AUSTRALIAN INSTITUTE OF PHYSICS

# 2022 STUDENT CONFERENCE

Hosted by the Physics Department of UWA

## Friday 2 December 2022

# Conference Program

| | | | |
|---|---|---|---|
| 8:45 – 9:00 AM | **Registration** Physics Atrium | | |
| 9:00 – 10:00 AM<br><br>**Welcome** | **Session 1** Ross LT | Rebecca D'Alonzo<br>Aidan Loasby<br>Ian Kemp | Tavis Bennett<br>Christine Anne Sinnott<br>Susmita Sett |
| 10:00 – 10:10 AM | **Break** Physics Atrium | | |
| 10:10 – 11:10 AM | **Session 2** Ross LT | John Tanner<br>Hannan Dempsey<br>Phil Pickering | Adam Singor<br>Hamid Satari<br>Kate Spicer |
| 11:10 – 11:20 AM | **Break** Physics Atrium | | |
| 11:20 AM – 12:20 PM | **Session 3** Ross LT | Corey Plowman<br>Andrei Ristea<br>Nathaniel Barry | Bithiah Esabunor-Nukie<br>Liam Tenardi<br>Benjamin Stone |
| 12:20 – 1:00 PM | **Lunch** Physics Atrium | | |
| 1:00 – 2:00 PM | **Session 4** Ross LT | Tyrone O'Doherty<br>Nowar Eric Koning<br>Gavin Pikes | Callan Michael Wood<br>Shawn Micheal Peter McSorley<br>Riley Croxford |
| 2:00 – 2:10 PM | **Break** Physics Atrium | | |
| 2:10 – 3:10 PM | **Session 5** Ross LT | Silvia Mantovanini<br>Edric Matwiejew<br>Ari Jenkinson | Kyran Williamson<br>Emma Paterson<br>Siqi Zhong |
| 3:10 – 3:20 PM | **Break** Physics Atrium | | |
| 3:20 – 4:30 PM<br><br>**Closing**<br>**Awards** | **Session 6** Ross LT | Nicholas Antonio<br>Andrew Lee<br>Weichangfeng Guo | Lucie Desage<br>Steven Samuels<br>Angelica Waszewski |
| 4:30 – 6:00 PM | **Sundowner** Physics Atrium | | |
| 6:00 – 10:00 PM | **AIP AGM Dinner** University Club<br>Ticketed event | | |

# Session 1

9:00 – 10:00 AM

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| **Rebecca D'Alonzo** | Low dose fractionated radiotherapy enhances immunotherapy treatment outcomes |
| **Aidan Loasby** | Enhancing the Resolution of Airborne Electromagnetic Geophysics |
| **Ian Kemp** | Commercial Supercomputing Comes to Radio Astronomy – a Blind Search for Fast Radio Bursts |
| **Tavis Bennett** | Quantum Computation and Combinatorial Optimisation |
| **Christine Anne Sinnott** | Modelling of the External Radiation Exposure to Healthcare Workers and the General Public from Nuclear Medicine Imaging and Therapy Patients |
| **Susmita Sett** | Image based pulsar searches using the Murchison Widefield Array |

# Low dose fractionated radiotherapy enhances immunotherapy treatment outcomes

R. A. D'Alonzo[1,2,3], S. Keam[2,3,4], K. M. MacKinnon[1,2,3], A. M. Cook[2,3,5], A. Nowak[2,3,4], S. Gill1[6], P. Rowshanfarzad[1], M. A. Ebert[1,6,7]

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Malignant tumours have decreased oxygenation due to malformed blood vessels. The hypoxia decreases the effectiveness of radiotherapy (RT), and the abnormal blood vessels prevents both systemic therapies and immune cells from reaching areas of the tumour. This study built upon our previous research, where it was found that 2 Gy x 5 fractions achieved and maintained tumour vasculature normalisation and reoxygenation for a week post-irradiation. This RT fractionation treatment plan was combined with various immunotherapy schedules to identify the RT plus immunotherapy combination that has the greatest synergistic effect and improves treatment outcomes.

BALB/cJAusbP mice were subcutaneously injected with AB1-HA mesothelioma tumour cells. Mice with established tumours received 2 Gy per day for 5 consecutive days, starting 10 days post-inoculation. Mice also received various schedules of immune checkpoint inhibitors (anti-PD-1 and anti-CTLA-4). Tumours were monitored and mice that had a complete response, determined by no observable primary tumour for 30 days, then underwent tumour rechallenge with the same cell line.

The combination of RT + anti-PD-1 significantly improved survival compared to anti-PD-1 alone. When anti-PD-1 was given concurrently with RT, half the mice had a complete response. The addition of anti-CTLA-4 to the treatment schedule significantly increased survival compared to both RT + anti-PD-1 and anti-PD-1 + anti-CTLA-4. All mice that received concurrent delivery of RT + anti-PD-1 + anti-CTLA-4 had a complete response. Cured mice resisted tumour rechallenge, regardless of the original treatment group.

The effects of 2 Gy x 5 fractions on the tumour microenvironment significantly improved the treatment outcomes of immune checkpoint inhibitors in murine models of mesothelioma. Concurrent delivery of RT + anti-PD-1 + anti-CTLA-4 resulted in 100% of primary tumours being cured. Gained immunity to the cell line was produced by all mice that had a complete response.

Acknowledgements: This study was supported by grant 1163065 from the Cancer Australia Priority-driven Collaborative Cancer Research Scheme. I would like to thank the Sir Charles Gairdner Hospital Radiation Oncology Scholarship in Radiobiology for their support.

# Enhancing the Resolution of Airborne Electromagnetic Geophysics

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[b] *Xcalibur Multiphysics, Perth, Australia.*

Airborne Electromagnetic (AEM) surveying has a well-established use history of mapping the sub-surface to identify conductive mineral deposits and water resources. Airborne techniques are often the only viable method to efficiently map the subsurface over large areas [1], however, the constraints imposed by an airborne environment mean that current technology faces limitations in resolution that leave valuable resources lost or poorly resolved amongst complex geology. In a world of growing global dependence on both ground water and new mineral discoveries [2] there are huge benefits to enhancing the reach of airborne exploration.

This project is a collaboration between UWA and Xcalibur Multiphysics that aims to provide a framework for increased resolution AEM surveying by combining innovation in geophysics, electronics, mechanics and data processing. In this presentation, I will explore how new concepts in transmitter waveform and loop geometry may be leveraged as to increase transmitter bandwidth and subsequently improve vertical ground image resolution. I will detail our future plans to turn these ideas from theoretical concepts to hardware that will be flight-tested within an commercial enterprise.

[1] Jared D. Abraham, Burke J. Minsley, Paul A. Bedrosian, Bruce D. Smith, and James C. Cannia. Airborne electromagnetic surveys for groundwater characterization. *ASEG Extended Abstracts*, 2012(1):1–4, 2012.

[2] Yoshihide Wada, Ludovicus P. H. van Beek, Cheryl M. van Kempen, Josef W. T. M. Reckman, Slavek Vasak, and Marc F. P. Bierkens. Global depletion of groundwater resources. *Geophysical Research Letters*, 37(20), 2010.

# Commercial Supercomputing Comes to Radio Astronomy – a Blind Search for Fast Radio Bursts

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[c] *CSIRO Space & Astronomy, Marsfield, New South Wales 2122, Australia.*

In radio astronomy, the availability of supercomputing resources is often a constraint on the amount of scientifically useful information that can be extracted from our observations. But the continued increase in raw computing power, and the rise of large commercial providers, allows us to consider how our science could change if and when high performance computing becomes a cheap, plentiful commodity.

The current work is a case study using a commercial HPC platform provided by DUG Technology in Perth, to scale up an image-based search for Fast Radio Bursts (FRBs) by mining the 8-year archive of the Murchison Widefield Array (MWA).

The origin of FRBs is a subject of active research worldwide, and at this point significant value can be obtained by cataloguing and characterising them. To date no FRBs have been identified using MWA data and little information is available on the low frequency spectra of these events.

Following an initial pilot study involving 10.5 hours of observations published in 2015 [1], a new search algorithm has been developed which is more conducive to parallel processing. This has reduced a 3-month search in 2015 to 25 minutes in 2022. Initial results indicate that the entire 44 Petabyte MWA archive could be searched in approximately 500 hours using current technology, and with current planned upgrades the full search could be reduced to less than 15 hours within 2 years.

[1] Tingay, S. J., et al. "A search for fast radio bursts at low frequencies with Murchison Widefield Array high time resolution imaging." The Astronomical Journal 150 (2015): 199-207.

# Quantum Computation and Combinatorial Optimisation

T. Bennett

*Department of Physics, The University of Western Australia, Perth, Australia.*

Solving combinatorial optimisation problems is a significant future application of quantum computing. These problems appear frequently, and across a broad range of settings. One of the things that makes it often impossible to find an optimal solution to problems of this kind, is that each problem may have an exponentially large number of unique solutions. For example, a travelling salesman that needs to visit only 21 cities has more routes to choose from than the number of sand grains on Earth!

Quantum computers present a unique opportunity to handle these problems because they can contain and process, in parallel, a number of computational states which grows exponentially in the number of qubits available. The travelling salesman could encode every solution to the 21-city problem in a quantum computer with only 66 qubits.

This talk will serve as an introduction to combinatorial optimisation, quantum computation, and how concepts like superposition and entanglement can be used to tackle these classically intractable problems.

# Modelling of the External Radiation Exposure to Healthcare Workers and the General Public from Nuclear Medicine Imaging and Therapy Patients.

C. Sinnott[1], P. Rowshan Farzad[1,2] and M. Djukelic[2]

[1] *School of Physics, Maths and Computing, University of Western Australia (UWA), Australia.*

[2] *Department of Medial Technology and Physics, Sir Charles Gairdner Hospital, (SCGH) Australia.*

External radiation exposure from nuclear medicine patients is an area of concern for those interacting with the patients, particularly medical radiation healthcare workers. Numerous studies have been conducted into the external exposure to those occupationally exposed, however there is limited literature available for healthcare workers who are not considered to be radiation workers, or the public, both of whom can be exposed to nuclear medicine patients whilst they are still radioactive. There is potential to close this gap through the development of a mathematical model to estimate the external exposure from nuclear medicine patients and assess the associated risk. This project aims to achieve this through the production of a versatile model which can be tailored to each specific circumstance.

This will be achieved through a three phased approach: mathematically modelling the external exposure from nuclear medicine patients and associated risks, production of a user-friendly software and the validation of the output. The model is to be produced based upon biokinetic models of radiopharmaceuticals and the Medical Internal Radiation Dose (MIRD) model. The validation of the external exposure estimation will be against both literature values and measurements conducted at Sir Charles Gairdner Hospital. The research for this project will be undertaken in the coming year (2023).

PET/CT imaging has seen an increase in the past two decades, this has consequently resulted in raised concerns for healthcare workers and the general public in contact with these patients. This concern further extends to nuclear medicine therapies. Predicting the expected exposure to these groups and tailoring this to individual circumstances, with the primary focus surrounding unplanned medical exposures from nuclear medicine patients. This will be beneficial to remove any uncertainties surrounding the risk posed by the patient and permit radiation monitoring for any effected parties.

# Image based pulsar searches using the Murchison Widefield Array

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Pulsars have been studied extensively over the last few decades and have proven instrumental in exploring a wide variety of physics. Discovering more pulsars emitting at low radio frequencies is crucial to further our understanding of spectral properties and emission mechanisms. The Murchison Widefield Array Voltage Capture System (MWA VCS) has been routinely used to study pulsars at low frequencies and discover new pulsars. The MWA VCS offers the unique opportunity of recording complex voltages from all individual antennas (tiles), which can be off-line beamformed or correlated/imaged at millisecond time resolution. Devising imaged-based methods for finding pulsar candidates, which can be verified in beamformed data, can accelerate the complete process and lead to more pulsar detections. Image-based searches for pulsar candidates can reduce the number of tied-array beams required, increasing compute resource efficiency. Despite a factor of ~ 4 loss in sensitivity, searching for pulsar candidates in images from the MWA VCS, we can explore a larger parameter space, potentially leading to discoveries of pulsars missed by high-frequency surveys such as steep spectrum pulsars, exotic binary systems, or pulsars obscured in high-time resolution timeseries data by propagation effects. Image-based searches are also essential to probing parts of parameter space inaccessible to traditional beamformed searches with the MWA (e.g. at high dispersion measures).

In this talk, I will describe the innovative approach and capability of dual-processing MWA VCS data, that is forming 1-second visibilities and sky images, finding pulsar candidates in these images, and verifying by forming tied-array beam. We developed and tested image-based methods of finding pulsar candidates, which are based on pulsar properties such as steep spectral index, polarisation and variability. The efficiency of these methodologies has been verified on known pulsars, and the main limitations explained in terms of sensitivity and low-frequency spectral turnover of some pulsars. No candidates were confirmed to be a new pulsar, but this new capability will now be applied to a larger subset of observations to accelerate pulsar discoveries with the MWA and potentially speed up future searches with the SKA-Low.

# Session 2

10:10 – 11:10 AM

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| **John Tanner** | Quantum Information Science and Quantum Circuits |
| **Hannan Dempsey** | Using 3D Printed Phantoms for the Comparison of Different Treatment Modalities: Moving Towards Safer Radiotherapy Techniques for Paediatric Brain Tumours |
| **Phil Pickering** | The foundational mysteries of quantum physics |
| **Adam Singor** | Fixed–Nuclei Photon Scattering Cross Sections for H+ |
| **Hamid Satari** | Seismic array configuration optimization for ambient seismic noise measurements: Applied to gravitational wave detection |
| **Kate Spicer** | Doubly differential cross sections for ionisation in p–He collisions |

# Quantum Information Science and Quantum Circuits

J. Tanner[a] and J. Wang[a]

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Quantum Information Science is the study of how quantum information is used and how information changes and spreads during quantum processes. The focus of my research is to study how initial information propagates through what are known as *Quantum Circuits (QCs)*, which are essentially descriptions of computer algorithms. We make use of something called the *Out-Of-Time-Ordered Correlator (OTOC)* to probe quantum circuits and look for correlations between the inputs and outputs of the associated computer algorithms. Our aim is to draw meaningful conclusions about which particular QCs are more or less prone to errors which has direct implications about their viability in modern-day Quantum Computing.

# Using 3D Printed Phantoms for the Comparison of Different Treatment Modalities: Moving Towards Safer Radiotherapy Techniques for Paediatric Brain Tumours

H Dempsey [a] (presenter) and P Rowshanfarzad [a]

[a] *School of Physics, Mathematics and Computing, University of Western Australia, Crawley, Western Australia 6009, Australia.*

## Introduction

In 2022, brain cancer is the second most commonly occurring tumour in Australian patients under the age of 19 years old, with 2.0 cases per 100 000 people [1]. These tumours are typically treated by surgical resection, which is then followed by chemotherapy and/or radiation therapy. Exposing a developing child's brain to ionizing radiation puts the child at risk of a wide range of long-term effects, including neurocognitive effects, neuroendocrine dysfunction, hearing loss, vascular anomalies and events, and psychosocial dysfunction. Additionally, due to the high survival rates of many paediatric brain tumours and the long life expectancy of a child post-treatment, the risk of the patient developing secondary tumours later in life is high. These risks are associated with the dose delivered and the volume of tissue irradiated and are inversely proportional to age. Therefore, there is a strong need to investigate the safest methods for delivering radiation therapy to paediatric brain tumour patients.

## Methods

A paediatric head phantom will be created from computed tomography scans of phantoms replicating a healthy 10-year-old male child. The brain will be 3D printed in slices with tumours of typical sizes and locations able to be slotted into the brain. A skull phantom will also be created from the CT scans using a combination of 3D printing techniques and additional materials. This phantom will then be treated using both a linear accelerator and a Cyberknife unit at Sir Charles Gairdner Hospital. A comparison between the two modalities will be made using film dosimetry techniques.

## Results & Conclusion

At this point in time, measurements are yet to be taken, but it is hoped that by comparing treatment modalities and assessing dose distributions, the results of this research are able to help reduce the impacts that radiation therapy has on a rapidly growing and changing brain, and in turn minimise the late effects and risks of treatment. This project also aims to solidify 3D printing as a fast, cheap and effective technique for creating patient specific phantoms for children, especially given the heightened risks that treatment poses and their smaller anatomy.

## References

[1] Australian Institute of Health and Welfare. (2022). *Australia's children.* Retrieved from https://www.aihw.gov.au/reports/children-youth/australias-children

# The foundational mysteries of quantum physics

P. Pickering[a]

[a] *University of Western Australia (UWA), Perth, WA, Australia.*

Using Einstein's concerns about quantum mechanics as a starting point, I consider some of the issues that remain the most interesting and troublesome aspects of foundational physics research. I present some of the philosophic questions that have plagued physics and remain unanswered after almost a century of quantum theory. I also discuss some emerging questions based on recent theoretical and experimental developments, in addition to new principle-based approaches to theory development.

# Fixed–Nuclei Photon Scattering Cross Sections for $H_2^+$

A. Singor, I. Bray and D. V. Fursa

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Photoionisation, Rayleigh, and Raman scattering cross sections have important applications in modelling radiative transport, opacities, and Raman spectroscopy, which in particular has important applications in hydrogen storage. We have recently developed a computer program capable of calculating two–centre Coulomb radial and angular wave functions in prolate spheroidal coordinates [1]. The development of this computer program has opened up the possibility for us to calculate photon scattering cross sections for the hydrogen molecular ion using techniques we have previously used to successfully calculate photon scattering cross sections for atomic hydrogen and the alkali atoms [2,3]. We present a set of photoionisation, Rayleigh, and Raman scattering cross sections for various electronic states of $H_2^+$ within the fixed nuclei approximation. The significance of including the electronic continuum when calculating cross sections for Rayleigh and Raman scattering between electronic levels of $H_2^+$ has been investigated. The ability to produce two–centre Coulomb radial wave functions also allow for the calculation of photoionisation cross sections of $H_2^+$.

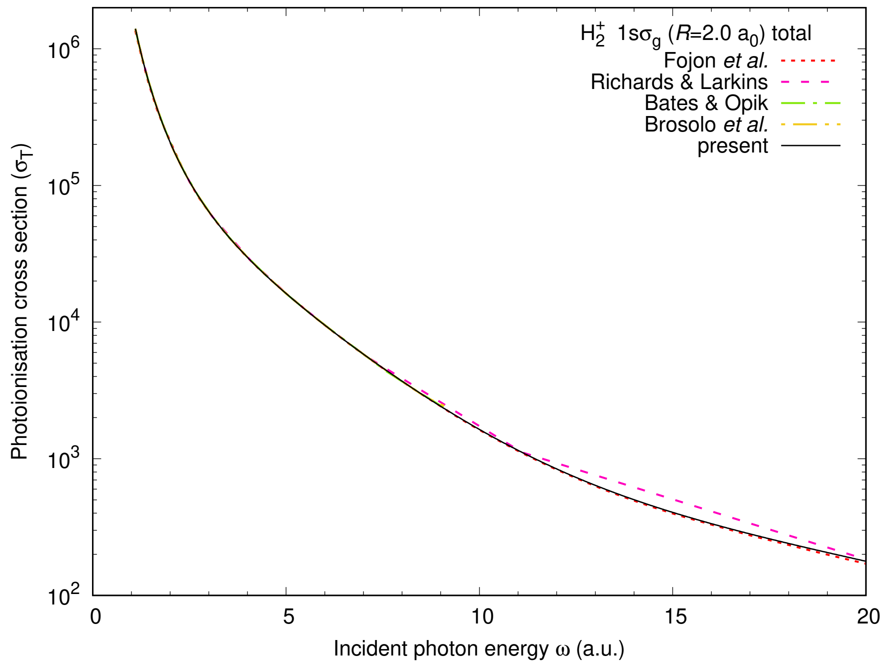


Figure 1: Total photoionisation cross section for the ground electronic state of $H_2^+$.

[1] A. Singor, J. S. Savage, I. Bray, B. I. Schneider, and D. V. Fursa, Computer Physics Communications p. 108514 (2022).

[2] A. Singor, D. Fursa, K. McNamara, and I. Bray, Atoms **8**, 57 (2020).

[3] A. Singor, D. Fursa, I. Bray, and R. McEachran, Atoms **9** (2021).

# Seismic array configuration optimization for ambient seismic noise measurements: Applied to gravitational wave detection

Hamid Satari[1], Carl Blair[1], Li Ju[1], David Blair[1], Chunnong Zhao[1], Erdinc Saygin[1,2], Patrick Meyers[3,4]

[1] *School of Physics, University of Western Australia, Australia.*

[2] *CSIRO, Deep Earth Imaging Future Science Platform, Australia.*

[3] *School of Physics, University of Melbourne, Australia.*

[4] *Theoretical Astrophysics Group, California Institute of Technology, Pasadena, USA.*

Low frequency ambient seismic noise is one of the main challenging issues for gravitational wave detection that calls for vibration isolation and subtraction methods based on array seismology. Array configuration for passive seismic noise measurements is a multidimensional problem because the geometric parameters are inter-related, but they must be set differently at different frequencies. In this paper we design an optimum seismic array for real-time measurement at Gingin gravitational wave test facility in Western Australia. This enables monitoring the changes in the spatio-spectral properties of microseism (0.1–1 Hz) and anthropogenic noise up to the instruments' latency limit (4 Hz) for data packing and transmission. Gain maximization [1] and array response function (ARF) analysis [2] are commonly used approaches to optimize a seismic array. However, first, gain maximization is effective for earthquake detection and rests on finding the optimum inter-station distances at which negative noise correlation minima occur in contrast to the well correlated signal. Second, ARF analysis results in pitfalls if the properties of the dominant seismic noise sources are overlooked. To deal with these issues, we first propose to use long time coherence length as a stable substitute for short time signal versus noise correlation. This enables us to estimate the optimal inter-station distances at 9 frequency intervals between 0.1 and 4 Hz. Then, we use the prior information from our recent seismic noise site characterization [3, 4] and design a multi-grid seismic array by distributing 37 sensors on 9 concentric rings with the optimal inter-station distances as their radii. Finally, we examine the ARF of the optimized array against those of 3 alternative configurations. The results prove the superiority of the optimized configuration over the others that use the same number of sensors and inter-station distances, but do not consider the properties of the seismic environment.

[1] Mykkeltveit, S., et al. "Seismic array configuration optimization." Bulletin of the Seismological Society of America 73.1 (1983): 173-186.

[2] Kennett, B. L. N., J. Stipčević, and Alexei Gorbatov. "Spiral-arm seismic arrays." Bulletin of the Seismological Society of America 105.4 (2015): 2109-2116.

[3] Satari, Hamid, et al. "Seismic noise characterisation at Gingin high optical gravitational wave test facility." arXiv preprint arXiv:2209.06559 (2022).

[4] Satari, Hamid, et al. "Low coherency of wind induced seismic noise: Implications for gravitational wave detection." Classical and Quantum Gravity (2022).

# Doubly differential cross sections for ionisation in p-He collisions

K. H. Spicer[a], C. T. Plowman[a], Sh. U. Alladustov[a], I. B. Abdurakhmanov[b], I. Bray[a], and A. S. Kadyrov[a]

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We present an investigation of the four-body proton-helium differential scattering problem using the two-centre wave-packet convergent close-coupling (WP-CCC) approach. The approach uses correlated two-electron wave functions for the helium target. Here, we focus on doubly differential cross sections for ionisation in the intermediate energy (50–300 keV) region where coupling between various channels is important. The greatest difficulty in calculating these cross sections is in representing the final electronic state as the ejected electron travels in the long-range Coulombic fields of both the projectile and the residual target. This state is challenging to take into account. Therefore, available theoretical approaches rely on low-order approximations. Furthermore, there are no comprehensive investigations of all three types of doubly differential cross sections. Our aim is to provide a complete doubly differential picture of ionisation and, thereby, fill this gap. We report results for the cross sections differential in any two variables out of three: the projectile scattering angle, the electron ejection angle and energy. Preliminary calculations suggest that the WP-CCC method agrees well with experimental data for all three types of the doubly differential cross sections.

# Session 3

11:20 AM – 12:20 PM

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| **Corey Plowman** | Theoretical description of the energy and angular distributions of emitted electrons in p + H2 collisions |
| **Andrei Ristea** | Galaxy evolution probed by misalignments between the rotation of stars and gas in the nearby Universe |
| **Nathaniel Barry** | Multi-observer delineations and agreement of FET PET volumes in glioblastoma patients: Results from the TROG 18.06 FET in Glioblastoma (FIG) credentialing program |
| **Bithiah Esabunor-Nukie** | Hydrogen Permeability in Steel Pipeline Materials |
| **Liam Tenardi** | Characterization of a Novel Composite Microwave Resonator for Vapor-Liquid Equilibrium Measurements of Binary Mixtures |
| **Benjamin Stone** | On the structure of interactions in conformal field theory |

# Lunch

12:20 – 1:00 PM

# Theoretical description of the energy and angular distributions of emitted electrons in $\mathbf{p + H_2}$ collisions

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Proton scattering on molecular hydrogen remains an active area of research, see e.g. [1] and references therein. This is partly due to the demand for accurate cross sections needed for Monte Carlo simulations for proton therapy treatment planning [2]. $\mathrm{H_2}$ is the simplest neutral molecular target and provides a useful starting point for developing theories to tackle collisions with more complex targets. However, developing accurate scattering theories for $\mathrm{H_2}$ targets still represents a considerable theoretical challenge in itself. The two-electron target wave function is not known analytically and the multicentre nature of the target provides an additional challenge over scattering on atomic targets.

We have extended the two-centre wave-packet convergent close-coupling approach to ion-atom collisions to study $\mathrm{p + H_2}$ collisions [3]. To our knowledge this is the first time two-centre coupled-channel calculations have been performed for this collision system. This approach includes all strong coupling effects between interaction channels and has previously successfully been applied to calculate total and singly differential cross sections.

We have now calculated the doubly differential cross section (DDCS) for ionisation across all energies and angles of the emitted electron at which experimental data are available. This type of DDCS has been thoroughly investigated experimentally [4]. However, very few attempts to calculate it are available in the literature. The currently available theoretical results are show significant deviation from the experimental measurements and are only available at select emission angles and energies. We have calculated the DDCS for ionization across the entire range of emission angles and energies where experimental data is available. The results agree very well with experiment and represent a significant step forward in bringing theory up to date with the latest experimental developments in the field of ion-molecule collisions.

**References:**

[1] M. Schulz, *et al. Ion-Atom Collisions: The Few-Body Problem in Dynamic Systems* (De Gruyter, 2019).

[2] I. Abril, *et al. Adv. Quantum Chem.* **65**, 129 (2013).

[3] C.T. Plowman, *et al. Eur. Phys. J. D* **76**, 31 (2022).

[4] M.W. Gealy, *et al. Phys. Rev. A* **51**, 2247 (1995).

# Galaxy evolution probed by misalignments between the rotation of stars and gas in the nearby Universe

A. Ristea[a,b], L. Cortese[a,b] and A.Fraser-McKelvie[a,b]

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Misalignments between the rotation of stars and gas are an indication of external processes that shape galaxies throughout their evolution. While it is established that misalignments are more frequent in gas-poor, early-type galaxies [1], the exact physical scenarios that produce a stellar-gas kinematic decoupling, and the frequency with which they occur, are still under debate.

We undertake a study based on 3068 galaxies in the final data release of the SAMI Galaxy Survey [2], finding misaligned stellar-gas rotation in 12% of cases. We identify the most probable physical cause of the kinematic decoupling by combining the spectral classification of galaxies with their misalignment angle measurements and optical morphologies.

Our results show that kinematically decoupled features are more prevalent in early-type/passive galaxies compared to late-type/star-forming systems. Star formation is the main source of gas ionization in only 22% of misaligned galaxies; 17% are Seyfert objects, while 61% show low-ionization nuclear emission-line region features. Accretion of new gas is the cause of the misalignment in 91% of cases, the rest being caused by outflows or gas stripping. Through comparison with a stellar mass- and star formation rate-matched aligned sample, we find that misaligned galaxies have higher Sersic indices and lower stellar rotational support.

Our results indicate that the timescale for accreted gas dynamical settling is regulated by morphology as well as a priori gas content and stellar rotational support, while the accreted gas is not fuelling new star formation in most cases. Specifically, torques on misaligned gas discs are smaller for more centrally concentrated galaxies, while the newly accreted gas feels lower viscous drag forces in more gas-poor objects.

[1] Bryant, Julia J., et al. " The SAMI Galaxy Survey: stellar and gas misalignments and the origin of gas in nearby galaxies." MNRAS, 483 (2019): 458-479.

[2] Croom, Scott, et al. " The SAMI Galaxy Survey: the third and final data release." MNRAS, 505 (2021): 991-1016.

# Multi-observer delineations and agreement of FET PET volumes in glioblastoma patients: Results from the TROG 18.06 FET in Glioblastoma (FIG) credentialling program

Nathaniel Barry[1], Martin A. Ebert[1,2], Pejman Rowshanfarzad[1], Eng-Siew Koh[3], Roslyn J. Francis[4], Andrew M. Scott[5].

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*[2]Department of Radiation Oncology, Sir Charles Gairdner Hospital, Nedlands, WA, Australia.*
*[3]Department of Radiation Oncology, Liverpool and Macarthur Cancer Therapy Centres, Liverpool, NSW, Australia; South Western Sydney Clinical School, University of New South Wales, Australia.*
*[4]Department of Nuclear Medicine, Sir Charles Gairdner Hospital, Nedlands, WA, Australia.*
*[5]Department of Radiation Oncology, Austin Health, Heidelberg, VIC, Australia.*

**Background:** FET PET In Glioblastoma (FIG) is an Australian prospective multi-centre study evaluating the impact of serial [18F]fluoroethyl-L-tyrosine positron emission tomography (FET PET) imaging in Glioblastoma. Participants undergo FET PET imaging pre-chemo-RT (FET1), one-month post-chemo-RT (FET2) and at suspected progression (FET3). FET PET analysis includes biological target volume (BTV) delineation by Nuclear Medicine (NM) physicians. Volume agreement in NM physician observer contours from the credentialling program is reported here.

**Methods:** Each trial site completed BTV delineation by at least 2 NM physicians on six benchmarking cases (3 x FET1 and 3 x FET3). Coefficient of variation (CoV) was calculated to assess variability in conventional FET PET parameters; maximum and mean tumour-to-background ratios ($TBR_{mean}$, $TBR_{max}$) across the benchmarking cases. Intraclass correlation coefficient (ICC) assessed inter-observer volume agreement. Observer pairwise analysis included spatial overlap assessed using the Dice Similarity Coefficient (DSC), and boundary agreement using the Hausdorff Distance (HD) and mean absolute surface distance (MASD).

**Results:** Data from 20 NM physicians across 10 FIG sites (total contours n = 120) has been analyzed to date. BTV agreement was found to be moderate to excellent (ICC=0.82; 95% CI, 0.63-0.97). Variability in $TBR_{max}$, and $TBR_{mean}$ revealed median CoV of 5.71% (range, 4.83-6.97%) and 5.15% (range, 3.20-6.16%), respectively. Pairwise overlap revealed good spatial agreement amongst observers (mean DSC = 0.83 ± 0.08), with mean DSC > 0.8 in all cases except one. Boundary agreement showed mean HD = 16.25 ± 7.93 mm and mean MASD = 1.64 ± 1.28 mm.

**Conclusion:** The comprehensive FIG trial credentialling program has expanded expertise in FET PET delineation and interpretation across centres in Australia. Quantitative assessment resulted in moderate to excellent inter-observer agreement, with good spatial overlap and boundary agreement in the pairwise analysis.

# Hydrogen Permeability in Steel Pipeline Materials


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The ability to safely and economically store and transport hydrogen is essential to enable the green energy transition. Pipelines are the most convenient choice for transporting large quantities of fuels across long distances, with the most relevant example being that of natural gas. Natural gas distribution networks have been built over decades, made mostly from carbon and low alloy steel grades. However, hydrogen permeation and induced degradation of steel (“embrittlement”) pose key technological challenges [2]. The transport process of hydrogen in steels has been often investigated using permeation methods, but it remains still not well understood because of experimental difficulties associated with low hydrogen solubility, surface resistances, and hydrogen trapping at microstructural heterogeneities. Furthermore, so far, most hydrogen permeability data have been obtained by the fusion materials research community concerned with tritium leaks into the atmosphere at high temperatures and low pressures [3]. On the other hand, room temperature permeability measurements have been mostly conducted using electrochemical methods which are not recommended for determining hydrogen transport properties of materials exposed to high-pressure hydrogen gas [3]. Therefore, currently, room temperature, high pressure data relevant to hydrogen pipeline operation has been deduced by extrapolation.

In this work we have developed a permeation rig and testing procedure to measure the flux of hydrogen through a metal foil exposed to high pressure hydrogen gas (up to 100 bar) at close to room temperature (20 to 100 °C)..

This rig will be deployed in a research program that aims at improving current understanding of the effect of hydrogen on materials relevant to many applications, including gas transport and distribution pipelines. Experimental data on transport properties of hydrogen gas and hydrogen-natural gas mixtures in carbon and low alloy steels will be gathered at actual pipeline operational conditions. Samples with grown-on and externally deposited films will be tested to assess the performance of different hydrogen barrier coatings for limiting hydrogen ingress in the pipe wall. Outcomes from this research program will contribute to reduce the large penalties imposed on materials grades used in new and existent pipelines [1] that currently result in higher costs due to lower operating pressures and thicker pipeline walls


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# Characterization of a Novel Composite Microwave Resonator for Vapor-Liquid Equilibrium Measurements of Binary Mixtures

L. D. Tenardi, P. L. Stanwix and E. F. May

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Cleaner forms of energy have received more publicity in recent times due to the ever-growing threat of global warming. These energy sources, such as natural gas and hydrogen, present new challenges in designing storage and transport processes, which rely on underlying thermophysical models developed from experimental measurements of density, composition and phase conditions. Measurements of these properties in vapor-liquid equilibrium (VLE) are important in characterizing the models for fluid mixtures.

VLE properties of binary fluid mixtures can be measured in-situ and non-invasively through novel microwave resonator technology. Presented is a composite microwave resonator designed for fast and reliable measurements of VLE composition and density. The novel resonator improves on re-entrant resonators through the distribution of sensing regions within the sample space, allowing it to better distinguish between liquid and vapor properties. Furthermore, the composite design allows for a reduced sample space and innovative mixing capability for faster equilibration of mixtures. A verification with a binary mixture of methane and propane is presented to compare the composite resonator to traditional measurement techniques and show the state-of-the-art progression in microwave based VLE measurements.

# On the structure of interactions in conformal field theory

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For the past century, symmetry principles have provided key insights into solving some of the greatest problems in physics. It is widely believed that at high energy scales, such as those encountered shortly after the big bang, the laws of physics may exhibit another type of symmetry known as conformal symmetry - a form of scale invariance. Quantum field theories possessing this symmetry are known as conformal field theories (CFTs) [1]; they play a significant role in descriptions of physics beyond the standard model, particularly in attempts to construct quantum theories of gravity, where dualities such as the AdS/CFT correspondence are of great importance [2]. The "building blocks" of conformal field theories are the scattering amplitudes of fundamental particles/fields, otherwise known as correlation functions. The correlation functions tell us how the fields in the theory interact at the quantum level and are highly constrained by conformal symmetry. However, constructing explicit solutions for correlation functions, particularly three-point functions, remains an open problem [3-5]. The aim of this talk is to explore some of the basic ideas underpinning conformal field theory and the AdS/CFT correspondence, with a particular focus on discussing some of the general features of three-point correlation functions in conformal field theories in three and four spacetime dimensions.

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# Session 4

1:00 – 2:00 PM

| | |
|---|---|
| **Tyrone O'Doherty** | Bamboozling Binaries |
| **Nowar Eric Koning** | The embedding formalism for supersymmetric field theory in anti de Sitter superspace |
| **Gavin Pikes** | Monte Carlo Simulations in the Modelling and Optimisation of Linac Bunker Shielding |
| **Callan Michael Wood** | Real-time Imaging of Relativistic Jets from Accreting Black Holes |
| **Shawn Micheal Peter McSorley** | Stabilised Optical Time and Frequency Transfer Using Digitally Enhanced Heterodyne Interferometry |
| **Riley Croxford** | Development of 3D Printed Patient-Specific Applicators for HDR Gynaecological Brachytherapy |

# Bamboozling Binaries

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The Milky Way is expected to contain of order $10^8$ stellar mass black holes (BHs), with an unknown fraction in binaries. There are currently less than 30 dynamically confirmed BHs in the Galaxy, with the vast majority in accreting binaries. Characterising the population of Galactic BHs is important for understanding stellar evolution, and particularly for understanding the formation channels of merging black holes that produce gravitational waves. Over the last 50 years many targeted searches and vast spectroscopic and photometric surveys have been undertaken with the purpose of finding non- or weakly-accreting BHs in binaries. However, thus far, whilst there have been many candidates, only a few have remained solid candidates after further study. A large number of these rejected candidates are binaries with two stars that are interacting, or have interacted, masquerading as binaries with an apparent BH companion (e.g., [1]).

Launched in 2013, the *Gaia* space telescope [2] is currently surveying the sky to build the largest, most precise 3D map of the Milky way. *Gaia* makes astrometric, photometric, and spectroscopic observations of nearly two billion objects multiple times a year. Recently, taking advantage of the massive *Gaia* survey, [3] produced a catalogue of more than 6000 candidate binaries with neutron star (NS) or BH companions. Their analysis was based on observed ellipsoidal variability, where deformation of a stars shape by a binary companion causes predictable variability in the observed brightnes of the system as a function of orbital phase. In this talk I will discuss an in-depth study we undertook of the most promising candidate from this sample, finding it to host neither a NS or BH companion, as well as highlighting significant sources of contamination which affect the sample as a whole.

[1] Kareem El-Badry, Rhys Seeburger, Tharindu Jayasinghe, Hans-Walter Rix, Silvia Almada, Charlie Conroy, Adrian M. Price-Whelan, and Kevin Burdge. Unicorns and giraffes in the binary zoo: stripped giants with subgiant companions. *MNRAS*, 512(4):5620–5641, June 2022.

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# The embedding formalism for supersymmetric field theory in anti de Sitter superspace

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Supersymmetry is believed by many to play a fundamental role in particle physics, in part because it is the only extension to the symmetries in the Standard Model consistent with relativistic quantum field theory [1, 2, 3]. The search for a quantum theory of gravity has been a long-standing goal in high energy physics, and as such supersymmetric field theory has gathered much attention since its inception in the late 1960's [4]. Among the various solutions that arise in general relativity, anti de Sitter (AdS) spacetimes are of particular interest due to their appearance in a wide variety of areas including supergravity, AdS/CFT, and higher spin [5, 6]. Off-shell supersymmetric field theories in AdS are naturally formulated in appropriate AdS superspaces for $d \leq 5$ [7]. We discuss a supertwistor realisation of AdS$^{4|4\mathcal{N}}$ and the techniques used for constructing field theory in such a space.

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# Monte Carlo Simulations in the Modelling and Optimisation of Linac Bunker Shielding

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Monte Carlo modelling allows for an efficient method of numerical integration through the use of random number sampling. As a result, it becomes ideal for the determination of linear accelerator (linac) bunker shielding capabilities where non-standard geometry and beams are in use, meaning the traditional manual calculations provided by the National Council on Radiation Protection and Measurements (NCRP) become less useful. An accurate knowledge of the bunker shielding is essential for ensuring that the dose rate outside the bunker remains at an acceptable level for the safety of both radiation workers and general staff/patients/public.

The aim of the project will be to develop a realistic model of the Marri linac head and surrounding bunker at Sir Charles Gairdner Hospital (SCGH) in GATE, a Monte Carlo simulation toolkit developed for medical purposes in Geant4. The data produced will be tested against measured results to verify the model's accuracy, before modifications are made to features of the bunker (including wall thickness, maze geometry, type of shielding concrete and addition of new shielding layers) to improve potential weak spots or make recommendations for a bunker design of increased cost/space efficiency.

Preliminary results show Monte Carlo simulated data of tenth value layers (TVLs) and percentage depth doses (PDDs) within the primary barrier and water phantom respectively to be within 2% of the measured/documented values. Additionally, a comparison between the dose rates present within the bunker due to scattered radiation provides a high level of agreeance between the simulated and measured values, further validating the model. Simulations have shown improvements in the bunker design through reduction in primary and secondary barrier thicknesses, reduced maze width and modified triple bend maze angles, changes to the concrete used and the addition of high density shielding materials to the bunker walls.

Monte Carlo methods can provide a high level of accuracy in determining the shielding capabilities and energy distributions within linac bunkers, and may act as a tool for improving the efficiency of their design.

# Real-time Imaging of Relativistic Jets from Accreting Black Holes

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As matter falls onto a black hole, liberated gravitational potential energy is often redirected into the form of powerful relativistic outflows, called jets. To better understand the physical mechanisms by which these jets are launched, we need to track their motions as they move away from the black hole. To image these jets, we use a technique called very long baseline interferometry by which multiple radio telescopes, separated by hundreds or thousands of kilometres, are combined to create a virtual telescope with enough resolution to make out a coin in Sydney from Perth. Unfortunately, these jets can be highly variable and can move across the resolution element of an image in a matter of minutes [1]. This violates a fundamental assumption of aperture synthesis and makes reconstructing images from long ($\sim$hour long) observations difficult. The most straight forward approach is to split the full observation into a series of short time bins, each to be imaged individually, however this reduces the quality and sensitivity of the reconstruction of each of these short time bins. New imaging techniques, such as those developed by the Event Horizon Telescope (EHT) Collaboration, who recently made an image of the supermassive black hole at the centre of our Galaxy [2], seek to improve upon this approach by simultaneously reconstructing all the time bins while explicitly enforcing continuity between them [3, 4]. We have developed a new time-dependent modelling technique by which we directly fit the measured data from the entire observation with a time-dependent model where we explicitly parameterise the variability and motion of model jet components. This allows us to reconstruct observations where the jets are so faint and fast moving that time binning is not adequate. The further development of these techniques is critical for the identification of signatures of jet ejection, which will allow us to better understand the nature of the jet ejection mechanisms. Future instruments, such as the next generation EHT (ngEHT) [5], will require new imaging and modelling techniques to be able to make reliable images and movies of jets launched from accreting black holes. This will allow us to better understand the nature of the causal connection between changes in the inflowing material and the launching of relativistic jets.

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# Stabilised Optical Time and Frequency Transfer Using Digitally Enhanced Heterodyne Interferometry

S. M. P. McSorley, D. Gozzard and S. Karpathakis

Precise time and frequency synchronization between distant points is essential for a huge range of scientific measurements. For example, radio telescope arrays must synchronise each antenna with both ultra-stable time and frequency reference signals – in the form of a 1 pulse per second (PPS) timing signal and radio or microwave frequency reference. For fundamental tests of physics, such as General Relativity, ground-to-space links also require ultra-stable synchronisation of time and frequency. To maintain strict long-term stability requirements in both telescope arrays and ground-to-space links, robust phase stabilisation systems are required to counteract disturbances on optical links which introduce noise that degrades the precision of the time and frequency signals.

Currently, the Square Kilometer Array (SKA) requires several optical channels for the dissemination of separate time and frequency reference signals, each with their own stabilisation control. Free space stabilisation technology is also under development by the Astrophotonics group at the International Centre of Radio Astronomy Research (ICRAR). To improve the capabilities of their ground to space synchronisation technology, a stabilisation system capable of ranging optical signals and recovering a 1PPS is required. In this project, I have implemented a stabilised time and frequency distribution system based on digitally enhanced heterodyne interferometry (DEHI) which offers lower cost and complexity than previous systems. This system can disseminate time and frequency reference signals on a single optical link, while also providing long-term stabilisation.

An all-digital phase-locked-loop (ADPLL) control system was implemented on a field programmable gate array (FPGA) and is capable of correcting phase perturbations on disseminated references in real time. This ADPLL has been experimentally verified with a phase noise power spectral density floor of $10^{-12} rad^2/Hz$ at 1kHz, and fractional stability of $10^{-22} Hz/Hz$ at 50 seconds integration time. This system also derives a stabilised 1PPS signal from the stabilised frequency signal.

The all-digital architecture has been successfully demonstrated in optical fibre stabilisation tests, on a one-kilometer optical fibre link in the laboratory. Fractional frequency stability on the order of $4 \times 10^{-21} Hz/Hz$ at 260 seconds integration time and noise density on the order of $10^{-6} rad^2/Hz$ at 1kHz was achieved in this setup. Time stability on the order of $10^{-10} s/s$ has been obtained, providing 6 orders of magnitude improvement in fractional stability, compared to the free-running performance. The optical control system has been modelled in the frequency domain, to ensure it can maintain strict stability requirements in its specified working bandwidth.

A stabilisation system is in development for use on free-space optical links, which will utilise the same ADPLL to provide stabilisation. Simulated models have been used to estimate a working bandwidth of 1kHz, and to estimate a phase noise power spectral density floor on the order of $10^{-6} rad^2/Hz$ at 100Hz, for a 4.8 km free-space link.

# Development of 3D Printed Patient-Specific Applicators for HDR Gynaecological Brachytherapy.

Riley Croxford[1,2], Joshua Dass[2], Martin Ebert[1,2], Rohen White[2], Ryan Toh[2], Warwick Smith[3], Pejman Rowshanfarzad[1]

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High dose rate (HDR) brachytherapy is integral to many treatment pathways thanks to its associated sharp dose fall-off. It uses a radioactive source, introduced into an inserted medical device, or applicator, at various dwell positions for various dwell times. The dwell positions relative to both the tumour site and the surrounding healthy tissue greatly affect achievable dosimetry, impacting treatment tolerability and efficacy. However, common applicators and the associated dwell positions that are currently being used to treat gynaecological cancers are too generic and limit treatment optimisation.

Using a 3D printer, patient-specific applicators can be created. These custom applicators can be tailored for each patient and tumour site, individualising dwell positions and additionally introducing vaginal shielding, potentially improving cancer outcomes, and reducing unnecessary toxicity. A part of this optimisation will include taking advantage of the vagina's structure and the 3D printers' capabilities to introduce shielding within the vagina. This would reduce the dose to the surrounding organs at risk (OAR) and healthy tissue.

This project aims to develop and design customisable applicators and then assess their performance in terms of tumour dose and OAR dose compared to typical applicators and another common treatment modality, volumetric arc therapy (VMAT). This will be done using 3D-printed patient-specific phantoms created in-house from MRI data and measuring the dose using appropriate dosimeters at various points within the phantom. The endpoint of this project will show the superior performance of the patient-specific applicators, able to maintain a high dose to the tumours while noticeably decreasing the dose to the OAR, resulting in a higher therapeutic ratio.

# Session 5

2:10 - 3:10 PM

| | |
|---|---|
| **Silvia Mantovanini** | New candidate supernova remnants identified using the Murchison Widefield Array |
| **Edric Matwiejew** | Quantum Optimisation for Continuous Multivariable Functions by a Structured Search |
| **Ari Jenkinson** | 3D-Printed Brachytherapy Nose Surface Applicators with Eye-Shielding for Clinical Use |
| **Kyran Williamson** | Energy Storage Rocks: Metal Carbonates as Thermochemical Energy Storage Materials |
| **Emma Paterson** | Verifying mode frequency shift in Twisted Anyon Cavity Resonators |
| **Siqi Zhong** | GW Early Warning Using UWA's SPIIR Pipeline |

# New candidate supernova remnants identified using the Murchison Widefield Array

S. Mantovanini, N. Hurley-Walker and G. E. Anderson

*International Centre for Radio Astronomy Research, Curtin University, Bentley, WA 6102, Australia.*

Supernova remnants (SNRs) are the energy and stellar material released during an intense explosion that results from the end of the life of a massive star. Taking into account the population of such stars we would expect to find thousands of sources, but so far only 294 are known with certainty. This is due to the fact that SNRs can be very compact or widely diffuse and fainter and so can be confused with other Galactic objects.

I am using an image of the Galactic Plane at 200 MHz which consists of $4600\,\mathrm{deg}^2$ covering $285° < l < 70°$ and $|b| < 16°$ with a noise level of $1 - 2$ mJy/beam, extremely low compared to previous surveys. I compare these data with WISE images in IR (at $12\,\mu$m and $22\,\mu$m) to distinguish whether the source has a thermal or non-thermal emission and so distinguishing SNRs from other sources such as HII regions. For further confirmation, the regions were compared with data from 3 other radio-band surveys.

I present here a preliminary list of 24 candidates I found in my initial analysis of the data. I expect to find even more candidates using the GLEAM-X survey; this will allow me to shed more light on how the medium interacts with the sudden input of energy it is subjected to. Ultimately, I will try to understand whether these sources could be cosmic rays accelerators.

# Quantum Optimisation for Continuous Multivariable Functions by a Structured Search

E. Matwiejew, J. Pye and J. B. Wang

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Quantum variational algorithms (QVAs) for optimisation problems are a promising near-term application of quantum computers [1]. These algorithms leverage quantum superposition and entanglement to optimise over exponentially large solution spaces using an alternating sequence of classically tunable unitaries. However, prior work has primarily addressed discrete optimisation problems [2]. In addition, QVAs are generally developed under the assumption that the space of valid solutions is unstructured, which constrains their speedup to the theoretical limits for the unstructured Grover's quantum search algorithm [3].

Structured approaches are ubiquitous in classical algorithms for Continuous Multivariable Optimisation Problems (CMOPs). We have demonstrated that quantum variational algorithms can efficiently optimise CMOPs by exploiting the general structural properties of a discretised continuous solution space. In particular, we have developed the novel Quantum Multivariable Optimisation Algorithm (QMOA)[4]. The QMOA solves CMOPs using concurrent continuous-time quantum walks over a superposition of grid points connected in a composite graph structure that conforms to the structure of the discretised solution space. Through numerical simulation, we have demonstrated that QMOA has an advantage over pre-existing quantum methods. Notably, the QMOA is most efficient when optimising high-dimensional and oscillatory functions - which are particularly challenging for classical optimisation algorithms.

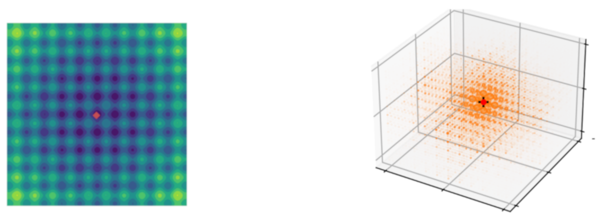

Figure 1: (Left) A contour plot of the Rastrigin function $f(\mathbf{x}) = 10D + \sum_{d=0}^{D-1} \left[x_d^2 - 10\cos(2\pi x_d)\right]$, two dimensions. (Right) Probability distribution produced by the QMOA for optimisation of the Rastrigin function in three dimensions over $32768$ grid-points ($15$ qubits). The red dot indicates the global minimum, and the black cross marks the highest-amplified grid point (also the global minimum). For both sub-figures $-5.12 \leq x_d \leq 5.12$.

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# 3D-Printed Brachytherapy Nose Surface Applicators with Eye-Shielding for Clinical Use

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***Introduction***

Exploration into the effectiveness or use of 3D-printed brachytherapy surface applicators with eye-shields is a new area. However, an uptake in 3D-printed surface applicators for high-dose rate brachytherapy is an expanding area. Studies into improvements of old methods with new 3D printing show an increase of conformity and reproducibility of dose[1]. The goal is to take new methodologies a step further and improve the 3D-printed surface applicators with patient eye-shielding.

***Method***

1. Taking the LASER scan of the patient with eye-shields in place
2. Generating a base 3D model from the LASER data
3. Creating a phantom and surface applicator
4. Taking a CT scan of the phantom with the surface applicator and eye-shields on
5. Planning treatment in Brachyvision™ from the CT scan
6. Proceeding with the treatment plan

A secondary plan is to 3D-print with a tungsten filament to act as shielding. However, this may not be available in time as a new printer is being ordered for this method.

***Aims***

The aims of this project are to:

- Improve accuracy and reproducibility of source positioning to within 0.5mm relative to the specific anatomy.
- Reduce geometric and dosimetric errors by 15-20% relative to the current bolus methods.
- Increase patient safety through eye-shields in the surface applicators.
- Investigate clinical implementation.

***Conclusion***

To increase patient safety particularly in avoiding unnecessary dose given to the eyes. Previously, work has been done in the area of 3D-printed surface applicators for clinical use. However, the introduction of eye-shields for patient safety and long-term cost savings are key advantages. Ultimately, this project could be adapted to other 3D-printed surface applicators to allow for shielding to patients, setting new standards in clinical high-dose rate brachytherapy.

***References/ Acknowledgements***

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# Energy Storage Rocks: Metal Carbonates as Thermochemical Energy Storage Materials

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The intermittent nature of renewable energy is a major challenge which can be overcome via cheap effective energy storage [1]. Thermochemical energy storage is an upcoming technology that can improve thermal to electric efficiency and lower cost in applications such as concentrated solar power [1]. Metal carbonates have great potential as thermochemical energy storage materials through the reversible endothermic release and exothermic absorption of carbon dioxide ($CO_2$) [2]. However, major challenges include the loss of cyclic storage capacity and slow kinetics [3].

It has been established that the release of carbon dioxide from barium carbonate ($BaCO_3$) can be thermodynamically destabilised by the addition of barium silicate ($BaSiO_3$) [4]. This lowers the operating temperature from ~1400 °C to 850 °C to allow operation with second generation concentrated solar plants. Moreover, the addition of a calcium carbonate ($CaCO_3$) catalyst improves kinetics by a factor of 10 [4].

This research explores the thermochemical gas-solid reactions of barium carbonate combined with iron oxide (III). This materials composite reduces the operating temperature from 1400 °C to 875 °C and improves reaction kinetics of carbon dioxide release and uptake. The study utilises *in-situ* synchrotron powder X-ray diffraction to show the co- existence of $\alpha$-$BaCO_3$ and $\beta$-$BaCO_3$ structural polymorphs of $BaCO_3$ and their effect on the thermodynamic parameters of calcination.

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# Verifying mode frequency shift in Twisted Anyon Cavity Resonators

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A strong candidate for dark matter is the Axion [1]–[3], a particle that has been postulated to solve the strong CP problem in Quantum chromodynamics and is theorised to be detectable using the coupling of axions to photons through the chiral anomaly [4], [5], which requires a non-zero E.B product in the detection system [6]–[9]. The ultralight dark matter mass range has been mostly off-limits for conventional detection methods (mainly so-called 'haloscopes') using photons, due to the large size of the resonant device which would be required to measure at such low frequencies [10]. Additionally, the reliance of haloscopes' on external magnetic fields eliminates the possibility of using superconducting materials; restricting achievable Q-factor and hence sensitivity to axions. The twisted anyon cavity resonators (see Fig. 1) are noteworthy for their geometrically induced high helicity modes, single-mode coupling to axions via helicity, and resulting sensitivity to ultralight axions [11]. The need for large external magnetic fields is removed, permitting superconductivity to be used to increase cavity Q-factors. In this work, we experimentally test the newly invented twisted anyon cavity resonator class across a wide range of twist angles to confirm simulated results. It is demonstrated that helicity increases with increasing twist angle, along with frequency deviation of the modes. The simulation results demonstrate that this new class of cavity has sensitivity to ultra-light dark matter which no other experiment has previously demonstrated.

Figure 1: 3D printed twisted triangular waveguides

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# GW Early Warning Using UWA's SPIIR Pipeline

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We present the online gravitational wave early warning effort at the University of Western Australia for the international LIGO-Virgo-KAGRA collaboration. We will present the status of our effort and expectations on signal recovery, trigger latencies, event rate, and parameter estimations including localization and mass parameter estimation. As a preparation for upcoming O4 runs, we are working on using O3 data to run the offline runs to test the SPIIR pipeline early warning data using the NSBH and BNS injections.

# Session 6

3:20 – 4:30 PM

| | |
|---|---|
| **Nicholas Antonio** | Fully Stripped Beryllium-Ion Collisions with Atomic Hydrogen Initially in an Excited State |
| **Andrew Lee** | Evaluation and Implementation of Total Skin Electron Therapy Techniques in Sir Charles Gairdner Hospital |
| **Weichangfeng Guo** | Mimicking Mergers: Are High-mass Binary Black Hole Signals Actually from Black Hole Captures? |
| **Lucie Desage** | Thermochemical energy storage materials and applications |
| **Steven Samuels** | Implementation of the Josephson Parametric Amplifier in Invisible Axion Haloscope Experiments |
| **Angelica Waszewski** | Identification of a heliospheric transient using Interplanetary Scintillation observations with the Murchison Widefield Array |

# Sundowner

4:30 – 6:00 PM

# AIP Dinner

6:00 – 10:00 PM

# Fully Stripped Beryllium-Ion Collisions with Atomic Hydrogen Initially in an Excited State

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The ITER and JET projects use beryllium-containing materials in plasma facing wall components. Due to the high temperature environments, the erosion of the wall followed by ionisation of Be is inevitable. Therefore, collisions between resulting Be ions with atomic hydrogen can take place when a neutral beam of hydrogen atoms is injected into the plasma for heating and diagnostic purposes. However, due to the toxicity of Be, there are no experimental measurements of cross sections for such collisions. This makes theoretical calculations of beryllium ion collisions with hydrogen [1, 2] the only source of data for plasma modelling. We studied collisions between bare beryllium ions and ground state atomic hydrogen in our previous work [3]. This was done using the wave-packet convergent close-coupling (WP-CCC) approach which solves the three-body Schrödinger equation by employing a two-centre expansion for the total scattering wave function. This work is now extended to $Be^{4+}$ ion scattering on hydrogen in its lowest excited states within the projectile-energy domain between 1 keV/u and 500 keV/u [4]. Specifically, this includes collisions with the hydrogen target initially in the 2s, $2p_0$ and $2p_1$ states. Integrated total and state-selective electron-capture cross sections are calculated. The results suggest that at low energies, collisions with hydrogen in each considered excited state produce a total electron-capture cross section approximately an order of magnitude larger than for scattering on the ground state. However, as projectile energy increases, the cross section for capture from the excited states falls well below the H(1s) electron capture cross section. A possible reason for this observation could be related with the way the target electron radial densities are distributed in different initial states. The results obtained in this work are compared to previous calculations where available. In terms of the *n*-resolved charge-exchange cross sections, where *n* is the principal quantum number of the formed $Be^{3+}$ ion in the final state, significant disagreement is found between our results and some previous calculations available in the literature.

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# Evaluation and Implementation of Total Skin Electron Therapy Techniques in Sir Charles Gairdner Hospital

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Total Skin Electron Therapy(TSET) is a specialised radiotherapy treatment technique used to treat mycosis fungoides, the most common form of T-cell lymphoma. This cancer is initially located in the skin and can cover large patches up to a majority of the skin surface. As a result, large electron fields deliver high dose to the target skin with minimal harm to underlying organs. This technique offers high rates of remission and palliation at late stages of mycosis fungoides. However, due to the low occurrence of mycosis fungoides and the challenging nature of TSET, it has not been implemented in Western Australia.

This study will investigate different techniques in TSET and their potential implementation in Sir Charles Gairdner Hospital(SCGH). The main techniques can be classified into the modified Stanford technique, rotational techniques and reclined techniques. These techniques all reach standards set by the European Organisation for Research and Treatment of Cancer but have relatively loose tolerances compared to standard radiotherapy due to the difficulty of the technique. This study will use a personalised 3D-printed phantom from CT scans to evaluate the different techniques. Personalised phantoms aim to more accurately simulate doses, particularly for patients with different body characteristics. This is important in TSET, where dose distributions have been linked to obesity index. These personalised phantoms can be produced with 3D-printing which is a cost-effective and accurate solution. This will allow for better testing of dose uniformity in typically underdosed areas. The phantom can also be customised to include slots at depth for radiochromic film to investigate the percentage dose distribution. Further ionisation chambers can be used for other organs at risk.

The study has not been performed yet but offers a number of potential benefits. TSET is not currently implemented in Western Australia, requiring patients to travel interstate for treatment. This project will test TSET techniques attainable at Sir Charles Gairdner Hospital and serve as a pathway into its clinical implementation. It will also be the first study to utilise 3D-printing in TSET, where personalised treatment planning has been a challenge. This would improve treatment planning procedures for TSET and could improve treatment outcomes.

# Mimicking Mergers: Are High-mass Binary Black Hole Signals Actually from Black Hole Captures?

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As the number of gravitational wave observations has increased in recent years, the variety of sources has broadened. Here, we investigate whether it is possible for the current generation of detectors to distinguish between very short-lived gravitational wave signals [1] from mergers between high-mass black holes and the signal produced by a close encounter [2] between two black holes, which results in gravitational capture and ultimately a merger. We exploit the deep learning network [3] to accelerate the parameter estimation, and compare the posterior probability distributions produced by analysing simulated signals from both types of progenitor events, both under ideal and realistic scenarios.

We show that while under ideal conditions it is possible to distinguish both progenitors, under realistic conditions they are indistinguishable [4]. This has important implications for the interpretation of such short signals, and we therefore advocate that these signals be the focus of additional investigation even when satisfactory results have been achieved from standard analyses.

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# Thermochemical energy storage materials and applications

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Reducing fossil fuel consumption is a global challenge triggering the transition to cleaner energy sources. Increasing the utilisation of renewable energy involves the development of large-scale energy storage systems to allow for constant power production. Thermochemical energy storage (TCES) is an alternative method to Li-ion electrochemical batteries to store energy in the form of heat. This process is enabled by using materials that undergo reversible endo- and exothermic reactions. Energy is stored and released through chemical reactions and an inherent transformation of the storage material's chemical structure [1]. Metal hydrides and metal carbonates are particularly interesting for this purpose because of their high energy densities, respectively 2 $MW_{th}/m^3$ for $CaH_2$ and 1 $MW_{th}/m^3$ for $CaCO_3$ [2,3]. These TCES materials have the potential to integrate high-temperature large-scale power production plants, such as concentrated solar power plants, or off-grid facilities, in the form of thermochemical batteries (TCB). As competitive advantages, these batteries can be charged by heat generated by renewable energy sources and uses abundant cost-effective materials, but several challenges arise from the development of TCB for these applications [4]. First, the storage materials need to endure as many cycles as possible to ensure the viability and reliability of the system. Therefore, additives are needed to maintain their cyclic capacity. Then, the TCB requires a heat extraction unit to transfer the heat generated by the storage material when discharging. This study presents and compares the performance of some metal hydrides and metal carbonates with additives, and the experimental results of a TCB prototype using $CaCO_3$-$Al_2O_3$ (20 wt.%) as the storage material and conduction through a metallic rod as the heat extraction unit.

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# Implementation of the Josephson Parametric Amplifier in Invisible Axion Haloscope Experiments

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The Quantum Technology and Dark Matter group (QDM) at the University of Western Australia is currently undertaking the Oscillating Resonant Group AxioN (ORGAN) experiment. ORGAN will search for invisible axions in the frequency range 15 GHz to 50 GHz with sensitivity levels that will cover the KSVZ and DFSZ QCD axion models [1]. ORGAN consists of different experimental stages and the 2$^{nd}$ stage aims to achieve the KSVZ/DFSZ sensitivity levels by implementing a Josephson Parametric Amplifier (JPA) as the first stage amplifier for a microwave cavity axion haloscope. JPAs are quantum-limited amplifiers (standard quantum limit noise temperature) with relatively high gain and thus are ideal for maximizing the signal to noise ratio (SNR) in axion haloscopes [2]. The JPA is first characterized for a lower frequency range to verify its viability. The characterization experiment used Raytheon's wide-band JPA in 3-wave mixing mode: a DC current source provided a tunable resonant frequency while a pump modulator was used to provide parametric amplification of an input signal. Results show that input frequency ranges of 6.2 GHz to 6.35 GHz and 7.4 GHz to 7.5 GHz can give up to 30 dB of gain with 13 MHz of maximum instantaneous bandwidth. Up to 100 MHz of bandwidth can be used if the tuning parameters are adjusted while performing the input frequency sweep. In the configuration tested, the JPA is suitable to be used in lower frequency (6 GHz - 7 GHz) ORGAN experiments as it provides adequate gain and bandwidth.

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# Identification of a heliospheric transient using Interplanetary Scintillation observations with the Murchison Widefield Array

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Our current understanding of coronal mass ejections, as well as other solar events in interplanetary space, is well-developed to forecast the effects on Earth [1]. However, it is still insufficient in its ability to predict the evolution of these events with a high degree of accuracy. Considering that a major space weather event could put crucial technologies at risk, predicting the severity of such events is of great importance to the space weather community.

Interplanetary scintillation (IPS) is a phenomenon which causes sufficiently small radio sources to "twinkle" in the solar wind. Since its discovery in the mid-1960s [2] [3], it has been developed as a powerful astrophysical tool, both for studying compact (<1 arcsecond size) objects, and for studying the solar wind.

In the last few years, we have breathed new life into this old technique, adapting it for modern low-frequency instruments such as the Murchison Widefield Array (MWA). The key advance we have made is to exploit the enormous field of view of the MWA. This allows us to monitor all IPS sources across a field of view 30 degrees across, leading to an unprecedented density of measurements. A recently completed survey of IPS sources in the sky above the MWA [4] has become the basis of this work.

We have conducted a blind search of 49 days of MWA IPS observations from mid-2019, with overlapping daily observations approximately East and South-East of the Sun at an elongation of 30 degrees. This search has revealed several interesting transient features characterised by higher than usual scintillation levels (in spite of the observations being taken at solar minimum). None have (yet) been linked to any known solar events. However, one solar wind enhancement is captured in two observations several hours apart, allowing the plane-of-sky velocity to be inferred.

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