivity data indicates the presence of strong coupling. We find that our open and half cavities show only minor modifications of the photoluminescence spectrum. For the full-cavity, for which the dielectric layer is bound both above and below by a metallic mirror, we find very significant modification, the photoluminescence clearly tracking the lower polariton. Based on our observations we suggest the usual strong coupling criterion based on the coupling strength needs to be supplemented by an additional condition based on the cavity finesse. Accordingly, we propose a new criterion for effective molecular strong coupling [1]. This technique may be of relevance in designing strong coupling resonators for chemistry and materials science investigations to probe a fascinating aspect of molecular strong coupling, a new field that spans physics, chemistry, and materials science and that promises to add cavity quantum electrodynamics to the chemistry/materials toolkit.

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Realization of quantum autoencoders using a learning control approach

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Abstract

Quantum autoencoders (QAEs) are at the forefront of automatic data compression within the realm of quantum information. Generally, a QAE consists of an encoder to compress high-dimensional input states into low-dimensional latent states with the discarded part denoted as the trash states, and a decoder to recover to the original space via the combination of the latent states and the reference states. The goal of QAE is to maximize the overlap between the trashed state and the reference state (i.e., the encoding fidelity) or the overlap between the recovered state and the original state (i.e., the decoding fidelity). When taking a pure state as the reference state, perfect QAEs (i.e., the encoding fidelity reaching 1) can be realized when the number of linearly independent vectors among the input states is less than the dimension of the latent space. Furthermore, there exists an upper bound for the encoding fidelity, which is determined by the eigenvalues of the density matrix representation of the input states. Then, we present a learning control approach for training QAEs using different learning algorithms~\cite{ma2023compression}. Numerical simulations on 2-qubit and 3-qubit systems demonstrate that our method is effective in training QAEs towards an optimal compression rate. However, the upper bound limits the compression rate for high-rank states when focusing on the density matrix representation of the input states. To address the entropy inconsistency between the input states and the reconstructed states, we allow the reference state to be a mixed state to further improve the decoding fidelity.

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Physical properties of Kerr-Vaidya solutions

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Abstract

The near-horizon behaviour of the spherically-symmetric black hole system was fully specified by considering the trapping of light as the defining feature of a black hole, assuming regularity at the horizon and seeking the finite-time formation of the trapped region according to a distant observer. The black holes with these features are termed as physical black holes (PBHs). In this case, the violation of the null energy condition (NEC) emerges as a necessary feature, but at the same time, this violation should be bounded by the quantum energy inequalities. In spherically symmetric spacetime, out of the four solutions, i.e., growing/evaporating black holes and white holes, only evaporating black holes and growing white holes exist as real solutions. Unlike the classical case, a test particle can enter the white hole horizon. However, the way it enters the horizon is rather peculiar. Astrophysical black holes (ABHs) are the cold and dark compact objects that are observed in the center of galaxies. If PBHs aptly model ABHs, then zero angular momentum black holes cannot grow. Since most of the observed ABHs are rotating, it becomes pertinent to look what happens in axial symmetry. We start with the simpler case of Kerr-Vaidya metrics, which are the extensions of the Kerr metric with a variable gravitational mass. All four Kerr-Vaidya metrics violate NEC. Except for the case of shrinking white holes, the other three solutions do satisfy the bounds on NEC violation. The apparent horizon of the Kerr-Vaidya black holes is not completely hidden by the event horizon, and thus, accessible to outside observers. The seperatrix of the Kerr-Vaidya metric coincides with the rindler horizon, enabling the computation of its Hawking temperature, hinting that the Kerr-Vaidya metric can serve as a consistent model that can include the backreaction to black holes through Hawking radiation.

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Memory Decoherence Time in Open Quantum Harmonic Oscillators and Finite Level Quantum Systems

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Abstract

This talk is concerned with open quantum harmonic oscillators and finite-level quantum systems described by linear and quasi-linear Hudson-Parthasarathy quantum stochastic differential equations. This framework includes isolated systems with zero Hamiltonian, whose internal variables remain unchanged (in the Heisenberg picture of quantum dynamics) over the course of time, making such systems potentially applicable as quantum memory devices. In a more realistic case of system-environment coupling, we define a memory decoherence horizon as the time for a weighted mean square of the deviation

of the vector of self-adjoint system variables on the system-field Hilbert space from its initial value to become relatively significant as specified by a real positive semi-definite symmetric weighting matrix and a fidelity parameter. The reference scale in this definition uses the real part of the matrix of second moments of the initial system variables.

We consider a problem of maximising this decoherence time or its approximation from a truncated Taylor series expansion

involving the first and second derivatives of the decoherence time with respect to the fidelity parameter.

The maximisation of the decoherence time or its approximate version is carried out at a given value of the fidelity parameter over the energy and coupling parameters of the open system as a model of quantum memory in its storage phase. Conditions are discussed under which the zero Hamiltonian delivers a suboptimal solution. This optimisation problem is also considered for system interconnections.

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Using elastic electron scattering experiments in the development of finite nuclear magnetisation models for high-precision tests of the standard model.

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Abstract

High-precision tests of the standard model in the large Z regime require particularly delicate care owing to the complex structure of the atomic nucleus. In particular, a complete understanding of nuclear size corrections, such as the Breit-Rosenthal (finite charge) and Bohr-Weisskopf (finite magnetisation distribution) effects, are fundamental to our ability to explain the observed hyperfine anomaly present in large atoms. Although many models of nuclear magnetisation distributions have demonstrated their efficacy, one of the more successful being the single-particle model, the choice in the particular parameterisation of the nucleus used is typically performed ad hoc. In this paper, we propose an alternative method for extracting the magnetisation distribution from existing elastic electron scattering experiments. Methods of extracting the transverse magnetic contribution to the scattering cross-section have been well-documented, which we adopt here. By considering the individual contributions to the transverse magnetic form factor, we demonstrate how the nuclear magnetisation distribution may be extracted from the J=1/2 contribution, and consider the effects on the hyperfine structure in heavy electronic atoms. We present a comparison between this approach and existing nuclear models in their predictions of the hyperfine anomaly due to the Bohr-Weisskopf effect.

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Using SOFIA ionised carbon data as a probe for sub-GeV cosmic rays in young Supernova Remnants

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Abstract

Supernova remnants (SNRs) have been, for decades, proposed as possible sources of galactic cosmic rays. Current gamma ray studies at GeV energies do not provide the resolution required to trace low-energy (GeV) cosmic rays effectively. Ionised gas tracers such as the 1.9 THz fine-structure line of carbon (I[C II]) uniquely offer an arc-minute resolution probe of low-energy cosmic-rays up to GeV energies. In this contribution, we present analysis of SOFIA C+ observations of SNR RXJ1713.7-3946, a young, gamma-ray-bright SNR, focusing on the gas associated with and surrounding the remnant. The data from the SOFIA, Mopra and Parkes+ATCA telescopes were used measure the ratio of I[C II] to I[12CO(J=1-0)] and I[C II] to I[HI] towards RXJ1713, in an attempt to measure the level of GeV cosmic rays potentially accelerated by the remnant. To put our findings in a wider context, we also compared our results to the Galaxy-wide HERSCHEL GOT C+ survey. This presentation will outline the details of our study and its implications for our understanding of cosmic ray origins in our Galaxy.

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Complex switching dynamics in Kerr ring resonator with coupled light

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Abstract

Micro-resonators represent the next generation of chip-scale optical systems offering low power and high performance. We study the dynamics of two coupled light in a ring resonator where the laser source is split in equal power and sent into the resonator. Recent works [1, 2] have shown that a wide range of interesting behaviour including symmetry breaking, periodic oscillations, and chaotic dynamics can be observed from this system. Using a dynamical system approach, we study the different behaviors this system can display by describing its bifurcations. In particular, we find a region where the system exhibits chaotic solutions with different switching patterns. To investigate the mechanisms leading to them, we compute the kneading invariant K across a wide range of parameter space. The kneading invariant K [3] is a topological invariant, that encodes how the temporal traces of each mode visit the regions of the broken states in the phase space. This technique has been used successfully to study the mechanisms leading to self-switching oscillations. Each switching pattern can be represented by color for plotting.

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Efficient optical frequency doubling in SiN loaded LNOI waveguides by mitigating lateral leakage through operating near a bound state in the continuum

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Abstract

Second-order nonlinear optical processes are crucial for applications such as frequency mixing and optical parametric oscillators. Lithium niobate (LN) is arguably one of the most used nonlinear optical materials due to its wide bandgap, the high second-order nonlinear coefficient, and the ability to quasi-phase match optical waves via periodic crystal inversion. Recent advancements in wafer-scale manufacturing of photonic circuit components in thin film Lithium Niobate on Insulator (LNOI) have propelled this platform to the forefront of photonic chip research. A remarkable second harmonic generation (SHG) normalized conversion efficiency of ~2600 W-1cm-2 has been demonstrated in periodically poled LNOI waveguides [1]. However, the complex fabrication of these periodically poled devices has led researchers to explore alternative approaches. One such method involves engineering the waveguide geometry to achieve modal phase matching. Unfortunately, the overlap of the modes is typically low, yielding low conversion efficiencies [2].

To address this challenge, we investigated a SiN-loaded LNOI waveguide material composition (see Fig. 1a) and optical modes (see Fig. 1b and c), which provide a high modal overlap in the LN thin film, while utilizing bound states in the continuum at the second harmonic wavelength to mitigate lateral leakage. These efforts resulted in a theoretical normalized conversion efficiency of ~400%W-1cm-2 [3] and an experimental conversion efficiency of ~300%W-1cm-2 (see Fig. 1f). This demonstration paves the way for potential applications in wavelength conversion, all-optical signal processing, and quantum optics.

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Microwave to Optical Frequency Conversion in Rare Earth Ions

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Abstract

Superconducting qubits are a particularly promising technology for quantum computing. However, superconducting qubits are naturally microwave devices, coupling to microwave photons. Microwave photons are unsuitable for long-distance transfer of quantum states; at any reasonable temperature the signal is swamped by thermal noise. Optical photons, however, have high enough energy to not be lost at room temperature, either in free space or guided in optical fibres.

A three-level frequency conversion system can be used to perform the frequency conversion. The rare earth ions are well suited to this three-level method, having narrow optical and easily accessible microwave transitions. Erbium in particular is excellent, with optical transitions around the lowest-loss window in silica fibre, and with sufficient magnetic moment to allow microwave Zeeman splitting at reasonable fields.

Raman heterodyne spectroscopy of erbium in yttrium orthosilicate (Er:YSO) with natural isotopic abundance has in the past shown number conversion efficiencies of 10^{-5} at 4 K with optical and microwave resonant enhancement. These measurements showed parasitic re-absorption by isotopic impurities and thermal populations limited the conversion efficiency. With an isotopically purified sample of ^{170}Er:YSO and resonant enhancement of only the microwave transition, strong coupling was seen between the microwave resonator and the ions in both microwave transmission and in the frequency converted photons at around 150 mK --- a necessary requirement for efficient conversion.

To improve the conversion efficiency, measurements of an isotopically purified sample with resonant enhancement of both the microwave and optical transitions at around 150 mK have been made. These measurements show a maximum conversion efficiency of 10^{-6} between microwave and optical photons. Unlike previous measurements, efficiency was not limited by saturation of the system, but by temperature control of the sample, by mechanical oscillations, and by limitations in the detector sensitivity. These measurements show some progress towards realising theoretical conversion efficiency.

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Period-two polarization dynamics in a Kerr resonator for an enhanced coherent Ising Machine

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Abstract

Here we demonstrate a novel coherent Ising machine (CIM) based upon spontaneous symmetry breaking (SSB) of the field polarization in a driven optical Kerr resonator. Specifically, we consider a ring resonator made of a Kerr nonlinear optical waveguide that presents two orthogonal polarization modes, and that is coherently driven by an external laser beam. Under suitable conditions, the polarization state of the intracavity field can exist in one of two symmetry-broken states. The resonator is synchronously driven with a train of short pulses so that each pulse can independently undergo polarization spontaneous symmetry breaking within the resonator, thus yielding independent spin-like states. By measuring the polarization state of each of the pulses and feeding the measurement results to a phase modulator that acts upon the driving field, we are able to obtain a network of spins that are coupled in a desired manner. Finally, scanning the driving laser wavelength across the symmetry breaking bifurcation point forces the spins to evolve towards the ground state of the corresponding Ising problem. Importantly, because of the use of polarization to define our spin states, we can operate in a recently-discovered period-2 regime, where the polarization modes of the resonator switch at each roundtrip due to the implementation of a pi-phase shift birefringent defect between the two orthogonal polarization modes of the resonator. This periodic alternation protects the symmetry of the system, guaranteeing that neither of the two spin states are statistically favored, and confers enhanced robustness to our Ising machine. In our presentation, we will discuss recent numerical results that highlight the potential advantages of our Ising machine against competing schemes. We will also present preliminary experimental results obtained with an optical fibre ring resonator.

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Quantum machine learning via Kerr non-linearity

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Abstract

Kernel methods are of current interest in quantum machine learning due to their similarities with quantum computing in how they process information in high-dimensional feature (Hilbert) spaces. Kernels are believed to offer particular advantages when they cannot be computed classically [1], so a kernel with indisputably nonclassical elements is desirable. Kerr nonlinearities, known to be a route to universal continuous variable (CV) quantum computation [2], may be able to play this role for quantum machine learning.

In this work we introduce a two-mode bosonic kernel with a cross-Kerr nonlinearity, and show its use as the basis for a support vector machine (SVM) classifier where classical data is encoded in quantum states. This scheme is a CV generalisation of the binary SVM classifer of IBM [3]. We explore the unique structure of the kernel and encoded data. We then discuss possible experimental platforms in superconducting quantum circuits and quantum optics.

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Explaining and evaluating quantum machine learning models

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Abstract

Quantum machine learning (QML) has emerged as one of the most promising quantum computing applications, especially on near-term devices. However, no single method for designing QML models has emerged as the most favourable. Further, while there are many empirical results supporting the idea that QML may be in some sense more powerful than its classical counterpart, there is little understanding about why one particular QML model may outperform a classical model on realistic tasks.

Here we gather together several quantum machine learning models and evaluate them with respect to several theoretical measures. We then examine the performance of these models on actual learning tasks. Emphasis is placed on understanding which features of a QML model lead to increased performance over classical model, and on the balancing of expressiveness, trainability and feasibility on near-term devices.

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Laser-based trace-level sensing of molecules in agricultural and environmental air

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Abstract

Near-infrared diode lasers, operating narrowband at molecule-specific wavelengths, are useful for spectroscopic sensing of molecules in the atmosphere, e.g., for greenhouse gas (GHG) or other agricultural and environmental species. However, the applicability of highly sensitive forms of cavity-enhanced spectroscopy is often limited by the need to maintain alignment, cleanliness and fine control of a high-finesse optical cavity. We therefore consider how to reconcile access to state-of-the-art performance (yielding high sensitivity and specificity) against the requirement that realistic instruments should be rugged, user-friendly and cost-effective in order to promote their uptake within the wider community. Our current research focuses on the less sensitive but more robust technique of wavelength modulation spectroscopy (WMS), applied to quasi-remote monitoring of CH_4 (methane – a significant GHG) at trace levels in air, as emitted on the breath of in-paddock ruminant livestock. Our laboratory-based feasibility study is intended to precede future major government- and industry-funded research projects and commercial opportunities in Australian agriculture. Our prototype WMS sensing equipment employs phase-sensitive detection of weak absorption of wavelength-modulated diode-laser radiation at a CH_4-specific wavelength (1653.7 nm). It is the forerunner of compact, rugged sensors that could ultimately be deployed at reasonable cost for remote, hands-free monitoring of CH_4 emissions from individually identified grazing livestock. Such instruments are needed to validate innovative feed supplements incorporated in agricultural feed blocks for ruminant livestock. This approach is being developed in our collaborative research program; it promises to substantially reduce CH_4 GHG emissions while benefiting animal productivity in the Australian agricultural industry.

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Near infrared color center integratednanophotonics in an integrated sample and singlephoton detector cryogenic system

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Abstract

The zero-phonon line emission of the nitrogen vacancy color center \(N_C V_{Si}\) is near the telecommunications O band at about 1243 nm. We present measurements of nitrogen vacancy centers in silicon carbide nanopillars at below 4 K temperatures. We integrated our single photon detectors directly into the sample chamber of the cryostat which eliminates the need for a secondary cryogenic system, saving on space and upkeep costs and establishes a lower cost of entry for new experimental solid state quantum optics groups.

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Probing Unusual and Energetic H-alpha features towards the Scutum Supershell

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Abstract

We have studied several prominent Hα features towards the Scutum Supershell. The features resemble an outflow and bow-shock type of morphology. Our study combines Hα, [S II], infrared, radio continuum, and X-ray observations to determine the origin of these intriguing phenomena. The existence of multi-TeV sources observed by HESS and other GeV sources observed by Fermi-LAT shows an energetic complex region. The outflow and bow shock features are estimated at a distance of 2-3 kpc, and they align with several OB associations and LS 5039, an X-ray binary system.

The bright Hα bow shock feature has an overlapping presence in [S II], infrared, and the radio continuum, indicating a possible post-shock region. The Hα outflow feature seems to point back to the potential birthplace of LS 5039, forming an impressive 5 degree outflow that is approximately 0.1 million years old. With Hα luminosities exceeding 10^36 ergs/s, our analysis suggests that the Hα outflow and bow shock could potentially be driven by a hypernova (related to the compact object in LS 5039) or, multiple supernovae within nearby OB associations.

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Recent Approaches to Proving the Penrose Conjecture in General Relativity

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Abstract

General relativity posits that singularities, crucial to our understanding of the nature of spacetime, must exist. The 1970s saw significant advancements in our comprehension of black holes, led by the groundbreaking work of Stephen Hawking and Roger Penrose, culminating in the Hawking–Penrose Singularity Theorem.

In his pivotal 1973 article "Naked Singularities", Penrose examined the concept of 'cosmic censorship', that singularities must necessarily be hidden from observers inside an absolute event horizon. Arraying a string of inequalities drawn from the ingredients of the singularity theorems, Penrose conjectured that if an isoperimetric inequality were violated, then spacetime would contain a naked singularity, implying a lack of predictability in classical physical theories. The Penrose inequality is a proxy for weak cosmic censorship:

After the proclamation of the Penrose conjecture followed a period of stagnation, with minimal progress for over two decades. Breakthroughs by Huisken and Ilmanen and Bray proving the Penrose inequality for the important case of time-symmetry, revitalized interest in this field, prompting a new wave of research.

This paper elucidates these recent developments, comparing their different approaches and assumptions to prove the general Penrose conjecture, which remains an important open problem in general relativity.

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Kernel Alignment for Quantum Support Vector Machines Using Genetic Algorithms

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Abstract

The data encoding circuits used in quantum support vector machine (QSVM) kernels play a crucial role in their classification accuracy. However, manually designing these circuits poses significant challenges in terms of time and performance. To address this issue, we build on the GASP (Genetic Algorithm for State Preparation) framework [1] to select the gate sequence for the kernel circuit architectures in QSVMs. Furthermore, we investigate the impact of supervised and unsupervised kernel loss functions on the optimisation of the encoding circuit. Our methodology is evaluated on several datasets, encompassing both binary and multiple-class classification scenarios. We benchmark our results against commonly utilised classical and quantum kernels. Our findings demonstrate that the GA-generated encoding circuits can match or even surpass the performance of several standard encoding techniques. We further show that unsupervised kernel loss function optimisation approaches, based on eigenvalue analysis of the kernel matrix, outperform supervised approaches for real data. Not only does this approach lead to enhanced classification accuracies for certain problems, but it also establishes a standardised and automated framework for kernel design, reducing the need for trial and error. Our approach also holds promise for identifying patterns in complex datasets and improving the performance of QSVMs across various domains, including finance, healthcare, and materials science. Future research directions include exploring the effectiveness of our approach on larger and more complex datasets and investigating the utilisation of other optimisation techniques to further advance the performance of QSVMs.

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Development of an ocean LiDAR for sensing of water column properties

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Abstract

The knowledge of subsurface water properties such as temperature, salinity and the concentration of algae is essential for monitoring environmental changes due to climate change and pollution. Current techniques include deploying sensors on buoys and from ships, which cover only a localized area, or satellite measurements of ocean surface temperature (a layer only several µm thick) and colour, which are low resolution and have a limited capacity to predict subsurface properties. We are developing a system based on Light Detection and Ranging (LiDAR) that measures depth-resolved water column characteristics and can be utilized from aircraft or drones for high-resolution large-area ocean profiling.

Mainstream LiADRs can map the coastal ocean floor and, to a certain degree, determine profiles of water absorption and scattering coefficients [1]. We have expanded the ocean LiDAR capabilities by adding channels collecting the light backscattered inelastically due to Raman scattering. The Raman spectrum of water and its polarization vary systematically with temperature and salinity [2]. We are using fast photomultipliers detecting the parts of the spectra most sensitive to temperature changes and kHz-repetition-rate lasers with fast data acquisition electronics averaging >100k measurements to achieve ~1°C temperature accuracy over a 5 m long water cell.

In this presentation, we will review our progress on the LiDAR design, including dual-wavelength excitation lasers, a telescope with a variable field-of-view, and a polarization-resolved multi-spectral-channel receiver. We will present the first length-resolved temperature measurements of a 5 m water cell (see Fig. 1) that has two sections at different temperatures, explain the temperature calibration process and show Raman returns collected in Sydney's middle harbour.

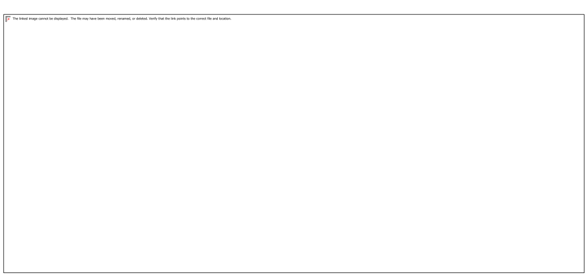

Fig. 1. Experimental setup and depth-resolved temperature measurement in a 5 m pipe.

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Photon-Number Encoded Measurement-Device-Independent Quantum Key Distribution Protocol

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Abstract

Decoherence is detrimental to quantum key distribution (QKD) over large distances. One of the proposed solutions is to use quantum repeaters, which divide the total distance between the users into smaller segments to minimise the effects of the losses in the channel. In this talk, we introduce a measurement-device-independent protocol which uses high-dimensional states prepared by two distant trusted parties and a coherent total photon number detection for the entanglement swapping measurement at the repeater station. We present an experimentally feasible protocol that can be implemented with current technology as the required states reduce down to the single-photon level over large distances. This protocol outperforms the existing measurement-device-independent and twin-field QKD protocols by achieving better key rates in general and higher transmission distance in total when experimental imperfections are considered. It also surpasses the fundamental limit of the repeaterless bound at a much shorter transmission distance in comparison to the existing TF-QKD protocols.

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High Sensitivity Measurement of Refractive Index Using the Orbital Angular Momentum of Light

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Abstract

The detection of refractive index is important for the characterisation and study of various materials and devices. Structured light, including beams possessing orbital angular momentum, may play a key role in this regard. A beam with orbital angular momentum may be generated with a mesoscopic spiral phase plate whose size is compatible with a lab-on-a-chip optofluidic refractive index sensing system.

Here, we demonstrate an ultracompact refractive index sensor based on spiral phase plate of a few tens of micrometers in diameter. The spiral phase plate converts an input Gaussian field to a Laguerre-Gaussian mode possessing orbital angular momentum. We exploit the fact that the output topological charge l of the mode is determined by the refractive index of the medium in which the plate is immersed. By measuring the topological charge l of the generated Laguerre-Gaussian beam, we can determine the refractive index of the liquid sample. The sensitivity of this approach reach 3.5×10^{-3} RIU for a beam of topological charge l=50. This opens up a new form of microfluidic refractive index measurement for various liquid media.

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Limits on the injection energy of Galactic positrons reconsidered

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Abstract

Around 5e43 positrons annihilate in the inner Galaxy every second as inferred from observation of the 511 keV annihilation line radiation from this region. The origin of most of this antimatter is unknown. Positrons injected into the interstellar medium at relativistic energies must lose most of their injection energy via radiative processes before they can thermalise and annihilate, and thereby contribute to the observed annihilation line radiation. Gamma-ray continuum measurements above 511 keV therefore constrain this characteristic positron injection energy scale. However, we will demonstrate that previously claimed severe restrictions to the injection energy are too constraining. Using the new cosmic ray propagation code CRIPTIC we show that positrons contributing significantly to the annihilation line radiation may be injected at highly relativistic energies, well into the 10's of MeV range. This re-opens the possibility that at least positrons may come from compact objects or some classes of WIMP dark matter.

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Constraints on Cosmology from SPT-3G power spectra

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Abstract

The standard model of cosmology, ΛCDM, has established itself as a robust and accurate way of describing the universe. Nevertheless, key questions remain open, such as: what is the nature of dark matter, what are the masses of neutrinos, and what is the origin of the difference between high- and low-redshift measures of the expansion rate?

In this talk, I will present the latest TT/TE/EE power spectra measurements from the SPT-3G instrument on the South Pole Telescope, and the resulting constraints on cosmology. I will explore implications for the standard model and for searches for new physics using the SPT-3G data alone and in combination with Planck data and baryon acoustic oscillation measurements. I will also say a few words about the next experiments, SPT-3G+ shortly, and CMB-S4 at the end of the decade.

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Sensing rotational inertia for fast viscometry measurements

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Abstract

The dissipation of inertia in microscopic systems is obscured by Brownian motion and sensing it enables orders-of-magnitude faster measurements of fluid rheology and particle behaviour than typical measurements of position relaxation. Accessing the inertial regime provides measurements close to real-time that could study systems out-of-equilibrium, such as in and around cellular systems. In an optical trap, the behaviour of a particle depends on the bandwidth of the restraining optical forces and the drag from the surrounding fluid. This leads to time scales characterising the rate of particle position relaxation, its velocity dissipation, and the fluid flow relaxation. Over the last decade, incredibly precise optical tweezers systems have been developed providing the capability to measure the translational inertia of micron-sized particles in fluids. However, there has been little-to-no work investigating the dissipation of rotational inertia leaving it an untapped source to study high-frequency rotational hydrodynamic effects and perform fast microrheometry. In this work, we describe our experimental results that measure the dissipation of rotational inertia using rotational optical tweezers to enable fast viscometry measurements in the rotational regime. An alignment torque can be exerted on a birefringent microsphere using a linearly polarised trapping beam. Thermal fluctuations of the angular position and velocities were then measured by monitoring the changes in the polarisation state of the scattered light and the corresponding characteristic time scales were extracted from the angular velocity power spectrum of the particle. This allows novel measurements of rotational dynamics in fluids and ultrafast measurements of viscosity to investigate rheology changes in highly dynamic systems.

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Searching for signatures of quantum gravity with low-energy bench-top tests

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Abstract

While a full theoretical quantum treatment of quantum gravity remains elusive, effective quantum field theories of gravity have been developed, by treating the quantum field as a perturbation from the classical solution. Low-energy laboratory-scale experiments are well within this perturbative regime. However, whether or not the gravitational field displays quantum properties, that is, if a quantum treatment is required at all, is a question that demands experimental resolution, with several proposed theories stating that the gravitational field may be fundamentally classical. Recently, there has been considerable interest in the possibility of low-energy experiments capable of distinguishing if the difference between a theory of gravity where the gravitational field is allowed to exist in a coherent quantum superposition, and theories where the gravitational field must remain classically valued.

We explore the possibility of testing the quantum nature of gravity with low-energy 'bench-top' style tests. We review some recent proposals based on micron-sized test-masses, opto-mechanical systems, and ultra-cold quantum gases, and discuss the merits, short-comings, and technical challenges. Finally, we discuss our recent proposal for fundamentally relativistic tests of quantum gravity based on the gravitational interaction of photons [1]. We demonstrate that there are multiple quantum gravitational signatures that can be extracted from the quantum state of the light, that cannot be reproduced by any classical theory of gravity. Crucially, the proposed tests are free of QED photon-photon scattering, are sensitive to the spin of the mediating gravitons, and can probe the locality of the gravitational interaction. We provide a metrological analysis of the proposed tests and discuss challenges with their experimental realisation.

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High accuracy protein identification: Fusion of solid-state nanopore sensing and machine learning

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Abstract

Proteins are arguably one of the most important class of biomarkers for health diagnostic purposes. Label-free solid-state nanopore sensing is a versatile technique for sensing and analysing biomolecules such as proteins at single-molecule level. While molecular-level information on size, shape, and charge of proteins can be assessed by nanopores, the identification of proteins with comparable sizes remains a challenge. Here, we combine solid-state nanopore sensing with machine learning to address this challenge. We assess the translocations of four similarly sized proteins using amplifiers with bandwidths (BWs) of 100 kHz and 10 MHz, the highest bandwidth reported for protein sensing, using nanopores fabricated in <10 nm thick silicon nitride membranes. F-values of up to 65.9% and 83.2% without clustering of the protein signals, were achieved with 100 kHz and 10 MHz BW measurements, respectively, for identification of the four proteins. The accuracy was further enhanced by classifying the signals into different clusters based on signal attributes, with F-values and specificity of up to 88.7% and 96.4%, respectively, for combinations of four proteins. The combined use of high bandwidth instruments, advanced clustering, and machine learning allows label-free identification of proteins with high accuracy.

Figure: Workflow for the label-free identification of proteins combining solid-state nanopores and machine learning

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Constraining cosmic ray transport with spatially- and energy-resolved observations

Mark Krumholz
Australian National University, Canberra, Australia

Abstract

I discuss prospects for constraining one of the largest unknowns in cosmic ray physics -- the transport coefficients describing cosmic ray propagation through the interstellar medium -- using spatially-resolved observations that measure the differential morphology of emission from cosmic rays of different energies, in both gamma-ray and radio bands. I demonstrate a sample application of this technique using emission from the globular cluster Terzan 5, where I show that the displacement of the HESS gamma-ray signal from the cluster centre offers the first direct and robust measurements of the cosmic ray pitch angle scattering rate. I demonstrate how future observations with better spatial and energy resolution will improve this measurement in the future.

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CTA and Overview of its Linkages to Radio Astronomy

Gavin Rowell
University of Adelaide, Adelaide, Australia

Abstract

I will provide an overview of the science synergies across gamma-ray and radio astronomy, focusing on CTA and its close connection with results from Australian radio facilities. The science synergies span a wide range of astrophysical and astroparticle topics. They include the study of extreme particle accelerators emitting transient and steady emission, and, fundamental astroparticle challenges such as the nature of dark matter, other cosmic 'relics', and constraints on cosmological parameters. I will conclude with a brief look at the future linkages between CTA and the SKA.

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Sub-monolayer manipulation of diamond surfaces using two-photon laser method

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Abstract

Diamond is an exceptional material with stable colour centres, a wide band gap and high thermal conductivity . Engineering the termination, orientation and defects of the surface is of great importance for quantum computing and sensing, and electronic applications. Techniques for manipulating the surface include processes based on plasma, chemical, electron and ion beams, and laser treatments. Though lasers offer a convenient technique for writing complex surface patterns, their applications have been limited due to, in part, typically poor depth resolution.

Here we report manipulation of the top monolayer of diamond surfaces using deep-UV laser processing. We show that laser pulses at 266 nm with fluence below the ablation threshold remove top-layer carbon atoms from the surface at an average rate of 10^{-6} to 10^{-3} layers per pulse through a 2-photon-induced photo-chemical ejection and oxidization. The effect of dose on the resistance of a hydrogen-terminated surface was investigated. The resistance increases with dose from the starting value of 2-3 kΩ up to the measurement limit of 100 GΩ for doses corresponding to 0.5 monolayers (ML). The observed behaviour agrees well with geometric and tunneling percolation arguments for the surface conduction.

We also find that dosing before hydrogenation produced up to five times higher surface conductivity compared to unexposed surfaces. The higher conductivity is found to result from a higher carrier concentration with only a minor reduction in mobility. Increases in the C=O density and nitrogen vacancies in the subsurface point toward the generation of surface defects upon UV laser exposure. XPS also shows 0.2 eV shift in the valence band maximum towards lower energies, which allows more electrons to be transferred to surface adsorbates. The enhancement in surface electronic properties with only sub-monolayer removal points towards a hitherto unidentified process for re-arrangement of surface atoms upon low-dose UV exposure.

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Multiwavelength InGaAs/InP quantum well nanowire array micro-LEDs for high-speed optical communications

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Abstract

Developing miniaturized light sources at telecommunication wavelengths is crucial for on-chip optical communication systems. Here, we demonstrate the growth and fabrication of highly uniform p-i-n core-shell InGaAs/InP single quantum well (QW) nanowire array light-emitting diodes (LEDs) with multi-wavelength and high-speed operations. Two-dimensional cathodoluminescence mapping reveals that axial and radial QWs in the nanowire structure contribute to strong emission at the wavelength of ~1.35 and ~1.55 µm, respectively, ideal for low-loss optical communications. Thanks to the simultaneous contributions from axial and radial QWs, we achieved broadband electroluminescence emission with a linewidth of 286 nm and a peak power of ~17 µW. A large spectral blueshift was also observed with increased applied bias, ascribed to the band-filling effect based on device simulation. This enables bias-tunable multi-wavelength operation at the telecommunication wavelength range. Moreover, we have fabricated nanowire array LEDs with different pitch sizes on the same substrate to achieve multi-wavelength operation, as a result of different QW formations. By increasing the pitch size, more precursor supply is made available, leading to enhanced radial QW growth. Element incorporation into the QW with different pitch sizes could also be different. Furthermore, we also demonstrated high-speed GHz-level modulation and small pixel size LED, indicating the promise for ultrafast operation and ultra-compact integration. The voltage and pitch size controlled multi-wavelength high-speed nanowire array LED presents a compact and efficient scheme for developing high-performance nanoscale light sources for future optical communication applications.

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CYGNUS-Oz: Australian R&D for a future directional dark matter detector

Victoria Bashu
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Abstract

In this talk, I will provide a general overview of CYGNUS-Oz, which is an Australian collaboration that aims to develop directional detectors for dark matter and neutrino applications.

The primary science goal is to search for Weakly Interacting Massive Particles (WIMPs), which are a well known theoretical Dark Matter candidates which have inspired major experimental search programs around the world. However, With the increased sensitivity of detectors, they will soon become blind to WIMPs because of solar neutrinos as neutrinos mimic the signal of WIMP interactions. Directionality gives the ability to search in the solar neutrino region of the parameter space by giving 3D track information of the particle interactions. The direction in which the primary particle was travelling, distinguishes between neutrino and WIMP interactions. Because, solar neutrinos will come from the sun and WIMPs will have the direction of the dark matter wind. To overcome the neutrino background challenge and continue looking for Dark Matter, CYGNUS-Oz is pursuing its directional detection goals using gas Time Projection Chamber (TPC) technology. CYGNUS-Oz is focusing on R&D to develop an optimal TPC design and achieve lower energy threshold in the TPC. It also aims to achieve stable and high gain gas mixtures, and excellent directional information. The final goal is to create an international network of underground directional detectors with a large volume equivalence to search for WIMPs.

A prototype CYGNUS-I is being developed at the Australian National University with the capacity to explore various operating gas mixtures, avalanche gain devices, and readout methods. With a summery of the near-future R&D challenges that CYGNUS-Oz hopes to address, this overview will include the current design and some preliminary results from CYGNUS-I prototype.

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On physics of the θ-vacua

Otari Sakhelashvili
Sydney Uni, Sydney, Australia

Abstract

The low energy spectrum of the theory can be totally different from the field content. A good example of the phenomena is the low energy QCD. Despite this difference, many aspects of the spectrum can be extracted from the vacuum structure. The QCD admits so called θ-vacua, which plays drastic role in formation of the low energy physics. Also, its existence poses the famous strong-CP problem. The most popular solution of the problem requires new degree of freedom axion, which should protected from UV physics. Hence, the problem is deeply connected to separation of UV physics from the IR physics.

In this talk, we will discuss the role of the θ-vacua at low energy in the context of standard model and beyond standard model physics. We will touch the issue how UV-physics can influence low energy physics and what kind of observations can be made from low energy to unfold high energy physics.

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Optical Long Baseline Interferometry with Quantum Hard Drives.

Benjamin Field, John Bartholomew, Joss Bland-Hawthorn
University of Sydney, Sydney, Australia

Abstract

In order to develop both optical long baseline interferometry and distributed quantum networks, it will eventually be necessary to overcome the high loss experienced in traditional light distribution methods such as optic fibres. We are exploring an alternate solution using Quantum Hard Drives (QHDs) to store incoming light before transporting the QHD to a secondary location to be released [1].

We investigate the feasibility of rare-earth ion doped crystals as a medium for QHDs. These materials have already demonstrated both long optical and extremely long spin coherence times exceeding 6 hrs [2], as well as numerous memory demonstrations. We are seeking to optimise the optical interaction strength, storage bandwidth and capacity, as well as determine any effect movement may have on memory storage capabilities.

There are a number of challenges in implementing such a QHD, particularly for astronomy. We will discuss some of our solutions including high performance optical filters and what is possible with intensity (Hanbury-Brown Twiss) interferometry as a means to greatly reduce the requirements for maintaining global phase.

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[2] M. Zhong et al., “Optically addressable nuclear spins in a solid with a six hour coherence time”, Nature 517, 1–18 (2015).

238

Meta-Lenslet Array Wavefront Sensor for Laser Guide Star Adaptive Optics

Sarah Dean, Josephine Munro, Israel Vaughn, Andrew Kruse, Tony Travouillon, Dragomir Neshev, Rob Sharp, Andrey Sukhorukov
The Australian National University, Canberra, Australia

Abstract

The Giant Magellan Telescope will use Laser Tomography Adaptive Optics to correct aberrations over a large fraction of the sky. It will be equipped with laser launchers, located around the periphery of the primary mirror, to excite artificial guide stars in the sodium layer of the atmosphere (altitude ~95 km). However, the physical properties of the laser guide star present challenges for wavefront sensing with a Shack-Hartmann. A laser guide star is a vertically elongated shape due to the finite thickness of the sodium layer. This results in each subaperture in a wavefront sensor imaging a unique perspective elongation radially dependent on its distance from the laser launcher. The maximum anamorphic ratio for a 40 m class telescope is ~1:10. A standard solution is to use a large pixel scale to avoid excessive truncation of the elongated spots, but this approach greatly increases the readout noise and thereby limits sensitivity. We suggest that flat nanostructured metasurfaces present a nuanced optical solution, where each meta-lenslet fabricated for an array can have a custom anamorphic ratio and elongation axis angle. Whereas Shack-Hartmann operation was previously demonstrated with arrays of single-layer dielectric metalenses, the parfocal operation across a broad range of magnifications requires a metasurface doublet configuration. We identify original designs of multiple anamorphic meta-lenslet pairs for anamorphic ratios from 1:1 to 1:10, optimised for operation with the same distance from the detector plane. The Optics Studio (Zemax) simulation of our bilayer meta-lenslet showed that the spot size was reduced to a 1:1.7 ratio; resulting in a significantly smaller spot size than a conventional spherical lenslet, along with the measured displacements induced by a 0.1 degree tip/tilt field. The results of this study show a meta-lenslet array could achieve anamorphic compression with a compact optomechanical layout.

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Laser Frequency Stabilisation for Mass Change Mission: Prototype Development and Performance

Emily Rose Rees, Andrew Wade, Kirk McKenzie
Centre for Gravitational Astrophysics, Canberra, Australia

Abstract

The Gravity Recovery and Climate Experiment (GRACE) missions use inter-satellite interferometry to measure changes in the local gravity of the Earth. These measurements have proven critical in understanding large scale mass-transport systems, particularly water and ice movement.

Both GRACE and its successor, GRACE-Follow On, relied on a microwave interferometer as the primary instrument. GRACE-FO also included a Laser Ranging Instrument (LRI) as a technology demonstration, achieving performance two orders of magnitude better than the equivalent Microwave Instrument (MWI).

The next mission in the GRACE series, the Mass Change Mission (MCM), is expected to launch in 2028.

A laser ranging instrument is expected to be used as the primary instrument for this mission and other future GRACE-like missions.

Laser frequency stabilisation is crucial to the operation of the LRI as the primary instrument. Short term frequency stabilisation (10-1000 seconds) allows the measurement of the local gravity field and is provided by stabilising the laser to an optical cavity using the Pound Drever Hall method.

Long term laser frequency stability (months and years) is critical for enabling comparisons of the gravity measurements over time. A new technique for long term laser frequency stabilisation is required to enable the use of the LRI as the primary instrument for these missions.

A dual frequency modulation scheme was first investigated to provide long term laser frequency knowledge by NASA/JPL and has been further developed at the ANU. A prototype electronics unit to provide this dual frequency modulation has been developed and tested in our flight-like testbed, demonstrating performance almost two orders of magnitude better than the expected mission requirements. Compatibility with NASA JPL's GRACE-FO flight hardware testbed has also been achieved.

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Holomorphic Quantum Kernels for Continuous Variable Quantum Machine Learning

Rishi Goel, Laura Henderson, Sally Shrapnel
University of Queensland, Brisbane, Australia

Abstract

The popular qubit framework has dominated recent work on quantum kernels, with recent results characterising expressability, learnability and generalisation. As yet, there is no comparative framework to understand these concepts for continuous variable (CV) quantum computing platforms. We develop a novel framework for understanding CV quantum kernels leveraging ideas from holomorphic function quantum computing [1]. Holomorphic functions have the unique property of characterising degrees of "quantumness" via the notion of stellar rank. Leveraging properties of the Segal Bargmann space, we construct an appropriate Reproducing Kernel Hilbert Space and utilise the notion of stellar ranks to provide a taxonomy for quantum advantage. We prove this kernel is universal - hence highly expressive - for any given compact data set and comment on learnability and generalisation. In doing so, we extend the potential for quantum kernel machine learning to CV bosonic sampling platforms.

[1] Ulysse Chabaud and Saeed Mehraban. Holomorphic Representation of Quantum Computations. Quantum, 6:831, October 2022.

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Hawking radiation into the electroweak instanton vacuum

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Abstract

Instantons are non-perturbative solutions in Euclidean Yang-Mills theories, describing quantum tunnelling between topologically distinct vacuum states. Generically accounting for these transitions demands the addition of a non-perturbative 'theta term' to the theory Lagrangian. In the standard model description of the weak force, such a term is usually unphysical, being removable by a chiral rotation of the fermion states, however, such a redefinition is not possible in the presence of an event horizon. We describe the effective field theory outside the event horizon of an evaporating black hole and identify the presence of a CP-violating chemical potential driving changes in baryon + lepton number. These effects, while strongly suppressed at low temperatures, could contribute significantly when Hawking radiation excites the horizon above the electroweak breaking temperature, such as in the decay of small primordial black holes.

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Quantum noise spectroscopy of non-Gaussian noise using arbitrary multi-axis control sequence

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Abstract

Accurately characterizing the spectral properties of environmental noise in open quantum systems has broad practical and fundamental significance. The comb-based quantum noise spectroscopy, where the basic idea is to engineer a multi-dimensional frequency comb via repetition of suitably designed pulse sequences, has been investigated and major progress has been made [1]. However, due to practical limitations, the assumption that M ≫1, where M is the number of repetitions of control sequences, can not be satisfied in experiment [2]. Moreover, the control pulses, which are often assumed to be instantaneous, are inevitably distorted. Those facts are the main obstacles stopping the QNS from achieving high accuracy, especially at low frequency.

We consider the comb-based quantum noise spectroscopy (QNS) of systems subject to non-Gaussian noise, either classical or quantum. To overcome some limitations of experimental results in the literature [2], we first proposed the M-correction method which can largely improve the accuracy around low frequency. Furthermore, the control-adapted representation of the system dynamics is investigated for proper modeling of the distorted control pulses. In this generalized description, the controls are on multi-axis, and some of the methods developed for single-axis problems can not be directly applied. Fortunately, we proved that the comb-based QNS can still be employed for the control-adapted representation after proper adjustments. Moreover, a new strategy for finding better control sequences is also explored. The results show that our protocol is successful in the non-Gaussian QNS, and the estimation accuracy can be greatly increased compared with existing results, especially around zero frequency. The proposed methods can be extended to other QNS problems with multi-axis control and benefit avariety of related problems.

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[2] Sung, Y., Beaudoin, F., Norris, L.M. et al., Nat. Commun 10, 3715 (2019).

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Catalyst-free fabrication of 1D single crystal W_nO3_{n-2} (n = 25) nano-wire bundles using low-energy He^+ ions

Maryna Bilokur[1], Matt Thompson[1], Matthew Arnold[2], Cormac Corr[1]
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Abstract

One-dimensional (1D) sub-stoichiometric tungsten oxide structures show immense promise in miniaturised gas and bio-sensors, photocatalysts, photodetectors, and electrochromic devices due to high-surface-area and tunable functionalities not achievable with the bulk counterparts. Synthesis of 1D tungsten oxide nano-assemblies is a technologically challenging task, often requiring a catalyst to facilitate the growth of the nano-wires. In this work, we report a fast and cost-effective approach to growing single-crystal nanowire bundles (NWBs) based on the monoclinic W_nO_{3n-2} (n = 25) without the need for a catalyst during the growth process. The rapid growth of the W_nO3_{n-2} –based NWBs is achieved via selective low-energy He^+ ion irradiation of the Mo-Ni doped WO_X surface at 700°C. The physical model is proposed to explain the plasma-assisted self-assembly of the W_nO3_{n-2} NWBs in the area shielded from direct exposure to He^+. The grown NWs show enhanced mechanical stability via partial burrowing into 100 nm WO_X (Mo-Ni) film. We observe the change in the effective refractive index and extinction coefficient indices and a blue shift in the LSPR peak with simultaneous amplification as confirmed by the micro-ellipsometry and spectrophotometric analysis.

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Variation of the Quadrupole Hyperfine Structure and Nuclear Radius due to an Interaction with Scalar and Axion Dark Matter

Victor Flambaum, Andrew Mansour
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Abstract

Atomic spectroscopy is used to search for the space-time variation of fundamental constants which may be due to an interaction with scalar and pseudoscalar (axion) dark matter. In this Letter, we study the effects that are produced by the variation of the nuclear radius and electric quadrupole moment. The sensitivity of the electric quadrupole hyperfine structure to both the variation of the quark mass and the effects of dark matter exceeds that of the magnetic hyperfine structure by 1–2 orders of magnitude. Therefore, the measurement of the variation of the ratio of the electric quadrupole and magnetic dipole hyperfine constants is proposed. The sensitivity of the optical clock transitions in the Yb+ ion to the variation of the nuclear radius allows us to extract, from experimental data, limits on the variation of the hadron and quark masses, the QCD parameter θ and the interaction with axion dark matter.

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Ion track formation in InSb after swift heavy ion irradiation

Taleb Alwadi[1], Christian Notthoff[2], Shankar Dutt[1], Jessica Wierbik[1], Nahid Afrin[1], Alexander Kiy[1], Patrick Kluth[1]
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Abstract

Indium Antimonide (InSb) is a narrow bandgap semiconductor with high mobility, which makes it a good candidate for high-speed electronic devices, infrared detectors, and memory devices. One of the interesting features of InSb is that it can be rendered porous upon heavy ion irradiation in the low energy regime [1], and medium energy [2]. However, swift heavy ion-induced porosification of InSb, and only two articles mention ion tracks in InSb, one by Szenes et al. [3] and another reported by Kamarou et al. [4] We are investigating ion track formation and porosification in InSb after irradiation with 185 MeV 197Au ions at various fluences. In addition, we present a comparison between the processes in InSb and GaSb which irradiated under the same identical irradiation conditions in our previous work. [5] Rutherford backscattering spectrometry in channeling geometry reveals an ion track radius of about 16 nm for irradiation normal to the surface and 21 nm for off-normal irradiation at 30° and 60°. Cross-sectional scanning electron microscopy shows significant porosity that increases when irradiation was performed off-normal to the surface. Off-normal irradiation shows a preferential orientation of the pores at about 45° relative to the surface normal, independent of the irradiation angle. Moreover, InSb samples demonstrate notably higher swelling compared to GaSb bulk samples [6].

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Quantum imaging techniques for astronomy: how to achieve super-resolution

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Abstract

The development of high-resolution, large-baseline optical interferometers would revolutionize astronomical imaging. However, classical techniques are hindered by physical limitations including loss, noise, and the fact that the received light is generally quantum in nature. We show how to overcome these issues using quantum communication techniques. I will present a general framework for using quantum error correction codes for protecting and imaging starlight received at distant telescope sites. We show that even a small quantum error correction code can offer significant protection against noise. For large codes, we find noise thresholds below which the information can be preserved. Our scheme represents an application for near-term quantum devices that can increase imaging resolution beyond what is feasible using classical techniques.

Then, I will discuss how to achieve super-resolution, with applications to exoplanet atmospheric spectrosocpy. The resolution limit of standard imaging techniques is expressed by the Rayleigh criterion, which states that two point-like sources are difficult to resolve if their transverse separation is smaller than the Rayleigh length. While the criterion is useful in the case of direct detection imaging, other measurement techniques may not be subject to this limitation. Estimating the angular separation between two sources is a challenging task for direct imaging, especially when their angular separation is smaller than or comparable to the Rayleigh limit. In addition, if one is tasked with first discriminating whether there are one or two sources, then detecting the faint emission of a secondary source in the proximity of a much brighter one is in itself a severe challenge for direct imaging.

Using quantum state discrimination and quantum imaging techniques, we show that one can significantly reduce the probability of error for detecting the presence of a weak secondary source, especially when the two sources have small angular separations.

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Ultra-Fast High-Contrast Optical Modulation in Silicon Metasurfaces

Khosro Zangeneh Kamali[1], Anton Trifonov[2], Lyuben Sashov Petrov[2], Kaloyan Georgiev[2], Lei Xu[3], Giulia Crotti[4], Unai Arregui Leon[4], Mohsen Rahmani[3], Giuseppe Della Valle[4], Ivan Buchvarov[2], Dragomir Neshev[1]
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Abstract

Ultra-fast modulation of dielectric metasurfaces has shown a great promise for novel optical switching [1] and wavelength conversion [2]. A number of mechanisms have been recently explored; however, the overall transmission modulation in such all-optical processes has remained low, typically a few percent. Here, we demonstrate a high-contrast transmission modulation metasurface with an ultra-fast response. The SEM of the metasurface and the schematics of the experimental optical setup are shown in Figures a and b respectively. In our metasurface design, the interference of the non-radiative asymmetric bound-state in the continuum (BIC) channel and a radiative electric dipole form a kink-type transmission response. Based on this engineered response, we demonstrate absolute transmission modulation of over 25% with a few tens of picoseconds time-response, driven by carrier injection in the crystalline silicon metasurface. Also, we found the slower thermal relaxation of the lattice, having a timescale of about 1 ns (Fig. c). We further confirm our finding using FEM simulation and temporal coupled mode theory (TCMT). The numerical results are in good agreement with our experiments [3].

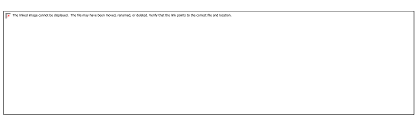

Figure 1: (a) Scanning electron microscope image of the fabricated Si metasurface. (b) Schematic of the ultra-fast time-modulation based on a pump-probe q-boosting time variant resonator. (c) Transient
dynamics for X-polarized probe at wavelengths of 1090 nm (red) and 1108 nm (blue).

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253

Dark matter detection via atomic interactions

Ashlee Caddell, Benjamin Roberts
The University of Queensland, Brisbane, Australia

Abstract

The mystery of dark matter (DM) is a long-standing issue in physics, with numerous dedicated experiments returning no confirmed detections. As many direct detection experiments rely on catching a signal of nuclear recoil, these types of experiments are not applicable to many DM models. Instead, we can utilise the precision that atomic physics allows to search for potential interactions between atomic systems and DM, with possibilities spanning a large mass range. If we have a DM particle with masses just above electrons, then we can search for signals of atomic ionisation. If we move to masses just below electrons, then we look to absorption of DM on atomic electrons. Moving much further down to where DM begins to behave like a classical field, then we can measure the effects with atomic systems, such as those in atomic clocks and variations in fundamental constants. Additionally, interactions such as these many be possible to detect with current and upcoming detection experiments. In this work, I will discuss the prospect for DM detection with atomic systems, the tools needed to accurately assess the possibility, and potential implications for experimental searches [1].

References

[1] A. R. Caddell, V. V. Flambaum, B. M. Roberts, "Accurate electron-recoil ionization factors for dark matter direct detection in xenon, krypton, and argon", arXiv:2305.05125 [hep-ph]

254

Charged pion decay rates with QED corrections

Rose Smail
The University of Adelaide, Adelaide, Australia

Abstract

The dominant decay channel of both charged pion and kaon mesons are to the final state of a muon and neutrino. Analysing this decay using lattice QCD methods leads to improved values for the meson decay constants and the parameters V_{ud} and V_{us} in the CKM matrix. High accuracy predictions will need to have electromagnetic effects included. Rather than correcting for QED effects perturbatively and by hand, we have developed an elegant way to compute electromagnetic corrections to hadronic processes in lattice QCD, requiring background field configurations with dynamical photons. In this presentation, we report results from the QCDSF/UKQCD/CSSM collaboration where we have applied this method to the case of the pion decay constant, f_π.

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Metasurfaces Based Polarimetry with Redundancy for Satellite Imaging

Sarah Dean, Neuton Li, Josephine Munro, Robert Sharp, Dragomir Neshev, Andrey Sukhorukov
The Australian National Univerity, Canberra, Australia

Abstract

Polarisation imaging has a range of remote sensing applications, such as organic aerosol detection or filtering sun glint from ocean imaging. These applications are often unrealised, as conventional polarimetry typically uses large, heavy optics unsuitable for affordable microsatellite systems. Metasurface optics can be used to create compact and lightweight full-Stokes polarisation imaging systems, as demonstrated for a static camera system in a bright environment. However, satellite-based systems require additional non-trivial considerations for redundancy, low-light conditions, and satellite movement. Here, we present a novel concept of polarisation satellite remote imaging based on topology-optimised metasurfaces.

A larger image can be formed over time by continuously imaging a narrow strip perpendicular to the satellite movement, where a metasurface diffracting the strip in the transverse plane can perform simultaneous polarisation measurements (Fig. 1a). We obtained a tailored metasurface design using topology optimisation (Fig. 1c) to project five measurements that form an over-determined Stokes system with effective redundancy. Note that any four out of five orders enable the reconstruction of the full polarisation state (Fig. 1b). The metasurface operates over a bandwidth of 840-850 nm, suitable for detecting water glint and collecting sufficient light for imaging. The imaging resolution scales with the size of the fabricated metasurface; for example, a 1 mm^2 metasurface can resolve an image sampling rate of over 20,000 camera pixels.

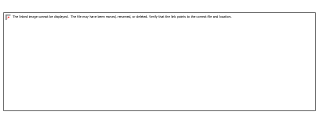

Figure 1: (a) Illustration of polarisation imaging principle with metasurfaces. (b) Normalised Stokes vectors S_m are different diffraction orders, providing robust polarimetry as any four of the five orders enable full reconstruction. (c) Topology-optimised metasurface with a 1 µm thick nanopatterned silicon on a 460 µm thick sapphire substrate. A single period (indicated in red) is 450×6750 nm.

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Enhanced coherent control of carrier spin states in a quantum dot using the AC Stark effect

Josiah Hsi, Tim Wohlers-Reichel, Undurti Satya Sainadh, Glenn Solomon
The University of Adelaide, Adelaide, Australia

Abstract

Coherent control of carrier spin-states in semiconductor quantum dots is of great interest in quantum state engineering and quantum information applications. In many of these systems state degeneracy is required; for example in the generation of entangled photon states. Coherent spin control, such as rotations, can be achieved with an in-plane magnetic field through the spin Larmor precession. However, the precession rate, proportional to the magnetic field strength, is limited by the ground state degeneracy requirement that is lifted through the Zeeman effect. Here we can enhance the rotation rate by increasing the magnetic field, while maintaining ground-state degeneracy through the AC Stark effect: The AC Stark effect compensates for the Zeeman shift. Furthermore, the AC Stark effect adds additional control of the Bloch sphere precession axis.

The AC Stark effect is applied through a red-detuned laser, which shifts the energy of one optical transition
while keeping the other unperturbed. Using the AC Stark effect, our simulations suggest we can increase
the Larmor precession frequency by an order of magnitude while maintaining degenerate energy levels, and increase control over the spin states in a quantum dot

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Multi-Spatial Mode Readout Of Optical Cavities For Reduced Brownian Coating Thermal Noise

Jue Zhang, Namisha Chabbra, Andrew Wade, Kirk McKenzie
Australian National University, Acton, Australia

Abstract

Active laser stabilization ties a laser's frequency to an ultra-stable reference, such as an optical resonator, by comparing the laser's frequency to the reference and using feedback control to regulate the laser. Coating Brownian thermal noise, arising from the random Brownian motions of the mirror coating materials, is the primary limitation of precision measurements at frequencies below 10 Hz. We propose a multi-cavity transverse mode readout scheme that achieves an equivalent thermal noise level to that of a mesa flat-top beam. The mesa flat-top beam is well-known for its efficiency in reducing thermal noise compared to a conventional Gaussian beam by effectively increasing the sampling area, although it presents technical challenges in its generation. With optimal weighting of different spatial modes, this novel approach allows us to improve the coating thermal noise by a factor of 2.46 with 25 modes and 1.61 with 3 modes in short cavities, equivalent to cooling the system from 300 K to 120 K. In this talk, we will present the progress of laser stabilization for the reference cavity and the design of the test cavity.

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Trigger and data acquisition systems for SABRE South

Lachlan McKie
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Abstract

The SABRE (Sodium-iodide with Active Background REjection) South experiment, located at the Stawell Underground Physics Laboratory (SUPL) in Australia, aims to measure an annual modulation in dark-matter interactions using ultra-high-purity NaI(Tl) crystals. In partnership with the SABRE North effort at the Gran Sasso National Laboratory (LNGS), SABRE South is designed to disentangle any seasonal or site-related effects from the dark matter-like modulated signal observed by DAMA/LIBRA in the Northern Hemisphere.

SABRE South is instrumented with 7 ultra-high-purity NaI(Tl) crystals surrounded by a liquid scintillator veto, and covered by 8 plastic scintillator muon detectors. Each NaI(Tl) crystal and muon detector is coupled to 2 photomultiplier tubes (PMTs) and a further 18 PMTs are used to detect interactions in the liquid scintillator giving a combined total of 48 channels. The data acquisition system for SABRE South utilises a number of CAEN digitisers to acquire waveform data for each of these PMTs. The trigger system is built upon a CAEN logic unit using custom FPGA logic which is extensively simulated and also tested in hardware to ensure long term reliability.

This talk will cover the design and status of the SABRE South trigger and data acquisition systems.

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Dispersion Spectroscopy using a Code Division Multiplexed Optical Frequency Comb

Anika Chan, Justin Wong, Malcolm Gray, Chathura Bandutunga
Australian National University, Canberra, Australia

Abstract

Molecular dispersion spectroscopy for the optical detection and characterization of anomalous dispersion is a developing field for the interferometric measurement of trace gas concentrations [1]. In performing a phase measurement, it removes the requisite baselining or normalization techniques in absorption spectroscopy methods which measure amplitude [2]. Furthermore, dispersion sensitive methods excel in measuring at high molecular concentrations, where they are not limited by the non-linear response of the Beer-Lambert Law [3]. This makes dispersion methods favourable in gas sensors requiring high signal dynamic range in conjunction with readout linearity. Here we present a technique for dispersion spectroscopy that utilizes code-division multiplexing to interrogate an optical frequency comb.

Digitally Enhanced Heterodyne Interferometry (DeHeI) is the core technique used in this architecture. This allows us to phase modulate a signal with a DeHeI binary pseudo-random noise (PRN) sequence, scrambling the optical phase. Following detection, specific signals can be extracted by decoding at time delays corresponding with the optical time-of-flight. This allows for multiple signals to be independently distinguished and measured based on their transit time. We apply this technique to an optical frequency comb generated via a frequency shifting re-entrant delay-line loop, into which the DeHeI is seeded.

The digitally modulated frequency comb is used to interrogate an $H_{13}C_{14}N$ vapor cell, where successive comb teeth experience differential phase shifts corresponding to the anomalous dispersion profile around the $H_{13}C_{14}N$ molecular transition. We digitally synthesise the full anomalous dispersion profile combining multiple teeth measurements together in signal processing. We present initial measurement results and performance characterisation of the system towards a multi-GHz spanning, digitally addressable frequency comb.

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262

Can ChatGPT pass a 2nd year quantum mechanics exam?

Adam Micolich
UNSW Physics, Sydney, Australia

Abstract

ChatGPT's version of the abstract: Concerns have arisen regarding students potentially leveraging tools like ChatGPT during online examinations. Contrary to the notion that this allows underqualified students to excel, my observation suggests otherwise. While ChatGPT can sometimes provide erroneous or misleading information, students who relied on it often performed worse in my course. It was evident that several of them used it, given the nature of their mistakes. This highlights the importance of critical thinking skills in discerning the accuracy of the information. Some students who effectively utilized ChatGPT demonstrated a deep understanding of quantum mechanics, suggesting that their achieved grades were merited. The crux lies in a student's ability to critically evaluate information and innovate with technology. Disregarding the transformative potential of AI in higher education will be detrimental. As the inevitable wave of change approaches, academic leaders must adapt rather than remain complacent.

Adam's version of the abstract: ChatGPT got a 75 DN (distinction) for the course and came 16th out of the 86 students in the course, despite the fact that it never turned up to a single class, has no idea what I even taught, and was never intended to be more than a large language model (i.e., has no explicit algebraic or advanced scientific knowledge capacities). If you're interested in the nuts and bolts of this -- what it did well and what it didn't -- and how to better design exams in light of it, come along.

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Phase-locked and Drifting Multicolour Solitons

Justin Widjaja[1], Antoine F. J. Runge[1], C. Martijn de Sterke[1,2]
[1]Institute of Photonics and Optical Science (IPOS), School of Physics, The University of Sydney, Sydney, Australia. [2]The University of Sydney Nano Institute (Sydney Nano), The University of Sydney, Sydney, Australia

Abstract

Optical solitons are pulses which balance dispersion and nonlinearity to remain unchanged as they propagate. We recently experimentally discovered a new class of solitons comprised of multiple copropagating spectral components which beat to produce oscillating temporal profiles [1]. These spectral features have the same phase (are phase-locked), so they appear as stationary temporal fringes beneath an envelope. Here, we discuss a novel regime where the spectral components have different phase velocities. This causes the relative phase to evolve as the pulse propagates such that the fringes now drift under a fixed envelope. Whilst this phenomenon was observed previously [2], its physical interpretation has not been explored until now.

We study this effect by conducting laser cavity simulations for both the phase-locked and drifting pulses, and measuring the output after each roundtrip. In the phase-locked case, all pulses are identical since the fringes do not move, whereas in the drifting regime, the bright and dark fringes shift after each roundtrip, producing a braid-like spatiotemporal pattern. These dynamics are best summarised by comparing how the pulse energy evolves as it propagates. Once again, the phase-locked solitons are identical at each roundtrip, so their energy remains constant. However, the energy of the drifting pulses oscillates, with the largest fluctuations occurring when a bright or dark fringe coincides with the envelope peak. Finally, our numerical and theoretical analysis reveals that multicolour solitons are the spectral analogue of birefringent vector solitons and are governed by strikingly similar physics [3]. We are currently pursuing this novel regime experimentally.

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Experiences in 'flipping' courses at higher years -- classical & quantum mechanics

Adam Micolich, Christine Lindstrom
UNSW Physics, Sydney, Australia

Abstract

I will present some lessons drawn from several years work on flipping 2nd year classical and quantum mechanics courses at UNSW. This will include what we've learned does work and doesn't work, some of the benefits you can gain by doing this approach beyond 1st year, and some of the important aspects you need to control for it to work optimally.

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Imaging the transverse distribution of forces in the proton with lattice QCD

Joshua Crawford, Ross Young, James Zanotti
The University of Adelaide, Adelaide, Australia

Abstract

Transverse force tomography is a new technique that allows us to visualise the distribution of forces in hadrons. We use lattice QCD to determine these distributions from first principles and we present the spatial distributions of these "colour-Lorentz" forces in the proton.

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Realising the potential of quantum technology through control

Richard Taylor[1], Pranav Mundada[2], Aaron Barbosa[2], Smarak Maity[2], Yulun Wang[2], Thomas Merkh[2], Tom Stace[1], Felicity Nielson[2], Andre Carvalho[3], Michael Hush[1], Michael Biercuk[1], Yuval Baum[2]
[1]Q-CTRL, Sydney, Australia. [2]Q-CTRL, Los Angeles, USA. [3]Q-CTRL, Berlin, Germany

Abstract

Q-CTRL is Australia's first VC-backed quantum technology company. It was founded on the hypothesis that quantum control, delivered through infrastructure software, can accelerate the commercialisation of quantum technologies. In this talk, two research results will be presented that prove this hypothesis and support the foundation of Q-CTRL's business. First, a demonstration that quantum control can improve the performance of a commercial gate-based quantum computer by >1000x with an automated deterministic error suppression workflow (here performance is quantified as the probability of producing the correct answer to the B. V. Algorithm with 16 qubits). Further results will be presented on how the workflow improves the performance of a suite of algorithms, including QAOA (163x improvement to structural similarity of optimisation landscape). Second, a demonstration of improved robustness and performance in a cold-atom analog quantum processor through the application of quantum control. Specifically, error in the preparation of a target quantum phase was reduced by over 5x using Q-CTRL's technology stack. Finally, an overview will be given of where Q-CTRL sees the opportunities for quantum control in the future.

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Optical Spectroscopy of Main and Satellite Lines in Erbium Lithium Fluoride

Lara Gillan, Toby Hardcastle, Matthew Berrington, Matthew Sellars, Rose Ahlefeldt
ANU, Canberra, Australia

Abstract

Quantum transducers, capable of conversion between optical and microwave frequencies, are a critical component for the realisation of quantum networks. Stoichiometric $ErLiF_4$ has been identified as a promising candidate for this application [1]. $ErLiF_4$ has optical transitions associated with the excitation of erbium ions, around 1550 nm. The strong erbium dipole-dipole interaction generates spontaneous magnetic ordering for temperatures below 380 mK [2]. This magnetic ordering enables the excitation of magnon modes with resonance at microwave frequencies.

We will present our optical studies of $ErLiF_4$. These have revealed rich optical structure, including Er^{3+} transitions predicted by a combined mean-field and crystal field theory model, magnon sidebands, collective excitations, and satellite features. Weakly absorbing satellite structure arises due to substitution defects in the crystal. Here, a defect occupies the site of an Er^{3+} ion, typically a different rare earth ion. The difference in ionic radii between Er^{3+} and this defect introduces strain in the crystal lattice, and the perturbed crystal environment causes a shift in the resonant frequency of neighbouring Er^{3+} ions. Our measurements of the coherent properties of these satellite features in $ErLiF_4$ demonstrated coherence times greater than those previously reported in the equivalent dilute system, Er:$YLiF_4$ [3]. The improved coherent properties observed in $ErLiF_4$ highlight the potential for use of this and other such crystals that are stoichiometric in erbium in quantum computing protocols.

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Digitally-enhanced Suspension Platform Interferometry Sensor Test at the Gingin High Optical Power Facility

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Abstract

In large optical systems, such as the Laser Interferometric Gravitational-wave Observatory (LIGO) [1], active seismic isolation is used to reduce the optical platform motion. However, inter-platform motion presents a significant noise challenge to the low frequency sensitivity of these instruments. Suspension platform interferometry (SPI) [2] provides a potential solution via the measurement of the relative displacement and tilt between platforms, that then allows for motion stabilization using the platform actuators. Such work is critical towards realizing the sensitivity goals of the future global gravitational wave (GW) detector network.

We present a project that integrates a multi-channel Mach-Zehnder displacement sensor prototype suitable for SPI with a suspended optical cavity, a collaboration between ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav) nodes at ANU and UWA. The SPI sensor [3] uses Digital Interferometry [4] to multiplex and isolate the individual sensing channels by their optical time-of-flight. This will be deployed at the Gingin High Optical Power Facility [5], to directly measure relative motion between the seismic isolation platforms that house a test optical cavity for longer-wavelength technology development for next-generation GW detectors [6]. This will reduce the fluctuations in the cavity control error signal, thus improving its performance. We present the latest commissioning developments in this collaborative experiment, including the latest results of the SPI sensor, seismic isolation platforms and optical test cavity work.

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Characterizing hazardous biological and chemical materials with stand-off Laser-induced Fluorescence

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Abstract

Exposure to unknown hazardous materials remains a challenge for defence, police and first responders who face an increasing diversity of hazardous materials that are either deliberately manufactured, or are byproducts of an action, accident, or natural event. Given the difficulty of rapidly and unambiguously detecting and identifying potential chemical and biological hazards, there is an urgent need to develop a robust stand-off detection method to protect personnel. One promising spectroscopic technique is laser-induced fluorescence (LIF), which can distinguish between biological and non-biological materials through spectral information to detect crucial biomolecules such as tryptophan and NADH (reduced nicotinamide adenine dinucleotide) and trace mineral signatures [1,2]. Furthermore, temporal fluorescence decay provides further information as the decay lifetime of organic molecules tends to be significantly shorter. [4] This work combines spectral and temporal LIF and investigates the role that excitation wavelength plays in determining the spectral regions of fluorescence emission. Innovative use of colourmaps shows that temporal and spectral data can be displayed on a single easy to interpret graphic to rapidly characterize a potential threat.

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2. **A. Martínez-Hernández et al, Analysis of heritage stones and model wall paintings by pulsed laser excitation of Raman, laser-induced fluorescence and laser-induced breakdown spectroscopy signals with a hybrid system, J Cult Herit, 32 (2018) 1-8.**
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Orb-web Spider Viscid Webs in Natural Light – Optics and Colour

Deb Kane
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Abstract

Sir Isaac Newton is reported to have noted the dewbows that can be seen on viscid orb webs with condensed dewdrops. These can be sighted on below dewpoint temperature mornings in early spring and autumn in south eastern Australia. The careful observer in nature can also sight a range of other aesthetically pleasing colour displays on such webs throughout the day. But, many more people have walked into a spider web they did not see, than have observed these non-dewbow light displays on webs. It was such displays that initiated our research on the optical properties of the various micro-optic silk and viscid droplet elements of these orb webs. The surprising research results of the high optical quality and characteristics of the micro-optical elements of the webs is bookended, to date, by [1-4]. Self-assembled spider silk proteins are a biomimetic opportunity for optics of the future. In parallel, observations of the colour displays seen in nature have been continued. In [5], we reported what we could contribute to the understanding of the geometrical and physical optics origins of the colour displays at that time. Others have made significant contributions to explaining particular observations they have made [6-10]. But, it is fair to say we do not have a full understanding of all the optical phenomena contributing to what can be observed. This presentation will be an update on recent observations and progress on explaining them. Expect to see some dazzling images of orb webs in natural light.

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Software ruggedising cold-atom sensors through error-robust quantum control

Stuart Szigeti, Jack Saywell, Max Carey, Phillip Light, Alistair Milne, Karandeep Gill, Matthew Goh, Viktor Perunicic, Nathanial Wilson, Calum Macrae, Alexander Rischka, Patrick Everitt, Nicholas Robins, Russell Anderson, Michael Hush, Michael Biercuk
Q-CTRL, Sydney, Australia

Abstract

Quantum sensors based on cold-atom interferometry have the potential to revolutionize navigation, civil engineering, and Earth observation. However, operating these devices in real-world environments is challenging due to external interference, platform noise, and constraints on size, weight, and power. Consequently, the advantages of choosing a quantum sensor over conventional alternatives are typically lost when transitioning from the laboratory to the field. Here we will report on Q-CTRL's efforts to reduce this performance gap between laboratory operation and real-world field deployment through error-robust quantum control. In particular, we will present the first experimental demonstration that tailored light pulses - designed and implemented in software using robust control techniques - mitigate significant sources of performance degradation in an atom-interferometric accelerometer. To mimic the effect of unpredictable lateral platform motion, we apply laser-intensity noise that varies up to 20% from pulse-to-pulse, and demonstrate that our robust control solution maintains performant sensing, while the utility of conventional pulses collapses. By measuring local gravity, we show that these robust pulse sequences preserve the interferometer scale factor and improve its precision by 10× in the presence of the applied laser intensity noise. We further validate these enhancements by measuring applied accelerations over a 200 μg range up to 21× more precisely for the largest applied noise. This shows for the first time that software-ruggedised quantum sensing can deliver useful performance in dynamic environments where conventional operation is severely degraded, providing a pathway to augment the performance of current and next-generation atom inertial sensors in real-world settings.

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Coupled Non-degenerate Photonic Resonators for Enhanced Optomechanical Sensing

Benjamin Carey
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Abstract

Optomechanics provides an appealing approach for detecting various stimuli at or even below the classical limits to sensitivity. On-chip optomechanical sensors with integrated photonic components are nearing readiness for deployment across a wide range of applications from under-sea to outer space, with various ambitions including mass, inertial, magnetic, and acoustic sensing. Many recent developments overcoming performance-limiting effects (e.g., shot noise and the standard quantum limit). There remains however, significant obstacles.

Laser phase/frequency noise is an ongoing and significant limiting factor for the performance of many optomechanical devices. Whilst this can in-part overcome by utilising narrow-linewidth feedback-stabilised illumination systems, which adds significantly to the size, weight, power, and cost of the sensor. Further, other classical sources of noise such as thermo-refractive noise remains a challenge, limiting the performance in various applications.

Here we present an on-chip, passive solution to supresses these sources of noise by utilising the coupled mode of two similar yet non-degenerate photonic cavity resonators. Such a configuration provides rejection of common-mode fluctuations thereby overcoming coherent noise sources within the device.

Our experimental results show a significant rejection of laser noise with suppressing down to the shot-noise level even for ‘cheap’ (~US $300) lasers and even demonstrate thermal-noise suppression. Further, we achieved a rejection of 50 dB in phase modulation, which holds promise for enhancing the sensitivity of photonic sensors and systems with a wide range of potential applications.

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Giant resonant skew scattering of plasma waves

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Abstract

The electron skew scattering by impurities is one of the major mechanisms causing the anomalous Hall effects in semiconductor nanostructures. In this Letter, we argue that in plasmonic setups the skew scattering of plasma waves can be engineered to be giant and observed directly via near-field probes. In particular, we consider the scattering of plasma waves in gated two-dimensionsional electron gas at the non-uniform magnetic field created by the adjacent circular ferromagnetic gate. The calculated scattering amplitude not only has a large asymmetry, or skewness, but has a resonant behavior. We identify that the resonance is due to the presence of a single chiral edge mode circulating the ferromagnetic gate. We also identify mathematical connections with electron scattering in topological insulators at magnetic impurities. The micrometer scale of the proposed setup allows probes into individual skew scattering events that have previously been inaccessible in electronic systems.

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Optical Tomographic Reconstruction of Objects within Diffuse Media.

Catherine Merx, Michael Suzzi, Matthew Randall, Galiya Sharafutdinova, Renee Goreham, John Holdsworth
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Abstract

Optical detection of objects possessing different optical properties embedded within a volume of highly scattering media has wide application from cancer detection to foreign object detection in pills or foodstuffs. A scanner [1] has been further developed and reconfigured for greater control and methodology and tested on translucent resin objects in water, red and green gelatine, and milk. An 8 mm dia. expanded He:Ne laser is focussed to a point before expanding to be detected by a CCD array. The sample is translated laterally stepwise into the beam path and rotated 360° at each step with a CCD exposure recorded each 5°. The CCD array signal is integrated to form a data element associated with a lateral position and angle in a sinogram. The accumulated lateral translation spans the sample diameter providing data for a cross-sectional tomographical slice to be reconstructed via the inverse Radon transform which is then filtered [2, 3]. Longitudinal sample translation provides volumetric coverage.

One of the more notable results has been the tomographic reconstruction of a slice of the object when completely obscured by scatter within a milk solution. This result from an opaque, highly-scattering liquid shows significant improvement from our previous approach and reinforces the idea of differential scatter being an approach to detection of hidden objects in diffuse media. Current work is expanding the scope of the apparatus to scan larger samples, refining the sample materials, and improving technique and image processing enhancements and filters for the reconstruction of a 3D object.

Please see the extended abstract for images of our key results, and our references for this abstract.

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Graybox quantum control

Alberto Peruzzo[1], Akram Youssry[2]
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Abstract

Understanding and controlling engineered quantum systems is key to developing practical quantum technology. However, given the current technological limitations, such as fabrication imperfections and environmental noise, this is not always possible. To address these issues, a great deal of theoretical and numerical methods for quantum system identification and control have been developed. These methods range from traditional curve fittings, which are limited by the accuracy of the model that describes the system, to machine learning methods, which provide efficient control solutions but no control beyond the output of the model, nor insights into the underlying physical process. Here we experimentally demonstrate a "graybox" approach to construct a physical model of a quantum system and use it to design optimal control. We report superior performance over model fitting, while generating unitaries and Hamiltonians, which are quantities not available from the structure of standard supervised machine learning models. Our approach combines physics principles with high-accuracy machine learning and is effective with any problem where the required controlled quantities cannot be directly measured in experiments. This method naturally extends to time-dependent and open quantum systems, with applications in quantum noise spectroscopy and cancellation.

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Nuclear pairing and superfluidity from a quark model

Katherine Curtis
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Abstract

As quantum chromodynamics cannot be solved exactly for many-nucleon systems, nuclear behaviour must be predicted with simplified models. These models require both an effective description of the nuclear interaction and an approximation to the many-body problem. Describing nucleon-nucleon interactions in terms of their constituent quarks, as exemplified by the quark-meson coupling (QMC) model, offers promise in addressing unresolved questions regarding quarks' influences on nuclear behaviour. Meanwhile, the ubiquitous mean-field approximation to the many-body problem must be augmented by a pairing interaction to reproduce pairwise correlations between nucleons, responsible for nuances of nuclear structure and dynamics such as superfluidity.

Recently, a pairing interaction was derived from the QMC model, inviting evaluation of its ability to reproduce nuclear phenomena. I examined its predictive accuracy for signatures of neutron-neutron pairing in 100–138Sn and 178–220Pb structures and the superfluid dynamics of rotating 158Er, as well as the implications for various model parametrisations. This work includes the first calculations using QMC-derived pairing in a 3D mean-field nuclear code without enforcing time-reversal symmetry, granting access to more sensitive measures of pairing than previously studied.

Examining pairing potentials derived from four recent versions of the QMC model, I highlight the risks of unphysical predictions of repulsive pairing at densities below nuclear saturation and underestimations of pairing correlations as measured by odd-even mass staggering. I thus emphasise the need for more rigorous validation of the recently proposed QMCπ-III-T pairing interaction, particularly in calculations unrestricted by time-reversal symmetry.

Nevertheless, I find that QMC-derived pairing qualitatively reproduces signatures of superfluidity, including backbending and phase transitions, in rotating 158Er. These signatures were not reproduced by alternative pairing interactions, suggesting the quark-based derivation of pairing considerably improves descriptions of superfluidity. This finding invites further investigation into how quark degrees of freedom manifest in nuclear pairing and superfluidity.

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Experimental demonstration of the Arm and Cavity laser frequency stabilisation for LISA

Jobin Valliyakalayil, Daniel Shaddock, Kirk McKenzie
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Abstract

The Laser Interferometer Space Antenna (LISA) mission is a future space-based gravitational wave (GW) detector that is proposed to detect GWs with a sensitivity of 10 pm/√Hz using a very stable laser. A novel laser stabilisation technique for LISA was proposed and analysed in which the laser is locked to two references simultaneously - the on-board optical cavity, and the inter-spacecraft separation or arms of the interferometer. In this paper, we present the results of an experimental setup to provide a proof-of-concept for the hybrid locking scheme by locking to a similar optical cavity and a fibre delay line of 10 km.

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Optical detection of VOCs using Quasi BIC metasurface with phase read-outs

Shridhar Manjunath[1], Justin Wong[2], Alishba John[3], Marius Graml[1], Buddini Karawdeniya[1], Krishnana Murugappan[4], Antonio Tricoli[5], Chathura Bandutunga[2], Dragomir Neshev[1]
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Abstract

Metasurfaces are arrays of structured subwavelength nanoparticles. They provide a great platform for point-of-care devices as they are non-invasive, rapid, and robust. Optical-sensing using metasurface detects changes in optical spectrum/intensity for sensing applications. Metasurfaces' sensitivity depends on the accuracy of spectrum/intensity read-outs. To increase the sensitivity, one must employ high-end cameras or spectrometers for better and more accurate read-outs. Hence, optical-sensing using metasurfaces has reached a bottleneck. At resonance, electromagnetic waves experience phase change as they pass through the metasurface. The phase of the transmitted wave changes relative to the change in refractive index (RI), similar to the change of resonant frequency in relation to RI. Here, we propose High Q-factor (Quality Factor) dielectric metasurfaces with phase read-out to improve the sensitivity by several orders of magnitude. Recent work shows that high Q-factors can be achieved by employing high-index dielectric metasurfaces based on the concept of Bound States in Continuum (BIC) [2]. As shown Figure 1a, one of the ovals is squeezed along the y-axis to introduce asymmetry to open a small radiation channel, thereby forming a quasi-BIC. By controlling the dimensions of these ovals, we obtained a very high Q-factor (~180) and high sensitivity (~250 nm/RIU). Hence, metasurfaces are highly desirable for gas/biosensing due to the aforementioned characteristics.

Metasurfaces coated with metal-organic frameworks (MOFs) are used to sense Volatile Organic Compounds (VOCs). Previously, we have demonstrated limit-of-detection (LOD) of 400 ppm of acetone vapour using MOFs-Metasurface combination. As aforementioned, LOD is highly dependent on a detection system. As shown in fig 1b, we predict a phase shift of 58 radians/RIU, corresponding to an expected LOD below 1 ppm with modest phase detection methods. This technique promises to decrease LOD by several orders of magnitude, thereby opening opportunities for highly sensitive and portable biosensors.

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Analysis of the off-focal source in transmission geometry x-ray systems

Klara Steklova, Levi Beeching, Adrian Sheppard, Andrew Kingston
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Abstract

For x-ray tubes in lab based computed micro-tomography systems, off-focal x rays are those emitted from the source but not produced at the primary focal spot of the electron beam. They can be attributed to both electron and photon scatter within the x-ray tube. Off-focal x rays can represent a significant fraction of the total x-ray flux and lead to artefacts in the radiographs, and reconstructed tomographic volumes, degrading contrast and resolution and therefore, they are an undesirable feature in industrial and medical x-ray CT scanners. In this work, a general model of an x-ray tube with a transmission target has been developed in TOPAS, a Monte Carlo (MC) simulation extension to GEANT4. MC simulations enable: (1) the analysis of the origin of various types of off-focal x rays; (2) quantification of the prevalence of each type for a specific tube geometry and (3) replication and understanding of experimental results affected by off-focal x rays. Our MC analysis herein shows that the amount of off-focal x rays can represent up to 25% of total x-ray flux. The most prevalent off-focal x rays were found to be the x rays created by the electrons back-scattered from the target into the aperture and generating x rays. Next to the model analysis, we also present tomography data from the ANU CTLab on success with mitigating the off-focal source by hardware – external aperture.

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Searching for Displaced Leptons at the ATLAS detector

<u>**Hitarthi Pandya**</u>
University of Adelaide, Adelaide, Australia

Abstract

Long lived particles are included in many Beyond the Standard Model (BSM) theories, including R-parity-conserving supersymmetry (SUSY), R-parity-violating SUSY, gauge-mediated SUSY breaking (GMSB) and many more. Long lived particles remain one of the appealing signatures to search for BSM physics with the ATLAS experiment at the Large Hadron Collider (LHC), which is mainly designed for new physics searches that measure decay products of short-lived heavy particles, with the assumption that those decay products will trace back to the collision point, or very close to it. In this scenario, decay products don't trace back to the interaction point, which makes the analysis extremely hard in certain areas. I will present new techniques which have been designed and implemented to help the search for unconventional signatures in the ATLAS data.

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Directional emission in an on-chip acoustic waveguide

Timothy Hirsch, Nicolas Mauranyapin, Erick Romero, Tina Jin, Glen Harris, Christopher Baker, Warwick Bowen
University of Queensland, Brisbane, Australia

Abstract

On-chip acoustic waveguides are a promising platform for realising phononic integrated circuits, which are interesting for uses ranging from quantum state transfer, to compact optomechanical devices, to nanomechanical computing [1,2]. To fully realise their potential they require a method for unidirectional acoustic wave emission. Here we demonstrate unidirectional emission [3], fully integrated into an on-chip membrane waveguide platform that can be used to construct phononic integrated circuits with purely mechanical coupling and access to nonlinearity [4-6].

Applying a technique widely used for RF radio antennas and surface acoustic wave transducers [7], we achieve a reconfigurable 99.9% directional suppression, with even better performance expected after optimisation. By eliminating -3 dB loss and allowing reconfigurable circuit designs, this is an important step towards on-chip and radiation-tolerant phononic integrated circuits for tasks like mechanical computing.

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GammaBayes: a Bayesian pipeline for dark matter detection with the Cherenkov Telescope Array

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Abstract

In this talk we present GammaBayes: a Bayesian pipeline for the detection of dark matter with the Cherenkov Telescope Array (CTA). It takes as input CTA measurements of gamma rays and a user-specified dark-matter model. It outputs the posterior distribution for parameters of the dark-matter model including the velocity-averaged cross section for dark-matter self interactions $\langle\sigma v\rangle$ and the dark-matter mass . It also outputs the Bayesian evidence, which can be used for model selection. We demonstrate GammaBayes using 4 months of simulated CTA data, corresponding to 10^7 gamma-ray events which includes a small contribution from 3.2 TeV singlet scalar dark matter annihilation. The dark matter mass is correctly recovered within a 90% credible interval of 3.0-3.7 TeV. Meanwhile, the velocity averaged cross section is restricted to 2.5-7.5 x 10^{-26} cm^3 s^{-1} (90% credibility). The no-signal hypothesis is ruled out with 5σ credibility. We discuss how GammaBayes can be extended to include more sophisticated signal and background models and the associated computational challenges.

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Graybox quantum control in the strong coupling regime

Arinta Auza[1], Akram Youssry[1], Gerardo Paz Silva[2], Alberto Peruzzo[1]
[1]RMIT University, Melbourne, Australia. [2]Griffith University, Brisbane, Australia

Abstract

The graybox (GB) approach in quantum control represents a novel and promising methodology for managing and optimizing quantum systems. It bridges the gap between two traditional control paradigms: blackbox (BB) and whitebox (WB) control. Previous works have demonstrated that the GB model is exceptionally well-suited for quantum system identification and control, consistently delivering high-fidelity results that surpass the performance of both WB and BB models. This paper presents a benchmark study comparing the GB approach with the standard GRAPE method, focusing on a one-qubit quantum system subjected to classical non-Markovian noise. Our findings reveal that the GB approach consistently outperforms the GRAPE method, achieving significantly higher fidelity levels across a range of noise strengths. These results underscore the robustness and adaptability of the GB approach in the face of real-world noise and environmental factors, making it a compelling choice for practical quantum system control.

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Taming the errors in nonlinear quantum optics

James Bainbridge, **Michael Steel, Mikolaj Schmidt**
Macquarie University, Sydney, Australia

Abstract

Ensembles of atomic systems can be used to control the polarisation, velocity and dispersion of light, or - through nonlinear processes - its frequency or statistics. In particular, atom-based schemes for squeezing light, or interfacing optical and microwave light channels, are recognised as key building blocks for the future quantum architectures [1]. However, to harness such atom-based quantum devices, we need to boost both their efficiency and fidelity, by learning to control the error introduced by higher-order nonlinear effects.

In this presentation we demonstrate how to approach this problem formally by applying a perturbative treatment, the Schrieffer-Wolff formalism, to two canonical quantum optical systems. The first setup enables the transfer of quantum states between the microwave and the optical domain, using an ensemble of erbium atoms as the nonlinear medium [2,3]. We characterise the efficiency of this protocol, and quantify the fidelity of the microwave-to-optics conversion. In particular, we estimate the strengths of the higher-order nonlinear optical processes (Kerr and cross-Kerr effect) - that can be detrimental to the fidelity of the state transfer.

We further show how this approach can be applied to a workhorse of quantum optics - a two-level system coupled to an optical cavity, described by the recently identified, and highly nonlinear, Quantum Rabi Model [4]. As we shown previously, this system can exhibit very strong optical nonlinearities, which signal the divergence from the Jaynes-Cummings Model, and the breakdown of the rotating wave approximation [5]. Our perturbative approach enables a systematic identification and estimation of these effects, providing new insights into the nonclassical signatures of elementary quantum systems.

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Domain Visualization of Periodically Poled Lithium Niobate Thin Films

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Abstract

Lithium niobate on insulator (LNOI) is an emerging photonic integrated circuit (PIC) platform that offers a broad transparency window with excellent electro-optic, acoustic-optic, and nonlinear optical properties. In LNOI waveguides, efficient frequency conversion can be achieved through quasi-phase matching, where the crystal's polarization is periodically inverted, also called periodically poled LN. Uniform domains with a duty cycle close to 50% are crucial for efficient phase matching. Hence, excellent dimensional control of the domains is desired, which is challenging due to the semi-random domain nucleation and growth process. To assess the inverted domains and optimize the domain inversion process, high resolution domain visualization methods are needed.

This contribution investigates the poling quality of 300nm thin-film X-cut LNOI. Domain inversion is achieved by applying a series of high-voltage pulses to comb-like electrodes patterned (Fig. 1a). The inverted domains are compared using two domain visualization methods: (i) a destructive approach through selective chemical HF etching of the LN thin film cross-section where the inverted domains are observed using scanning electron microscopy (SEM) (Fig. 1b), providing insight into in-depth nucleation. (ii) a non-destructive approach using second harmonic confocal imaging, where a fundamental beam in the near-infrared range is tightly focussed into the LN crystal. The incident intensity of the pump signal results in the generation of a second harmonic (SH) signal, which is collected in the backward direction (Fig. 1c). An example image is shown in Fig. 1(d), where dark lines between the electrodes can be interpreted as the signatures of the domain wall. Both approaches complement each other in providing insights into domain quality/shape, which helps to optimize the domain inversion process and achieve uniform domains for efficient quasi-phase matching.

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Understanding the complex magnetic effects in a low-dimensional frustrated magnet through inelastic neutron scattering

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Abstract

Frustrated and quantum magnetic systems have gained a lot of recent interest for their capacity to exhibit exotic quantum magnetic states such as spin-liquid, spin-ice, and spin-glass phases [1,2,3]. The spin characteristics of such magnetic states make them applicable to emerging spintronic technologies. The natural mineral atacamite, Cu2Cl(OH)3, is within this class of magnetic materials, having demonstrated frustrated quantum magnetic properties [4].

Atacamite has a complex magnetic phase diagram [5], which is not yet completely understood. In order to characterise the magnetic Hamiltonian for a magnetic material, inelastic neutron scattering (INS) is typically performed, as neutrons allow for the magnetic spins in a system to be probed directly. This is exactly what has been performed for single-crystal atacamite on the time-of-flight Pelican instrument at the Australian Centre for Neutron Scattering. Data has been captured in the H0L plane and the HK0 plane in two experiments.

INS data will be compared with linear spin wave theory calculations for a proposed zigzag spin-chain model along the H-direction for atacamite. This model also includes single-axis anisotropy which introduces a spin gap, for which there is experimental evidence. The comparison between the experimental INS data and the linear spin wave theory calculations provides a close agreement, and gives insight into the nature of atacamite's magnetic frustration.

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What was the state of an incoherently pumped two-level atom just prior to photo-emission? Answers from quantum state smoothing.

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Abstract

Consider a two-level atom undergoing incoherent excitations and de-excitation (radiative damping), which you are observing. After some time you detect a photon. What is the state of the atom immediately prior to the photo-emission?

Conventional intuition suggest that the answer is ``the excited state''. This answer is exactly that predicted by classical state smoothing theory. Smoothing is an optimal state estimation technique that constructs an estimate using both prior and posterior measurement information from a continuous-in-time measurement. However, it is well known, that the non-commutative nature of quantum mechanics causes classical smoothing fails when applied to the estimation of quantum states and only works when the underlying dynamics of the system is limited to a set of mutually orthogonal pure states.

One might guess, based on the filtered estimate (based on the past record) and the retrofiltered effect (describing the future measurement outcomes) sharing a common basis, that the underlying dynamics of the atom under (imperfect) continuous photon detection is limited to the ground and excited state. This is not the case. Using the quantum state smoothing theory of Guevara and Wiseman, we prove that the answer to the question posed is not so simple. One must take into consideration how the remaining information in the environment affects the dynamics. By modelling the complex interaction with the remaining environment by a secondary continuous measurement, we show that not only can the state of the atom change depending on the environmental measurement chosen, but the solution may be inconsistent with the common basis of the filtered and retrofiltered state. Furthermore, we show that, despite what one might think, the answer based on classical smoothing is not necessarily better than those obtained by assuming that the underlying dynamics are more `quantum' (containing states with coherences between the ground and excited states).

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Biomedisa AI: Automated Segmentation of Micro-CT Image Data using the Biomedisa Online Platform

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Abstract

Analysing volumetric biological or geological image data, such as from X-ray micro-tomography, often requires isolating specific structures from the 3D volume through segmentation. Manual or semi-automated segmentation by experts is a common approach, but it is time-consuming and limits large-scale analysis of morphological data.

Biomedisa (https://biomedisa.org) is an online segmentation platform designed for effortless accessibility via web browsers, eliminating the need for complex configurations. Tailored for scientists with diverse expertise levels, it accommodates those without in-depth computer or software knowledge. Additionally, it can also be installed locally for enhanced versatility and offers seamless integration into custom Python projects.

While Biomedisa's smart interpolation can aid in generating training data for subsequent machine learning or segmenting individual samples [1], Biomedisa's deep learning capabilities enables automated segmentation, facilitating extensive analysis of distinct objects within the volume, such as insect brains, and can provide insights into animal behaviour, ecology, and evolution [2]. Notably, Biomedisa's functionality extends to segmenting repetitive structures in large volumes, like cells in biological samples, particles in rocks, or roots in soil, without requiring image resizing. Here, we demonstrate Biomedisa's patch-based deep learning approach to segment distinct objects, including 187 bee brains from 3D image data, bone fragments from broken ankles of 76 patients, and repetitive structures in volumes of up to 2,500 x 2,500 x 10,000 voxels. Our approach successfully identifies plant roots in fertilised soil and separates hundreds of thousands of particles from a crushed rock scan by predicting particle boundaries and separating connected regions.

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Nuclear Structure Contributions to the Hyperfine Structure in Heavy Atoms

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Abstract

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**Increasing interest in low-energy, tabletop tests of beyond standard model (BSM) physics is demanding greater accuracy in our understanding of atomic hyperfine structure. Our theoretical accuracy is currently limited by nuclear structure effects, owing to the challenges of microscopic nuclear theory. Motivated by recent works [1, 2], it is possible to bypass this obstacle by considering a combination of muonic atom and H-like ion experiments. Being 207 times the weight of an electron, a muon orbits much closer to the nucleus, and thus experiences enhanced nuclear effects. The two systems are sensitive in different regimes and thus provide us with two independent measurements between which we can empirically infer nuclear structure information. We empirically derive the absolute Bohr-Weisskopf (BW) effect [3, 4] in Hg isotopes, and compare the result with the empirical Moskowitz-Lombardi rule [5, 6] that estimates the relative BW effects between isotopes. We also show that Nuclear Polarisability (NP) contributions to hyperfine splitting in 203,205 Tl and 209 Bi are small, contributing $< 3\%$ of the total hyperfine energy. By implementing these techniques, we can constrain nuclear structure contributions and allow searches for BSM physics
to progress.**

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Contact Resistance Study of Graphene-based Devices for Next-generation Electronic Device Applications.

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Abstract

Graphene has high thermal and electrical conductivity and is of interest for a range of electronic device applications ranging from sensing to field effect transistors [1]. However, devices are often limited by the high contact resistance at the graphene-metal contacts [2]. Here, we investigate defect engineering as a means of reducing the contact resistance; This is based on the use of ion-implantation to create defects within the graphene that increase the metal-carbon bonding.

The quality of the CVD-grown graphene was characterised by Raman analysis (Figure 1a). Back-gated devices were fabricated from CVD-grown graphene using standard optical photolithography and Cr/Au electrodes. The contact resistance of un-implanted and ion-implanted devices was then determined using the Transfer Line Method (TLM). The contact resistance of un-implanted devices was found less than 50Ω, consistent with the literature, and back-gated field-effect transistor (GFET) measurements of un-implanted devices showed Dirac points at 50V for increasing voltage and 90V for decreasing voltage, respectively (Figure 1c) [3]. The impact of ion implantation on contact resistance and transistor characteristics is currently being assessed and will be reported and discussed as a part of this presentation.

The current approach relies on increasing the metal-carbon bond density under the contact region and, if successful, will be explored in other 2D material systems.

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Ultra-fast Q-boosting in Nonlocal Semiconductor Metasurfaces

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Abstract

Time-variant semiconductor metasurfaces [1, 2] have recently provided an ultra-fast approach to manipulating the optical response compared with conventional tunable approaches, like thermal and electric tuning. They allow for femtosecond scale switching by tuning under high-energy pumping sources. However, despite the recent advances in this field, the ability to precisely tailor the metasurface bandwidth with ultra-fast time response has not been carefully explored.

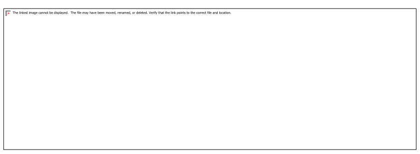

Figure 1: (a) Schematic of Q-boosting time variant resonator. (b) Simulated transmittance of time-variant metasurface with one side grating pumping. Top figure of (c) is Q-boosting in transmittance at k = 10, and the bottom (c) shows the transmittance interference at -0.5 delays with various energy rising speeds (k).

Here, we explore a time-variant metasurface's optical response and Q-boosting phenomenon, as shown in Fig. 1(a). We manipulate the nanoresonators' spectral bandwidth through external pumping, causing time-domain compression or expansion of the probe pulse due to changes in the semiconductor resonators' permittivity. The calculated optical response of the metasurface is shown in Fig. 1(b), where we break the structure symmetry to generate a Bound state in the Continuum (BIC) resonance and compensate for the in-plane disbalance by the side pumping, illustrated in its inset. And optical response is narrowed from blue to pink. In Fig. 1(c), we show resonance shifting and Q-boosting based on pump-probe delay when the probe pulse touches the permittivity change boundary. Overall, our results demonstrate a novel way to engineer the time-bandwidth response of time-variant metasurfaces by balancing the geometric and dynamic asymmetries in the metasurface parameters.

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Bouncing Gaussian unitary operations off of a two-mode squeezed state

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Abstract

It is well known that a unitary acting on one half of an entangled state is equivalent to a different unitary acting on the other half. We study this in the continuous-variable (CV) setting and find the explicit form for Gaussian unitaries "bounced" from one half of a two-mode squeezed state (TMSS) to the other. We extend this result to other important cases, including to Gaussian unitaries that act nontrivially on other CV systems beyond the TMSS. Even then, the bounced form is still unitary — surprising because in this case bouncing involves a partial transpose, which does not usually preserve unitarity. Our technique provides a new and important tool to the emerging toolbox for CV quantum circuit analysis.

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Extending Global Fits of 4D Composite Higgs Models with Partially Composite Leptons

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Abstract

Composite Higgs Models offer an attractive solution to the hierarchy problem. We extend previously examined models based on a SO(5) → SO(4) symmetry breaking pattern and 3rd generation quarks, with two representations of the τ and its neutrino. We conduct Bayesian global fits of these models using a wide array of constraints in order to find regions in the parameter volume that best fit experimental measurement. We then study the effects of including lepton parameters and constraints on the fit results for similar scans, as well as analyse the fine-tuning of each model by calculating the Kullback-Lieber divergence between their respective priors and posteriors, and the robustness of each scan. Both models were found to satisfy all constraints at the 3σ level and capable of predicting gluon-fusion produced Higgs signal strengths that are agreeable with the Standard Model order of unity. Additionally, we present the predicted leptons' experimental signatures for valid points in said models and discuss their potential phenomenology at future high-luminosity LHC runs.

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Gravitational Wave Signals From Early Matter Domination: Interpolating Between Fast and Slow Transitions

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Abstract

An epoch of matter domination in the early universe can enhance the primordial stochastic gravitational wave signal, potentially making it detectable to upcoming gravitational wave experiments. However, the resulting gravitational wave signal is quite sensitive to the end of the early matter-dominated epoch. If matter domination ends gradually, a cancellation results in an extremely suppressed signal, while in the limit of an instantaneous transition, there is a resonant-like enhancement. We present a study of the enhanced gravitational wave signal from early matter domination without assuming either limit and show how the signal smoothly evolves from the strongly suppressed to strongly enhanced regimes.

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Enhancing quantum teleportation efficacy with noiseless linear amplification

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Abstract

Quantum teleportation constitutes a fundamental tool for various applications in quantum communication and computation. However, state-of-the-art continuous-variable quantum teleportation is restricted to moderate fidelities and short-distance configurations. This is due to unavoidable experimental imperfections resulting in thermal decoherence during the teleportation process. Here we present a heralded quantum teleporter able to overcome these limitations through noiseless linear amplification. As a result, we report a high fidelity of 92% for teleporting coherent states using a modest level of quantum entanglement. Our teleporter in principle allows nearly complete removal of loss induced onto the input states being transmitted through imperfect quantum channels. We further demonstrate the purification of a displaced thermal state, impossible via conventional deterministic amplification or teleportation approaches. The combination of high-fidelity coherent state teleportation alongside the purification of thermalized input states permits the transmission of quantum states over significantly long distances. These results are of both practical and fundamental significance; overcoming long-standing hurdles en route to highly-efficient continuous-variable quantum teleportation, while also shining new light on applying teleportation to purify quantum systems from thermal noise.

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Large Area Two Wavelength Colour Routing via Multilayer Huygens' Metasurfaces

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Abstract

Multifunctional optical responses, such as achieving spectrally selective wavefront shaping, are one of the core advantages of meta-optical systems over conventional refractive or diffractive counterparts. These spectrally controlled meta-optical devices can replace complex optical systems with a single, thin element. Specific to this work, colour routing metasurfaces focus and route design wavelengths into different spatial channels at efficiencies much greater than using filters or diffractive gratings. To achieve high-efficiencies and multiple optical functions, advanced free-form inverse design techniques with high degrees of freedom are currently state-of-the-art and the preferred metasurface design approach. However, these techniques do not scale to centimetre-sized metasurfaces as the computational domain becomes unfeasibly large. This limitation hinders the integration of free-form inverse-designed colour routing metasurfaces into systems that rely on critical aperture sizes, necessitating additional focusing optics. For example, optical systems operating in low signal-to-noise conditions, such as atmospheric monitoring, long-distance laser communications and astronomical imaging.

Using a scalable inverse design strategy based on, in which 2π phase spanning meta-atom libraries are generated within the locally periodic approximatio, we demonstrate non-interacting multilayer Huygens' metasurfaces as a platform to create a centimetre scale polarization insensitive two-wavelength colour routers. In this configuration, each layer focuses a specific wavelength to a different point on the focal plane while achieving high transmittance and low phase disturbance at alternative wavelengths. This allows for light captured across the whole aperture to be routed into separate channels whilst only requiring two metasurfaces, which can be fabricated individually.

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Longitudinal-shear hybrid acoustic wave Brillouin scattering in tailored chalcogenide waveguides

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Abstract

Stimulated Brillouin Scattering (SBS) – a coherent interaction between optical and hypersound waves, has found many applications in optical signal processing and distributed fibre systems. More recently, SBS was successfully observed in chip-scale platforms, and in particular, soft-glass waveguides have been shown strong Brillouin gain in excess of 50dB. The strong on-chip Brillouin gain marked a new paradigm for signal processing in compact devices and enabled the first sub-mm resolution Brillouin sensing demonstration.

However, those demonstrations were limited to a single purely longitudinal acoustic mode, and on-chip Brillouin interactions with their shear counterparts have so far been elusive. The lack of access to shear acoustic waves is hindering practical applications of on-chip Brillouin sensors, as the longitudinal wave is restricted to the waveguide core and hence cannot directly sense the surrounding. Furthermore, the nature of the acoustic mode sets performance limits of on-chip signal processing applications due to the short lifetime that determines the resolution. Tailoring high Brillouin gain chalcogenide waveguides to support not only one strong longitudinal acoustic mode but also their lower frequency shear counterparts offers new capabilities for high-resolution signal processing and sensing applications. Acoustic shear modes have been shown in optical fibre tapers to exhibit longer acoustic lifetime and hence narrower linewidth and can also offer novel sensing applications due to their sensitivity to the topography of the surface and unique response to temperature and strain.

Here, we numerical model and experimentally demonstrate Brillouin scattering from multiple guided phonon modes in tailored chalcogenide waveguides. Numerical modeling and experimental measurements of chalcogenide waveguides with different waveguide core thicknesses and glass composition show Brillouin scattering by multiple acoustic modes with different shear and longitudinal components and several acoustic mode anti-crossings. These new insights into on-chip Brillouin scattering have the potential to enable new on-chip sensing and signal processing applications.

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Strong light-matter coupling in tunable open microcavities

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Abstract

Optical resonators can be utilized to enhance interactions between light and solid-state emitters. In particular, the coupling strength between the exciton within the material can overcome the dissipation rate. In such a case, the eigenstates of the system are mixed light-matter quasiparticles referred to as exciton-polaritons. In this work, we demonstrate an open, planar cavity platform for investigating a strong coupling regime.

Our microcavities consist of two independent distributed Bragg reflectors (DBRs), separated by a micrometer-scale distance. The exact length of the gap determines the resonant frequency of the optical cavity mode. This allows for in situ tunability of the photonic resonance, when the distance between the DBRs can be precisely controlled with a voltage applied to a piezoelectric chip.

Another advantage of the open cavity approach is the ease of integration of diverse material systems. Different active materials can be directly deposited on top of a DBR and assembled into a microcavity. In this work we characterize the strong coupling regime in three different material systems.

The high exciton binding energy in monolayer tungsten disulfide (WS_2) and phenylethylammonium lead iodide perovskite allows observation of exciton polaritons at room temperature. However, the microcavity can also be operated at cryogenic temperatures, granting stability of excitons in CdTe quantum wells. In the last case, upon pulsed excitation we observed a nonlinear behavior and polariton lasing.

M. Król et al, Opt. Mater. Express 13, 2651-2661 (2023).

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Theoretical characterisation of the Ra ion for the development of atomic clocks and studies of fundamental physics

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Abstract

As well as the canonical application of atomic clocks (positioning, navigation, and timing), their unparalleled stability makes them exceptional tools for fundamental physics studies, including as probes for evidence of exotic physics, such as violations of the equivalence principle, the search for possible variations of the fundamental constants, and the search for dark matter and dark energy. There are many proposals to develop new optical atomic clocks in alkali atoms (Rb, Cs) and alkali-like ions (Sr+, Ba+, Ra+). In particular, there has been progress on the development of an optical atomic clock in singly-charged Ra ion [1]. This ion is also of interest for tests of Lorentz symmetry and studies of atomic parity violation, due its large nuclear charge (and hence enhanced relativistic effects). In this work, we use the highly-precise methods that have been recently tested and extended in [2], and applied in [3], to perform a full theoretical characterisation of Ra, including lifetimes, transition amplitudes, polarisabilities, and sensitivities to new physics signatures. Combined with the new measurements [1], our calculations allow a test of atomic theory with unprecedented accuracy for a very heavy ion, including tests of nuclear physics and QED.

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Investigation of underscreening in electrolytes

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Abstract

Surface force measurements have revealed a hitherto unknown increase in the electrostatic decay length at very high (> 0.5 M) electrolyte concentrations[1]. This has major implications for our understanding of electrolytes and also for the properties of colloidal and soft matter at very high salt concentrations. Traditionally, the expectation has been that these systems would be unstable, but an extended electrostatic decay length would imply stability in these very high salt systems. We have investigated a number of different colloidal systems to determine if these systems show reentrant properties that are indicative of long range electrostatic interactions. The systems studied include polyelectrolytes, silica nanoparticles, surfactant micellisation, the thickness of thin soap films and the capacitance of the double layer. In most cases reentrant properties are exhibited, highlighting the importance and wide applicability of underscreening and the need to better understand very concentrated electrolyte solutions. How this work connects to specific ion effects will be described and a brief survey of our recent developments in this field will be provided.

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Tachyonic media in analogue models of special relativity

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Abstract

In sonic models of special relativity, the fact that the sonic medium violates (ordinary) Lorentz symmetry is apparent to observers external to the sonic medium but not to a class of observers existing within the medium itself. We show that the situation is symmetric: internal observers will judge physics in the external laboratory to violate their own sonic Lorentz symmetries. We therefore treat all observers on an equal footing such that each is able to retain a commitment to their own Lorentz symmetries. We then generalize beyond the case of subsystem-environment decompositions to situations in which there exist multiple phonon fields, all obeying Lorentz symmetries but with different invariant speeds. In such cases, we argue that all observers have freedom to choose which field is symmetry preserving, and so -- in a certain precise sense -- which other fields are perceived as having an 'ether.' This choice is influenced -- but not determined -- by a desire for simplicity in the description of physical laws. Sending information faster than sound serves as a model of tachyonic signalling to a distant receiver. Immutable causality of the laboratory setup when perceived externally to a sonic medium manifests internally through the confinement of the tachyons to an apparent ether (with a rest frame), which we call a 'tachyonic medium,' thereby preventing tachyonic exchange from emulating the scenario of a round-trip signal travelling into an observer's past causal cone. The assignment of sonic-Lorentz-violating effects to fields that obey 'photonic' Lorentz symmetries thus ensures that causality associated with the 'sonic' Lorentz symmetries is preserved.

S. Bilson-Thompson, S. L. Todd, J. Read, V. Baccetti, and N. C. Menicucci, to appear in Physical Review D (accepted 12 Sep 2023), arXiv:2305.12113

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Event-Based Imaging for Biophotonics: Optimising the Tracking of Passive & Active Matter

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Abstract

In microscopic regimes, studies of both passive and active Brownian particles are an area of important interest as they possess great potential in health care, environmental sustainability, and security applications. Passive particles are inert objects, whereas active particles perform directed motion by extracting energy from their environment [1]. Such studies depend on successful tracking and identification of individual particles in complex environments. This motivates the use of advanced camera technology and appropriate algorithms, invariably complicating data acquisition and analysis. Very large file sizes can accrue for the tracking of objects over extended periods of time, limiting the practical duration of possible studies.

We describe the merits of using an event-based camera (EBC) versus established camera technology, namely sCMOS, for these studies. The EBC's sensor functions differently to that of a traditional camera: instead of collectively integrating over incident intensity, pixels in the EBC record local changes in brightness independently. This removes redundancy in image acquisition as the EBC output is a stream of 8-bit integers, rather than a series of images [3]. Remarkably, we show the EBC reduces pre-analysis data requirements by up to 100x compared to standard sCMOS. We demonstrate this by tracking both sperms and Brownian particles in water; with tracking parameters determined by both cameras being near equivalent. The EBC heralds an important route for tracking dynamic changes for biophotonics applications.

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316

A soft matter physics approach to the origins of life

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Abstract

We self-assemble and characterise model primitive cells (protocells, Figure 1) with the aim of trying to

understand the properties of chemical systems that could have led to life as we know it. One critical

feature of life is the presence of lipid bilayers, which are the semipermeable barriers that delineate all

cells. On early Earth, lipid bilayers would have self-assembled from amphiphilic molecules of abiotic

(non-biological) origin. By definition, in an abiotic world, the membrane loses its biological nature and

becomes a soft material. Therefore, our studies of protocells are guided not only by the field of membrane

biophysics, but also by the field of soft matter physics.

Our research focuses on a fatty acid protocell system, that has intriguing properties arising from the

dynamic nature of the membrane. For instance, we have observed pH-dependent permeability and lysis

tension [1], distinguishing it from comparable phospholipid systems. Additionally, the model system can

also deform and undergo topological transitions to achieve division [2], endocytosis [3], and fusion [4].

We also use digital holographic microscopy, a one-shot 3D imaging method, to probe the encapsulation

properties of these protocells [5].

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Quantifying the difference in logical quantum error suppression between the rotated and unrotated surface code.

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Abstract

To create a scalable, fault-tolerant quantum computer, quantum error correction must be implemented efficiently. The rotated surface code is a quantum error-correcting code that has been used in recent experimental demonstrations of increasing logical error suppression with increasing code distance. One of its advantages is that it uses fewer physical qubits than the unrotated surface code to create a distance d logical qubit. We perform numerical simulations to quantify this reduction for desirable logical error rates.

If d physical errors occur on a logical qubit it is more likely to result in a logical error on the rotated surface code than the unrotated surface code. This is due to the unrotated code having more qubits, thus there are more ways d errors can occur without forming a logical operator as they get dispersed amongst the higher qubit count. For a given physical error rate and distance, the unrotated code consequently has a lower logical error rate than the rotated code. Hence, a lower distance is required if using the unrotated rather than the rotated surface code to achieve the same logical error rate.

We show that as the target logical error rate decreases, this difference in required code-distance increases. We quantify the rate of increase and find the ratio of qubit requirements between the two codes. We investigate physical qubit error rates from the threshold rate down to one in a thousand, this being the typical error rate of qubits in state-of-the-art quantum technologies, and down to logical error rates of one in a trillion. Additionally, we find that the order of two-qubit gates in the stabiliser measurement circuits could be better chosen to reduce the unrotated surface code's logical error rate. Our findings justify the use of the rotated surface code over the unrotated surface code.

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The hardness of nano- and microcrystalline lonsdaleite and diamond

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Abstract

Carbon atoms can form many allotropes based on their hybridization state. Cubic diamond is widely accepted to be the hardest, in which carbon atoms are purely sp^3 bonded in a tetrahedral structure with identical bond lengths and angles. Lonsdaleite, another carbon allotrope which also contains sp^3 bonds only, has an hexagonal lattice instead. It has been predicted by Pan et al. to have an indentation hardness greater than cubic diamond by first principles calculations, based on a two-stage shear deformation mode. However, this has not been confirmed experimentally. One of the limitations arises from the indentation method, where a diamond tip is usually used and assumed to be rigid for precise property measurements, which is unlikely to be true for superhard samples. In this current study, indentation running with a sharp Berkovich tip made of diamond was used to measure the hardness of both nano- and microcrystalline lonsdaleite. The hardness of these two samples was determined using both the Oliver–Pharr and Meyer methods, and is compared to those of diamond. Our results (Figure 1) show that the hardness of lonsdaleite is similar to that of diamond if they are close in grain size. Therefore, there is no experimental evidence that these forms of polycrystalline lonsdaleite are significantly harder than similar forms of diamond.

Figure 1: Hardness obtained using (a) the Oliver and Pharr method and (b) the Meyer hardness method for microcrystalline lonsdaleite and diamond (m-Lons and m-DIa), nanocrystalline lonsdaleite and diamond (n-Lons and n-Dia). Each data point represents the spread of a group of indentations using the same labeled maximum load.

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Calculating metrological potential from quantum phase-space methods

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Abstract

Quantum-enhanced sensors leverage entangled quantum states to perform high-precision measurements beyond the shot-noise limit (SNL). Schemes for quantum-enhanced atom interferometers typically focus on spin-squeezed states, however, these states only form a small class of metrologically useful states. There are more general states that offer significant enhancements to both precision and sensitivity. The metrological potential of such states can be assessed via the classical and quantum Fisher information.

The Truncated Wigner (TW) Approximation is a semiclassical stochastic phase-space tool for simulating quantum sensors. The TW approximation is particularly useful for simulating many-atom quantum sensors because exact methods become numerically intractable. While the TW approximation is useful for approximating moments of observables, it cannot be directly used to compute Fisher information apart from some limited circumstances.

In this work, we propose novel methods of computing Fisher information using stochastic TW that are scheme agnostic. We show that it is possible to compute classical and quantum Fisher information from stochastic TW samples without making assumptions about the sensing scheme or the quantum state. Hence, these methods can be applied to nontrivial sensing schemes which was previously not possible using stochastic TW.

We demonstrate that quantum Fisher information for a pure state can be written down simply in terms of the Wigner function, which admits an interpretation in terms of stochastic samples. By extending the particle number binning procedure of Lewis-Swan et al, to be sensitive to infinitesimal changes in the quantum state, we are able to construct the classical Fisher information. We show that these methods can be used to study metrologically useful quantum states beyond the spin-squeezing regime.

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Extension of radiative potential for superheavy atoms

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Abstract

Superheavy elements are the class of elements with nuclear charge $Z \geq 104$. In recent decades, synthesis and experimental investigation of superheavy elements have been achieved up to element 118 (oganesson). The measurements and calculations for superheavy elements have reached the level of accuracy where quantum electrodynamics (QED) radiative corrections should be taken into account. Therefore, the development of accurate methods for calculating these QED corrections is necessary. This has been addressed recently for the model-operator approach for QED radiative corrections [1]. In the current work, we extend the arguably simpler radiative potential method [2,3] into the superheavy region, up to and beyond the heaviest synthesised elements.

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Reservoir-induced linewidth broadening of exciton-polariton laser

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Abstract

Microcavity exciton-polaritons (or simply polaritons) can form a Bose-Einstein condensate (BEC) in semiconductors. Decay of this macroscopic coherent state releases coherent photon emission – a polariton laser. Continuous-wave photon emission from a polariton BEC is only possible under continuous pumping due to ultrashort polariton lifetime of ~1-102 ps. Furthermore, the pump directly generates an incoherent excitonic reservoir which causes decoherence of the BEC [1], thereby adversely affecting its quantum application [2]. In order to increase coherence time and narrow the linewidth of the polariton laser, it is important to understand and control the decoherence mechanisms. In this work, we create condensates with ultra-narrow (< 0.1 GHz) Lorentzian spectral profile, corresponding to > 3.2-ns coherence time, greatly exceeding the polariton lifetime. This is achieved by confining a polariton BEC in an optically induced round trap created by a single-mode off-resonant laser to minimize the condensate-reservoir overlap and to reduce number fluctuations in the condensate [3]. To uncover the main driver of decoherence, we add an off-resonant beam to inject incoherent reservoir particles on top of the condensate. This results in a homogeneously broadened linewidth (see Figure 1). Our results confirm the detrimental role of the reservoir on the polariton coherence and demonstrate an ultra-narrow linewidth polariton laser.

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Manipulation of Electric and Magnetic Dipolar Emission from Lanthanides Using Nanoscopic Structures for Polarization-Controlled Light Emission

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Abstract

This work explores the precise control of electric and magnetic dipolar emission from trivalent lanthanide ions, by using silicon nanodimers engineered to exhibit polarization-dependent responses. The Purcell effect can modify the radiative decay rate of quantum emitters by manipulating their photonic environment [1]. High refractive index dielectric nanostructures supporting Mie-type resonances are used to enhance the local density of optical states (LDOS) relative to the background medium, consequently intensifying the emission from the emitter. These nanodimers support magnetic and electric hotspots for orthogonal linear polarizations, suggesting precise control of the emitted light polarization [2]. The resonances overlap with the magnetic dipolar (MD) and electric dipolar (ED) transitions of $Eu(TTA)_3$ metal-organic complexes within the visible range at specific wavelengths of 590 nm and 610 nm, respectively.

Experimental realization of these hybrid structures is achieved through a two-step electron-beam lithography (EBL) process, with careful placement of the $Eu(TTA)_3$ emitters exclusively within the dimer's gap [3]. This ensures the confinement of emitted light and its selective coupling to the desired MD and ED transitions. The optimized dimer design includes specific geometric parameters such as height, diameter, and gap width, as determined through numerical optimization.

We suggest that the optimized structure can route the light emitted through the MD (ED) transition of the Eu(TTA)3 complex into different polarization channels in the far-field.

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Atomic-scale identification of diamond surface defects using scanning tunnelling microscopy

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Abstract

Diamond quantum sensors exploit the remarkable properties of the nitrogen-vacancy center (NV) for nanoscale magnetometry and electrometry. Considering the theoretical limit of NV sensitivity, future devices could be employed in medical or autonomous environments for on-demand and room-temperature chemical analysis. Unfortunately, these applications cannot currently be realised due to surface defects, which introduce deleterious magnetic noise through paramagnetic spins and electric field screening through charge traps.

Realising the next generation of diamond quantum sensors therefore requires enhanced surface preparation protocols to eliminate undesired defects. The development of such protocols would be greatly enhanced by an understanding of the defects' atomic structure. Unfortunately, despite extensive characterisation using wide-field spectroscopic techniques, this structure is currently unknown. This motivates the use of scanning-probe based techniques, such as scanning tunnelling microscopy (STM), capable of characterising surface defects with atomic-scale spatial precision.

Consequently, this work pioneers an STM-based technique for identifying surface defects on diamond. This is achieved through quantitative comparison of simulated and experimental STM images of surface defects. Existing computational tools for simulating STM on diamond are ineffective, because they do not consider extreme electrostatic effects inherent to wide bandgap semiconductors. Hence, this work develops a multi-scale STM technique which combines mesoscale electrostatic modelling with nanoscale first-principles calculations. The success of the technique is then demonstrated experimentally through identification of defects on the H-terminated (100) surface, including paramagnetic spins and charge traps. Furthermore, we identify key defects related to surface growth through chemical vapour deposition, thereby providing direct confirmation of longstanding theoretical models.

In summary, this work develops a state-of-the art simulation tool for STM on wide bandgap semiconductors. The effectiveness of this tool is then demonstrated through identification of surface defects on diamond. It is therefore of broad interest for researchers in the fields of first-principles simulations, surface physics, and quantum technologies.

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Synergies between CTA and SWGO Gamma-ray Observatories to Trigger and Resolve Transient Events

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Abstract

The Cherenkov Telescope Array (CTA) and the Southern Wide-field Gamma-ray Observatory (SWGO) will detect gamma rays over the same energy range, from hundreds of GeV up to PeV. Both observatories will be deployed in South America and they will have complementary characteristics. CTA consists of imaging Cherenkov telescopes with good angular resolution (0.05° at TeV and 0.02 at 100 TeV), but with a limited FoV (<8°), while SWGO being a particle ground array has a large FoV (~120°) and a 100% duty cycle. SWGO is developing analysis algorithms to identify transient events in real time and send follow up trigger alerts. On the other hand, CTA is developing fast reaction mechanisms that will allow to re-point the telescopes in a few seconds. Therefore, any transient event triggered by SWGO could be followed up by CTA and the source morphology might be resolved. The synergy between CTA and SWGO will increase the detection efficiency of gamma ray transients and the corresponding image resolution. Radio In this presentation the current status regarding the identification of transient events (in both observatories) will be described.

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Hyperspectral holographic microscopy

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Abstract

Proposed is a new application for the Fourier spectrometer: the ability to record hyperspectral holograms of microobjects in incoherent light. Detailed theory is developed for recording hyperspectral holograms of microobjects in cases of Fresnel diffraction and focused image holograms. Various registration optical schemes for both transparent and reflective objects are discussed. The method involves placing a flat microobject in one arm of an asymmetric Fourier spectrometer. The output signal, representing interference between the reference wave and the object-diffracted wave, is captured by a 2D-sensor. The recording process involves registering interferograms in each pixel of the receiver matrix during incremental changes in the optical path length in the reference arm of the interferometer. One-dimensional Fourier transformation of the interferogram in each pixel yields the complex amplitude distribution of all spectral components of the hyperspectral object field. The proposed ideas have been experimentally confirmed in [1]. Hyperspectral amplitude and phase images of microobjects are aquired with diffraction-limited resolution, showcasing speckle noise suppression and accurate color rendition [2]. Commonpath hyperspectral holograms of focused microobject images and registration capabilities with various light sources were demonstrated in [3]. The method holds potential for applications in terahertz or X-ray research where coherent light sources are limited. The proposed technique inherits the strengths of Fourier spectroscopy principles (Fellgett's and Jacquinot advantages), offering high signal-to-noise ratio and superior spatial-spectral resolution compared to tunable wavelength laser holography.

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Threshold Switching Dynamics of V_3O_5 Memristors and Its Application as a Leaky Integrate-and-Fire Neuron

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Abstract

Neuromorphic computing implemented with spiking or oscillatory neural networks is an energy efficient computing paradigm to address the von Neumann bottleneck [1]. Metal-oxide-metal (MOM) devices that exhibit volatile threshold switch (TS) or current controlled negative differential resistance (NDR) are of interest as the basis of solid-state neurons in such neuromorphic computing arrays [2]. Oxides that undergo an abrupt insulator-metal transition (IMT) are of particular interest for energy efficient operation [2, 3] but while VO_2 has been well studied for such applications, its insulator-metal transition temperature (T_{IMT}=340 K) is too low for practical application. In this study we explore V_3O_5 a promising alternative as it has an IMT temperature of ~420 K and has been shown to exhibit reliable threshold switching [4].

Two terminal planar devices were fabricated on 500 nm-thick V_3O_5 layers by depositing 50 nm Pt electrodes using e-beam evaporation. As-fabricated devices exhibited reliable voltage-controlled threshold switching and current-controlled negative differential resistance (NDR), with <3% variability in the threshold voltage during thousands of subsequent cycling. The switching dynamics of the devices and their application as a leaky integrate-and-fire (LIF) neuron are reported and discussed with reference to finite element and lumped element modelling. The threshold switching response of V_3O_5-based devices is shown to be dominated by the temperature dependent conductivity of the insulating phase rather than the IMT. However, devices based on this material exhibit reliable, forming free threshold switching and effective operation as a LIF neuron.

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Updated Quantum Master Equations for Simulation of Open Quantum Dynamics

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Abstract

Predicting the dynamics of a quantum systems is a key task in quantum theory. Doing so for large Hilbert spaces is impractical. A qubit coupled to a bosonic environment, for example, has infinite dimensions and thus keeping track of the dynamics of both system and bath is typically not possible. Alternatively, following the dynamics of the qubit is possible by tracing out the environment, leading to methods such as the quantum master equation. In such open quantum system approaches, one only needs the correlations of the bath operators, which can be experimentally obtained by performing the quantum noise spectroscopy, in order to simulate the dynamics. However, this method is used together with the weak coupling, Gaussian correlation assumptions, and Born approximation, in order to limit the amount of required seed information about the environment. This usually implies that the prediction is often only reliable for short times. In this work, we introduce a new method to simulate the dynamics of an open quantum system by using a hierarchy of update rules, which update not only the relevant information about the system but also the leading correlations of the bath operators. Our method takes into account the fact that the state of the bath evolves not only due to its own dynamics but also due to the coupling to the system, therefore it provides a more accurate description of the dynamics. We compare the performance of our method to the well-known Nakajima & Zwanzing master equation, and show that by updating the correlations one can predict the dynamics of the system for longer time using the same seed information. We also show how we can accurately track the relevant bath correlations relative to the system-bath state at a given time.

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Precision limits and uncertainty relations for quantum multiparameter estimation

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Abstract

Determining optimal measurements for estimating multiple parameters of a physical system is an important task practically. For estimating parameters in quantum systems, the uncertainty principle fundamentally limits the estimation of incompatible parameters---there is a trade-off in terms of the accuracy with which each parameter can be measured. Limits on the precision of estimation have been formulated, in analogy to classical theory, as a lower bound on a weighted sum of estimation variances, such as the Nagaoka--Hayashi Cram\'er--Rao bound (NHCRB) [1]. Recently, an alternative limit called the Lu--Wang uncertainty relation (LWUR) was proposed based on an uncertainty relation [2]. It is a non-trivial trade-off between mean squared error elements, quantifying the manifestation of Heisenberg's uncertainty principle on the joint estimation of two parameters. Of interest for any estimation limit is its attainability: does there always exist a measurement saturating the limit?

In this work, we investigate the differences between the limits that the NHCRB and LWUR place on estimation variances. We compare the NHCRB and the minimum sum of variances allowed by the LWUR, using a model problem of estimating orthogonal rotations of a quantum state. We find estimation problems where both approaches place an identical limit on the estimation variances. However, we also find problems where the difference between the limits is arbitrarily large, and the LWUR cannot be attained. In particular, we highlight a flaw of the figure-of-merit used to derive the LWUR---there are estimation problems in which measurements optimising this figure-of-merit do not obtain any information about the system's parameters. To circumvent this, we present an uncertainty relation for parameter estimation based on the NHCRB, which can define an attainable uncertainty relation. Additionally, we show that this approach can provide non-trivial trade-off relations for estimating more than two parameters, something that the LWUR cannot do.

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Tight large deviation bounds for quantum adversarial setting with applications to quantum information

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Abstract

The theory of large deviations is commonly used for statistical inferences. Its basic statement is that the probability of extreme events gets (exponentially) small with respect to the number of trials. In quantum information theory, the large deviation bound is widely used such as in quantum cryptography, hypothesis testing, and quantum state verification. For certain applications such as quantum cryptography, one needs to consider adversarial setups in which not all known large deviation bounds are applicable due to the possible correlations in quantum states or probability distributions. Our aim is to obtain tight bounds applicable in these setups. Our results are two fold. The first result is applicable when the quantum state is symmetric under the permutations of finite-dimensional quantum systems but has no guarantee other than that. This setups has already been studied in the quantum de Finetti theorem; our result is thus a refinement of the conventional bound. Another result is when we perform independent and identical finite-outcome measurements on an arbitrary quantum state in possibly infinite-dimensional systems. Here, the theory essentially reduces to that of a classical probability distribution, and thus one can use concentration inequalities for classical probability distributions. The large deviation bound we found has, however, tighter exponent than those of previously known bounds applicable in this case. Finally, we numerically demonstrate the tightness of our new bounds compared to conventional bounds.

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Improved construction of graph states in linear quantum optics

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Abstract

In this work, we examine efficient construction of graph states, which are used for quantum communication, as resource states for quantum error correction, and for algorithm-specific graph states (ASGs). ASGs, as described in is a model of quantum computation similar to measurement-based quantum computation where a quantum circuit is transformed into a graph state, and the circuit can be executed with only non-Clifford measurements on the graph state, but the ASG has no fixed topological structure. Unlike for quantum circuits, little research has been done into ASG optimisation.

In linear optical quantum computing, two-qubit gates are inherently probablistic, which necessitates single qubit operations for efficient construction. While single qubit transformations can be determined for up to 12 qubits by using an existing database, this technique is impractical for larger states.

The first optimisation is an extension of 'graph unraveling', in which fully connected or fully connected bipartite regions are unraveled into intermediate states with ancillary nodes but lower size and node degree. Our extension to this method is to apply the technique to dense (but not fully connected) regions which benefit from unraveling by reducing the cost of the intermediate graph state. This technique is done with the KarateClub Python library for graph clustering.

We measure this optimisation using a photonic cost function based on optical fusion success rates. Preliminary results suggest for dense graphs of order 30, a photonic cost saving of a factor of 10 compared to the previous unraveling methods.

The second optimisation is to use local complementation to reduce the size of a graph for which we use a Markov Chain Monte Carlo method.

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Fragility of edge states in topological photonic structures

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Abstract

Topological photonics investigates nontrivial topological phases within photonic structures such as photonic crystals and coupled ring resonator arrays. Akin to topological insulators in electronic systems, the photonic structures are expected to provide reflectionless waveguiding that is robust to disorders, hence mitigating issues such as fabrication imperfections. This unique attribute arises from the presence of the gapless edge states which are protected by the intrinsic bulk band topology. The study of topological photonic structures has generated significant recent interest, with applications spanning large cavity single-mode lasing, quantum optical interfaces, and protected quantum emitters.

However, recent studies in topological photonic structures have uncovered evidence contrary to the expected topological robustness. For example, reflections of the edge modes are observed in experimental studies. This is usually attributed to certain fabrication imperfections.

In this work, we report an intrinsic limitation in the topological protection of the edge states in existing photonic topological insulators. In contrast to expectations, the edge bands are gaped in energy and are susceptible to reflection and localization. Fundamentally, this limitation arises from the lack of genuine Kramers degeneracy in photonic systems and hence the utilization of other symmetries to induce pseudo spins. For example, the commonly studied topological photonic-crystal structure relies on C6 symmetry to establish photonic pseudo-spin states in a quantum spin-hall model. However, the mere presence of a boundary inevitably breaks the C6 symmetry. Consequently, the edge itself induces a cross-spin coupling between the two pseudo-spin bands. Drawing an analogy to electronic systems, the edge is effectively a distributed array of magnetic defects, thereby creating an intrinsic energy gap in the edge bands. Furthermore, should there be corners or defects at the edge that disrupt its 1D translational symmetry, the edge modes can be reflected and localized as a result.

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Investigating spatial mis-modelling in point-source inference

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Abstract

The identification and description of point sources is one of the oldest problems in astronomy; yet, even today the correct statistical treatment for point sources remains one of the field's hardest problems. For dim or crowded sources, likelihood based inference methods are required to estimate the uncertainty on the characteristics of the source population. Parametric approaches, such as the Compound Poisson Generator (CPG) and Non-Poissonian Template Fitting are known to be susceptible to biases when the assumed spatial distribution of the observed flux is not correctly specified. This is especially relevant for application of point-source inference to the galactic-center gamma-ray excess. I will present recent work on addressing this problem with the CPG formalism.

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Entanglement entropy for scale-invariant states: universal finite-size scaling

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Abstract

A universal finite system-size scaling analysis of the entanglement entropy is presented for highly degenerate ground states arising from spontaneous symmetry breaking with type-B Goldstone modes in exactly solvable one-dimensional quantum many-body systems. These states appear to be scale-invariant, but not conformally invariant. Our findings are based on a physical argument, imposing three constraints on the entanglement entropy, in addition to further confirmation from an asymptotic analysis of the entanglement entropy for the SU(2) spin-1/2 ferromagnetic states. The resulting universal scaling form is demonstrated for three fundamental models -- the SU(2) spin-s Heisenberg ferromagnetic model, the SU(N+1) ferromagnetic model, and the staggered SU(3) spin-1 ferromagnetic biquadratic model. The results point towards a classification for distinct types of scale-invariant states, relevant to a complete classification of quantum states of matter.

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Fractal dimension and the counting rule of the Goldstone modes

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Abstract

It is argued that highly degenerate ground states arising from symmetry spontaneous breaking with a type-B Goldstone mode are scale invariant, with a salient feature that the entanglement entropy S(n) scales logarithmically with the block size n in the thermodynamic limit. As it turns out, the prefactor is half the number of the type-B Goldstone modes N_B. This is achieved by performing an exact singular value decomposition of the degenerate ground states, thus unveiling their self-similarities - the essence of a fractal. Combining with a field-theoretic prediction [O. A. Castro-Alvaredo and B. Doyon, Phys. Rev. Lett. 108, 120401 (2012)], we are led to the identification of the fractal dimension df with the number of the type-B Goldstone modes N_B for quantum many-body systems undergoing symmetry spontaneous breaking.

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Asymptotic Non-utility of Collective Quantum Measurements for Qudit Tomography

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Abstract

The best precision attainable in a quantum estimation scenario is a fundamental question in quantum information science with wide-ranging implications for metrology and sensing. In this regard, it has been established that entangling or collective measurements on multiple copies of a state yield greater precision than measuring each copy individually. However, the limits of this improvement have not been quantified by a direct comparison between the optimal individual and the optimal collective measurement strategies.

In this work, we answer this question by investigating how large the ratio between the best precision attainable via entangling collective measurements and the best precision attainable by simply measuring each probe state one at a time can be. We show that the ratio can never be more than the number of parameters being estimated and that for estimating a generalization of Pauli matrices in qudits, the ratio is at most d+1, d being the dimension of the qudit. We conclude that the largest possible improvement in precision upon performing resource-intensive entangling operations on asymptotically-many copies before measurement is limited by the dimension of the quantum system being probed.

Collective measurements are challenging to implement in real estimation scenarios and experimental demonstrations are few and far between. Resultantly, the ratio between the two optimal precisions serves as a useful quantifier of both (a) the quantum advantage offered by collective measurements, and (b) the utility or uselessness of performing complicated entangling measurements and expending vast amounts of resources. Our work suggests that though entangling measurements lead to precision enhancements and, thus, are useful for state tomography, state discrimination, and other metrological tasks, the improvement in precision grows slowly with number of copies, requiring an exponentially-large amount of resources for an improvement linear in the dimension.

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Threshold Behaviours and Higher-order Trotterisations effects in Quantum Simulation

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Abstract

Quantum simulation is one of the main applications in which quantum computers can outperform classical computers. Trotterisation is currently the leading approach for implementing programmable quantum simulation on gate-based quantum computers. In this technique, the full target evolution is broken down into simpler quantum gates, which are performed in a repeated sequence of discrete time steps. The effects of this discretisation step size on simulation accuracy have been studied in recent works [1-3], that found simulation accuracy completely breaks down beyond a critical step size, showing a sharp threshold which marks a transition between localised dynamics and quantum chaos. Importantly, the threshold's location is at the same step size for various quantities, e.g., local observables and simulation fidelity. Here, we studied Trotterisation performance and threshold behaviours in the context of higher-order Trotterisations, which will be needed to reduce simulation errors in real quantum computing applications. We analysed various performance signatures for higher-order Trotterisations produced by different methods, such as Suzuki's fractal method, Yoshida's method, and other recently improved product formulae [4]. We showed that thresholds persist at all orders across all methods tested. While the threshold for a given product formula stays at the same position for different physical quantities, we observed that the location shifts with Trotterisation order. Understanding this behaviour will be essential for understanding how discretisation errors limit the performance of real-world quantum simulations, and may help optimise the computational power of quantum computers for modelling.

[1] M. Heyl, P. Hauke, and P. Zoller. Sci. Adv. 5, 4 (2019).
[2] L. M. Sieberer, T. Olsacher, A. Elben, et al. npj Quantum Inf. 5, 78 (2019).
[3] C. Kargi, J. P. Dehollain, L. M. Sieberer, et al. ArXiv (2022).
[4] M. E.S. Morales, P. C.S. Costa, D. K. Burgarth, et al. ArXiv (2022).

349

The SKAO and high-energy synergies, a Science Operations outlook

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SKAO, Perth, Australia

Abstract

I will provide an update on the Square Kilometre Array Observatory (SKAO), the fundamental science drivers together with their synergies with high-energy astronomy, and the expected design and scope of the project. I'll outline the plan for the Science Operations team within the broader observatory, the breakdown between commissioning, verification and operations, and highlight pathways for involvement (from students through science engagement to employment opportunities). I will then provide an update on the progress of the growing SKAO entity, and details of the roll out plan of the Observatory and how it might align with gamma ray astroparticle physics.

350

Quantum Phase Recognition via Quantum Kernel Methods

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Abstract

The application of quantum computation to accelerate machine learning algorithms is one of the most promising areas of research in quantum algorithms. In this paper, we explore the power of quantum learning algorithms in solving an important class of Quantum Phase Recognition (QPR) problems, which are crucially important in understanding many-particle quantum systems. We prove that, under widely believed complexity theory assumptions, there exists a wide range of QPR problems that cannot be efficiently solved by classical learning algorithms with classical resources. Whereas using a quantum computer, we prove the efficiency and robustness of quantum kernel methods in solving QPR problems through Linear order parameter Observables. We numerically benchmark our algorithm for a variety of problems, including recognizing symmetry-protected topological phases and symmetry-broken phases. Our results highlight the capability of quantum machine learning in predicting such quantum phase transitions in many-particle systems.

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Mergers of double white dwarfs and their associated transients

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Abstract

Over the last decade it has become clear that the progenitors of Type Ia supernovae (SNe Ia) likely originate from more than one formation scenario, and the observed diversity may be partially due to a difference in explosion mechanism. However, it is still uncertain what the different SN Ia progenitors are in terms of exploding white dwarf mass, nature of the mass-losing companion star, and how these are connected to the observed sub-classes of SNe Ia (e.g. 'normal' SNe Ia useful for cosmology; 91bg-like faint events, Type Iax peculiar events, etc). Knowing the stellar mass(es) is important, because the exploding WD mass (thus density) directly influences the types of elements that are synthesised in the explosion – which has important consequences for chemical evolution. I will discuss more generally white dwarf mergers and the types of sources they likely create from a theoretical perspective, such as SNe Ia, accretion-induced collapse neutron stars, and hydrogen-deficient carbon stars. With the Vera Rubin Observatory coming online by 2025 and with the launch of LISA in 2037, the forthcoming years hold immense promise for unprecedented discoveries about the origin and evolution of transients, shedding crucial light on the origin type Ia supernovae, which stand as one of the Universe's most dependable standardizable candles.

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Opportunities and Challenges for Quantum Advantage in Quantum Machine Learning

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Abstract

The meteoric rise of artificial intelligence in recent years has seen machine learning methods become ubiquitous in modern science, technology, and industry. Concurrently, the emergence of programmable quantum computers, coupled with the expectation that large-scale fault tolerant machines will follow in the near to medium-term future, has led to much speculation about the prospect of quantum machine learning, namely machine learning solutions which take advantage of quantum properties to outperform their classical counterparts. Indeed, quantum machine learning is widely considered as one of the frontrunning use cases for quantum computing. In recent years, research in quantum machine learning has gained significant global momentum, see for example Ref. [1,2]. In this tutorial style presentation, I will briefly introduce the fundamentals of quantum machine learning and provide an overview of the recent literature, highlighting key opportunities for achieving quantum advantage in machine learning tasks and open challenges currently facing the field of the quantum machine learning.

[1] Nature Computational Science 2, 711, 2022.

[2] Nature Machine Intelligence 5, 581, 2023.

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Sample efficient deep learning for quantum optics and quantum control

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Abstract

Optical alignment plays a crucial role in numerous quantum experiments involving optical and atomic systems. Achieving and maintaining the precision required for these applications is often a labor-intensive task, traditionally reserved for domain experts. There are, however, instances where systems remain inaccessible or beyond the control of conventional methods and expert knowledge.

Machine learning, specifically deep learning, has demonstrable success in tackling high-dimensional problems across various fields. Deep learning presents an unparalleled data driven approach to crafting feature extractors without explicit programming or design by domain experts. This capability has opened up a plethora of applications in quantum information science, particularly where traditional theoretical descriptions fall short, are intractable or entirely forgo analytical or numerical treatment.

While deep learning methods are typically considered data-intensive, in the present work we present sample-efficient approaches tailored for use with quantum technology. We achieve this through careful design of network structures and associated methods, thereby addressing the constraint of requiring large datasets. We exemplify this approach in the auto-alignment of an optical cavity, demonstrating its adaptability to arbitrary optical setups and higher order modes.

Once alignment is accomplished, we incorporate a sample-efficient black box control system, drawing on recent advances in reinforcement learning. Although we use the optical system as a testbed, we also explore the potential of our approach in addressing broader quantum control challenges.

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Development of a Fibre-Coupled Erbium Based Quantum Memory

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Abstract

Erbium-doped rare-earth crystals are promising candidates for use in quantum memory due to long hy- perfine and coherence times, all while conveniently operating at a wavelength compatible with existing fibre optic networks. These properties have recently been used with the Rephased Amplified Stimulated Emission (RASE) protocol to demonstrate highly efficient storage and generation of entangled optical pulses. RASE could be used as the basis for a quantum repeater network, allowing for the transmission of quantum states between remote nodes through entanglement swapping. Scaling a single RASE system into a network of distributed memory nodes requires highly efficient coupling between the crystal and the interconnecting fibre pathways. Using current freespace optics the collection efficiency is currently around 20%, with significant losses occurring during transmission and recovery through the cryostat windows. Further losses occur during the mode-matching process to ultimately couple this light into a single-mode fibre. This research focuses on the development of a full-fibre system that delivers light directly into a memory crystal in order to boost this efficiency. This system requires no other associated optics or alignment, bypassing the cryostat boundaries entirely. Four-level echo experiments were performed using this con- figuration, resulting in an ≥ 80% collection efficiency while being highly insensitive to mechanical vi- brations. Ensemble Rabi frequency was also 20 times higher than equivalent freespace, indicating the possibility of operating a memory with very narrow 10 MHz bandwidths. Further results will be discussed, and a handful of novel design configurations will be highlighted, with potential applications in other non-quantum systems.

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Simulating Digital-Analog Control of the Diamond Quantum Processor

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Abstract

For quantum computers of the NISQ regime, each gate operation within an algorithm accumulates a significant amount of error. This results in an exponentially growing number of qubits required purely for correction, amplifying algorithmic complexity without necessarily providing a commensurate boost in computational power. Analog control alternatives have great potential to reduce the number of qubit operations required in an algorithm, minimising error accumulation opportunities by efficiently harnessing the inherently analog nature of quantum information. Digital-Analog Quantum Computing (DAQC) and Analog Quantum Computing (AQC) are promising examples, with Quantum Annealing (QA) already demonstrating specialised practical applications.

Our previous work showcased the adaptability of the diamond quantum processor, demonstrating how to realise an Ising model computational topology from the nitrogen-vacancy centre's spin dynamics. By applying novel control techniques, we showed how it can operate as a room-temperature quantum annealer, serving as a proof-of-concept for analog control of the diamond quantum processor. Shortly after, we showed how diamond's dynamically coupled Ising model enables us to not only perform DAQC, but improve upon existing statically coupled DAQC techniques to reduce circuit depth even further via the Rodriguez formula.

This study delves into the practicality of these techniques, scrutinising the impact of various error sources through comprehensive, physics-based simulation of an Ising-controlled diamond quantum processor. These simulations include the effects of crosstalk, control errors, nuclear spin relaxation and electron spin dephasing, investigating their individual contributions to overall fidelity under a variety of qubit connectivity graphs. The quantum Fourier transform serves as a benchmark for comparison, executed under the conventional gate-based approach, fixed coupling DAQC, and reduced-depth dynamic coupling DAQC. We present these findings, demonstrating the advantages and challenges associated with error accumulation using these new control techniques.

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Layer Codes

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The University of Sydney, Sydney, Australia

Abstract

The surface code is a two dimensional topological code with code parameters that scale optimally with the number of physical qubits, under the constraint of two dimensional locality. In three spatial dimensions an analogous simple yet optimal code was not previously known. In this talk I will introduce a construction that takes as input a stabilizer code and produces as output a three dimensional topological code with related code parameters. The output codes have the special structure of being topological defect networks formed by layers of surface code joined along one dimensional junctions, with a maximum stabilizer check weight of six. When the input is a family of good low density parity check codes, the output is a three dimensional topological code with optimal scaling code parameters and a polynomial energy barrier.

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Development of a compact ytterbium magneto optical trap for use in precision timekeeping applications.

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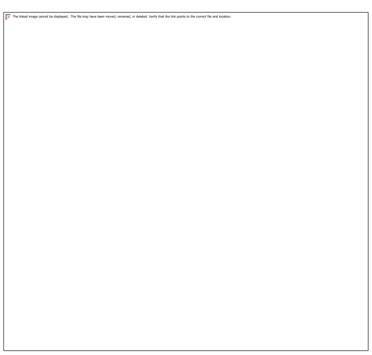
Abstract

High performance atomic timing systems are essential components in modern technology, with applications ranging from navigation and geodesy to tests of fundamental physics [1]. Current commercial timing systems are based on microwave technology, which is over half a century old. State-of-the-art atomic clocks are based on optical transitions, but due to their size and complexity these are mostly confined to laboratories. To realise a step-change in in optical clocks performance we must reduce their size, weight, and power (SWaP) requirements, making them compact, portable, and robust. Motivated by this need, we are developing a compact cold atom trap-based ytterbium clock. The target being a portable device with better than commercially available long-term stability and fundamental accuracy.

We will present our latest results on the development of a compact magneto-optical trap (MOT), capable of trapping 3.3 x 10^6 ytterbium-171 atoms (image 1). This includes efforts towards the integration of an efficient diffraction optic to create grating MOTs (gMOTs) [2], fabricated using electron beam lithography. This development will drastically reduce the SWaP and complexity of the cold atom system, allowing for integration within a robust and fundamentally accurate field-deployable optical clock.



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[2] Sun, X. et al., Optics Express. 29, 37733 (2021).

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Quantum Information Processing Using an $^{167}Er^{3+}:Y_2SiO_5$ Quantum Memory

James Stuart, Kieran Smith, Ellen Zheng, David Pulford, Rose Ahlefeldt, Matthew Sellars
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Abstract

Many proposed protocols for optical quantum information processing use the combination of a source of entanglement and a compatible, on-demand, optical quantum memory. These include the linear optics quantum computing proposal of Knill et al. and the DLCZ quantum repeater [1,2]. The role of the memory is to store the collapsed states resulting from measurement operations on the entanglement resource. The memory allows the output states from these probabilistic measurements to be synchronised for subsequent processing steps and is critical to achieving a meaningful quantum advantage. An approach to achieving compatibility between the entanglement source and the memory is to use the quantum memory to both create the entanglement and to store the collapsed states. By operating the quantum memory as an amplifier, during its input mode, it is possible through amplified spontaneous emission, to create entanglement between the state of the memory medium and the output field. The state of the memory can then be recalled later as a second optical field which is non-classically correlated with the original emission.

Here we present results from an experimental demonstration of one such source/memory protocol, Rephased Amplified Spontaneous Emission [3], operating in the 1550nm optical communication band, using $^{167}Er:Y_2SiO_5$ as the memory medium. Non-classical correlations between the ASE and RASE fields was observed with a confidence level of 3.7σ at a recall efficiency of 27%. Further, it is shown that with frequency multiplexing it should be possible to store over 5000 optical modes at a single spatial location in the crystal. Preliminary results on distributing entanglement between quantum memories will also be reported.

[1] Knill, E., et al., Nature 409, 46 (2001).

[2] Duan, L. M., et al., Nature 414, 413 (2001).

[3] Beavan, S.E., et al., Phys. Rev. Lett. 109, 093603 (2012)

366

Tackling quasiparticle poisoning errors in Majorana qubits via quasiparticle detection

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Abstract

Quasiparticle poisoning errors in Majorana-based qubits are not suppressed by the underlying topological properties, which undermines the usefulness of this proposed platform. This work tackles the issue via quasiparticle measurement. Error-detecting Majorana stabilizer codes are constructed whose stabilizers can be measured by means of Wannier position operators. For a logical qubit encoded in one of these codes, the Pauli error rates are exponentially suppressed in the code distance, a result tied to the exponential localization of Wannier functions. The benefit comes at the cost of a qubit loss rate that increases linearly with the distance, but these can be readily compensated for by a suitable outer code. The framework developed here serves as a basis for understanding how realistic measurements, such as conductance measurements, could be utilized for achieving fault tolerance in these systems. The work also demonstrates that the theory of Wannier functions could lead to error correcting codes beyond the standard stabilizer codes, uncovering another fruitful connection between condensed matter physics and quantum information theory.

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Euclidean and Hamiltonian formulations of black hole thermodynamics in cosmological settings

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Abstract

We describe the difficulties, both technical and conceptual, of extending black hole thermodynamics to the cosmological realm. We discuss the relationship between the Hamiltonian and Euclidean formulations of the laws of black hole thermodynamics: how they differ, where they coincide, and the utility of each approach to different classes of problems. By considering a regular black hole geometry as a prototypical example, which contains a number of confounding features in its construction, we are able to highlight the roles of symmetry inheritance, matter content, and equilibrium in the formulation of the laws of black hole thermodynamics. We demonstrate how both the Euclidean path integral and Hamiltonian forms can be applied to the problem, and show consistency between the two descriptions in regimes where appropriate comparisons can be made.

Based on the following preprints: 2309.13894, 2309.09439

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Swift Heavy Ion Modified Materials: Applications and Characterisation using Synchrotron Small Angle X-ray Scattering

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Abstract

When highly energetic heavy ions traverse through a target material, the high electronic excitations can generate long cylindrical damaged regions termed 'ion tracks'. Ion tracks have many interesting applications across a variety of scientific areas such as materials science and engineering, biophysics, nanotechnology, geology, archaeology, nuclear physics, and interplanetary science. Ion track damage often exhibits preferential chemical etching over the undamaged material. This etch-anisotropy can be used to create pores of up to tens of microns in length, with pore diameters as small as several nanometres. Membranes fabricated by this method are ideal for many advanced applications including ultra-filtration, bio- and medical sensing, nano-fluidics, and nano-electronic devices. A key advantage of the technique is the ability to generate highly parallel pore arrays with extremely narrow size distributions.

Small angle X-ray scattering (SAXS) provides an interesting tool to study the structure of ion tracks and track-etched nanopores, as it is sensitive to density changes on the nanometre length scale. It is non-destructive and can yield high precision measurements of the track and pore structure in many materials. Short acquisition times associated with the high photon flux at 3rd generation synchrotron facilities enable in situ studies.

The presentation will give an overview of our recent results on the development of functional nanopore membranes in polymers and inorganic materials using ion track etching. This will include fabrication of pores in SiO2 and SiONx and their application in nanofluidic diodes, separation membranes and biosensors. A particular focus will be put on the characterisation of ion tracks and nanopores using SAXS which ultimately enables precise fabrication of the nanopores. Results include the determination of the detailed morphology and etching kinetics of nanopores as well as the detailed geometry of tracks and pores in polymers.

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Inverse Design of Aperiodic Multi-notch Bragg Gratings Using Neural Networks

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Abstract

Detecting signals from celestial Positronium (Ps) in the near-infrared band improves the angular resolution by at least a thousand times compared to current gamma-ray detections. The problem is that the target recombination lines of Positronium (Psα lines) lie in the intense background of OH emission lines from the earth atmosphere and will be potentially overwhelmed by the OH lines.

An aperiodic multi-notch fiber Bragg grating (AFBG) has been demonstrated as an effective solution for OH suppression. In previous work on celestial Psα detection, we already demonstrated fabrication of astronomy J-band AFBGs and proposed a design of OH-suppressed spectrograph. We also pointed out designs based on the traditional layer peeling algorithm, facing significant computational challenges during the optimization steps. Inspired by the rapid advancements in photonic design techniques based on neural networks, we recently developed a novel AFBG optimization design approach employing Artificial Neural Networks (ANN) in conjunction with Genetic Algorithms (GA) for the first time. Here, we report a detailed implementation and outcomes of this method. Additionally, we will present the latest progress in the development of an OH-suppressed spectrograph for Psα detection.

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Optimizing Laser-Induced Periodic Surface Structures: A New Approach to Nanostructuring Control

Vlalden Shvedov, Yana Izdebskaya, Ilya Shadrivov
ANU, Canberra, Australia

Abstract

Nanostructured surfaces have grown in demand for various industrial, biomedical, and scientific applications. While lithography techniques are commonly employed for achieving precise nanostructuring, they suffer from drawbacks, such as multiple steps, relying on masks, and incurring high costs and time consumption [1].

Ultrashort laser irradiation generating laser-induced periodic surface structures (LIPSS) has emerged as a reliable and cost-effective alternative to lithography for the nanostructuring of various solid surfaces. LIPSS formation can be achieved in many complex forms on a wide range of materials by varying wavelengths, pulse durations, and polarization [2]. Presently, it is possible to create nanostructured patterns on the surfaces of solids where the formation of LIPSS can reach a speed up to ~ 1 cm2 per 1s [3]. However, there are inherent challenges in controlling LIPSS's formation. Typically, LIPSS forms in the femto- or picosecond pulse range with periods equal to the incident wavelength, and orientations orthogonal to polarization. Therefore, achieving precise control over the periodicity of the nanostructure and the orientation of the forming nanopattern remains challenging especially for low-cost long-pulse laser systems.

Addressing these control challenges, we propose an approach to manipulate LIPSS orientation and period by adjusting incidence angles, beam scan directions, and laser polarization angles. Our method achieves full control over LIPSS periodicity and orientation on large surfaces, using pulsed lasers in the nanosecond range. Contrary to conventional understanding, we found LIPSS can be predictably tilted relative to polarization. This enhanced control opens up unprecedented possibilities for tailoring the properties of nanostructured surfaces, positioning laser-writing technology as a highly competitive solution for advanced industrial applications reliant on surface nanostructuring.

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The Cherenkov Telescope Array Observatory – Unveiling the Very-High-Energy Gamma-ray Sky

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Abstract

The Cherenkov Telescope Array is the next-generation observatory (CTAO) for ground-based gamma-ray astronomy. With more than 100 telescopes equipped with state-of-the-art technologies, it will provide a new view of the sky at energies from 20 GeV to 300 TeV at unprecedented sensitivity and angular resolution. CTAO will be a key contributor to multi-wavelength and multi-messenger astronomy, and its unique capabilities will allow us to explore the most extreme phenomena in the Universe. For example, the telescopes' very large collection area and rapid slewing are crucial to capture and probe transient phenomena, such as gamma-ray bursts and fast radio bursts.

In this contribution, I will present the status of the observatory, introduce its key science projects, and highlight synergies between CTAO and Australian facilities and research interests. In particular, I will discuss the importance of combining gamma-ray and radio observations, motivating the partnership to the Square Kilometre Array Observatory - the world's largest radio telescopes in the near future.

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Towards a Dynamic and Switchable All-Optical Image Processing Device

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Abstract

The urge for immediate, software-independent all-optical image filtering without the need for post-processing is increasing with the requirement for fast operation, reliability, and robustness. This study unveils a fascinating new approach towards switchable image filtering devices drawing inspiration from the concept of a Salisbury screen [2]. This novel method paves the way to real-time dynamic image processing holding immense potential in various fields of applications such as microscopy, facial recognition, or medical and biological imaging.

The general concept is based on the possibility of altering the properties of a conducting polymer by driving its inherent electrochemical redox reaction. By simply changing the applied voltage between a positive and negative CMOS-compatible value, the material properties such as the refractive index can be adapted. This change in the refractive index can be directly utilized to adapt the functionality of devices such as an optical filter. Besides turning the operation of a system fully on and off, a gradual change of the refractive index can be used to continuously vary the performance of the image processing device.

Combining this approach of changing the material properties with the concept of Fourier filtering of certain spatial frequencies known from static approaches such as the Salisbury screen generates the possibility of working our way towards a novel device with adaptive properties.

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Inverse Designed Multimode Photonic Devices for Classical and Quantum Information Processing

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Abstract

Traditionally photonic integrated circuits have primarily sought to avoid the effects of higher order transverse modes by tailoring waveguides to only operate within the single-mode regime. More recently, the additional transverse modes contained within a multimode waveguide have been proposed for error mitigation in classical optical processors and demonstrated for quantum gates and engineered integrated near-ideal photon-pair sources. However, the design of multimode components is often more challenging than their single mode counterparts. Using photonic inverse design methods to optimise the devices topology we design a dual mode multiplexer and beamsplitter, for the purposes of preparing and mixing the two lowest order transverse modes of a multimode waveguide. We demonstrate a total transmission of 36.7% (44.2%) for the TE0 mode, and 43.4% (42.5%) for the TE1 mode for the through (cross) ports at the design wavelength of 1550nm. The demonstrated devices are useful for the realisation of large-scale programmable classical and quantum processors which utilize the transverse mode degree-of-freedom

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Learning out-of-time-ordered correlators with quantum kernel methods

John Tanner, Jason Pye, Yusen Wu, Shengxin Zhuang, Jingbo Wang, Lyle Noakes, Wei Liu, Du Huynh
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Abstract

Out-of-time-ordered correlators (OTOCs) [1,2] have been used to diagnose chaotic evolutions or "scrambling" in quantum systems undergoing unitary evolutions, particularly in the study of black holes and quantum many-body systems. OTOCs are also used in the famous Lieb-Robinson bound to specify upper bounds on how quickly local information can propagate and "spread" through highly-interacting quantum systems so determining OTOCs is of significant theoretical interest for a variety of topics in physics. However, calculating OTOCs classically is intractable since working in the Heisenberg picture of quantum mechanics requires us to represent unitary matrices whose size grows exponentially in the number of qubits, so relying on classical simulations is not practical.

Quantum kernel methods [3,4] are an active topic of research in the field of quantum machine learning, mostly thanks to the celebrated representer theorem, which allows us to reformulate a possibly infinite-dimensional risk-minimisation problem in a feature space called the reproducing kernel Hilbert space, into a finite dimensional optimisation problem in the same space. A handful of instances of quantum kernels achieving a theoretical advantage exist in the literature and in this work we discuss how quantum kernel methods can be used to predict the values of a certain class of OTOCs and provide another opportunity for quantum advantage.

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Tailoring bubble surfaces for microalgae flotation

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Abstract

The presence of nuisance and harmful algae blooms is increasing globally due to increased eutrophication and climate change. This induces poor water quality in natural water systems and causes challenges for drinking water treatment. Conventionally, algae are typically treated by chemical dosing with a coagulant to enable agglomeration into larger particles which can then be separated by downstream processes, such as flotation, which is a popular separation process for algae as it takes advantage of their natural buoyancy. However, algae can be difficult to coagulate and flocculate due to their highly variable morphology, the mobility of some species, and the associated algal organic matter. Unsuccessful flocculation means downstream separation can be unsuccessful, leading to carry-over of algae into final water. To circumvent this issue, rather than relying on upstream flocculation, we instead tailored bubble surfaces to make them more attractive to algae, a technique termed PosiDAF. Specifically, hydrophobically-modified polymers were used to both create a positively-charged bubble surface, while increasing the bubble's swept volume to enhance cell capture without needing to flocculate. Our subsequent research showed that the associated algal organic matter interacted with the polymers to improve cell separation by forming extensive, web-like, polymeric strands, that enhanced the process. These suprastructures were integral to the success of the separation and it was determined that these were formed by interactions between uronic acids and proteins via glycosylation. Overall, a detailed understanding of soft matter was critical to explain and optimise algae separation using this PosiDAF technique.

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Bridging the Gap: Industry Mentoring of Undergraduate Physics Students to Connect First-Year Education with Career Prospects

Annette Dowd, Tracey Glover Chambers
University of Technology Sydney, Broadway, Australia

Abstract

Students continuously compare their learning experiences with their expected career. They may become discouraged if they find a mismatch between the two contexts. Preliminary surveys showed this is a factor in retaining students in physics at UTS. Although our physics programs are designed for the holistic development of the students as professionals in physics-based careers, there are several reasons why students may still mistakenly judge themselves as unsuitable for such professions, including an incorrect vision of the diverse physics-based careers available, and the first year focus on mastering challenging technical skills necessary for further learning.

Mentoring has been shown to have a positive effect on mentees' retention and career planning by promoting science outcomes for the mentees and positive attitudes about science. This has been particularly effective for students belonging to underrepresented groups in science.

We delivered a one-semester mentoring program for first year physics students at UTS. This began with a workshop on Designing Your Career, tailored for physics students, encouraging them to think about career development from their first year. This was followed by a panel session with the mentors to enthuse the students about a range of career paths. The mentors were AIP members and UTS alumni with a range of career paths and experiences. Students were given a choice of mentor with whom they took part in a structured weekly program of discussions on career concepts relevant to physics-based careers.

Students who took part in the program are more aware of the importance of developing both technical skills and soft skills while an undergraduate and a wider range of career trajectories. Analysis of interviews revealed that students find incredible value in being shown bridges between where they are now and where they could be in future, particularly in the challenging environment of first year physics.

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Er sites in Si for quantum applications

Alexey Lyasota[1], Ian R. Berkman[1], Gabriele G. de Boo[1], John G. Bartholomew[2,3], Shao Qi Lim[4], Brett C. Johnson[4,5], Jeffrey C. McCallum[4], Bin-Bin Xu[1], Shouyi Xie[1], Rose L. Ahlefeldt[6], Matthew J. Sellars[6], Chunming Yin[1,7], Sven Rogge[1]
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Abstract

Rare-earth ions incorporated in several solid-state hosts were shown to exhibit low homogeneous broadening and long spin coherence at cryogenic temperatures making them a promising candidate for quantum applications, such as optical quantum memories, optical-microwave transductions, and quantum communication. However, long electron spin coherence has not been demonstrated in Si, a leading material platform for electronic and photonic applications. Here, we present the first demonstration of Er sites in semiconductor (Si) with a millisecond electron spin coherence time, optical homogeneous linewidths below 100 kHz, spin and optical inhomogeneous broadening approaching 100 kHz and 100 MHz, correspondingly. Er properties were measured using photoluminescence excitation spectroscopy within a nuclear spin-free silicon crystal (<0.01% 29Si) doped at 1016 cm-3 Er level. Er homogeneous linewidth and spin coherence were addressed using optical comb-based spectral hole burning and optically detected magnetic resonance. To enhance Er emission collection efficiency, samples were directly positioned on top of dedicatedly fabricated superconducting single photon detectors and resonantly excited using fiber optics. Measurements in naturally abundant Si revealed that the Er electron spin coupling to 29Si nuclear spins significantly shortens Er spin coherence times. Long spin coherence time and narrow optical linewidth show that Er in 28Si is an excellent candidate for future quantum information and communication applications.

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Photoluminescence excitation spectroscopy comparison study of multiple erbium sites in silicon

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Abstract

Erbium doped materials provide interaction with light at the technologically important C-band (1530-1565 nm). Whereas the classical application of erbium doping is to create an optical gain medium, for quantum application erbium can also be used to create quantum memories, single photon sources and transducers between optical and microwave photons. Silicon is an appealing host material because of the electronic and photonic structures that can be fabricated with it.

When erbium is doped into silicon, it can form various sites with different electronic structures. Which sites form depends on the doping method, the doping concentration and the presence of other dopants in the silicon. It is essential for fabricating effective erbium doped silicon devices that specific sites can be created preferentially.

We will present a photoluminescence excitation spectroscopy study of erbium in silicon where we vary the density of the erbium as well as the density of oxygen, phosphorus and boron in the silicon host. We find that as the concentration of erbium is reduced, the number of luminescence lines decreases, indicating that fewer erbium sites are formed. The inhomogeneous linewidth of these lines also reduces with lower doping density. We find that at low temperatures and low erbium densities, we can polarise the spin population and measure a spin-lattice relaxation time up to 30 s. The relaxation time decreases as the magnetic field is increased and we find a field dependence of B^{-5}. Creating specific erbium sites with long spin lifetimes will enable various quantum applications.

386

Nanohertz-frequency gravitational wave astronomy with the Parkes Pulsar Timing Array and beyond

Daniel Reardon
Swinburne University of Technology, Melbourne, Australia

Abstract

The Parkes Pulsar Timing Array (PPTA) is a major project on the Parkes Radio Telescope (Murriyang), with the primary aim of detecting nanohertz-frequency gravitational waves (GWs). A background of GWs (GWB) modulates pulsar arrival times and manifests as a stochastic process, common to all pulsars, with a signature spatial correlation. In this talk I describe our recent search for an isotropic stochastic GWB using the third data release of the PPTA. We recover a noise process with a common spectrum among the pulsars, which exhibits characteristics consistent with that expected of a GWB from supermassive black hole binaries. We also search for the spatial correlations expected from a GWB and estimate the significance of these correlations as 2 sigma in our data set. However, contrary to expectations for the GWB from an isotropic population of inspiralling supermassive black hole binaries, we demonstrate that the apparent signal strength is changing with time. I will discuss these results in the context of recent analyses from other international pulsar timing array collaborations and describe the exciting outlook for nanohertz gravitational wave astronomy with the sensitive new MeerKAT pulsar timing array.

388

On-chip microwave generation with the Josephson laser

Maja Cassidy
University of New South Wales, Sydney, Australia

Abstract

Superconducting electronic devices have reemerged as contenders for both classical and quantum computing due to their fast operation speeds, low dissipation, and long coherence times. In this talk, I will discuss our recent work in Josephson photonics to generate microwave radiation on-chip. We use one of the fundamental aspects of superconductivity, the ac Josephson effect, to demonstrate a laser made from a Josephson junction strongly coupled to a multimode superconducting cavity. A dc voltage bias applied across the junction provides a source of microwave photons, and the circuit's nonlinearity allows for efficient down-conversion of higher-order Josephson frequencies to the cavity's fundamental mode. The simple fabrication and operation allows for easy integration with a range of quantum devices, allowing for efficient on-chip generation of coherent microwave photons at low temperatures. Future devices, including single microwave photon generators and detectors will also be discussed.

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Quantum data science

Barry Sanders
University of Calgary, Calgary, Canada

Abstract

I provide a perspective on the development of quantum computing for data science, including a dive into state-of-the-art for both hardware and algorithms.

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The future is here! Diprotodon’s, Potoroo’s, ORC’s and other new wonders of radio surveys.

Miroslav Filipovic
University of Western Sydney, Sydney, Australia

Abstract

This is an exciting time for the discovery of SNRs and PWNe in our and other nearby galaxies. They offer an ideal laboratory as they are near enough to be resolved yet located at relatively known distances. Various new-generation surveys through the entire waveband reflect a major opportunity to study different objects and processes in the elemental enrichment of the interstellar medium (ISM). SKA pathfinders' observations in radio regime with high sensitivity detects new SNRs and PWN in our Galaxy and the MCs, which are either old and too faint, young and too small, or located in a too confusing environment and have thus not been detected yet. In addition, the SKA pathfinders' observations also allow high-resolution polarimetry and are key to the study of the energetics of accelerated particles as well as the magnetic field strength and configurations.

Gamma-ray studies provide answers to the long-standing question in high-energy astrophysics: Where do cosmic rays come from? The gamma-ray emission seen from some middle-aged SNRs is now known to be from distant populations of cosmic rays (probably accelerated locally) interacting with gas, but there is still much work to be done in accounting for the Galactic cosmic-ray flux. Young PeV gamma-ray supernova remnants require different techniques to address the question of cosmic-ray acceleration. The Cherenkov Telescope Array will allow us to do this.

I will review the most recent scientific outcomes from various new high-resolution (~arcsec) and sensitivity surveys such as ASKAP, MWA, ATCA and MeerKAT (radio). This is in addition to large multi-frequency surveys from XMM-Newton & eROSITA (X-rays), Herschel and Spitzer (IR), MCELS (optical) and HESS (gamma rays).

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Catching the earliest radio light from TeV Gamma-ray Bursts

Gemma Anderson
Curtin University, Perth, Australia

Abstract

The excitement of the publicly announced 2019 TeV-detected GRBs motivated global multi-wavelength follow-up efforts, reinvigorated this field of transient astrophysics. Such detections have revealed the unexpected: TeV GRB emission may not be generated via synchrotron self-Comptonisation. Studies of the X-ray to VHE gamma-ray light curves of GRB 190828A by the H.E.S.S. collaboration demonstrated the afterglow may be better described by a single-component synchrotron spectrum up to TeV energies, which violates the maximum synchrotron photon energy assumptions.

While high-energy and optical follow-up of the 2019 TeV GRBs occurred within minutes of the discovery, most radio follow-up lagged behind by several days. This is concerning as only early-time radio detections of GRBs can constrain the properties of the GRB ejecta and environment or disentangle other emission components from the forward shock. Luckily, the discovery of GRB 221009A (coined the B.O.A.T. or the "brightest of all time") has resulted in the most comprehensive early-time radio follow-up of any GRB to date. It has revealed that the standard synchrotron afterglow models fail in the radio band at early times.

Motivated by our need for early-time radio follow-up to aid our interpretation of TeV GRBs, we developed the PanRadio GRB program in collaboration with H.E.S.S. and CTA astronomers, which uses the Australia Telescope Compact Array (ATCA) to rapidly and automatically follow-up newly discovered Swift GRBs, providing the very earliest radio detections of these events. I will present early results from the PanRadio GRB programme, including the detection of the earliest radio detection of a GRB to date! Finally, I will discuss the ongoing radio monitoring of GRB 221009A as we continue to unravel the blast wave components of this TeV GRB. Such experiments are an excellent demonstration of the transient science that could be achieved via CTA and Square Kilometre Array synergies.

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Dark matter searches at the Cherenkov Telescope Array and beyond

Martin White
University of Adelaide, Adelaide, Australia

Abstract

I will present a brief summary of our current knowledge of the particle properties of dark matter, based on comprehensive global fits of candidate theories with a wide range of observational data. I will then detail the preparations for dark matter searches at the Cherenkov Telescope Array, including the required knowledge from other astrophysical sources in order to reach the discovery potential of CTA.

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Protein engineering via quantum machine learning

Shengxin Zhuang[1], Matthaus Zering[1], John Tanner[1], Jason Pye[1], Wei Liu[1], Du Huynh[1], Frederic Cadet[2], Jingbo Wang[3]
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Abstract

Engineering proteins with desired functionality has broad applications in molecular biology, biotechnology, biomedical sciences, health, and medicine [1,2]. However, the vast expanse of protein sequence possibilities presents a formidable challenge for protein engineering efforts employing directed evolution and rational design. Similar to how natural languages consist of sequences of letters, protein sequences are structured in a manner that lends itself to computational analysis. In recent years, there has been a growing effort to utilize computational techniques, including classical deep learning-based models, in protein research. Nevertheless, these approaches face limitations due to data scarcity, the high cost of training, and the substantial number of required training parameters, all of which impede the development of cost-effective yet powerful models [3].

On the other hand, quantum computers are gradually becoming a reality, and their potential for exponential growth in computational power holds the promise of significant acceleration [4]. This research seeks to explore solutions within the realm of quantum computing to address the challenges that classical machine learning and deep learning approaches encounter in the field of protein research. The overarching goal is to enable faster and more efficient biomolecule design, ushering in new possibilities for advancement in the field.

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Single photons: from the Hanbury-Brown Twiss experiment to photonic learning machines.

Gerard Milburn
University of Queensland, Brisbane, Australia

Abstract

**the concept of a single photon lies at teh heart of quantum optics. I will discuss the concept of a single photon state state from its beginning wiht Einstein to early experiments in quantum optics through to quantum learning machines. Examples will inline their application to quantum sensing, quantum computing and communication and tests of proposed theories of quantum gravity.
One example, based on a quantum optical perceptron, suggests that power consumption of quantum learning machines can be very low compared to classical equivalents because, at optical frequencies, the temperature is effectively zero so this perceptron is as efficient as it is possible to get. The example illustrates a fundamental general point: In a classical learning machine, measurement is taken to reveal objective facts about the world. In quantum learning machines what is learned is defined by the nature of the measurement itself.**

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Sustainable and compostable plastics

Luke Connal
Australian National University, Canberra, Australia

Abstract

Petrochemically sourced polymers, including synthetic rubbers and silicones, are environmentally unsustainable. These plastics are sourced from non-renewable fossil fuels, prepared using harsh and toxic chemical reagents, and end their life in landfill (at best) or discarded in the natural environment (at worst). This places an economical and environmental burden on not only the manufacturer, but also the consumer.

Eventually, the use and production of these petrochemical plastics will have to be phased out. However, modern society is dependent on the use of these materials. As such, transitioning to a sustainable and renewable alternative which still provides the advantages of conventional plastics represents an impending and time-sensitive challenge. Current solutions on the market for sustainable materials typically fail to offer a practical shelf life or sustainable end-of-life strategies, with many being biodegradable but only in specialised facilities. In addition, they are not typically competitive with respect to economic viability.

This presentation will highlight some of my groups strategies to prepare sustainable plastics from renewable feedstocks. In particular our development of a novel and entirely green vitrimer system using sustainably sourced vegetable oil mixed with spent coffee grounds.

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Einstein-Podolsky-Rosen correlations, an objective-field Q model, and hidden causal loops.

Margaret Reid
Swinburne University, Melbourne, Australia

Abstract

The Einstein-Podolsky-Rosen (EPR) paradox was presented in 1935 as an argument that quantum mechanics is an incomplete theory. The argument motivated Bell's theorem, which ruled out that any local hidden variable theory could complete quantum mechanics. The correlations of EPR, which are based on entanglement, were realised in quantum optics, and provided a foundation for the field of quantum information. Here, we review EPR correlations. We explore the responses of Bohr and Schrödinger, and point to Bell's discussions of the importance of the measurement problem - how does the wavefunction collapse to the eigenstate on measurement?

By examining the dynamics of the phase-space variables of the Q function, we present a model for measurement based on amplification that may elucidate the nature of EPR nonlocality. The measurement dynamics is shown equivalent to backward-propagating and forward-propagating equations in time, for phase-space variables x and p. For superposition and entangled states, the counter-propagating trajectories are linked by a boundary condition defined at the time after the measurement setting is fixed, but before amplification. Despite the apparent retrocausality of the amplified variable, we demonstrate consistency with macroscopic realism - a system in a superposition of macroscopically distinct states (a cat state) has a predetermined value for a measurement that will distinguish those states. This gives a mechanism explaining why there is no macroscopic retrocausality: Examination of the boundary condition reveals that entanglement leads to hidden causal loops. Similar forward-backward equations are derived for the two-mode interaction generating EPR entanglement. A link with Born's rule motivates a model in which Bell violations are explained as arising not just from a failure of realism, nor just from failure of locality: The violations are consistent with a weak form of local realism, defined for the system after the measurement setting has been fixed.

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Towards gravity and force gradient sensing on compact devices: A readout free scheme for measuring phase shifts and differential phase shifts with overlapped spatial fringes matter-wave interferometry

Yosri BEN AICHA, Ryan Thomas, Zain Mehdi, Simon Haine, Paul Wigley, Kyle Hardman, John Close
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Abstract

Recent advancements in Large Momentum Transfer (LMT) have accentuated the potential of Bragg tran- sitions in atom interferometry, as highlighted in recent studies [1, 2]. These developments underscore the profound capabilities of multiphoton transitions with large momentum transfer, complemented by an innate robustness to AC Stark shifts. Nevertheless, a traditional hurdle with Bragg transitions, in contrast to Raman transitions, has been the difficulty in distinguishing between the interferometer's output ports immediately after the final beam-splitter pulse. This limitation typically meant allowing the atom clouds to spatially separate, which introduced a readout delay and reduced the total time available for phase interrogation. While recent mitigation strategies, such as the use of a Bloch separator , have addressed this issue to some extent [3], they also introduce challenges like cross-coupling effects between the two output ports. In response to these challenges, we've developed a scheme using overlapped spatial fringes, enabling the effective extraction of phase information and eliminating the need for readout delays. An additional advantage of this method is its capability for concurrent sensing of gravity and force gradients. Building on the progress in LMT and this new approach, we foresee atom interferometer designs can evolve towards both enhanced compactness and versatility.
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Validating GBS quantum computers in phase-space

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Abstract

There are multiple claims of computational advantage with quantum computers. This raises questions of validation for the tasks that are solved. How is quantum advantage verifiable? Are the answers obtained even correct? Brute-force computational verification of outputs is impossible as no classical computer is sufficiently powerful. Computing all the results is exponentially hard, not just from computational hardness, but because the measured data is often exponentially sparse in many current experiments.

Gaussian boson sampling is used in several computational advantage claims. We show that simulations in quantum phase-space can solve the validation problem by generating any correlation or diagnostic of the outputs that is measurable. This uses an FFT algorithm to obtain binned, computable statistics, with up to 16,000 qubits in test cases, which is far larger than in any current experiment. We find that recent experimental data from China and USA is significantly different from theory, with over 100 standard deviations of discrepancy with predictions of the measured statistics. Physical explanations are explored for this.

This does not disprove the computational advantage claims, and we explain why. We show that quantum network outputs do not currently survive the chi-squared tests normally employed to test validity of random numbers. However, some of the datasets give evidence of quantum advantage for another task, of decoherent GBS. This may still be exponentially hard. Another use of our methods is to show that faking the results is far tougher than previously thought, since a random subset of exponentially many high-order binning methods can rule out classical fakes. We test this on proposed faking algorithms, although this is not yet conclusive.

Finally, we point out how similar techniques may be useful in other quantum network and quantum computer designs. The principle is to use scalable theories that generate probabilities, rather than wave-function based methods.

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Weak Coupling Renormalization Group Approach to Unconventional Superconductivity

Sebastian Wolf
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Abstract

Topological superconductivity constitutes a class of unconventional superconductors which are sought after for their applications as a material platform for fault-tolerant quantum computing. Until now, however, only a handful of candidate materials are known, and the lack of understanding of what exactly drives those phases represents a major challenge. The presented work extends the weak coupling renormalization group method, which we employ to provide a systematic study of unconventional superconductivity in two dimensional lattice systems. One of the major goals is to find out which of the possible "ingredients" – lattice symmetries, longer-range effects, multi-orbital effects, topology of the non-interacting system, and spin-orbit interactions – can promote the formation of topological superconducting states. We apply our method to paradigmatic lattice models and study applications to real materials.One of the overarching conclusions is that strong longer-range effects, like longer-ranged hopping and nearest-neighbor interactions, tend to benefit topological superconductivity. Furthermore, lattices with hexagonal symmetry seem to be especially beneficial for topological superconducting states with (relatively) high critical temperature.

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Calibrating the role of entanglement in variational quantum circuits

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Abstract

Entanglement is a key property of quantum computing that separates it from its classical counterpart, however, its exact role in the performance of quantum algorithms, especially variational quantum algorithms, is not well understood[1–4]. In this work[5], we utilise tensor network methods to systematically probe the role of entanglement in the working of two variational quantum algorithms, the Quantum Approximate Optimisation Algorithm (QAOA)[6] and Quantum Neural Networks (QNNs)[7], on prototypical problems under controlled entanglement environments. We find that for the MAX- CUT problem solved using QAOA, the fidelity as a function of entanglement is highly dependent on the number of layers, layout of edges in the graph, and edge density, generally exhibiting that a high number of layers indicates a higher resilience to truncation of entanglement. This is in contrast to previous studies[1] based on no more than four QAOA layers which show that the fidelity of QAOA follows a scaling law with respect to the entanglement per qubit of the system. Contrarily, in the case of QNNs, circuits trained to classify images in the standard image datasets (MNIST[8], FMNIST[9] and CIFAR[10]) to high accuracy are underpinned by higher entanglement, with any enforced limitation in entanglement resulting in a sharp decline in test accuracy. This is corroborated by the entanglement entropy of these circuits which is consistently high suggesting that, unlike QAOA, QNNs may require quantum devices capable of generating highly entangled states. Overall our work provides a deeper understanding of the role of entanglement in the working of variational quantum algorithms which may help to implement these algorithms on NISQ-era quantum hardware in a way that maximises their accuracies.

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Coulomb excitation of ^{124}Te: persisting seniority structure in the 6^+_1 level

Martha Reece
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Abstract

Atomic nuclei are complex many-body quantum systems which demonstrate a wide range of excitation modes. Analogous to electrons in atomic systems, nuclei exhibit closed shells of protons and neutrons at particular `magic numbers'. Close to the magic numbers, nuclei are usually spherical, and are dominated by single-particle excitations, while far from the closed shells they often excite via `collective' motions. Observed excitation energies in isotopes near the Z = 50 magic number have historically been described by a vibrational model, though recent investigations have found that measured shape and collectivity observables fail to reproduce predictions of the vibrational model. A new research program at the Australian Heavy Ion Accelerator Facility is examining the nature of vibrations in near-spherical nuclei using `Coulomb-excitation' measurements. Coulomb excitation, the excitation of a nucleus via the Coulomb interaction at energies below the Coulomb barrier, is ideal for probing vibrational modes as it preferentially populates low-energy collective states. To facilitate these measurements, a new silicon photodiode particle detector system has been developed and integrated into the CAESAR array of Compton-suppressed ɣ-ray detectors. The first experiments studies ^{124}Te, a nucleus that lies near a transitional point between single-particle and collective behaviour just beyond the Z = 50 proton shell. The value B(E2; $6_1^+ \rightarrow 4_1^+$)=25(7)W.u was measured for the first time in this nucleus; this is significantly below the collective limits of the spherical-vibrator and triaxial-rotor models. The experimental results are compared to shell-model calculations for $^{120\text{-}128}$Te, which show remarkable agreement for the known B(E2; $6_1^+ \rightarrow 4_1^+$) values. It appears that, despite approaching mid-shell, ^{124}Te retains its single-particle structure for the 6_1^+ level. This is in contrast to other B(E2) values in ^{124}Te, and neighboring ^{120,122}Te, in which collectivity becomes enhanced as more neutrons are removed.

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Proof-of-concept of a 90-port arbitrary spatiotemporal vector beam shaper over 90nm bandwidth and two planes of phase manipulation

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Abstract

Simultaneous controlling all the properties of a multimodal optical beam (spatial, polarization, spectral/temporal) is the holy grail of the spatiotemporal light field community [1], with potential application in non-linear optics and specific light-matter interactions. Recently, a device was proposed to generate arbitrary spatiotemporal vector beams, with the independent control of 90 spatial/polarization modes and 420 spectral/temporal modes across the C-band. While this device provides, to our knowledge, the largest control of spatiotemporal light fields, its main drawback is its spatiotemporal field dependent loss, due to its single plane of phase manipulation to control both amplitude and phase of the optical beam.

In this conference paper, we present the second generation of such spatiotemporal beam shaper, which should enable in theory lossless arbitrary spatiotemporal field generation. The first proof-of-concept device was conceived in cascading a wavelength selective switch (WSS) with polarization diversity, and a multiplane light conversion device. The hologram that would reshape the spatiotemporal profile of the output beam is located in the WSS by means of a spatial light modulator. The second generation of the device, whose diagram is presented in Fig. 1, presents an additional optical system (wavelength blocker), which provides access to a second plane of phase manipulation. Such novel prototype allows to control 90 spatial/polarization modes across 110nm of bandwidth centered at 1550nm with less loss than the first prototype, which provides three times more bandwidth of control than the first prototype, opening new possibilities to control shorter pulses of light and thus allowing more control of light-matter interactions.

431

Investigation of shape coexistence and triaxiality from fast-timing measurements in Pt-188 and Pt-190

Hanaa Alshammari
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Abstract

Nuclear level lifetimes provide essential insights into the underlying structure of atomic nuclei. This study utilized fast-timing measurements to investigate neutron-deficient platinum isotopes, 188Pt and 190Pt, employing LaBr3 detectors and the ANU 14UD pelletron accelerator. These isotopes are particularly intriguing due to their low-lying energy states exhibiting behaviour suggestive of triaxial deformation, while their lighter neighbours show clear evidence of shape coexistence providing an opportunity to explore the interplay between different nuclear shapes. The Generalised Centroid Difference method was employed to determine mean lifetimes, enabling the calculation of reduced transition strengths for the 2+ → 0+ transitions, establishing an evolving behaviour as the mass number increases. Additionally, longer lifetimes that were observed for selected states e.g., 7- and 12+ in 188Pt and 190Pt enabled a more traditional exponential-decay method to be used and these transition strengths are expected to help resolve outstanding issues particularly in 188Pt regarding the interpretation in terms of shape-coexisting prolate and oblate shapes.

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Cosmogenic radioisotope production in NaI:Tl

Lindsey Bignell
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Abstract

High-energy cosmic rays, particularly high-energy neutrons, may interact with nuclei through spallation and other processes to produce radioisotopes. Cosmogenic radioactivity is a key concern for rare event particle physics searches, so that predicting, understanding, and perhaps mitigating it, is of great interest. However, models of the processes that give rise to cosmogenic production vary greatly, suggesting the need for additional work, especially experimental constraints. Established measurement methods involve exposing a sample to ambient cosmic rays, followed by underground measurements. In this work, I will give an overview of a new technique used by our group of collaborators that makes use of a cosmic-like neutron beam at a spallation neutron source. Our approach offers complementary systematics to existing methods of assessing long-lived cosmogenic isotope production, and allows the measurement of short-lived isotopes, which may also be used to help better constrain model predictions.

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Directional Dark Matter Detection and the CYGNUS Collaboration

Alasdair McLean
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Abstract

Dark Matter (DM) constitutes 85% of the mass in the known Universe; however, a DM candidate particle, such as a Weakly Interacting Massive Particle (WIMP), has never been measured directly. The University of Sheffield (UoS) has a rich history in the field of DM detection with a particular focus on directionality. Directionality is seen as a viable method for discriminating between potential WIMP interactions and solar neutrinos, which will soon become a limiting factor for the leading particle DM experiments. This passion for uncovering the mystery of DM drove the foundation of what is now the UKs national underground laboratory at Boubly. Located 1.1 km below the surface in a fully operational polyhalite mine, Boulby Underground Laboratory has been the host to several pioneering experiments including the Directional Recoil Identification From Tracks (DRIFT) experiment which currently boasts the most sensitive directional DM search to date. The DRIFT group at the UoS is now part of the international CYGNUS collaboration which represents the next generation of directional DM detectors. In this talk, we will give a broad overview of directional DM detection, its history at the UoS, and the future of the field with the CYGNUS collaboration.

POSTER PRESENTATIONS

3

General Introduction to Inverse Anti-mass Gravitation Space Coupling Plasma By John Downes

John Downes
Australian Institute of Physics, Melbourne, Australia

Abstract

General Introduction to Inverse Anti-mass, Gravitation Space Coupling Plasma Abstract By John Downes Gravitational rotation coupling of space between two objects, A and B, is due to the inverse acting, anti-mass, of the rotation coupling space between the two objects. The normal external gravitation mass of each coupling body and the inverse acting anti-mass of the outer coupling space, do not annihilate each other but can rotate area around each other, in such a way as to align the bidirectional motion of space rotation between the two objects. Theoretically, object A's bidirectional gravitation mass interaction creates a clockwise space rotation about object B. At the same time, the gravitation mass interaction of object B creates a coupling mirror image with anti-clock-wise space rotation about object A. Creating a space motion rotation axis that will depend on which object you are observing space motion rotation axis. The observer on each object remains stationary, while the observer on the other object will appear to be rotating around the stationary observer. Assuming the two gravitationally attracting objects have the same gravitation mass and are separated by coupling radial distances, r(A-B), equal to r(B-A), respectively, the attraction circular coupling space orbit diameter d, of each object is d = r(A-B) + r(B-A), and the orbit peripheral path distance of each object, 2ð r(A-B), and 2ð r(B-A), respectively, rotating in opposite directions. The rotation space alignment between the two objects is controlled by gravitation coupling Planck constant, hG, and combined rotation, space-time, motion acceleration. The Solar System space gravity constant, G(astro) , can occur at different gravitation coupling levels, G(strong), G(star), G(bulge), etc. The existence of the astrophysics gravitation coupling Planck constant, hG, also modulates gravitation coupling expansion and squeezing of terms between objects.

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Experimental observation of linear pulse evolution with high-order dispersion

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Abstract

Chromatic dispersion is one of the most important phenomena in optics, with implications in a wide range of applications. In most cases, dispersion is dominated by low orders (second and third) while high orders are only considered in systems with extremely broad spectra such as supercontinuum generation. There has been a growing interest in novel families of optical solitons arising from the balance of Kerr nonlinearity and a single, negative high, even order of dispersion. However, in this work, high-order dispersion effects are interacting with nonlinear effects, and only a handful of theoretical and numerical studies have investigated high-order dispersion acting alone on an optical pulse.

We recently developed a conceptual understanding of the effect of high-order dispersion, based on the observation that the effect of the dispersion is small for the part of the spectrum that is close to central frequency while the remaining part of the spectrum is strongly affected, leading to the formation of a pedestal in the temporal domain. Therefore, the evolution upon propagation is mainly determined by the central part of the pulse, which is well characterized by its full width at half maximum (FWHM).

In this work, we experimentally study the linear propagation of optical pulses affected by a single high order of dispersion. We use a programmable spectral pulse-shaper to apply a phase, centred around ω_0, that equals the phase that results from propagation in the presence of high-order dispersion up to order m = 12. The temporal intensity profiles of the resulting pulses are characterized by a set of phase-resolved measurements. Our results are in very good agreement with our previous theoretical results. They show that, provided that m is sufficiently large, the central part of the pulses follows the same evolution, with m only determining the rate of evolution.

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Disorder effects in the non-linear anomalous Hall effect of PT-symmetric Dirac fermions

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Abstract

Studies of the non-linear anomalous Hall effect (NLAHE), which underpin considerable theoretical and experimental research, have focussed on intrinsic mechanisms. Here we demonstrate that, in PT-symmetric systems, disorder contributes substantially to NLAHE and often overwhelms intrinsic mechanisms. In PT-symmetric systems, the non-linear response must be even in relaxation time and it is possible to show that the leading contribution scales with τ^2 while the sub-leading contribution scales as τ^0. Here we focus on the zeroth order coefficients where only the purely intrinsic sector has been studied so far. By purely intrinsic we mean a coefficient that depends only on band structure quantities. Then, in addition to this coefficient, we identify terms to zeroth order in the disorder strength stemming from skew scattering and side-jump, as well as an extrinsic Berry curvature dipole contribution. Importantly, the Berry curvature dipole contribution has been considered in PT-broken systems and we show that it also exists in PT-symmetric systems as a consequence of an electric field correction of the collision integral. We show that all non-linear coefficients originate from the Fermi surface. We discuss implications for experiments.

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Enhanced generation of optical harmonics from resonant silicon metasurfaces

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Abstract

Dielectric metasurfaces supporting optical resonances, such as Mie resonances, guided-mode resonances (GMR), and bound states in the continuum (BICs), may enhance significantly nonlinear light–matter interaction at the nanoscale. However, nonlinear dielectric metasurfaces made of centrosymmetric materials typically possess only odd-order nonlinearities, being limited by crystalline symmetry. Silicon, the most common semiconductor with a well-developed fabrication method, does not possess second-order nonlinearity in bulk. Here we demonstrate that, by employing high-Q optical resonances, it becomes possible to significantly enhance even harmonic generation from structured surfaces made of silicon. Our silicon metasurfaces are designed and fabricated to support both GMR and BIC optical resonances at the pump wavelength in the near-IR spectral range. THG and SHG demonstrated a huge enhancement up to 1500 which is strongly dependent on the pump wavelength and size parameters. Moreover, metasurfaces supporting BIC resonances demonstrate the fourth harmonic, while it is not observed in the film even at high power. Thus, we have observed the generation of second-, third- and fourth- optical harmonics from silicon metasurfaces enhanced by three orders of magnitude due to GMR and BIC resonances in the near-IR frequency range. We believe our work demonstrates that dielectric metasurfaces made of centrosymmetric materials can exhibit very strong second-order nonlinear effects provided they are empowered by high-quality optical resonances.

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Accurate Image Multi-Class Classification Neural Network Model with Quantum Entanglement Approach

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Abstract

Over the past decade, quantum machine learning (QML) has garnered significant attention in research. Numerous models have been developed to showcase the practical applications of quantum properties. This study begins by demonstrating that the previously proposed Quanvolutional Neural Network (QuanvNN) with a randomly generated quantum circuit enhances the image classification accuracy of a fully connected neural network on the Modified National Institute of Standards and Technology (MNIST) dataset from 92.0% to 93.0%, and on the Canadian Institute for Advanced Research 10 class (CIFAR-10) dataset from 30.5% to 34.9%. Furthermore, a new model called Neural Network with Quantum Entanglement (NNQE) is introduced. It employs a strongly entangled quantum circuit along with Hadamard gates, resulting in even better image classification accuracy on MNIST and CIFAR-10, achieving 93.8% and 36.0%, respectively. Notably, unlike other QML methods, this proposed approach does not require optimization of parameters within the quantum circuits. As a result, it only employs a limited use of the quantum circuit. Due to its small number of qubits and relatively shallow circuit depth, the proposed method is well-suited for implementation in noisy intermediate-scale quantum computers. While the outcomes were promising for the MNIST and CIFAR-10 datasets, when tested against the more complex German Traffic Sign Recognition Benchmark (GTSRB) dataset, the image classification accuracy decreased from 82.2% to 73.4%. The specific reasons for these performance improvements and degradations remain an open question, necessitating further research into understanding and designing appropriate quantum circuits for image classification neural networks, particularly for coloured and intricate data.

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Quantitative Polychromatic Dual Energy X-ray Imaging and Tomography

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Abstract

X-ray computed tomography (XCT) is a powerful tool, renowned for its ability to non-destructively produce highly-detailed 3D images of an object's internal structure. The scanning process involves taking a series of X-ray projections of the object of interest from many different angles and then computationally reconstructing a volumetric map of the object's X-ray attenuation coefficient. Conventional lab-based XCT invariably employs polychromatic (or broadband) X-ray radiation, which causes imaging artifacts since attenuation is a function of x-ray energy, making it difficult to differentiate materials, let alone obtain quantitative information.

We propose a two-material (2M) model for polychromatic XCT, inspired by Sellerer et al. [1]. This model builds on the well-known Alvarez-Macovski (AM) model, which demonstrated that X-ray attenuation for a material can be approximated by a simple function of its density, atomic number, and the energy of X-rays. The 2M model assumes that X-ray attenuation for a material can be modeled by a linear combination of that of two known materials (basis materials). We can then effectively reconstruct a quantitative estimate for density and atomic number from those of the two basis materials. Moreover, since these models capture the energy-dependence of attenuation, they inherently account for common reconstruction artifacts. The 2M model simplifies laboratory XCT calibration. Unlike the AM model, which requires full spectrum knowledge, the 2M approach only needs measurements of X-ray attenuation for specific basis material combinations to approximate where our target material fits.

We show that the 2M model to be an effective approximation for lower atomic-number elements, and it can completely remove beam-hardening artifacts in simulations of reconstructions. Further, we will present results on the application of the 2M model in a laboratory XCT system and discuss the potential for quantitative tomography.

[1] T. Sellerer et al., PLoS One 14, no. 7 (2019): e0219659.

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Macroscopic quantum three-box paradox

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Abstract

The interpretation of the quantum three-box paradox introduced by Aharanov and Vaidman has been the subject of debate. A particle is prepared in a superposition of being in one of three boxes A, B and C. Bob then makes a measurement to detect the particle by either opening box A or B. After applying a unitary transformation (shuffling), Alice is able to deduce by opening box C whether or not Bob had detected the ball in the box he opened. Paradoxically, it seems that the ball would have been with certainty in both boxes, A and B. It has been argued that the paradox is due to the assumption that Bob performs a non-invasive measurement. Alternatively, it is argued that, at the quantum level, realism does not hold, and it cannot be assumed that the particle in the superposition is actually in any one of the boxes. We strengthen the case for the former argument by transforming the paradox into a macroscopic version, involving macroscopic superposition states and nonlinear interactions. Macroscopic realism (MR) assumes the particle to be in one of the three boxes regardless of whether Bob or Alice opens any boxes. The results show consistency with MR if we define the premise carefully, as weak macroscopic realism (wMR), which applies only after the unitary transformation that determines the measurement basis, and which assumes a predetermination of the measurement outcome on a Box K, but does not make assumptions about the nature of the state of the particle. This means that a local unitary transformation on Box K is necessary to change the predetermination. However, consistent with wMR, the macroscopically paradoxical results are not obtained if Alice makes only a local transformation. We argue that the paradox is due to Bob's measurement disturbance, which has a non-classical origin.

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Scattering from a temporal medium

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Abstract

The electromagnetic waves can be controlled either by space, as it happens in the case of photonic crystals, or by similar variations in time-dependent parameters of the medium. For a spatially homogenous medium, if there is a sudden increase or decrease in the permittivity of the medium, it gives rise to the reflection and transmission of incident waves. Earlier studies had proposed that the reflected wave travels backward in time while the transmitted wave follows a normal way. It is expected that a periodic variation of permittivity, with respect to time, might give rise to several interesting phenomena, like frequency band gap and generation of new frequencies. The medium with periodic variation of the permittivity is called \say{temporal photonic crystal (TPC)}. In the frequency domain, the amplitude of the electromagnetic wave propagation through TPC may increase/decrease depending on the increase or decrease of the permittivity of the medium.

As the permittivity obeys causality and Kramer-Kronig relations, the incident wave convolves with time-varying permittivity. Thus, the displacement vector is the convolution of the permittivity and electric field. Using the finite-difference time-domain method on a one-dimensional spatio-temporal slab, it is possible to study the reflection and transmission coefficients. This paper reports an apparent violation of the conservation of energy that can be explained in terms of the work done by the medium on the wave. Various cases involving the switching time of the temporal permittivity would be discussed and analyzed.

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Enhancing Efficiency of High-Powered AlGaAs Edge-Emitting Laser Through Coupled Waveguides at 793nm

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Abstract

High-powered edge-emitting semiconductor lasers are compact, reliable, and efficient sources; for instance, for pump lasers. Previous research has highlighted the potential of maximizing output optical power [1], and recent studies have investigated the implementation of coupled waveguides within the laser cavity [2] for 885 nm. This work utilizes coupled waveguides to optimize the power output of an AlGaAs 793nm pump source for Thulium Lasers.

Within the semiconductor cavity, the integration of coupled waveguides forms an interaction of fundamental modes. This interaction generates symmetric and antisymmetric supermodes, evenly distributed across the waveguides. This design allows strong localisation of the fundamental mode within the n-type waveguide layer, reducing optical losses from the cladding. To further suppress high-order modes, the laser design utilizes a reduction in mode intensity within the active waveguide [2]. With higher-order modes suppressed, the design allows for a reduction of p-cladding width and a subsequent reduction in series resistance. The narrow spatial modes further decrease optical losses that are due to absorption in p-doped material. The result is an increase in efficiency and output power of the laser.

The Transfer Matrix Method [3] is employed to calculate the distribution of the optical field. Laser gain and efficiency are simulated, optimising the overlap with the quantum well and reducing the spatial mode within the p-doped material. The laser structure is grown using molecular-beam epitaxy with testing using photoluminescence analysis. The work presents optimized simulations of an AlGaAs-base laser structure that includes coupled waveguides to improve the gain and reduce the loss of high-powered edge-emitting lasers.

1. **R. Han, et al., 88x nm High-Efficiency Narrow Divergence Angle Laser Diodes With Coupled Waveguide Photonic Crystal (2023).**
2. **L. Han, et al., Progress of Edge-Emitting Diode Lasers Based on Couple-Waveguide Concept. Micromachines (2023).**
3. **P. Yeh, Optical Waves in Layered Media (Wiley, 1998).**

51

Resolving Schrödinger's paradoxical analysis of the EPR argument.

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Abstract

Einstein, Podolsky and Rosen (EPR) gave an argument that quantum mechanics is an incomplete description of reality. Schrödinger replied, presenting a paradox about a cat. Less well known is the argument at the end of his paper, which considers EPR's system. Two separated particles A and B have correlated positions x and anti-correlated momenta p, so that one can infer either x or p of one particle, by making a measurement on the other. EPR argued that the measurement of one particle cannot affect the other particle, and hence that there exists a predetermination of both x and p for each particle. The paradox is that no quantum state exists for which x and p are simultaneously exactly defined, suggesting incompleteness. Schrödinger considered the set-up to measure x of particle A and p of particle B. Here, both x and p of particle A can be measured, "one by direct, the other by indirect" measurement. Schrödinger debated whether the outcomes of both measurements could be simultaneously exactly predetermined, prior to detection. Schrödinger argued how x^2+p^2 can be measured to give an odd number, seemingly countering this possibility.

Here, we resolve the questions raised by Schrödinger, using the objective field model for reality based on the Q-function. The EPR paradox is realised using parametric down conversion where x and p are field quadrature phase amplitudes. We analyse the measurement dynamics by solving the Q-function amplitudes using future boundary conditions. With sufficient amplification, "elements of reality" appear. These are values predetermining the readout of the measurement when the system is coupled to a meter. By noting the amplification is reversible, we demonstrate the predetermination of both x and p of system A once the measurement settings have been fixed and after sufficient amplification. We address Schrödinger's final question and propose an experiment.

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A Frequency Measurement Method for the MEMS Infrared Resonance Sensor

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Abstract

There has been a growing interest in the MEMS (Micro-Electro-Mechanical System) sensors depending on microelectronic technology manufacturing process because of their small size, low power consumption, and low cost. MEMS resonance sensors have attracted much attention due to their superior performance whose sample current almost has no thermal effect to sensing structure, signal-to-noise ratio and sensitivity are higher, especially, and frequency output signals are readily adapted for digital processing. Various MEMS resonance sensors such as pressure, acceleration and rotation sensors etc. have successfully become commercial products. The performance of a MEMS sensor is not only related to its sensing material and structure, which should be suitable to receive the detected signal and convert the received signal into the signal to be process, and its manufacturing processes, but also associated with the measurement method for the converted signal. In this paper, the frequency measurement method for an infrared resonance sensor manufactured by MEMS technology is presented. Firstly, in accordance with the theory of mechanical-electrical integration, the resonance structure used for sensing infrared radiation is equivalent to a spring-damping mechanical system, subsequently, the system is equivalently modeled as a RLC circuit with parameters determined by the system. This modeled RLC circuit is used for circuit simulation. The resonance frequency of the resonance structure is determined by the frequency-amplitude response of the circuit at a given temperature. Then, an entire set of circuits that are amplification circuit, peak detection circuit, voltage comparison circuit, and switch circuit is designed for processing resonance frequency signals. Finally, a digital phase-locked loop circuit is proposed, which is used for tracking the change in resonant frequency of the sensing structure with temperature attributed to the infrared radiation from targets. The simulation results show that the designed digital phase-locked loop has better frequency tracking performance.

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Development Of An Automated Steerable Radio Telescope.

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Abstract

We presents an innovative approach towards the design and construction of a steerable radio telescope with an automated control system. The telescope uses a combination of motors and sensors to steer towards celestial objects of interest, with the ability to track moving targets such as satellites. The authors detail the technical specifications of the telescope, including its radio frequency range, sensitivity, and accuracy, and discuss the challenges encountered during its development. This research paper is highly relevant to the field of astrophysics as radio telescopes play a critical role in studying the properties of the universe. The development of an automated steerable radio telescope presents new opportunities for data collection and analysis, allowing astronomers to observe the universe more efficiently and effectively. The paper demonstrates the application of physics principles, such as mechanics and electromagnetism, in the design and operation of the telescope. The findings of this study can contribute to further research in astrophysics, including studies of the cosmic microwave background, radio galaxies, and other extragalactic sources. Overall, the development of an automated steerable radio telescope represents a significant advancement in the field of astrophysics and presents new avenues for research and discovery in the coming years.

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Detecting Exoplanets in Multiplanetary Systems using HILine Analysis through Gaussian Fitting.

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Abstract

The paper describes the detection of exoplanets in multiplanetary systems using HI line data is an approach in astronomy. Traditional methods for detecting exoplanets have limitations in terms of sensitivity and range, which makes it difficult to detect small and distant planets. We propose a mathematical model based on the analysis of the HI line emission and absorption spectra to predict the presence of exoplanets.The model is based on fitting the observed HI line profile to a 2 2Gaussian distributionf (v) = Aexp[−(v − vθ) /(2δv)] + δf (v) where δf (v) is the perturbation caused by the exoplanet. The amplitude of the perturbation depends on the mass, orbital distance, and other properties of the exoplanet. and searching for significant deviations that 2may indicate the presence of an exoplanet.The chi-squared statistic,x , measures the difference between the observed and expected HI line profiles: x2 = P∞

2−n = 1[fobs(v) − fexp (v)]2 /σ 2 .

n=1The deviation caused by the exoplanet can be quantified using a perturbation term in the Gaussian distribution. The amplitude of the perturbation depends on the mass, orbital distance, and other properties. We use statistical tests such as the chi-squared test to measure the significance of the deviation and estimate the properties of the exoplanet and the Extragalactic distance scale.

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Nonlinear properties of femtosecond-laser inscribed waveguides into Gallium Lanthanum Sulfide glass

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Abstract

Chalcogenide glasses have attracted attention as important materials in mid-infrared photonics due to their high nonlinearity and transparency at long wavelengths. In this paper, we study the linear and nonlinear optical properties of waveguides fabricated using the femtosecond laser direct-writing technique in Gallium Lathanum Sulfide (GLS), a prominent and non-toxic member of the chalcogenide glass family. The nonlinear optical properties of GLS waveguides have been investigated by self-phase modulation (SPM)-induced spectral broadening experiments at 1.5 m. We demonstrate that waveguides inscribed via a multi-scan approach better preserve the high nonlinearity of the bulk glass as compared to waveguides inscribed in the cumulative heating regime. Furthermore, we show that this finding has important implications for the fabrication of integrated nonlinear devices. We present a practical design for an ultrafast saturable absorber for mid-infrared fiber lasers based on nonlinear coupled waveguide arrays. Leveraging the unique properties of GLS glass, nonlinear waveguide arrays exhibit a distinct transmission behavior. More specifically, these arrays feature a predominance of linear diffraction at low to moderate input peak power levels. With only the central waveguide excited, the input power is thus continuously re-distributed to the neighboring waveguides by evanescent wave coupling. However, with increased input peak power, nonlinear self-focusing gradually overcomes the linear diffraction, and the power remains in the central waveguide, resulting in transmission through the central waveguide only. This intriguing phenomenon yields a transmission behavior that resembles the action of a quasi-instantaneous saturable absorber. Our research findings indicate that nonlinear-coupled GLS waveguide arrays have the potential to enable the development of robust hybrid chip-fiber mid-infrared light sources that are fully integrated and thus compact for important applications in spectroscopy, material processing, chemical and biomolecular sensing, security, and industry.

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Gradient Order Effect in the Gradient Echo Memory: Revisiting the 3-level Atom

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Abstract

The gradient echo memory (GEM) is an optical quantum memory scheme based on a frequency gradient along the memory length, which we have demonstrated many applications for, most recently the storage and retrieval of single photons generated by a spontaneous parametric down-conversion source. This memory is highly versatile in its applications, due to the control over storage and retrieval of light allowed by applying and reversing the frequency gradient.

We revisit the equations governing the memory operation to show that the order in which gradients are used in storage and recall significantly affects the efficiency of the memory. This as due to an increase or decrease in lossy absorption that occurs to either side of the resonant frequency of the memory, namely, due to electromagnetically-induced transparency or absorption. Avoiding the lossy absorption slightly reduces the versatility of GEM, but also boosts its efficiency in others.

A parameter analysis gives a simple relationship between the two basic memory parameters of optical depth and off-resonant detuning that governs the size of this effect, and means it is important in most applications of the GEM.

We present experimental data to support the theoretical analysis, and to study the operation of GEM in different settings than those specifically used to demonstrate high efficiency.

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Temporal characteristics of stationary switching waves in a normal dispersion pulsed-pump fiber cavity

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Abstract

Kerr cavities driven in the normal dispersion regime are known to host switching waves. These consist of a travelling wavefront that connects separate regions associated with high and low-intensity steady states of the cavity. Such switching waves are crucial to the existence of a plethora of coherent normal dispersion frequency combs, currently an active area of research due to their high conversion efficiency and spectral flatness. We drive a 230 m custom-built fiber ring cavity with strong normal dispersion using nanosecond pulses, allowing us to directly resolve the fine structure of individual switching waves, including resonant oscillations occurring over periods on the order of ~10 ps. We characterise the evolution of these resonant oscillations with respect to cavity parameters, namely the detuning and pump desynchronisation. We show that not only the modulation frequency but the decay rate of the dispersive waves are accurately captured by a model previously developed in the context of resonant radiation shed by solitons and pulses in the presence of higher-order dispersion under CW pumping conditions. This work provides the possibility of new insights into how switching waves present in coherently driven Kerr cavities, as well as the operation and manifestation of normal dispersion Kerr frequency combs in both macro and microresonator systems.

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Analysis on Optical Coherence Tomography Scans to Detect Irregularities and Restoration Work on Paper-Based Artwork

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Abstract

This project aims to analyse Optical Coherence Tomography (OCT) images to detect restoration in paper-based artwork. We worked on an etching titled 'Landscape with an Obelisk' by Rembrandt van Rijn, made in the 1650s. Carl Schweidler, who restored the artwork in the 1920s, was renowned for his almost invisible restoration technique, whereby carefully shaving the edges of the restored part and the artwork itself, he assembled the two together perfectly. The etching was brought to Aotearoa New Zealand in the 1960s. Due to environmental changes, the two papers expanded differently, resulting in two areas of slight separation of the restoration from the original. Carl Schweidler's restoration is so impressive that it is practically invisible to the naked eye, meaning the exact outline of the restored work - except for the two white lines revealed by the paper shrinkage - is unknown.

As a result, our first aim was to analyse OCT images to detect the restoration outlines automatically. We took OCT scans along the entire hypothetical restoration boundary on the artwork using a portable OCT system from Lumedica with a central wavelength of 840 nm. We developed multiple scripts to automatically detect the restoration outlines on the OCT images that are invisible to the naked eye. The results are plotted on an en-face projection of the artwork section to reveal the outline of Carl Schweidler's restoration. We applied our techniques successfully on other paper-based artworks to test the feasibility of this analysis outside of the Rembrandt etching. In the future, we believe this technique will be used on paper-based artwork to detect restoration and defects where other conventional techniques cannot be used.

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Free Space Optical Transceiver: Mechanical design review

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Abstract

Free space optical communication transceiver (FSO) is a telecommunication technology that utilizes modulated optical beam to transmit data wirelessly through air, outer space, or vacuum. Laser based communication (laser-com) system provides accurate direction over long distance taking the advantage of laser beam characteristics. This system is a perfect implementation for temporary installation. The system can transmit data over 50-100 km distance. In addition, geometrical barriers like rivers, seas and mountains do not affect the operation of the system.

Our objective is to design and manufacture a compact optical transceiver suitable for ground to ground and space to ground applications. The main criterion of the design is to be compact with the size constrain of 1U size (10 cm × 10 cm × 10 cm). This document displays mechanical design of free space optical transceiver which is intended for both space and ground application. The preliminary design structure, the system requirements and optical layout and path are covered. Thermal, stress and vibration tests and analysis will be performed to validate feasibility and functionality of the design.

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III-V Nanowire Quantum Well Infrared Photodetectors

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Abstract

III-V semiconductor-based quantum well infrared photodetectors (QWIPs) based on intersubband absorption have facilitated mid- to long-wavelength photodetection and thermal imaging with excellent pixel operability, uniformity, and stability. However, all existing QWIPs are based on epitaxially grown planar structures containing in-plane quantum wells, in which the intersubband transition at normal incidence is forbidden by the light polarization selection rules. Additional fabrication steps need to be implemented for device fabrication to create optical structures such as gratings or surface texturing, which, without careful design and optimization, could cause much-compromised efficiency. In this work, we report for the first time, nanowire QWIPs (NwQWIPs), consisting of five radial InGaAs/InP, quantum wells, enabling normal incident operation. The NwQWIP demonstrates sensitive photoresponse in the mid-wavelength infrared band with a peak responsivity and detectivity (D*) of 120 mA/W and 1.3×107 Jones at 4.2µm (operating at a temperature of T=108K) respectively. Together with the mature, scalable, and highly uniform growth and precise control of quantum well nanowire position, size, and composition, the developed NwQWIPs open up great opportunities for next-generation large-scale, low-cost, high-performance IR focal plane arrays.

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Functionalization of Track Etched Amorphous SiO_2 Nanopores for the Fabrication of Bioinspired Nanofluidic Devices

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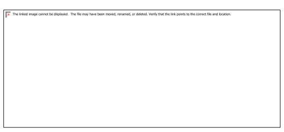
Abstract

Living organisms perform many important biological processes such as signal processing and transmission by modulating the ionic conductivity of pores in cell membranes. This has been a source of inspiration for the development of abiotic solid-state nanofluidic iontronic devices. The ionic conductivity through solid-state nanopores depends on the surface charge and pore morphology. In this work, we present a method to fabricate functionalized track etched conical nanopores in amorphous SiO_2 (a-SiO_2) membranes. One of the important characteristics of conical nanopores, which plays a crucial role in different applications, is their rectifying properties making them a promising platform for nanofluidic devices. In a rectifying nanopore system, the conductance depends on the voltage polarity across the membrane. Functionalization of the nanopore wall with chemical moieties opens up an opportunity to use the membrane for different sensing, switching, or separation applications.



In this project, conical nanopores were fabricated in a-SiO_2 by irradiating membranes with 2.2 GeV ^{197}Au ions followed by chemical etching from one side in 2.5% HF solution. The membranes contain approximately 16 pores with a tip radii of ~5 nm, lengths of ~700 nm, and half cone angles of ~13º. The nanopore surface is functionalized by using 0.1% (v/v) solution of APTES in toluene in a custom-made setup at 70°C for 24h until the pore surface is completely covered with amino silane groups. An ionic current in a 100 mM KCl solution is measured as a function of pH. Figure 1 shows an example of an ionic current-voltage plot which displays excellent rectification with a ratio as high as 5. The amino groups allow attachment of a multitude of specific bio-receptors which make the nanopore membranes highly versatile for applications such as separation of charges, switching or recognition elements, or building blocks for advanced biosensors.

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Characterising the Sun's open-closed magnetic flux boundary towards understanding the origin and acceleration of the slow solar wind.

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Abstract

The acceleration of the slow solar wind (SSW) has become a pivotal research area in recent years in the fields of solar physics and space weather forecasting. The question of the origin and properties of the SSW has motivated the recent launches of the NASA Parker Solar Probe (2018) and the NASA/ESA Solar Orbiter (2020) flagship missions. The high-energy particles that comprise the solar wind fluctuate dramatically, driving space weather events that in severe cases could result in economic losses amounting to hundreds of billions of dollars.

It is hypothesised that the acceleration of SSW is linked intrinsically to 'interchange magnetic reconnection' (IMR) at the Sun's open-closed magnetic flux boundary, however current global models lack details of how this phenomenon occurs. The next breakthrough needed is a comprehensive model of the magnetic topology of the corona, which is precisely what we are aiming to accomplish in this project. We will develop an automated 3D model of the Sun's global magnetic field, with a focus on characterising the Sun's open-closed magnetic flux boundary. We are interested in studying the evolution of topological structures present at this boundary such as separatrices and quasi-separatrix layers (QSLs), since these are plausible locations for IMR processes. The model we develop may in turn provide insight into the global transportation of energy and mass in the corona that drives the acceleration of the SSW.

Here we present our latest results for the analysis of a global, potential model for the Sun's magnetic field. This includes numerical magnetic field extrapolations of solar photospheric data, as well as computations of a geometric measure for QSLs known as the 'squashing factor'.

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Measuring water temperature and salinity simultaneously with a laser.

Carolyn Taylor, Ondrej Kitzler, Simon Curtis, Brad Neimann, Judith Dawes, James Downes, David Spence, Helen Pask
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Abstract

The ocean's temperature and salinity vary with depth. These two properties affect ocean currents, ocean habitats, the world's climate, and the propagation of sound and light. Therefore, the ability to measure subsurface temperature and salinity profiles is highly desirable for a range of environmental and defence applications.

In this work, we report on our laboratory implementation of a method, first proposed in [1], to simultaneously determine the temperature and salinity of water. It involves measuring three portions of its unpolarised, Raman OH stretching band, which exhibit systematic dependence on temperature and salinity, using a compact, 3-channel Raman spectrometer. Our spectrometer uses a 532nm pulsed laser and commerically-available bandpass filters. We measured the three sections of natural seawater's Raman OH stretching band at different temperatures and salinities and calculated Raman two-colour ratios from them. We then determined a linear mapping between the Raman ratios and temperature and salinity using partial-least-squares (PLS) regression and cross-validation. Our implementation had a predictive accuracy of PSU and °C. Our next steps will be to incorporate the 3-channel spectrometer into our LiDAR system so that it can be tested in the field.

[1] Artlett, C.P. and Pask, H.M. "New approach to remote sensing of temperature and salinity in natural water samples", Optics Express 25(3), February 2017.

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Detecting single photon events with superconducting thin film Niobium Nitrate

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Abstract

Superconducting nanowire single photon detectors (SNSPDs) have emerged as pivotal devices in quantum optics research, with prospective applications in astronomy, nanophotonics, quantum cryptography, and LiDAR systems [1]. SNSPDs have shown single-photon detection with over 98% efficiency [2]. These detectors have thus far outshone their major competitors, solid-state single photon avalanche photodiodes (SPADs) in the infrared regime, and in general have broader wavelength sensitivity (x-ray to mid infrared) and a larger signal-to-noise ratio [3,4]. SNSPDs have a simplistic detection mechanism in comparison to their SPAD counterparts. A serpentine thin film (5-10 nm) nanowire (width 50-100 nm) of superconducting material, such as niobium nitride (NbN), is held well below its critical temperature, Tc, and DC biased slightly below its critical current. Incident single photons will locally disrupt Cooper-pairs, the fundamental particular in superconductors, in a superconducting region of wire such that it becomes resistive, and the current is diverted around this excited 'hotspot'. This diversion results in current crowding that forms a barrier of finite resistance (i.e., a classical conducting state) across the nanoscale wire. When the nanowire's resistance jumps to a finite value after disruption, a measurable voltage output is generated [4].

Plasma enhanced atomic layer deposition (PEALD) will be used to optimise growth parameters (i.e. temperature) for ideal crystal structure. We will outline our plan to characterise the NbN using X-ray diffraction, and then discuss our strategic approach to addressing optical properties pivotal to the thin film NbN functionality as a SNSPD. This will primarily involve optical coupling of the device, polarisation dependence in the nanowire, and photon number resolution (PNR) [4].

Please see references in attached PDF file

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Fundamental physics with a mass-imbalanced entangled system of $^{4}He^{*}$ and $^{3}He^{*}$ atoms

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Australian National University, Canberra, Australia

Abstract

Extended abstract is attached

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Polarization and spectral tuning using VO2 nano-fins

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Abstract

We will review our recent exploration of strong polarizing and mid-infrared spectral tuning in VO2 nano-fins produced using self-assembly methods. Co-sputtering of aluminium with another suitable metal produces highly-aligned nanofins due to suppression of surface diffusion in aluminides and geometric shadowing. These fins produce strong optical polarization, in transmission, reflection and emission. This polarization can be modulated by the presence of an underlayer during growth. Use of a suitably refractory material such as Mo enables stability at elevated temperatures, and many other metals can produce fins. Vanadium metal fins can be oxidized to form VO2 fins, which possess an insulator metal transition. These fins open up a variety of new possibilities in switchable optical functionality, including angular, polarization and spectral selectivity. The optical properties are strongly modulated by the oxidation conditions, which can be used to optimize polarization and spectral selectivity.

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Gap-surface plasmon-induced Indium selenide photoluminescence enhancement

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Abstract

2D materials have been widely studied in the past two decades with their distinct characteristics compared to their conventional bulk counterparts. Indium selenide (InSe), a monochalcogenide van der Waals layered semiconductor is receiving significant research attention due to its thickness-dependent optical characteristics. For InSe to be used as a versatile light source, enhancing the emission of InSe is required. Here, photoluminescence (PL) enhancement from multi-layer InSe is demonstrated using the gap-surface plasmon-enhanced cavity effect. With the support of multiple resonances from plasmonic structure, one of which overlaps with InSe's band edge PL emission, 6-fold PL enhancement was experimentally shown at room temperature. This study paves the way for the applications of 2D InSe into nanophotonic devices. This study was published in physica status solidi (b) in January 2023.

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Wavefront Beam Characterization Through Turbulence Emulator

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Abstract

Free space optical communication is getting attractive to increase the data rate and reduce the latency. It also offers high levels of security since the optical beam size and divergences can be designed to be as directive as possible. As a result, the optical beam pointing is very challenging to achieve long distance links. The other challenge of this technology is the atmospheric propagation channel that affects the optical beam properties (wavefront, intensity, pointing and divergence). Several works have been carried out to understand the turbulence theories and to model its effect [1-3]. The common solution to overcome the turbulence effects is the adaptive optics (AO) system that has an active correction of the wavefront beam. This approach requires to know the media conditions (refractive structure index, wavefront deformation, atmospheric variation speed) and drive the deformable mirror to compensate for the distortion.

In this paper, we will cover the latest version of our full atmospheric turbulence emulator we have developed for indoor tests. The temperature gradient, relative humidity and wind speed are the parameters considered for this design that can be tuned separately to create different turbulence strengths. An overview of the design and the specification will be described along with beam quality analysis to evaluate the beam centroid and the intensity fluctuation under different turbulence conditions. Finally, an adaptive optics system will be integrated to correct for the emulator effect and illustrate the beam status at different stages, before distortion, after distortion and after correction

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Benchmarking quantum gates for continuous-variable quantum information processing

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Abstract

Continuous-variable (CV) systems provide novel ways to store and manipulate quantum information for computation. In order to benchmark the performance of a quantum circuit encoded in a CV system, it is imperative to characterize the noise affecting the logic gates that act on the encoded qubits. Existing techniques to this end are based on quantum process tomography; however, their overhead is exponentially large in the number of qubits in the circuit. We aim to construct a scalable protocol that provides information about the noise affecting the quantum gates acting on a CV quantum circuit. As a first step to this construction, we design a twirling protocol that converts a general bosonic noise channel into a single-parameter quantum channel, where this parameter relates to the average fidelity of the original channel. Our twirling protocol is implemented using a combination of displacement, phase rotation and squeezing operations randomly applied to the encoded qubits. As a followup to this work, we aim to employ this twirling protocol to construct a benchmarking scheme that scalably determines the average fidelity of the noise channel affecting the CV quantum gates. Successfully designing such a scheme will lead to experimental verification of the noise characteristics of a CV quantum circuit.

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Nonlinear Up-Conversion Imaging Using Lithium Niobate Metasurfaces

Laura Valencia[1,2], Rocio Camacho Morales[1], Jihua Zhang[1], Isabelle Staude[2], Andrey Sukhorukov[1], Dragomir Neshev[1]
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Abstract

In recent years, there has been a growing interest in advanced infrared (IR) vision, driven by applications in surveillance, security, health, and industry. However, conventional IR image devices based on narrow-bandgap semiconductors are limited by low temperature operations, high noise levels, and the inability to augment with visible light. To address these limitations, upconversion IR imaging based on parametric nonlinear processes has gained recent interest [1]. This technique preserves the coherence of the incident wavefront but often relies on bulky crystals and high-power lasers, limiting practicality. The use of nonlinear sum-frequency generation (SFG) metasurfaces has recently been offered as a compact all-optical alternative [2]. However, the low-quality factor (Q-factor) resonances from the metasurface and the high absorption of the used GaAs materials have limited the applicability of this scheme.

Here, we demonstrate high-efficiency IR imaging using a high-Q bound-state in guided mode resonance metasurface of lithium niobate nonlinear film. The LiNbO3 metasurface was fabricated by electron beam lithography and etching processes. [3] The linear spectrum was measured, and it shows a resonant behaviour at 1530 nm with a Q factor of ~ 40. The nonlinearity enhancement was tested through the SHG response produced by the metasurface. The efficiency of the SHG from the metasurface of LiNbO3 register up to 458 times enhancement for SFG and 132 times for SHG at 1530 nm compared with the nonlinear response of the thin film. Finally, we present the upconversion IR imaging enabled by the LiNbO3 metasurface and captured using a conventional CCD camera. Our study has important applications in the future development of compact night vision instruments and sensor devices and multi-colour imaging at room temperature.

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Creation and storage of non-classically correlated light fields in an erbium-based quantum memory

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Abstract

Rephased Amplified Spontaneous Emission (RASE) is an atomic ensemble based memory protocol that generates entangled light states. In RASE, an excited population is used to amplify the vacuum state, creating an entanglement between the amplified vacuum state and the atomic ensemble. The entanglement stored on the atomic ensemble is retrieved programmatically as a second light field, resulting in a two-mode squeezed state.

I will present our work on the implementation and characterisation of RASE utilising erbium-doped yttrium orthosilicate (167Er:Y2SiO5) as the solid-state host. Our results demonstrate entanglement between the amplified spontaneous emission (ASE) and RASE fields with a inseparability violation of 3.7σ below the classical boundary. Additionally, we have demonstrated a write time of 150.6μs,storage of 27 temporal modes, spin storage time of 24.5μs, peakRASE recall efficiency of 74%,and a record solid-state memory efficiency of 80% using an inverted four level echo.

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Designing a Microstructured Optical Fiber Hydrophone

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Abstract

Underwater acoustic monitoring typically involves electric hydrophones, yet the deployment of optical fiber hydrophones offers a range of advantages, primarily the potential for distributed acoustic measurements. However, the implementation of optical fiber hydrophones without mechanical actuation remains relatively scarce, largely due to the low sensitivity of standard optical fibers to acoustic pressures. This sensitivity can be increased through the use of microstructured fiber, although some microstructured fibers suffer from high attenuation. By keeping the doped single-mode core and incorporating the microstructures, a low attenuating pressure sensitive fiber for distributed acoustic sensing can be obtained. As the stress around the microstructures is greater this can cause a larger stress-optic change in the core and hence a greater phase change. In this work a fiber was numerically modelled to conduct an optical and mechanical analysis of different microstructured fibers which showed an improved response to hydrostatic pressures. One design was selected to be fabricated and subjected to hydrostatic and acoustic pressure measurements within a Mach-Zehnder interferometer, comparing its performance to a single-mode optical fiber.

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Vibrational Spectroscopy for the Imaging of Art

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Abstract

This research describes spectroscopic measurements taken of the Auckland Art Gallery Toi o Tāmaki Rembrandt van Rijn etching, Landscape with an Obelisk (c.1650). Building on previous analysis, Raman and Near-Infrared (hyperspectral image) spectroscopy was used to differentiate between the original and restored sections of the artwork.

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Comparison of lidar sensing methods for oceanic temperature measurement

Brad R. Neimann, David J. Spence
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Abstract

Light Detection And Ranging ('lidar') systems use short pulses of light to interrogate the properties of a target. A profiling oceanographic lidar system detects light scattered by the water column, to gain information about oceanic properties such as phytoplankton and particulates.

Raman-scattered light is of particular interest, as the polarised Raman spectrum of ocean water depends on both temperature and salinity. Thus, Raman lidar approaches are promising for depth-resolved temperature measurement of subsurface waters. This is an area for which no remote sensing capability currently exists. Several different methods have been proposed for Raman temperature measurement, using the spectra and/or polarisation of the Raman returns.

This work uses Monte Carlo simulations to compare and contrast these measurement methods, while exploring the effect of changing lidar system parameters such as field of view and altitude. Our results show that confounding effects such as multiple scattering and differential absorption can be significant in realistic situations, and we present methods for correcting for these systematic errors. Thus, this work informs our understanding of the optimal method for remote temperature sensing of the water column.

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Quantum State Stabilization via Measurement-Driven Deep Reinforcement Learning

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Abstract

The stabilization of quantum states is a fundamental problem for realizing various quantum technologies. Measurement-based-feedback strategies have demonstrated powerful performance, and the construction of quantum control signals using measurement information has attracted great interest. However, the interaction between quantum systems and the environment is inevitable, especially when measurements are introduced, which leads to decoherence. To mitigate decoherence, it is desirable to stabilize quantum systems faster, thereby reducing the time of interaction with the environment. In this work, we utilize information obtained from measurement and apply deep reinforcement learning (DRL) algorithms, without explicitly constructing specific complex measurement-control mappings, to rapidly drive any quantum state to the target state. The proposed DRL algorithm has the ability to greatly speed up the convergence to a target state, which shortens the interaction between quantum systems and their environments to protect the coherence. Simulations are performed on two-qubit and three-qubit systems, and the results show that our algorithm can successfully stabilize any quantum system to the target entangled state, with a convergence time faster than traditional methods such as Lyapunov feedback control. Moreover, it exhibits robustness against imperfect measurements and delays in system evolution.

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Rubidium MOT as a high-density target for Positronium formation via Positron-Rubidium scattering.

Neil Shah, Joshua Machacek, Stephen Buckman, Sean Hodgman
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Abstract

[1] Berko, S., & Pendleton, H. N. (1980). Positronium. Annual Review of Nuclear and Particle Science, 30(1), 543–581. https://doi.org/10.1146/annurev.ns.30.120180.002551

[2] Machacek, J. R., Blanco, F., Garcia, G., Buckman, S. J., & Sullivan, J. P. (2016). Regularities in positronium formation for atoms and molecules. Journal of Physics B: Atomic, Molecular and Optical Physics, 49(6), 064003. https://doi.org/10.1088/0953-4075/49/6/064003

[3] Kowalski, Krzysztof & Van, Cao & Khoa, Dinh & Głódź, Małgorzata & Nguyen Huy, Bang & Szonert, Jerzy. (2010). Magneto-optical Trap: Fundamentals and Realization. Computational Methods in Science and Technology, Special Issue (2), 115-129. DOI:10.12921/cmst.2010.SI.02.115-129

"The electron and the positron (anti-electron) form a bound state known as positronium. This leptonic atom is hydrogenic and unstable to annihilation [1]. Only recently have theoretical and empirical [2] models provided a means of determining the positronium formation cross section but lack detailed kinematics and state-specificity. Thus, we are planning to investigate positron collisions with an ensemble of quasi-one electron atoms (e.g., Rubidium) and measure both the kinematics and state-specific production of positronium in the threshold regime.

Cooling the Rb-87 atoms requires the construction of a rubidium Magneto-Optic Trap (MOT), which uses laser cooling and a magnetic trap to produce trapped clouds of rubidium atoms at sub-millikelvin temperatures [3]. MOT technology provides a high-density target of rubidium atoms for the cold positrons beam and consequently increases the total scattering cross section. The reaction products will be detected using electron multipliers, gamma-ray scintillators, and absorption imaging to determine scattering and production cross sections in detail.

The scientific aims of the project are to measure exothermic positronium formation from positron-rubidium collisions leveraging to state-of-the-art techniques. Detailed results of this work will provide a benchmark for theoretical and empirical models. The state-specificity will provide insight not previously investigated in detail in the threshold regime."

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Polarization effects on light propagation in gravitational fields

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Abstract

Light propagation in curved spacetime is often described within the geometric optics approximation. Geometrical optics approximates high-frequency electromagnetic waves as rays that follow null geodesics. Going beyond this model reveals a polarization-dependent deviation of the light trajectory known as the gravitational spin Hall effect of light. For light propagating over large distances, these corrections can be significant. We investigate the gravitational spin Hall effect in spherically symmetric gravitational fields. We perturbatively calculate these polarization-dependent corrections for light propagating in the Schwarzschild spacetime. We present analytic expressions that astronomers can use to calculate this effect for cases of interest such as light propagating (i) in the solar system setting where gravity is weak, (ii) near compact objects, (iii) near Schwarzschild black holes etc. We also investigate the gravitational spin Hall effect for radiation in the Schwarzschild spacetime.

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Towards understanding the effects of quantum noise in Ramsey spectroscopy

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[1]Griffith University, Brisbane, Australia. [2]Dartmouth College, Hanover, USA

Abstract

We study the effects of quantum noise in the Ramsey spectroscopy of a single probe qubit, showing the detrimental impact of the entanglement of the system with the bath degrees of freedom. Taking into account that after each measurement shot it is not possible to completely reset a quantum bath interacting with the system, we find that the evolution of the bath affects the results obtained on an ensemble of measurements, making them deviate completely from those predicted for a classical bath. Our results are based on an exact expression for the expectation values of the qubit observables under general zero-mean Gaussian stationary pure dephasing. This expression was calculated using a cumulant expansion technique, which provides an efficient method for the analytical study of non-Markovian open quantum systems. Furthermore, we performed numerical simulations where the bath consisted of a finite number of qubits under classical stochastic noise and, as the analytical results, these simulations showed the non-negligible effect of the quantum bath on the measurement of the system. Our analysis paves the way for the full characterisation and control of quantum noise in a variety of configurations used in sensing and estimation applications.

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Resonance-driven optical torques at the nanoscale

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Abstract

The study of dielectric Mie resonances in high-index dielectric nanoparticles open many opportunities for a design of compact devices based on metaphotonics and metasurfaces. In this talk we discuss the effects of Mie resonances and their hybridisation on resonant optical manipulation, and optical torque in particular. We study the resonant optical trapping and spinning in the anti-node of the standing wave with non-zero spin angular momentum (AM). We find that there is a very strong enhancement of the optical torque on the particular particle's resonance but not on the others. The eigen mode decomposition shows that the mode of interest is combined of electric dipole (excited by the local electric field) and magnetic quadrupoles (excited by gradient of the magnetic field).

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Size Dependent Two-photon Absorption in Au and Ag Nanospheres

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Abstract

Optical nonlinearities play an increasingly important role in many applications such as telecommunications, manufacturing, medical imaging and in therapeutics. For optimal performance across such a diversity of applications, it is necessary to characterise the nonlinear optical properties of a broad range of materials and different morphologies. Au and Ag nanoparticles are particularly useful in medical applications due to their relative inertness and biocompatibility. This study uses the Open Aperture z-scan technique to determine the two-photon absorption coefficient (β) for seven Au nanosphere samples and five Ag nanosphere samples with diameters ranging from 20 nm to 100 nm to establish the effect nanoparticle size has on nonlinear absorption. Z-scans were conducted under irradiance from a 532 nm wavelength pulsed laser with a pulse duration of 5 ns and average input powers of 0.15 mW, 0.20 mW and 0.25 mW. Open aperture z-scan traces were simulated over a broad range of β values and a least squares fitting method was used to determine the best fit value for the experimental data. The nonlinear absorption coefficients for Au nanospheres are 4.7, 8.1, 12, 17, 18, 16 and 11 GW/cm2 for particle diameters of 20, 30, 40, 50, 60, 80 and 100 nm, indicating a diminishing nonlinear absorption effectiveness for very large or very small Au nanospheres. The nonlinear absorption coefficients for Ag nanospheres show an increasing trend for increasing particle size and are 0.79, 8.8, 21, 26 and 31 GW/cm2 for particle diameters of 20, 50, 60, 75 and 100 nm.

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Single-photon source for rare-earth doped crystal quantum memories

Luke Trainor[1,2], Helen Chrzanowski[3], Xavier Barcons Planas[3,4,5], Janik Wolters[3,5], Jevon Longdell[1,2]
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Abstract

The storage of single photons is an ongoing technological challenge. Storage in an on-demand quantum memory would enable new technologies such as quantum repeaters, which would allow creation of a quantum network over longer distances than currently possible. Hosting part of the network on satellites could allow even better distance scaling, beating the current exponential loss seen in optical fibres.

Rare-earth doped crystals are a promising platform for quantum memories, in particular due to their long coherence times. Europium-doped yttrium orthosilicate is well known for its nominal 10 ms coherence time between hyperfine levels, that can be extended to six hours under the right conditions. That long coherence time has enabled storage of classical pulses for up to one hour.

We present a monolithic photon pair source compatible with rare-earth ion memories. The photon source is made of a periodically poled crystal. Pairs of photons are generated by spontaneous parametric down conversion from a pump laser. The wavelengths of the generated photons are targeted for the optical transitions of erbium- and europium-doped yttrium orthosilicate (1536 nm and 580 nm). To improve the conversion efficiency and reduce the photon bandwidth, the crystal is shaped into a Fabry-Perot cavity and its end faces are coated with mirror coatings. The detection of a photon at one frequency heralds the generation of a photon in the other frequency, which will trigger storage in a memory.

The source generates over ten million photon pairs per milliwatt of pump power. The arm efficiencies are 26.7% at 1536 nm and 9.7% at 580 nm. The difference in the two is due to asymmetric detector efficiencies. We will discuss the current efficiency limitations and the filtering we are exploring to improve this.

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Microwave magnon and optical satellite spectroscopy on an antiferromagnetically ordered $NdGaO_3$ crystal towards quantum transduction

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Abstract

Coherent frequency conversion between microwave and optical photons, known as quantum transduction (QT), is essential for communication between superconducting quantum processors operating in the microwave range, connected by an optical fibre-based quantum network, which allows lossless transmission at optical frequencies. One of the promising candidates for QT is rare-earth (RE) ion-doped solids, owing to their extended microwave and optical coherence times. However, these systems suffer from low conversion efficiency due to the low concentration of RE ions. Here, from an alternative perspective, we present microwave and optical spectroscopy on $NdGaO_3$, an antiferromagnetically ordered crystal with fully concentrated RE ions (Nd^{3+}). We observe the collective excitation of electronic spins, known as a magnon, which exists only in such fully concentrated magnets, through strong coupling between a microwave cavity and Nd^{3+} ions. By varying the frequency of the cavity mode and the magnetic field strength, we investigate the field dependence of magnon resonances and the crystal's magnetic phases. Optical transmission spectra near an optical transition of Nd^{3+} under various magnetic fields also show a magnetic field dependence of optical transition frequencies, allowing us to estimate the electronic spin configuration of Nd^{3+} in $NdGaO_3$. Moreover, we observe optical resonances, outside the inhomogeneous broadening of the single-ion excitation, with narrow linewidths expected to be close to that of the main line. These absorptions are called satellite lines and are considered to be the optical transitions of Nd^{3+} ions next to a different RE ion species accidentally included as a dopant. Recent studies show that these satellite lines can be used for quantum processing. In summary, we conducted microwave and optical spectroscopy on an antiferromagnetically ordered $NdGaO_3$ crystal and observed magnons and satellite lines. This spectroscopy enables us to better understand the microwave and optical transitions for future use as a quantum transducer.

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A Non-Intrusive Optical Fibre Sensor to Measure Pressure Pulsations in Pipework On-board Naval Vessels

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[1]ASC, Adelaide, Australia. [2]UniSA, Adelaide, Australia

Abstract

Pressure pulsations driven by pumps and other rotating machinery can contribute to the underwater radiated noise of naval vessels. Underwater radiated noise links to the detectability of the vessel which highlights the importance of pressure pulsation measurements. Traditional measurement techniques require intrusive pressure sensor boss connections integrated into the vessel's pipework. This is not ideal in the context of naval vessels as it introduces system failure points and increased flooding risk.

Optical fibre sensors can be used as a non-intrusive measurement technique in the form of a Mach-Zehnder interferometer. This interferometer consists of two single mode fibre arms in which one is used for pressure sensing and the other acts as a reference. Laser light propagating through the sensing arm is subject to pressure from the pipe which causes strain on the fibre and a relative phase change in the light due to the induced change in fibre length. The sensing and reference fibre arms recombined using a coupler to produce an interference pattern detectable by a photodetector. A Fourier transform can be applied to the output to determine the frequencies at which pressure pulsations occur.

Three different configurations for wrapping the fibre around the test pipe have been tested: helical, looped and axial. Additionally, a range of path length differences between the sensing and reference fibre have been investigated. Results demonstrate that the helical and looped configurations detect pressure pulsations at frequencies consistent with theoretical expectations based on the blade pass frequency of the pump. The findings are also verified against measurements taken concurrently with a traditional pressure sensor integrated into the test rig intrusively with a boss connection. This indicates that optical fibre sensors are consistent with traditional measurement methods but offer the benefit of being non-intrusive which is favourable in naval vessel applications.

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Resolution of the Quantum Clock-Time Observable

Khai Bordon, Joan Vaccaro, Fatema Tanjia
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Abstract

Time is perhaps the most enigmatic concept in physics. The lack of a universally accepted treatment of time has produced deficiencies such as the lack of an acceptable explanation of the observed evolution time and the definition of an operator to represent the time observable.

Vaccaro's recently introduced Quantum Theory of Time (QTT) describes the evolution of a quantum state over time as a variable, undergoing virtual fluctuations. Despite basing the theory as a heuristic model of time, it is currently, without reference to an operator that represents the time observable. The aim of this work is to rectify this shortcoming and investigate how the time observable can be represented.

Any time observable needs to have a canonically conjugate relationship with the Hamiltonian, due to the fact that the Hamiltonian is the generator of translations in time. We apply the complement of the Hamiltonian, Pegg's Age operator, as a basis for defining the time observable in QTT. Whereas Pegg defined the Age to represent time associated with a system, it has merit as the time associated with a clock-time observable. In QTT, a composite system is represented as a clock entangled with a T-violating background field, here we apply the Age operator and explore whether the uncertainty in clock time is independent of background correlation fluctuations. We define the uncertainty relation for energy and time in its simplest form. We further examine the relationship of the observable to conventional studies of time in quantum mechanics such as the time associated with flight measurement.

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Optical Lattice for ultracold metastable Helium Bose-Einstein condensate

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Abstract

Understanding the behaviour of strongly correlated quantum systems is crucial for addressing key chal- lenges in modern physics, including the explanation of high-temperature superconductivity and the under- lying mechanisms of thermalization at the quantum level. The dynamics of highly entangled systems are poorly understood due to challenges in classical numerical simulations. Experimentally simulating these quantum systems using ultracold atoms in an optical lattice is a promising approach. The allowed Hamiltonian-engineering, along with access to a wide range of observables, allows the investigation of a wide range of phenomena commonly encountered in solid-state systems.

Our current experimental configuration realizes a BEC in a Crossed Optical Dipole Trap (CODT). We plan to establish three pairs of counter-propagating lattice beams (wavelength = 1550nm) to create a standing wave potential. These intersecting beams will form a lattice. Subsequently, we will transfer the BEC from the CODT into the lattice.

The high internal energy of metastable Helium (≈ 20eV) allows for single-atom detection capabilities and the measurement of higher-order correlation functions. With this setup, we plan to conduct experiments to study the dynamics of nth-order correlation functions following a quantum quench. In particular- we will investigate the critical behaviour for the Mott insulator to Superfluid phase transition using higher order correlation functions. This will bring valuable insight regarding the differences in the rate of evolution for two-body and many-body correlations.

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Quenching ultra-cold He* gas across the Bose-Einstein Condensate Phase Transition

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Abstract

Many exotic phenomenon such as lasing, superfluidity and Bose-Einstein condensation (BEC) can be described by a coherent quantum state. Such states are identified through measurements of the many-body correlation functions. We can use the correlation functions as a novel probe into the many-body dynamics during the non-equilibrium emergence of quantum coherence, such as that of a BEC.

Theoretical studies suggest a delayed BEC formation. That is, when the temperature of a thermal cloud is reduced below the phase transition point in a non-equilibrium manner, a BEC does not form immediately. Instead, the atoms close to each other will form local BEC fragments, and vortices may form during a quench. As time passes, vortices disappear, local BECs grow larger, and correlation length increases until the formation of a uniform BEC. A number of experimental studies showed that this is true for the condensate fraction during the phase transition, however there has been no experimental investigation into the growth of higher order coherence.

At the ANU, we have obtained a gas of ultracold metastable helium atoms in a cross-beam dipole trap. Due to the high internal energy of metastable helium atoms (~ 19.8 eV), when they are released from the trap, full 3D far-field positions of the atoms can be re-constructed using a multi-channel plate and delay-line detector, allowing us to measure 2nd and higher order correlation functions. We intend to cool the atoms to just above the condensate critical point, and then quench the dipole potential across it and study the ensuing evolution of correlation functions. By releasing the quenched atoms after various holding times, we can observe the growth of BEC and quantify the coherence of the system.

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Ultra Lightweight Handheld Optical Coherence Tomography Probe for Tissue Imaging

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Abstract

Optical coherence tomography (OCT) is a non-invasive imaging technique for measuring tissue morphology [1]. Recent progress has demonstrated promising applications in intravascular imaging [2] and cancer diagnostics [3]. A significant amount of research has been done on designing OCT probes for tissue imaging, but most probes are either bulky and require external mounting (not lightweight) [4], or lightweight but unstable and yield asymmetric profiles during scanning [5]. Our work systematically tackles these challenges, resulting in an ultra-lightweight, stable, low voltage, compact, and robust handheld imaging probe for precise soft tissue examination. This miniaturized probe (see Figure 1) features highly compact all-fiber optics with a diameter of 250 µm and utilizes innovative central deflection magnetic actuation for controlled beam scanning. To ensure stability while scanning soft tissues, the fiber was passed through multiple slits (< 0.5 mm in length), which were positioned at various locations within the probe, before reaching a final slit located at the center of the probe's distal end. This apparatus was encased in a biocompatible hexagonal cylinder tube (12 mm major axis, 10 mm minor axis and 150 mm in length, weighing < 10 grams), suitable for use in space-limited locations such as the oral cavity for detection of oral cancer. A low voltage microcontroller was used and kept outside of probe to reduce weight and improve the inherent safety of the design. To validate the feasibility of this probe, we conducted assessments on spatial resolution phantoms and human tissues, visualizing microstructural features with high contrast.

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Optical Fibre Environmental Sensors for use in Sewers

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Abstract

Sustainable management of wastewater networks is a global problem with sewer pipes afflicted by harsh conditions causing concrete corrosion. The result is premature pipe failure that comes with high financial, public health, and environmental costs. Currently, water utilities do not have an in-situ, long-term monitoring capability for their concrete wastewater assets as conventional electrical sensors fail within days/weeks of installation due to the corrosive, biofouling environment. Recently, optical fibre Bragg grating (FBG) sensors were shown to withstand deployment in wastewater pipelines over long periods [1]. Here we report the development of an optical fibre dew point sensor for use in such environments.

A climate chamber was used to simulate the formation of dew on a glass surface. Type II-IR FBG sensors were inscribed (without the use of a phase mask) in commercially available polyimide coated fibre using a point-by-point (PbP) technique and ultrashort laser pulses [1]. Temperature and humidity sensors successfully predicted (and measured) the onset of condensation on the glass slide in a static environment and one with 'pipeline' airflow simulated using a fan. Electronic resistive measurements validated the optical approach. Dew point measurements on concrete surfaces are ongoing.

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Thermal Phase-only Tuning of Huygens Metasurfaces

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Abstract

Thermal tuning based on the thermo-optical effect has been widely used in many applications, ranging from tuning waveguide response resonance wavelength of ring resonators and metasurfaces. In the realm of metasurfaces, thermal tuning has been utilised to construct tunable images [1] and programmable meta-optical devices with a sub-millisecond switching time [2]. Some works have demonstrated the possibility of designing phase modulators by thermally tuning the Huygens metasurfaces [3]. Here, we designed a polarisation-independent extreme Huygens metasurface by overlapping optical modes with high quality factor of ~ 200 (Fig. 1a). The thermo-optical effect results in having a narrow-band region with unity transmission and varying optical phase output (Fig. 1b). The experimental validation of the design is achieved by comparing the transmission spectra of fabricated and simulated metasurfaces (Fig. 1c). The phase profile of the simulated metasurface is depicted in Fig. 1d, indicating about 3π/2 phase shift with unity transmission intensity by varying temperature from room temperature up to 300◦C. The proposed approach has the advantage of high spectral selectivity compared to conventional Huygens metasurfaces.

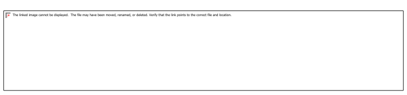

Figure 1: (a) Simulated transmission spectra of resonator arrays with different lattice distances. (b) Simulation of the Huygens metasurface transmission response at different temperatures. (c) Transmission spectra of the fabricated Huygens metasurface at different temperatures, and (d) phase response of the Huygens metasurface at different temperatures. Inserts in (b) and (d) are the transmission intensity and optical phase response of the metasurface at λ = 1506 nm. Inserts in (a) and (c) are the layout and the SEM image of the fabricated sample, respectively.

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Integrated Silicon-on-Insulator Optomechanical Magnetometers.

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Abstract

Optomechanical sensors exploit the dual enhancement from both optical and mechanical resonances. These mechanical elements of these devices can be tailored into providing transduction for various stimuli forming precise sensing elements with optical readout. One such realisation of these is precision magnetometry using magnetostriction to facilitate the magnetic-to-mechanical transduction.

Due to their fibre-optic compatible and chip-scale dimensions such optomechanical magnetometers provide potential for applications in ranges from fundamental physics, biomagnetic-imaging, marine anomaly detection to geological mineral surveying.

To date, many such optomechanical magnetometers rely on off-chip optical readout techniques such as evanescent coupling from tapered optical fibres. Such techniques are incompatible the with out-of-the-lab deployment required for these applications.

We present Si photonic optomechanical magnetometers that are fabricated on commercially available silicon-on-insulator (SOI) chips. These magnetometers utilise Si electronics and photonics compatible fabrication techniques such electron-beam lithography, reactive ion etching and sputter deposition. The transduction element is a magnetostrictive thin-film of galfenol ($Fe_{82}Ga_{18}$) sputtered onto free-standing silicon. Such planar fabrication techniques are critical for enabling the potential for high throughput scalable device fabrication.

The Si magnetometers fabricated achieve sub-nT/Hz$^{1/2}$ sensitivity at room temperature for frequencies within the 100's kHz range and are readily capable of being fibre bonded for sensor deployment.

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Feedback Cooling of Degenerate Quantum Gases

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Abstract

Currently, ultracold quantum gases are prepared via the two-step process of laser and evaporative cooling. However, the latter an inherently lossy process, resulting in the lost of almost all (99.9%) of the initial atoms. Recently, advances in optical control have lead to considerable interest in an alternative, number-conserving procedure based upon principles of feedback cooling [1]. Previous attempts to model feedback cooling of atomic gases have struggled to capture the complex quantum correlations induced by the measurement process, as well as finite temperature effects associated with thermal fluctuations. To this end, the applicability of feedback cooling to complex, multi-mode systems such as quantum gases is still an open question.

A new field-theoretic technique based upon existing phase-space methods is developed for scalable numerical simulations of controlled quantum systems, and used to model feedback cooling of a Bose gas subject to periodic, non-destructive measurements via phase-contrast imaging. We check the validity of our approach in a two-mode system, which permits an exact solution due to its low-dimensional nature, and observe exceptional agreement across various moments of pseudospin operators. In addition, we benchmark our approach with existing techniques such as the Number-Phase Wigner particle filter, which has been the leading choice for existing simulations of controlled quantum systems [2].

Finally, we present preliminary results demonstrating successful cooling of a thermal state with low condensate fraction to condensate formation in both quasi-1D and 2D geometries, correctly accounting for measurement induced backaction and spontaneous emission effects. It is shown that the final achievable condensate fraction is dependent upon experimental parameters such as the measurement strength, rate, and detector resolution, and a simple model is constructed to derive optimal values for the parameters above.

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Flexible metasurface-nanowire LED integrated device for optical sensing

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Abstract

Metasurfaces with resonance wavelength in near infrared are promising for optical sensing of chemical or biological samples [1]. However, metasurface sensing system is generally based on an open optical platform using a series of optical components, including laser, camera, filters and lenses, which limits their wide applications. To minimise the bulky sensing system, in this work, we design and fabricate a metasurface-nanowire (NW) light-emitting diode (LED) integrated device to achieve a portable and miniaturised sensing system.

A double-ellipse shaped metasurface with resonant wavelength at 1500 nm was designed and simulated using Finite Element Method implemented in the commercial software COMSOL Multiphysics to match an InGaAs/InP quantum well NW LED's broad electroluminescence spectrum from 1300 to 1600 nm [2]. The double-ellipse shaped metasurface was fabricated from amorphous silicon deposited by plasma enhanced chemical vapour deposition on a nickel film coated glass substrate. The double-ellipse shaped metasurface was then half-submerged into an SU8 layer and then removed from the thin nickel film by wet etching method and transferred onto the prefabricated NW LED device.

The transmission spectrum measured from the as-fabricated, flexible metasurface shows a resonance wavelength dip at 1500 nm which is in good agreement with that obtained from simulation and also overlaps well with the electroluminescence spectrum measured from the InGaAs/InP quantum well NW LED. Further work is underway to transfer the flexible metasurface onto the NW LED to investigate their performance for optical sensing of chemical or biological molecules.

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Quantum Computer Error Structure Probed by Quantum Error Correction Syndrome Measurements

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Abstract

Steady progress is being made in the development of quantum devices containing increased numbers of qubits with improved coherence times and reduced gate error rates. With this comes additional challenges characterizing the performance of these large-scale devices in different regimes of operation. One important regime is that of the quantum error correction circuits for fault-tolerant quantum computing. These require optimized implementation of syndrome measurement circuits [1], efficient (fast and scalable) processing and decoding of syndrome data [2], and understanding the role of complex noise particular to syndrome measurement [3]. The multiple repetitions of mid-circuit measurement and reset present in large depth syndrome measurement circuits have been shown to cause additional noise sources to emerge beyond those readily identifiable by techniques such as randomized benchmarking on local logical components [1, 3]. With the circuit volume of fault-tolerant quantum computers expected to be dominated by syndrome measurement, the associated data stream forms a rich source of information describing the current state of devices [4]. We have investigated the characterization of device performance based on syndrome measurement data for the heavy-hexagon code and compared it to simulations under depolarizing, biased and inhomogeneous noise models [5, 6]. While effective error rates can be extracted from this data, our results bring attention to the need for further exploration of error models beyond the single parameter depolarizing channel.

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Classical Gaussian Boson Samplers

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Abstract

A Gaussian Boson Sampler (GBS) is a non-universal optical quantum computer designed to demonstrate quantum advantage without requiring error correction. Its output distribution is #P-hard to calculate or sample from, and recent experimental implementations have claimed quantum advantage. However, there is no rigorous and tractable method known to verify samples from a GBS and as such there is no strict proof of quantum advantage in these devices. This has prompted multiple groups to design classical algorithms to sample from approximate GBS distributions. These groups claim that the results from these classical samplers are closer to the ideal GBS distribution than the experiment and argue that this constitutes a refutation of quantum advantage. We here compare all currently competitive classical samplers, a novel phase space sampler of our own design and the experimental data against phase space simulations of the GBS. These phase space simulations enable us to calculate binned count distributions that are sample-efficient but still contain contributions from high-order correlations, and achieve an error scaling better than the experiment. We find that the Jiuzhang 2.0, 65-micrometer beam waist experimental data matches the theoretical binned count distribution better than all available classical samplers on 4 out of the 5 datasets giving evidence for quantum advantage.

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Enhanced Second Harmonic Generation in freeform dielectric metasurfaces

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Abstract

In recent years, the use of metasurfaces has garnered extensive interest in the scientific community due to their potential application in a broad range of photonic applications. Devices based on metasurfaces enable new optical functionalities offered by their capability to manipulate light and re-emit it with on demand frequency, phase, radiation, and polarisation patterns. In dielectric metasurfaces, the efficiency of frequency conversion processes has been increased through the strong field enhancement generated at the resonant wavelengths [1]. Among the various nonlinear optical processes employed for frequency conversion, second-harmonic generation (SHG) is one of the most widely explored. SHG is a second-order nonlinear effect that coherently doubles the frequency of the incident light. However, to date, dielectric metasurfaces rely on conventional designs to enhance the conversion efficiency of SHG. To exceed the limits of conventional designs and meet the many challenges associated with resonant frequency conversion in metasurfaces, designs based on more complex topological features have been proposed [2].

Here, we demonstrate enhanced SHG using a GaAs metasurface designed by topology optimization. We realise a resonant GaAs metasurface having a freeform design of increased geometric and fabrication complexity. The metasurface was fabricated by epitaxy, electron beam lithography and etching processes. Subsequently its linear transmission spectrum was measured showing a resonant behaviour around the telecommunication window, corresponding to a quality factor of ~ 40. The fabricated metasurface was illuminated by a fundamental beam having a central wavelength of 1550 nm, generating a strong SHG. Driven by the resonant behaviour, the metasurface shows an enhancement of up to 30 times in the SHG emission as compared to the GaAs thin film. Our results open new avenues for novel nonlinear imaging and sensor devices.

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Brillouin laser at 1064 nm with Cascade-Control Using an Etalon Input Coupler

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Abstract

We report a novel approach to Brillouin laser design that enables reconfigurable operation between single-frequency narrow-linewidth and Brillouin comb output. The design uses an etalon input coupler in a three-mirror folded cavity that allows for a large, collimated pump beam on the etalon and a small waist size inside a TeO2 high-gain medium. In single-frequency configuration, the threshold for laser action was 10 W and an output beam power of 0.25 W was achieved. The Brillouin-shifted output was 17.4 GHz from the 1064 nm pump had a measured reduction in the Lorentzian linewidth by a factor 3. For frequency-comb configuration, the threshold was 2 W, 0.4 W was generated per output beam, and a total of 6 Stokes orders were generated, spanning frequencies over 104 GHz. Controlling the number of Stokes orders was performed by changing the cavity length. The Brillouin laser was also configured to generate only the first two Stokes orders, which were then photo-mixed using a 25 GHz photodiode. The heterodyne signal showed an 18 dB reduction in noise at offset frequencies above 1 MHz compared to the pump noise dominated pump-first Stokes spectrum. With variations in cavity design and Brillouin material, we believe this design is amenable to a wide range of power, generation of ultra-narrow linewidths and synthesis of low-noise microwave and mm-Wave frequencies.

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Isolator-Free 40 W Diamond Raman Laser at 607 nm

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Abstract

We present an intra-cavity frequency doubled diamond Raman laser (DRL) that is free of isolators in the path of the pump beam. The DRL is a 4-mirror cavity with a z-fold layout with an intra-cavity lithium triborate crystal (LBO). Using a highly-transmitting end mirror that resulted in generating two output beams at 607 nm, a slope efficiency of 35% was achieved, and a summed output of 60 W. When using an end mirror that was highly reflecting (HR) for the 607 nm light (double-pass SHG) the maximum power achieved in the single output beam was 40 W. In a free-running configuration, stable single longitudinal mode (SLM) operation was achieved at lower powers for periods on the order of 10 s before a mode-hop occurred. The stability of SLM was hindered by higher order modes of stimulated Brillouin scattering (SBS), which was suppressed by cavity length adjustment and an intra-cavity aperture. The high average power output of this DRL and power-scalable design show promise for the future of DRLs. Improved methods of suppressing SBS and de-stabilising effects are being investigated.

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High-performance liquid-metal-printed Indium oxide transistor with steep subthreshold swing

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Abstract

The development of field-effect transistors (FETs) based on ultrathin oxide semiconductors with high carrier mobility are of interest due to their high-performance and CMOS compatibility, and liquid printing of oxide nanosheets using the native oxide on low melting point metals or alloys offers an interesting means of fabricating high-performance devices. Herein, we propose a feasible scheme for fabricating high-performance FETs with low subthreshold swing (SS) and high I_{ON}/I_{OFF} ratio using a liquid-metal-printed indium oxide channel and a thin ALD-grown Al_2O_3 gate dielectric.

In this work, ~27 nm of Al_2O_3 was deposited on highly doped Si wafer under 250 degree by using plasma-enhanced atomic layer deposition (PE-ALD) with O_2 plasma and trimethylaluminum (TMA) as precursors. Then a droplet of indium was placed on Al_2O_3/Si wafers which were heated to 250 degree under ambient air. After a squeezing and separation procedures, homogeneous ultrathin indium oxide was exfoliated onto Al_2O_3/Si wafers. Electron-beam lithography (EBL) and e-beam evaporation were used to define Cr/Au Source/Drain electrodes on indium oxide.

The FET device shows excellent back-gated n-type transistor characteristics (Fig. 1). Analysis of IV data shows that the FETs have a steep subthreshold swing (SS) of ∼194 mV/Decade along with an I_{ON}/I_{OFF} ratio of more than 10^6.

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Figure 1. (a) 3D schematic of the fabricated FET, (b) Typical transfer curve and (c) Output characteristic of the FET.

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Characterization of Local Friendliness Polytopes

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Abstract

Recently the Local Friendliness (LF) no-go theorem has gained a lot of attention, owing to its deep foundational implications. Canonically, this no-go theorem has been exhibited in scenarios which combine Bell-experiments with Wigner's friend-type set ups, containing space-like separated superobservers who are assumed to be capable of measuring a local observer, also known as their friend. Analogously to the hypothesis of local hidden variables in Bell scenarios, the assumptions underlying the principle of Local Friendliness constrain the space of probabilistic behaviour of the superobservers to be a subset of the no-signalling polytope in such scenarios. It has additionally been shown, that there are scenarios where the set of behaviours compatible with the principle of Local Friendliness is genuinely larger than than the Bell-local polytope, while in some scenarios those sets are in fact equal. In this work, we complete the picture by identifying all the canonical Local Friendliness scenarios, with arbitrary number of superobservers, friends, measurements and outcomes, where the set of LF correlations admit a local hidden variable model, and where they do not. Our proof is constructive in the sense that we also demonstrate how a local hidden variable model can be constructed, given behaviour compatible with LF in the appropriate scenarios. While our principle motivation is the foundational question of better understanding the principle of Local Friendliness, the same inequalities constraining LF polytopes have been shown to arise in a priori unrelated contexts of device-independent information processing. Our results may thus find use in those research areas as well.

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A general analytic method for finding soliton solutions

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Abstract

Solitons are a unique phenomenon, observed and studied in a range of physical systems with nonlin- ear effects, identified by their unchanging pulse shape as they propagate. Most notably, the nonlinear Schrödinger equation, known to be integrable, has been used to understand and predict these solutions, and in the field of optics, the balance of nonlinearity and quadratic dispersion produces soliton solutions which are analytically defined and widely studied [1]. New experimental breakthroughs have resulted in the observation of soliton solutions with complicated dispersion profiles, where higher order dispersion effects dominate [2, 3]. These new solutions clearly exhibit soliton behaviour, but require modified forms of the nonlinear Schrödinger equation which are no longer integrable, and finding analytic solutions for these systems is significantly more difficult. We present a general approach to generate analytic, station- ary solutions to generalized nonlinear Schrödinger equations with complicated dispersion profiles. Our method is systematic, and does not require initial guesses or assumptions, and thus can even find solutions where numerical methods struggle. The solutions we find take the form of an exponentially converging sum of functions, each with an infinite number of discontinuous derivatives at the origin, which disappear upon summation. This discovery now opens up new directions of research for a range of different fields, from physics, to engineering, to applied mathematics, which rely on or use analytic expressions.

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305

Formation and growth of photodeposited Ag microstructures on ZnO thin films.

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Abstract

Semiconductor photocatalysis is a promising field of study for environmental remediation technologies such as hydrogen production and carbon dioxide decomposition. The binding of noble metal and semiconductor nanoparticles can create a hybrid photocatalyst with sensitivity to solar illumination. These hybrids could potentially enable energy intensive chemical degradation reactions to be performed in sunlight, reducing existing environmental pollutants to simpler molecules. Currently, the reactions used to produce these hybrid photocatalysts are not well understood as there are many chemical and optical parameters that control the reaction rate and results. This study elaborates on the formation process of Ag microstructures created using these photocatalytic reactions by carefully controlled application of laser light as the excitation source. Ag structure growth was shown to be influenced not only by the total energy applied through laser exposure, but by altering the delivery profile of that energy to a ZnO thin film substrate. Previously, these reactions were known to be strongly dependent on the photon flux through the interaction area, however our work has shown that 'off periods' can significantly influence the formation of structures. Our results may support the fabrication of devices based on these hybrid photocatalysts by optimising the delivered light energy.

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Characterising cartilage degeneration using polarisation-sensitive optical coherence tomography

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Abstract

Osteoarthritis (OA) affects millions worldwide, costing billions in healthcare and productivity in Aoteoroa, New Zealand alone. OA is characterised by micro-scale degeneration of the articular structure which can lead to large-scale degradation of the articular surface. Early-stage diagnosis of OA is crucial for effective management, as invasive surgery becomes necessary at later stages. Hence, there is a need for a high-resolution imaging modality capable of tracking structural changes in articular cartilage (AC).

The progression of OA disrupts collagen organisation, reducing birefringence. Therefore, to address the pressing need for high-resolution imaging in tracking structural degeneration within AC, we have employed polarisation-sensitive optical coherence tomography (PS-OCT) to detect collagen disorganisation associated to early-stage micro-scale damages.

This study aims to utilise PS-OCT to study the dynamics of collagen in AC under compression. Our study proposes a direct investigation of collagen orientation using a custom built fibre-based PS-OCT system with a compression imaging head, that allows quantification of the depth-resolved optical axis (OpAx). By analyzing the OpAx during cartilage compression, which serves as a proxy for collagen orientation, our approach enables accurate interpretation of early micro-scale changes associated with OA development. Utilizing compression-based imaging, we aim to capture a time sequence of high-resolution OpAx images at various stages of compression. Preliminary investigation on indented AC have revealed increased birefringence at the indented region and a radial reorientation of the OpAx away from the compression center. Indentation was done over the course of one hour by a 4.5mm indenter with approximately 4.9MPa stress before chemical fixing.

In summary, our study displays potential for enhancing our understanding of collagen dynamics and its correlation with AC degeneration. This novel utilization of compression-based depth-resolved OpAx imaging shows promise in both research and clinical applications, paving the way for better diagnostic and therapeutic strategies for cartilage-related conditions.

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Frequency Stabilised Diamond Raman Laser

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Abstract

High-power, single longitudinal mode (SLM) laser sources are a current challenge in the field of laser physics. Power scaling of SLM sources are limited by spatial-hole-burning, and other inhomogeneities in the laser gain media which result in multimode behaviour at higher powers. Diamond Raman lasers (DRLs) are a promising candidate, due to the spatial-hope-burning free Raman gain, and high thermal performance of diamond. While high-power SLM has been demonstrated for short durations, prolonged SLM operation that is locked to a frequency reference has not been explored in detail. Here we report a 9W DRL operating at 589 nm, stabilized using a wavemeter and piezo-control of the cavity length. The DRL had a linear cavity length of 96 mm, a fundamental Stokes wavelength of 1178 nm, and was intracavity frequency doubled to 589 nm. The laser had a free-running thermal drift of up to 100 MHz/min. With locking activated, the effects of the thermal drift were compensated, and the laser's frequency noise was reduced to < 200 MHz over several minutes. Mode-hop-free operation was obtained for up to 12 minutes and was limited by the PID operating range. The laser's power spectral density (PSD) was measured using a linewidth analyser, which yielded an effective linewidth of 8 MHz over the 20 ms integration time and an intrinsic linewidth of less than 950 Hz (instrument limited).

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Grey-box noise characterisation and control for initially correlated systems

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Abstract

The grey-box method was introduced by Youssry et al. [1] to characterise open quantum systems using a combination of known physics and machine learning approaches. This work extends the grey-box method to work with initially entangled systems using the bath-positive decomposition introduced by Paz-Silva et al.; we dub this approach the grey-box alpha. [2]. Furthermore, we show how the grey-box alpha approach can still be effective in conventionally more difficult scenarios, such as when the control signal leaks into the bath. Using the trained grey-box network, we show how backward propagation can be leveraged to calculate gradients with respect to input parameters, allowing for the utilisation of gradient-based optimisation protocols providing faster convergence than gradient-free methods. We test our methods on numerical simulations of physically motivated qubit systems. Finally, we explore the possibility of propagating the grey-box alpha in time to predict the system's dynamics past the initial training duration.

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All-metal air-channel devices: nanofabrication, comparison of device geometries, and applications

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Abstract

Half a century ago vacuum electronics remained key components of integrated circuits (IC) before being replaced by solid state devices. It is well demonstrated that scalability is the crucial factor where solid-state devices dominated over vacuum electronics. However, recently demonstrated nanoscale vacuum channel devices or air-channel devices have a special advantage over solid-state devices due to the promise of vacuum-like ballistic transport in air, radiation insensitivity, and nanoscale size. Being a new field key aspects that needs better understanding and that are discussed here are device physics and modelling, experimentally achieving high current at low voltage along with considerable mechanical stability, and repeatable and consistent nanofabrication methods. The comparative and experimental analysis of four planar and metallic electrode-pair geometries at 10 nm channel length is presented. The impact of nano-electrode-pair geometries on overall device performance is investigated. Further, a simple lumped-element circuit model for a resonant vacuum nano-antenna driven by beyond 100 THz optical excitation is presented. This demonstrates a capability of THz integrated memory and logic operations. Experimental investigations provide strong directions for high-performance and stable devices. In-depth theoretical discussions and circuit model will enable the accurate modelling of emerging low-power, high-speed, radiation-hardened, and opto-electronic integrated nanoscale vacuum electronics.

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Quantum noise spectroscopy for simultaneous reconstructions of generalised quantum environments

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Abstract

\noindent The loss of coherent quantum information is an inevitable consequence of a system that cannot be completely isolated from environmental interactions. Obtaining precise knowledge of the spectral features of noise sources introduced by varied system-environment couplings is a fundamental prerequisite to dynamical error suppression via optimal control or dynamical decoupling routines. Open-loop quantum control protocols have recently provided experimental demonstrations of simultaneous first-order spectral reconstructions of noise associated with non-commuting system operators [1]. This approach leverages sequences of optimally band-limited ``Slepian'' control envelopes to efficiently characterise both dephasing and control noise induced by an engineered zero-mean Gaussian spectrum. We introduce a general-purpose theoretical framework that expands this control protocol to a minimal-assumption setting of multi-axis and non-gaussian noise. We employ a repeated sequence of Slepian functions to generate high spectral concentration frequency-comb [2] filter functions that accurately reconstruct high-order polyspectra through a novel strategy that linearises the response of the control to the qubit decay and dephasing. We furthermore outline how our method naturally extends to more intricate settings of quantum environments, offering substantially enhanced precision of noise characterisation.

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[2] Gonzalo Alvarez and Dieter Suter. Measuring the spectrum of colored noise by dynamical decoupling. Physical Review Letters, 2011.

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Automated quantum circuit design with nested Monte Carlo tree search

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Abstract

Quantum algorithms based on variational approaches are one of the most promising methods to construct quantum solutions and have found a myriad of applications in the last few years. Despite the adaptability and simplicity, their scalability and the selection of suitable ansatzes remain key challenges. In this work, we report an algorithmic framework based on nested Monte Carlo tree search coupled with the combinatorial multiarmed bandit model for the automated design of quantum circuits. Through numerical experiments, we demonstrate our algorithm applied to various kinds of problems, including the ground energy problem in quantum chemistry, quantum optimization on a graph, solving systems of linear equations, and finding encoding circuits for quantum error detection codes. Compared to the existing approaches, the results indicate that our circuit design algorithm can explore larger search spaces and optimize quantum circuits for larger systems, showing both versatility and scalability.

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Quantum-enhanced multispectral Raman imaging

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Abstract

The shot noise caused by the random arrival of photons at the detector introduces a precision limit in speed and sensitivity for light microscopes. The typical solution is to increase the illumination power to reduce the shot-noise precision limit. However, bright light can severely disturb and damage living samples, necessitating an alternative solution to the shot noise precision limit.

Recently, quantum advantage was demonstrated in a high-performance microscope, where quantum correlations were introduced in the illumination. This allowed us to reduce the noise floor below the shot noise level, and the quantum-enhanced signal-to-noise ratio was not reproducible under classical illumination without causing photodamage.

In this work, we present an improved quantum microscope and report an increased level of quantum correlations, multispectral capabilities, and imaging time compatible with video-rate imaging. This represents an important step toward wider use of quantum technology in biological studies.

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Quantum Chaos in Open System Digital Quantum Simulation

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Abstract

Digital quantum simulation (DQS) is one of the most promising applications of quantum computers (QC). Employing product-formula based Trotter algorithms, DQS can simulate dynamics of quantum systems by decomposing it into a sequence of gate-based Trotter steps. Moving to shorter steps can improve simulation accuracy, but at the cost of using more gates, which therefore also generally increases the noise burden on the processor, and thus its computational power. On the other hand, recent results show that simulation performance can exhibit a rapid breakdown threshold as step size increases, beyond which the dynamics can become quantum chaotic [1]. These results were observed for closed quantum simulators, whereas real (noisy) QCs are open quantum systems. Open quantum dynamics can also be exploited directly, such as in quantum algorithms that use system cooling to generate entangled quantum states [2]. Understanding whether Trotterisation thresholds also exist in open DQS could therefore help understand performance limits for novel quantum computing applications that employ open quantum systems.

In this work, we study a range of experimentally relevant open quantum system models and observe Trotterisation thresholds that show the onset of quantum chaos. We explore the relationship between different performance signatures such as dynamical quantities, steady-state parameters, and eigenvector component statistics [Fig. 1], and also apply new analytical techniques to the context of open-systems quantum chaos.

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[2] X. Mi et al., arXiv:2304.13878 (2021).

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Complexity analysis of weakly noisy quantum states

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Abstract

Fault-tolerant quantum computers are widely recognized for their proven advantages over known classical computational models. However, in the current noisy intermediate-scale quantum (NISQ) era, a pressing challenge of fundamental importance is to determine whether such quantum advantages can be extended to NISQ quantum computers. This challenge arises due to the inherent difficulty in quantifying the complexity of noisy quantum states. In this paper, we focus on a detailed analysis of the complexity of weakly noisy quantum states, which we define as the minimum quantum circuit depth required to prepare these states. We address, in particular, the question of whether a weakly noisy state can be approximated efficiently by a quantum estimator with a specific architecture. We develop a novel quantum learning algorithm, which exploits the intrinsic structure of specific quantum circuit architectures to characterize the power of noisy quantum computation. Specifically, the quantum learning algorithm returns the necessary minimum quantum resources under the specified quantum circuit architecture in order to reproduce the weakly noisy states under study, which provides an upper bound on their complexity. We validate our algorithm by conducting a numerical benchmark on the time dynamics of a quantum many-body system in the presence of local noisy channels, and our results highlight the capability of quantum learning algorithm in characterizing the power of NISQ quantum devices and explore their potential applications.

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Constraints on the Dark Sector Through Electroweak Precision Variables

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Abstract

The idea that a portal exists that bridges the dark matter sector with Standard Model particles is of particular interest in the particle physics community. One such example is the so-called dark photon, which couples to weak hypercharge before electroweak symmetry breaking. This results in the dark photon mixing with both the Standard Model photon and and Z boson, hence coupling to other Standard Model particles. The dark photon may also couple to some or all particles in the dark sector.

One way to place constraints on the dark photon is through electroweak precision observables (EWPOs), some of which will deviate from typical Standard Model values within the dark photon framework. We start by performing a global fit to EWPOs within the Standard Model framework. We then reperform the fit with rederived quantities within the dark photon framework, and place exclusions on the dark photon in terms of deviations from the Standard Model fit.

In this work, we first examine the implication of the latest CDF measurement of the W boson mass on the dark photon parameters. We then set exclusion limits on the dark photon couplings to dark matter particles in the case of Dirac fermions and also scalar dark matter.

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Optimising State Preparation in an Erbium Orthosilicate Quantum Memory

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Abstract

Future quantum computers and quantum communication technologies require a network to connect devices together. Crucial to this network is a quantum memory: a device to controllably store and release quantum information. Promising candidates for quantum memory applications are erbium doped crystals [1], including ^{167}Er:Y_2SiO_5 [2]. Er:Y_2SiO_5 has a long 1.3 s hyperfine coherence time [2] and an optical transition at 1538 nm in the low-loss telecommunication waveband used in optical fibre networks. A crucial step towards achieving practical quantum memories with Er:Y_2SiO_5 is increasing the storage-to-retrieval (memory) efficiency to above 90%.

We will present our work towards optimising the memory efficiency in Er:Y_2SiO_5. We have achieved the highest memory efficiency in Er:Y_2SiO_5 at 80%, which is soon to be published. One source currently limiting our memory efficiency is background absorption of incoming light due to imperfect spectral preparation and isotopic impurities [3]. Reducing background absorption in Er:Y_2SiO_5 is difficult due to complex uncharacterised relaxation processes. Hence, we are investigating the use of deep neural networks to optimise laser burn sequences used to prepare energy state populations. Deep neural networks have seen success in other experimental systems with complex physics [4]. In our system, deep neural networks can sample laser burn parameters much faster than any human experimenter, resulting in more optimal laser burn sequences. Our new optimal control techniques may increase memory efficiency, memory duty cycle rate, the possible quantity of information storage and give insights into uncharacterised physical processes causing relaxation.

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[3], Stuart, J.S., et al., Phys. Rev. Res. 3, 032054 (2021).

[4], Tranter, A.D., et al., Nature Communications 9, 4360 (2018).

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Optical coupling in lasing semiconductor nanowires

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Abstract

Semiconductor nanowires are a keystone in the miniaturization of optoelectronic devices, because they are promising candidates for compact and scalable nanolasers. While attractive properties such as excellent waveguiding properties, high optical gain, and low power consumption of nanowires have been widely studied for lasing applications, controlled evanescent coupling between two adjacent nanowire lasers can potentially yield interesting applications in nanoscale photonics, such as sensing based on coupling-induced mode-splitting and far-field beam profile tuning. In recent years, the optical resonances in nanowire pairs have been investigated for Si nanowires, GaN nanowires and CdS nanowires for various geometric arrangements and with disparate measurement techniques. In this study, we precisely control the position of the nanowires. Further, we utilize FDTD simulations to examine the effect of a varying overlap of the evanescent fields for nanowire pairs on a SiO2 substrate. In addition, micro-photoluminescence measurements with a nanosecond pulsed 355nm laser were conducted and compared against the simulation results to verify coupling.

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Yttrium Spin Bath Dynamics in $^{167}Er^{3+}:Y^2SiO^5$

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Abstract

Photon losses restrict the range of quantum communications through optical fibre networks to the order of 100 km. Quantum repeater protocols, such as the DLCZ protocol, can substantially increase this range, but require quantum memories that can store quantum states of light for at least the classical transmission time across the network [1]. Global implementations require storage times on the order of 100 milliseconds.

We are developing a quantum memory for light based on 167Er3+:Y2SiO5 for quantum computing and communication applications. We have recently demonstrated memory operations where optical states are stored and recalled from the 167Er3+ ground hyperfine state with efficiencies of over 80%. We are looking to optimise the memory's storage time and data storage density, both are ultimately limited by interactions between the 167Er3+ ions and the Y nuclear spin bath of the host crystal. In this poster we report on optical and radio frequency coherent studies investigating these interactions and the dynamics of the spin bath around the Er ion. We characterise the trade-off between the available data storage density and the storage time. A key finding is that for storage times up to 100 ms the full data storage capacity of the memory should be available with no significant loss of fidelity.

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Impact of Data Augmentation on QCNNs, Compared to Classical CNNs

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Abstract

Abstract: In recent years, Classical Convolutional Neural Networks have been applied for image recognition successfully. CNNs models take the value of image pixels as input and utilize convolutional and pooling layers to learn the features and classify the images. Quantum CNNs are proposed as a promising alternative to classical CNNs. The quantum mechanism realised a more efficient training process by reducing the number of N inputs to $\log^2(N)$. In this paper, both CNNs and QCNNs are implemented and compared by the testing losses and prediction accuracy. To ensure fairness, the same source of hand-written digits images is used, and all the models are properly trained to convergence. Additionally, data augmentation, a technique commonly used in CNNs to improve the performance of classification by generating similar images based on original inputs, is also implemented in QCNNs. Surprisingly, the results showed that data augmentation didn't improve QCNNs performance. The reasons and logic behind this result are discussed, hoping to expand our understanding of Quantum machine learning theory.

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Metasurface-nanowire photodetectors for polarization sensitive infrared photon detection and imaging

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Abstract

Polarization is a crucial property of electromagnetic waves, offering additional information about subjects, like intrinsic material characteristic and surface curvature, enhancing photodetection and imaging for various applications including remote sensing, astronomy and biological studies. Therefore, developing high-performance miniaturized optoelectronic systems with polarization detection and imaging capability at infrared range has attracted increasing research interest in recent years. Meta-optics, based on wavelength scale nanostructure has demonstrated to be promising alternatives to the bulky optical components to manipulate light-matter interaction such as polarisation control. Here, we demonstrate the design and fabrication of multipixel metasurface-nanowire array integrated photodetectors (PDs) for polarization detection at infrared wavelength. The device is based on GaAsSb nanowire array grown by gold-seeded vapor-liquid-solid (VLS) by metalorganic chemical vapour deposition technique, which has a strong absorption at the wavelength of ~750nm to ~900nm, optimal for near infrared range (NIR) detection. L-shaped Ag thin film based metasurface oriented at different angles for different polarisation responses at 850 nm were designed using the finite element method based on COMSOL Multiphysics and fabricated on top of the NW array photodetector using focused ion beam technique. The spectral responses were measured from each of the 2x2 pixel of the metasurface-nanowire array integrated photodetectors. Consistently with the simulation results, polarization angle dependent photoresponses were obtained. Furthermore, we also demonstrated polarization imaging based on a single pixel imaging system [1] , indicating the ability for polarization imaging of our miniaturized metasurface-nanowire array integrated photodetector device. Our work presents a promising approach for developing advanced infrared photodetectors for future advanced optical systems.

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Highly ^{28}Si enriched silicon by localised focused ion beam implantation

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Abstract

Solid-state spin qubits within silicon crystals at mK temperatures show great promise in the realisation of a fully scalable quantum computation platform. Qubit coherence times are limited in natural silicon owing to coupling to the ^{29}Si isotope which has a non-zero nuclear spin. Here we present the production of highly enriched localised volumes within natural silicon wafers by irradiation using a 45 keV ^{28}Si focused ion beam with fluences above $1X10^{19}$ ions cm^{-2}. Nanoscale secondary ion mass spectrometry analysis of the irradiated volumes shows unprecedented quality enriched silicon that reaches a minimal residual ^{29}Si value of 2.3 +/- 0.7 ppm and with residual C and O comparable to the background concentration in the unimplanted wafer. Transmission electron microscopy lattice images confirm the solid phase epitaxial re-crystallisation of the as-implanted amorphous enriched volume extending over 200 nm in depth upon annealing.

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Quantum Variational Circuits for Document Classification

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Abstract

With the advent of near-term quantum computers, there is a growing interest in exploring the quantum potential for computationally intensive tasks such as Natural Language Processing (NLP). This is especially motivated by the observation that Variational Quantum Circuits (VQC) and neural networks exhibit similar mathematical structures [1]. As an emerging field of research, Data-Driven Quantum Natural Language Processing (QNLP) aims to leverage the power of quantum circuits to develop innovative algorithms for parameter efficient NLP models. Limited attempts in QNLP focus on re-implementing Long Short-Term Memory (LSTM) and Transformers by using VQCs as replacement blocks of the affine transformations [2]. While Quantum LSTMs have arguable success on tiny contrived datasets (e.g., trained on two short sentences), Quantum Transformers are deemed not yet computationally feasible. In this paper, we demonstrated the possibility of directly designing VQCs for binary document classification tasks on a real-world text dataset. Although we did not match state-of-the-art performances of classical implementations, we have achieved 83% test accuracy with only 50 trainable parameters and demonstrated capability of generalization on a real-world dataset which could inject some hope into the current NLP field dominated by Large language models.

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[2] Di Sipio, Riccardo, et al. "The dawn of quantum natural language processing." ICASSP 2022-2022 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP). IEEE, 2022.

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Exploring Barren Plateau Phenomenon in Quantum Data Re-uploading

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Abstract

Quantum machine learning is an exciting area of development that promises possible quantum advantages with current noisy, error-prone (NISQ) devices [1]. By employing a parameterised circuit, quantum machine learning models are able to iteratively learn the optimal solution [1]. This promising area of development is limited by trainability, with many models exhibiting the barren plateau phenomenon [1][2][3][4]. This project aims to investigate whether or not data re-uploading quantum neural networks (QNNs) suffer from the barren plateau phenomenon. Specifically, a rigorous mathematical relation between the variance of a cost function's gradient and number of qubits for a data re-uploading QNN will be developed. The relationship shall then be demonstrated by simulating the trace of the Fisher information matrix for a data re-uploading QNN, while varying the number of qubits and the circuit depth.

[1] Marco Cerezo et al. "Challenges and opportunities in quantum machine learning". In: Nature Computational Science 2.9 (2022), pp. 567–576.

[2] Amira Abbas et al. "The power of quantum neural networks". In: Nature Computational Science 1.6 (2021), pp. 403–409.

[3] Marco Cerezo et al. "Cost function dependent barren plateaus in shallow parametrized quantum circuits". In: Nature communications 12.1 (2021), p. 1791.

[4] Jarrod R McClean et al. "Barren plateaus in quantum neural network training land- scapes". In: Nature communications 9.1 (2018), p. 4812.

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Microstructural studies of carbon phases in ureilite meteorites

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Abstract

Ureilites are primitive achondrite meteorites that result from fractional melt extraction from deep within the ureilite parent body [1]. These meteorites contain up to 7% carbon and exhibit a range of carbon phases, including amorphous carbon, graphite, diamond, and diamond-like structures [2-4]. The hexagonal form of diamond, lonsdaleite, has also been reported, despite recent speculation that it may not exist [5]. Analysis of carbon phases in ureilites can prove difficult due to very small sample volumes for techniques like Raman spectroscopy and x-ray diffraction.

In this study, optical petrography, electron probe microanalysis (EPMA), and electron microscopy techniques were used to investigate the carbon phases present in several ureilite meteorites. The key to our study was the use of EDS and CL spectroscopies in the EPMA to produce maps of polished sample surfaces that distinguish between different carbon phases. Areas of interest were targeted for TEM analysis by preparing site specific specimens using a focused ion beam (FIB). Graphite, diamond and lonsdaleite were all identified, with a crystallographic orientation relationship observed between graphite and lonsdaleite. Analysis of diamond and graphite suggests that there is no crystallographic orientation dependence, rather, the diamonds appear to form via a chemical vapor deposition (CVD)-like process.

Furthermore, the textures in meteorites indicate that polycrystalline lonsdaleite replaced and preserved the shape of pre-existing graphite, implying that a pathway exists for manufacture of shaped ultrahard tools, given predictions that lonsdaleite has superior mechanical properties to diamond. Additionally, our TEM analysis of other ureilites provided evidence for not only defective cubic diamonds, but also defective lonsdaleite. This suggests that the varying conditions these ureilites experienced led to vastly different microstructural outcomes. Overall, our study sheds new light on the distribution and microstructure of carbon phases in ureilites, providing important insights into the origin of these intriguing meteorites.

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Selective Area Epitaxy of Multi GaAs/AlGaAs Radial Quantum well Nanowire Lasers

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Abstract

GaAs/AlGaAs quantum wells (QWs) are important heterostructures for optoelectronic device applications such as LEDs, lasers, photodetectors, and solar cells, due to their strong quantum confinement effect and negligible lattice mismatch for a wide range of Al composition allowing large bandgap tunability. To further harness these characteristics for cost effective, high density, low power applications, one promising device architecture is nanowire (NW) arrays, as their one-dimensional nanoscale geometry leads to unique optical and electrical properties offering the opportunity in design of new optoelectronic devices with enhanced performance and functionalities outperforming their planar counterparts. GaAs/AlGaAs QW NWs grown through Au seeded vapour liquid solid (VLS) have been reported with good optical quality and demonstration of room temperature lasing [1]. The position controlled, catalyst-free selective area epitaxy (SAE) grown GaAs/AlGaAs QW NW array was also reported with QW formed predominantly in the axial direction [2]. So far there are very few reports on the growth of radial GaAs/AlGaAs QWs and their device applications. In this work, by separately optimizing the GaAs core and AlGaAs shell growth conditions, we demonstrate the successful SAE of a 5-QW GaAs/AlGaAs NW array by metal organic chemical vapour deposition technique. A strong QW photoluminescence peak is observed at 760 nm at 4 K and optically pump lasing achieved at a low threshold of 35 uJ cm-2 pump fluence. The cross-sectional transmission electron microscopy study reveals the formation of radial QWs along the NW axis with no distinct axial QW formation, which is different from the previously reported SAE based GaAs and InP QW systems [3]. The radial QW NW arrays are promising structures for further demonstration of high-performance optoelectronic devices.

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Ultrafast All-Optical Valleytronics in WSe_2 Monolayers

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Abstract

With electronics reaching their performance limits in terms of speed and size, light is the ideal candidate to realise superior devices thanks to all-optical operations. A promising approach in this direction is based on valleytronics using two-dimensional transition metal dichalcogenides (TMDs). TMD monolayers have two energetically degenerate but non-equivalent valleys in the K and K' points of the Brillouin zone which can be selectively excited (write) since light of opposite helicity couples to opposite valleys. The detection (read) of valley polarization (VP) is so far mostly based on polarization-resolved photoluminescence (PL). However, this approach has two main drawbacks: (1) it detects an averaged light emission over a time scale that is much longer compared to the valley and spin lifetimes; (2) it is intrinsically an invasive method, which measures the VP only after light emission. Nonlinear optics and in particular second-harmonic generation (SHG) overcomes these disadvantages and provides an ultrafast and non-destructive method for the detection of the VP in TMDs. The presence of a VP breaks the time-reversal symmetry of TMDs and thereby leading to new terms in the nonlinear optical susceptibility which can be probed by polarization-resolved SHG measurements.

Here, we simultaneously pump (write) and probe (read) the VP in WSe2 with one single elliptically polarized pulse at room temperature. We probe the VP using polarization-dependent SHG measurements at different fundamental wavelength values and find that resonant SHG at the A:1s exciton state is the best probe of the VP. In addition, we investigate the mechanism of VP generation under our experimental conditions. Looking at the combined results of two-photon PL measurements and power-dependent valley SHG, we deduce that the observed VP is generated by an ultrafast coherent optical Stark-shift. Our work provides direct evidence of ultrafast and all-optical coherent generation and detection of valleys in TMD monolayers.

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InAs/InAsP/InP core-shell nanowire arrays for SWIR photodetector applications

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Abstract

Nanowires (NWs) made of narrow-bandgap III-V semiconductors such as InAs and InAsSb have great potential for short-wave infrared (SWIR) photodetection due to their resonance-enhanced light absorption, geometry-tunable absorption spectrum, high carrier mobility, and a wide operating temperature range. They are therefore promising for applications such as remote sensing, photovoltaic devices, and infrared imaging. However, progress in this field has been impeded by challenges associated with the significant surface and Auger carrier recombination in typical NW structures, often resulting in high dark currents and reduced detectivity. Although different surface passivation methods have been employed to reduce the dark current levels, most of these approaches either have limited success due to sub-optimal passivation interface [1] or have to rely on integrated plasmonic gratings to improve the signal-to-noise ratio [2]. In this work, by engineering the device architecture of an InAs/InAsP/InP core-shell NW array, we demonstrate a SWIR photodetector device with excellent photoresponsivity at room-temperature. Every individual NWs of the device consists of a light-absorbing InAs core that is encapsulated by InAsP and InP shell layers, which function as a strain-relaxing buffer layer and an in-situ passivation layer, respectively. Furthermore, with an in-situ doping process during the NW growth, a p-i-n device architecture was engineered for optimal alignment between the active light-absorbing region and the built-in electric field across the NW. With our optimised device architecture and fabrication process, an excellent room-temperature photoresponse has been successfully achieved at zero bias in wavelengths range of 1 to 3 µm, with a peak responsivity of 8.8 mA/W recorded at 1.65 um. Furthermore, our simulation results show tunability of SWIR photodetection by varying NW diameters.

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412

Estimating ground state properties of spin models using quantum computed moments

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Abstract

The determination of ground state properties of quantum systems is a key problem in physics and chemistry that presents a promising near-term use case for quantum computing. Such problems are typically approached via variational methods [1], which involve the preparation of a trial state on a quantum computer followed by direct measurement of its energy and other quantities of interest. However, current hardware constraints typically prevent an accurate description of the target ground state, limiting the performance of such approaches at any practically useful scale. Based on Lanczos expansion theory [2-4], we present a method which, via the quantum computation of Hamiltonian moments, offers a correction to variational estimates of the ground state energy [5-7] and arbitrary ground state observables [8]. The moments-based estimates not only deal with sub-optimal trial states, but are also highly robust to noise. We demonstrate the potential of this approach on real quantum hardware for models in quantum magnetism. Our method provides meaningful estimates of ground state properties in the intermediate circuit depth regime, pointing the way to quantum heuristic approaches to practically useful problems in the future.

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416

Parametric Study of Nozzle Throat Dimensions on Plasma Properties of a Bidirectional Gas Injected Radio-Frequency Inductively Coupled Plasma Torch.

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Abstract

A radio-frequency (RF) inductively coupled plasma (ICP) torch with a bidirectional gas injection method offer many advantages in industry applications such as material processing and space propulsion. However limitations still occur such as a strong gas instability which limits the ability to reach higher gas temperatures which restricts industry applications. Nozzle throat size can have a significant affect on the bidirectional gas dynamics and could solve these limitations. In this study we investigate the effect of the nozzle sizes (from 1.5mm to 4.0mm in 0.5mm increments) on plasma characteristics. We use indirect diagnostic measurements to find thermal efficiency and stagnation temperature, along with optical emission spectroscopy (OES) to investigate gas temperatures and electron densities. We use a combination of the Boltzmann plot approach and leaking in N_2 at low percentages to map spectra in SpecAir to find excitation and ro-vibrational temperatures. We find the stagnation temperatures plateau out at approximately 3300K for the smaller nozzles, whilst the 3.5mm and 4.0mm nozzles reach slightly lower temperatures and then experience a sharp decline in temperature post peak. We find increasing nozzle size leads to increasing thermal efficiency from 29\% to 70\%. (1.5mm to 4.0mm). We investigate the electron density of the plasma via electron recombination, the Saha-Boltzmann method and RF antenna coupling. Additionally the application of the Boltzmann plot is used to find the excitation temperature. Electron densities were found in the order of high 10^{19} to low 10^{20} m^{-3}, and maximum excitation temperatures where found between 8500K to 10000K. In general for a set pressure, decreasing nozzle size leads to increase in electron density and excitation temperature. This study has characterized the plasma for a range of parameters that can be applied to industry applications such as material procession and space propulsion.

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Optical power requirements for inter-satellite laser links

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Abstract

This poster compares the minimum received optical power requirements for different inter-satellite interferometric laser links.

In inter-satellite interferometric missions, such as the Gravity Recovery and Climate Experiment - Follow on (GRACE-FO) mission, real time phase measurement is performed using a phasemeter; a feedback loop utilising a digitally implemented phase-locked loop. GRACE-FO generates critical date in the monitoring of ice mass and ground water movement, two critical measurements in tracking the impact of climate change. For future Earth geodesy missions, different optical architectures are being explored to increase operational robustness and relax mission requirements.

A limiting factor in mission design is the minimum optical power at which the phase of the incoming signal can be reliably tracked, as minimum operating optical power constrains parameters such as spacecraft separation and telescope design. Recent developments in weak field optical phase tracking have experimentally shown that robust phase tracking is possible at the femtoWatt level and below. This poster asses the impact different satellite interferometric mission configurations and optical architectures have on the minimum optical power required to perform optical phase tracking. The results of this work relax requirements on mission system design and highlight the feasibility of cheaper mission architectures thought to be infeasible based on optical power constraints.

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Highly Directional and Long-Propagating Ghost Phonon Polaritons through Selective Mode Excitation

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Abstract

The precise manipulation of phonon polaritons (PhPs) offers unique possibilities in the realm of nanophotonics. This technology finds diverse applications in fields like on-chip optical communication, quantum information processing, and controlled thermal radiation. A recent discovery introduced us to ghost hyperbolic phonon polaritons (g-HPs), which exhibit distinctive features, including hyperbolic dispersion on the surface and oblique wavefronts within the bulk [1]. These g-HPs possess a remarkable ability to propagate over long distances with a ray-like quality, making them highly desirable. Nevertheless, achieving versatile control over the directionality of g-HPs remained a challenging puzzle. In our present study, we unveil an experimental breakthrough by demonstrating that modifying the geometry of the launching nano-antenna provides the capability to selectively excite specific polaritonic modes. This controlled excitation empowers us to dictate the direction and propagation length of the g-HP mode. Using a lone, asymmetric, triangular gold antenna meticulously crafted on the surface of a calcite crystal, we showcase an exceedingly directional excitation of g-HPs. Furthermore, we reveal that the directionality of the excited g-HP can be fine-tuned by altering the excitation wavelength or by rotating the asymmetric antenna to function as a negative reflector. This versatility opens a range of options for precise control. Remarkably, our near-field imaging experiments validate that the selectively excited g-HP, triggered by our specially designed triangular antenna, exhibits an unprecedented propagation distance, surpassing the limits observed in previous research, extending beyond 36 micrometers. In summation, our work leverages a fusion of g-HP theory and structural engineering to expand the potential of anisotropic materials. This expansion enables unexpected levels of control over g-HPs, opening new avenues for an array of applications.

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Non-adiabatic transport of charged particle beams

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Abstract

In the field of charged particle scattering experiments, the prevailing assumption posits the adiabatic transport of charged particles through the apparatus. This study scrutinizes this assumption, focusing on the spatial distribution and area density of particles transmitted through an aperture within a magnetic field.

An examination of the parallel energy distribution of ejected electrons was conducted by a retarding potential analyzer. The energy distribution results, measured with a full width at half maximum of 33 meV, are closely aligned with room temperature values. However, after transport to the collision cell, the beam energy spread increases.

This investigation delves into the potential impact of non-adiabatic transport. Despite the unfitting Gaussian spatial distribution in this area, the data served to deduce relationships with the filling factor in limiting cases. The study also explores the role of Ohmic heating and its independence from the rotating wall after a sufficient cooling process. Notably, after passing through the chamber and aperture, the increase in beam potential points towards non-adiabatic beam transport, contradicting the anticipated potential dependence due to Ohmic heating. This observation underlines the potential role of the beam width in affecting the electron's energy spread.

Additionally, this research contributes a tentative model to comprehend the relationship between adiabatic invariance and spatial distribution. Utilizing previous simulation data in the literature and combined with mathematical analysis, the model provides significant insights into the behavior of charged particle beams, revealing a rapid increase in the results when the spatial distribution increases at a certain turning point.

In conclusion, this study illuminates the limitations of existing assumptions and proposes an improved approach. The control of the upper limit of the filling factor (about 0.3), with the rotating wall, allows for more accurate and reliable experiments in scattering processes.

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Phase Transformation of Silicon Originates from Slip Along the {111} Planes

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Abstract

In this study, we explore pressure-induced phase transformations in single-crystal diamond-cubic silicon (dc-Si), subjected to pressures up to 10 GPa using a diamond anvil cell and a methanol-ethanol pressure medium. Transmission electron microscopy reveals two distinct behaviors on the {111} planes: the emergence of planar slip-like defects and crystals of a different Si phase, specifically a body-centered cubic structure known as bc8-Si. We propose that these planar defects form initially and, through a slip-stick mechanism, create localized higher-pressure zones. This facilitates the transformation to bc8-Si via a well-established pathway involving the meta-stable metallic beta-Sn-Si phase. Both phenomena are observed on the {111} planes, confirming their critical role in the nucleation process. This aligns with previous findings that planar defects, such as twinning and slip, frequently originate on these planes in cubic materials like Si. Our results provide insights into the mechanistic initiation of phase transformations in silicon under high-pressure conditions.

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Cathode Spot Dynamics in Magnetic Fields

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Abstract

Cathodic spots (CS) are the source of highly ionised plasma in cathodic arc (CA) thin film deposition and space propulsion systems. Understanding the physics of cathode spots offers the potential for optimisation for the CA thin film deposition and thruster fuel efficiency. [MB1] The effects of an axial magnetic field (AMF) on CS in CA systems were studied using two photography techniques: (i) long exposure and (ii) high-speed framing photography. Long exposure imaging results are showcased and discussed in light of currently accepted models. The cathode spot dynamics captured by high-speed framing photography showed a statistically significant reduction in the speed of CS motion in increasing AMF. The results on retarded CS motion speed were assessed against available experimental and simulation results from the literature. The weak AMF's impact on CS and their immediate environment was outlined, providing a step towards better understanding CS motion and optimising CA systems.

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Switchable Edge Detection with Multilayered Thin Film Structures

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Abstract

Edge detection plays a crucial role in image processing, with a plethora of applications in computer vision, biological and medical imaging, robotics, and the automotive industry. In recent years, the application of metasurfaces and thin film devices in optical image processing has received significant attention due to their ultra-compactness, superior integration capability, and ability to perform real-time image processing with virtually zero energy consumption. In this work, we numerically demonstrate switchable edge detection using a compact device in a Salisbury screen configuration. The device incorporates a thin layer of conductive polymer known as polyaniline (PANI), enabling electrical switching with ±1 V. We numerically demonstrated its switchable edge detection performance. Our analysis combines a finite element method (FEM) and a transfer matrix method (TMM). Furthermore, we investigate the influence of the fabrication imperfections and potential solutions for their mitigation. Our results open novel opportunities for dynamic photonic image processing with low power consumption.

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Spatial and polarisation characterisation of photonic lanterns

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Abstract

The photonic lantern is an exciting new technology that will play an important role in future astronomical instruments. In short, the device converts a multimodal electric field into an array of single mode outputs. Leveraging the mixing of phase and amplitude information could allow the clear separation of atmospheric effects from a faint companion at very close separations, and also provide real-time wavefront correction signals to the telescope's adaptive optics system. In this work, we outline our method for characterising the photonic lantern using off-axis digital holography to reconstruct the complex electric field response of the photonic lantern for every input input mode. Our approach uses motorised fibre injection stages to autonomously search through all modes by optimising coupling and injection into the device. Technical details and generalisable lessons are drawn from preliminary results, characterising a 55 mode oversampled lantern in two polarisation states. This characterisation will allow for optimising and corroborating the use of photonic lanterns as wavefront sensors, and playing a greater role in high contrast imaging.

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The proton-proton correlation from two-proton transfer reaction in ^{16}O + ^{28}Si

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Abstract

Transfer reactions are powerful tools to probe single particle configuration as well as correlations of nucleons inside atomic nuclei. Advances in theoretical models and increasing computational power have paved the way to achieve a good description of transfer reactions induced by heavy ions and to study details in the two-nucleon transfers. In such a process, the two particles can be transferred simultaneously, as a single entity, or sequentially, in which a first particle is transferred followed by the second. To disentangle these two mechanisms is rather a challenge both from an experimental and theoretical standpoints.

In this work, we explore the one- and two-proton pick-up transfer in the $^{16}O+^{28}Si$ system at Elab. = 240 MeV. Results for the one-proton transfers in $^{27}Al(^{16}O,^{17}F)^{26}Mg$ from this same experimental campaign at the same beam energy are also presented. These measurements were performed at the INFN - LNS, Catania, Italy, and analyzed by the MAGNEX spectrometer. Elastic and inelastic scatterings, also measured in this experimental campaign, set strong constraints to the optical potential parameters in these systems [1]. Angular distributions for the two-proton pickup and both one-proton pickup transfers are presented and compared with Coupled Reactions Channel (CRC) calculations using spectroscopic amplitudes from shell-model calculations. The validity of the model space was tested against the one-neutron stripping for the same systems [2]. This methodology well describes the data presented in this work and shows that the one-nucleon transfers favor the population of ground-to-ground transfer reactions and contrasts with the results of the two-nucleon transfers, which does not favor the ground state population. This is an indication that pairing plays an important role in the two-proton transfer.

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An Ultra-Thin Film Chemiresistive Sensor for Acetone Sensing Applications

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Abstract

The increased prevalence of diabetes in society has led to a boom in technologies for detecting and monitoring related conditions. One such life-threatening complication is diabetic ketoacidosis, which can be detected through the concentration of acetone in exhaled breath. An indium phosphide (InP) nanowire array with chitosan surface functionalisation has previously been proven as an effective chemiresistive sensor for both sensitively and selectively detecting acetone. However, the fabrication process for such nanowire-based sensors requires specialised and expensive nanofabrication techniques, which could limit their opportunity for commercialisation. Here, an InP thin-film transistor based acetone sensor has been designed and modelled with COMSOL Multiphysics to assess its viability as a cheaper and simpler alternative to the nanowire sensors, with device characteristics further optimised for acetone detection. These optimal characteristics were found to be an undoped film, with the thickness on the order of 100 nm and operated under a low applied gate voltage and high drain voltage. Moreover, a proof-of-concept InP thin-film sensor was fabricated and tested for both sensitivity and selectivity, showing promising sensitivity to acetone, albeit at a significantly lesser level than that of the nanowire counterpart. Further, issues such as selectivity and stability are observed, which could be addressed by implementing the proposed InP thin-film transistor sensor structure in future work.

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Extraordinary second harmonic generation modulated by divergent strain field in pressurized monolayer domes

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Abstract

The most prominent form of nonlinear optical (NLO) frequency conversion is second harmonic generation (SHG), where incident light interacts with a nonlinear medium producing photons at double the input frequency, which has vast applications in material and biomedical science. Emerging two-dimensional nonlinear optical materials led by transition metal dichalcogenides (TMDs) have fascinating optical and mechanical properties and are highly anticipated to overcome the technical limitations imposed by traditional bulky NLO materials. However, the atomic scale interaction length and low conversion efficiency in TMD materials prevent their further implementation in NLO applications. While some uniaxial strain-engineering studies intensively investigated the anisotropic SHG response in TMDs, they did not realize giant SHG enhancement by exploiting the opto-mechanical characteristics. Herein, we employ proton (H+) irradiation to successfully fabricate large pressurized monolayer TMD domes ($d \geq 10$ μm) and conduct a comprehensive investigation and characterization of their SHG performance enhancement. We show that the intensity of SHG is effectively enhanced by around two orders of magnitude at room temperature. Such giant enhancement arises from the distinct separation distance induced by capped pressurized gas and the hemi-spherical morphology, enabling constructive optical interference. Moreover, the unique divergent strain field in TMD domes promotes the first experimental study on the anisotropic nonlinear optical behavior based on biaxial strain conditions in terms of varying strain orientation and relative weights. Our work demonstrates a promising system with enhanced NLO performance and well-preserved biocompatibility, paving a way toward the future nano-scaled quantum optics design and biomedical applications.

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Cranial Car Key Communication: Human Heads as Microwave Antennas

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Abstract

The Purcell effect describes how the rates of spontaneous emission can be enhanced or suppressed by the environment surrounding a quantum emitter: an atom or a molecule. However, fully classical realisations of this effect have been proposed and realised in electronic, acoustic, and mechanical systems, where the rate of dissipation of energy was increased by the presence of appropriately constructed antennas. Here we critically evaluate a folk-tale which seems to describes similar effects, where by holding a car key fob to one's head, one can increase the range of the signal. Explanations propose that the head acts as a microwave antenna for the car key, since the local wavelength is similar to its radius. Outside of anecdotal evidence or informal experimentation, to the best of our knowledge there has been no detailed analysis of this effect. Using Finite Element Method, we compute the microwave scattering properties for varied car key orientations and distances from a model of the human head above a concrete substrate. The human head is approximated by a 10 cm radius sphere of salty water with a high refractive index and low absorption (n =8.77+0.06i), and the key is described as a magnetic dipole, emitting at 434 MHz frequency. We find that such an antenna indeed provides modest increase to the emitted power, and modifies the radiation pattern, possibly extending the effective range of the car key.

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EMU discovery of a young X-ray binary associated with a new Galactic SNR G289.6+5.8

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Abstract

Evolutionary Map of the Universe (EMU) is a new-generation radio survey conducted with the Australian SKA Pathfinder (ASKAP). Covering the entire Southern sky, EMU aims to create the most sensitive wide-field atlas of Galactic continuum radio emission ever made. In this poster, we present the EMU discovery of a young X-ray binary system, associated with a pulsar wind nebula and a supernova remnant (SNR) G289.6+5.8, both of which were previously unknown. Located high above the Galactic plane, G289.6+5.8 has expanded within a low-density environment, preserving the characteristic circular SNR shape. The central complex and extended emission suggest the presence of a pulsar accompanied by a bow-shock nebula, coinciding with a hard X-ray source catalogued as a low-mass X-ray binary by the Swift legacy. This class of objects, a young neutron star residing in an X-ray binary, is exceptionally rare and provides unique insights into their birth properties and early evolution.

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Modelling mid-spatial frequency manufacturing errors for aspherical optics

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Abstract

Mid-spatial frequency manufacturing errors are often present in aspherical optics. These errors arise from the nature of the asphere manufacturing process, whereby many passes are made on multi-axis polishing machines. The process results in mid-spatial frequency artifacts which can typically be characterised into 2 types of form error: rings and spokes. The standard tolerance specifications of form and slope error used in asphere manufacture does not capture the range of possible outcomes for an as manufactured part. The fact that the current tolerance standard does not adequately describe the range of outcomes for as manufactured aspheres has been known for some time. In this work, we present a set of orthogonal basis functions which represent rings and spokes, combined with statistical form errors sampled from an appropriate power law statistical distribution in frequency space. We use real data to verify that our error representation is more efficient mathematically as compared with the standard Zernike decomposition. Furthermore, we present a statistical model to use for error analysis, based on the standard form and slope error specifications, which better captures the possible variation for as manufactured parts.

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Enhanced absorption in two-dimensional materials via inverse-designed metasurface

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Abstract

Optoelectronic devices using two-dimensional (2D) materials have been in the spotlight due to their interesting optical and electrical properties, such as valley selectivity and ultra-high sensitivity. However, the low light absorption of 2D materials due to their atomic thickness limits the maximum achievable external quantum efficiency. For example, in visible and near-infrared regions, monolayer MoS_2 absorbs only about 10% of the incoming light. Silver nano-disks and one-dimensional (1D) cavity structure were applied to enhance absorption, but the maximum absorption is still limited due to the lack of optimization of the structure.

In this paper, we propose an inverse-designed metasurface using adjoint optimization to maximize the absorption of 2D materials. The adjoint optimization enables designing the photonic devices with high-quality Figures of Merit (FoM) that can be uniquely customized for each application. By using the adjoint optimization, we demonstrate a light-absorbing device with the metasurface that maximizes the electric field at the 2D material. The device shows significant performance compared to the reported 1D cavity or plasmonic structures. This device will provide a new way to improve the external quantum efficiency of optoelectronic devices using 2D materials and contribute to their commercialization.

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Short-timescale laser frequency stabilisation at the 0.1 Hz/√Hz level

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Abstract

Precision optical instruments rely on the frequency stability of its light source to reach unprecedented sensitivities. While atomic and optical standards provide excellent long-term frequency stability, they fall short at short integration timescales. To reach the state-of-the-art measurement sensitivity at high Fourier frequencies, optical references specialising in fast timescales are required. The most common reference in this category is an ultra-low-expansion (ULE) cavity. They deliver unrivalled performance under ideal laboratory conditions, but become challenging to operate in harsh environments such as field deployment and space interferometry.

Our work presents a potential solution for laser stabilisation in hostile conditions. The use of fibre-optic interferometry mitigates the need for alignment and resonance tuning. A high dynamic range readout allows the continuous monitoring of laser frequency drift, at up to 20,000 times per second. This readout information can then be used to feed back to the laser, or passed forward and removed from subsequent metrology measurements.

To characterise the performance of our fibre frequency reference, we build a second identical interferometer to measure the same optical source. The subtraction of the two interferometers removes common-mode laser frequency noise, and provides an estimate for their relative stability. At high Fourier frequencies of above 70 Hz, we achieve the state-of-the-art fibre reference sensitivity at 0.1 Hz/√Hz. Between 0.4 - 2 Hz, we demonstrate measurement of the intrinsic fibre thermal noise [1]. The experimental observation of this fundamental yet less known noise source provides a valuable reference for future scientific endeavours.

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Resource Estimation for Fault-Tolerant Quantum Supremacy via Algorithm-Specific Graph Execution

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Abstract

In the measurement-based model of quantum computing, a highly entangled, multi-qubit resource state is prepared prior to the computation. Individual qubits are then measured sequentially, effectively simulating a quantum circuit through space instead of time. This is favourable for computation in the fault-tolerant regime, because the circuit depth on each physical qubit is constant. In this work, we develop a compilation strategy and scheduler to optimise a fault-tolerant quantum supremacy experiment, aiming to demonstrate the scalability and practicality of our approach on sparse Instantaneous Quantum Polynomial-Time circuits. We also test this optimisation process using a novel resource estimation cost technique. The envisaged architecture is a 2-dimensional array of logical qubits with a fixed width in one direction. The scheduler creates and then measures a relevant subpart of a larger resource state at each time step, only storing a small portion the total cluster at any one point in time. This iterative construction strategy allows us to explore space-efficient execution scenarios, where resource limitations necessitate careful management of the available surface code patches. Preliminary results using our compilation strategy reduce the number of logical patches needed by roughly 63%. We aim to provide a lower bound on the qubit requirements for this experiment. Additionally, there is an obvious trade-off seen in the depth of the algorithm and we aim to explore a middle-ground that additionally optimises for space-time volume.

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Gates for protected superconducting qubits via their internal modes

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Abstract

Following the original proposal for a 0-π qubit [1], Brooks, Kitaev, and Preskill (BKP) presented a method for performing a protected gate on a π-periodic superconducting qubit [2]. This protected gate can is achieved by adiabatically coupling a 0-π qubit to a high-inductance LC oscillator. This analysis was agnostic with regards to the actual circuit implementation of the 0-π qubit. Further analyses [3, 4] showed that coupling to the LC oscillator also leads to unwanted interactions between the internal modes of the 0-π qubit. This interaction persists even in the presence of zero circuit disorder seemingly ruining the possibility of performing a BKP-style protected gate. In this note we analyse whether the internal degrees of freedom of the 0-π qubit can be used as the requisite ancilla mode for the protected gate proposed by BKP.

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Photon transport in two-dimensional atom arrays

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Abstract

We present initial results into an investigation of photon scattering off an infinite two-dimensional array of identical atoms. Previous theoretical work has focussed on the linear regime and subradiance. In addition, such work has also elucidated the interplay between cooperative resonances in the atomic array and the propagating optical fields. However, the quantum effects of such a process are currently not well understood, particularly in the context of multi-photon dynamics. We present initial analytical results pertaining to the single-photon and two-photon dynamics. Our aim is to study collective effects in such systems. The behaviour of light in such a context is relevant to a broad range of areas in optical science, with applications ranging from the development of atomically thin metasurfaces to nanomechanics.

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Revealing the spin-texture in the surface states of the topological insulator $Ta_2Ni_3Te_5$

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Abstract

Transition Metal Chalcogenides (TMCs) are a material class that has been extensively investigated over the past decade, as candidates for not only next generation electronics and optoelectronics, but also a platform for studying novel quantum topological states [1,2]. Recently, a new class of TMCs $Ta_2M_3Te_5$ (M = Ni and Pd) have been theoretically predicted to host non-trivial band topology [3]. Yet, little is known experimentally about the electronic band structure of these materials, in particular the TMC $Ta_2Ni_3Te_5$. The premier experimental technique used to verify non-trivial band topology is spin- and angle-resolved photoelectron spectroscopy and has been instrumental in the discovery of a variety topological insulators and topological Dirac semimetals [4]. Here we utilize spin- and angle-resolved photo-electron spectroscopy (SARPES) to study the spin-resolved electronic band structure of an in-situ cleaved bulk crystal of $Ta_2Ni_3Te_5$. The overall electronic band structure measured with ARPES is reasonably consistent with density functional theory (DFT) calculations. However, the spin-ARPES measurements show the bands near the Fermi level are strongly spin-polarized in both the in-plane and out-of-plane spin components which is in contradiction to DFT theory. This spin-polarization is evidence for $Ta_2Ni_3Te_5$ being a higher order topological insulator, but requires further DFT calculations of the surface states of Ta2Ni3Te5 to understand the origin of the spin-polarization.

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Strong-field nanophotonics with wide-bandgap semiconductors.

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Abstract

Strong-field nanophotonics forms a new research frontier in light-matter interactions when the intensity of the laser pulse approaches or overcomes interatomic binding strengths. Underpinned by the phenomenon of high order harmonic generation (HHG), the field offers new pathway towards sources of extreme-ultraviolet radiation and atto-second pulses in an ultra-small all-solid-state form-factor. Even though the mechanism of gaseous phase light matter interaction was a major source of HHG generation over decades, they lack the advantage of inexpensive methods and infrastructure for the frequency conversion. This led to the quest for novel materials that can be employed as an efficient source for HHG.

Here we employ first-principle supercomputer simulations of Multiscale Maxwell's time dependent density functional theory to probe the HHG in a promising new class of wide-bandgap photonic materials. Figure 1 shows an exemplary comparison of HHG in the Wurtzite structure w-AlN thin films versus one of the most common nanophotonic materials – Si. We observe a higher brightness and slower decay rate of HHG in w-AlN vs Si at a pump wavelength of 800 nm. We further demonstrate control over the generation of even harmonics dependent on the orientation of the crystal lattice. The comparative study with Si shows that the wide band-gap class of semiconductors is a promising material platform for the future strong-field nanophotonics research towards applications in the attosecond science and femto-chemistry.

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Fig.1. High Harmonic Generation in AlN thin film. (a)The crystalline structure of w-AlN gives rise to even harmonics upon oblique incidence. (b) The total transmittance spectra of the AlN thin film of thickness 50 nm. At normal incidence (top) odd harmonics and at an oblique incidence even harmonics were generated respectively. (c) The comparison of HHG in AlN (c) and Si (d).

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An interaction-driven quantum engine fuelled by particle transfer

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Abstract

Quantum thermodynamics is a rapidly developing field, largely focused on the theoretical and experimental investigation of quantum engines. Such devices may leverage uniquely quantum resources in order to enhance their performance, in some cases beyond what is possibly classically. Engines are typically fuelled by thermal contact with a hot and cold reservoirs, interspersed with work strokes where the working fluid is isolated.

In this work, we investigate the operation of a quantum Otto cycle, where the working fluid consists of a harmonically trapped one-dimensional (1D) Bose gas with tuneable contact interaction. The engine cycle utilizes the control over interactions to derive beneficial work output. Further, we establish how such an engine cycle may be fuelled through allowing particles to flow between the system and the external reservoirs, establishing a finite temperature `quantum chemical engine'.

Analysis of the engine cycle is performed in the sudden quench and adiabatic limits by leveraging exact numerics provided by the thermodynamic Bethe ansatz. We derive analytic bounds on both the net work and efficiency of the chemical engine cycle. Additionally, we investigate finite time dynamics of the unitary work strokes across the entire parameter space of the 1D Bose gas by utilizing the recently discovered generalized hydrodynamic framework.

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Addressing Optomechanical Drift in a Spatiotemporal Beam Shaping System

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Abstract

An arbitrary vector spatiotemporal beam generator was recently demonstrated [1] and could find applications in specific light-matter interactions [2]. This system utilises a spatial light modulator (SLM) giving it independent spatial and temporal control of 45 Hermite Gaussian (HG) modes and 293 time steps respectively across 30ps of delay [1]. Recently, drift from the SLM and mirror subsystem shown in Figure 1 was identified to occur overnight. Usually this drift was on the order of magnitude of 10μrad which increased crosstalk and decreased power, in turn, significantly degrading the device's performance.

Potential causes of drift include: daily lab climate fluctuations (1-2°C temperature cycling and up to 14% humidity difference) affecting a thermally susceptible tip/tilt mount, instability in utilising posts, post holders and clamps for mounting, floating optical table movement changing the SLM's alignment and movement of an unfixed mirror to/from the SLM. To reduce drift: the previous tip/tilt mount was replaced with a thermally stable mount attached directly to the SLM stage, the SLM stage was attached to a floating breadboard and the previously unfixed mirror to/from the SLM was glued on the base plate. A 3D printed SLM holder was also custom designed to increase stability by minimising the thermally stable mount to SLM distance. These solutions have improved system stability by considerably reducing the frequency of significant drift and could benefit similar free-space subsystem relays.

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Quantum Entanglement Distribution via Entanglement Swapping through Uplink Satellite Transmission

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Abstract

Long-distance entanglement distribution has potential applications not just in quantum communications, but also to realize remote error correction among distributed quantum computers (DQC). This study considers the utilization of satellites for the distribution of entanglement via uplink transmission channels, a method different from the downlink transmission previously examined within the contexts of QKD and surface-coded distributed quantum computing. In the context of fault-tolerant distributed quantum computing, previous research suggests the limited practicality of downlink transmission due to power constraints on satellites. Alternately, we have proposed an innovative entanglement distribution protocol utilizing uplink satellite transmission. This protocol situates the entanglement sources at ground stations, with satellites implementing Bell measurements in orbit. The two ground stations generate bell pairs at the source, and one-half of each of the bell pairs is sent to the satellite via an uplink channel. The satellite has a bell-measurement apparatus consisting of a beam-splitter, two 45° polarizers, and two polarization-resolving detectors. Bell measurement is performed on the satellite, thus distributing entanglement between two ground stations, for performing remote lattice-surgery on surface-coded logical qubits at the ground stations. Our results indicate that relocating the entanglement source to ground-based stations significantly bolsters the available power, therefore significantly enhancing the rate of creation of surface-code error-corrected logical bell pairs. Furthermore, our investigation includes an analysis of the fidelity and entanglement rate of the resulting state, taking into consideration various factors, such as mode mismatch i.e. the misalignment of the wavefunctions of the uplink-transmitted photons due to path difference, the gating window and resolution of the detector, dark counts of the detector, atmospheric and dispersion losses, measurement apparatus errors, and interference from stray photons due to Earth's blackbody radiation. Our findings illustrate a promising avenue for making advances towards faster entanglement distribution, essential for scalable error-corrected distributed quantum computing.