COMBS

ARC Centre of Excellence in

Optical Microcombs for Breakthrough Science

ANNUAL REPORT

2024

Australian Government

Australian Research Council

Centre vision

We envision a future where optical frequency combs are as inexpensive, readily available, and accessible as today's consumer electronics, leading to breakthrough science and new industries that will have broad societal impacts.

Centre mission

COMBS will establish its identity as a global nexus for advancing optical frequency comb science, technology, and applications. We will proactively link industry and academia and collaborate to discover how chip-based optical frequency comb technologies can transform society. COMBS will establish specialist infrastructure and educate diverse scientists, technologists, entrepreneurs, and end-users to build an ecosystem that is specifically adapted to be self-sustaining in the unique Australian economic and geopolitical environment. We will emphasise communication of our research in a way that engages the broadest cross-section of society, recruiting as much of the community as possible to understand the potential of microcomb technology and work with us to achieve global impact and benefit for Australia.

COMBS

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Message from the Director

It is my great pleasure to introduce this first Annual Report for the ARC Centre of Excellence in Optical Microcombs for Breakthrough Science (COMBS). Since our commencement we have grown from a core team of 20 people to a team of more than 120 and the momentum is still building.

The year started with our first Annual Workshop at Cape Schanck in Victoria which brought the whole centre together. This really showed the diversity of our COMBS community and the breadth of opportunity to create impact with our microcomb technology. We worked together to transform our shared vision into plan.

We spent much of the first half of the year building our teams – drawing in our collaborators and learning about each other and our research. We established our five research themes, nominated theme leaders and early-career theme coordinators and organised focus workshops. These refined the research agenda for each theme and defined the ways in which each of the themes could work together.

The highlight of the year for me was the COMBS Launch in October – this had more than 100 attendees from academia, industry and government. We had hands on (or in some cases feet-on!) demonstrations of our research driven by our industry partners. I feel we really communicated our vision for what we believe we can achieve and the societal impact that might be possible.

Beyond the research of our Centre, we have established four committees to build our ecosystem – Education and Outreach; Impact and Translation; Equity, Diversity and Inclusion and Infrastructure. We have engaged dedicated professional staff to coordinate each of these committees and as you will read in this report, we have already undertaken a significant number of initiatives to build a vibrant community and connect to the world.

By the end of 2024 each of our research themes has recruited most of their required research staff, and our committees are fully operational with a vibrant agenda. We have a clear vision and the momentum of more than 100 people working together to achieve this vision.

I am proud of what we have already achieved and excited about what we will do next.

Distinguished Professor Arnan Mitchell

Director, ARC Centre of Excellence in Optical Microcombs for Breakthrough Science

RMIT University

Message from the Chair of the Advisory Board

It is a privilege to share this year's COMBS Annual Report as the Centre completes its first year of operation.

Over the past year, the Centre has recruited key staff, formed their research teams and established committees to focus on infrastructure, education and outreach, impact and translation and importantly equity diversity and inclusion. With these teams in place the Centre is now set up to achieve its ambitious long-term objectives.

COMBS is committed to taking the world's most precise measurement tool – the optical frequency comb – out of specialised research laboratories where they may transform our everyday lives. Opportunities range from enabling our ever growing internet, creating sensors for smart cities and better understanding the cells in our bodies and looking for planets orbiting distant stars in our galaxy.

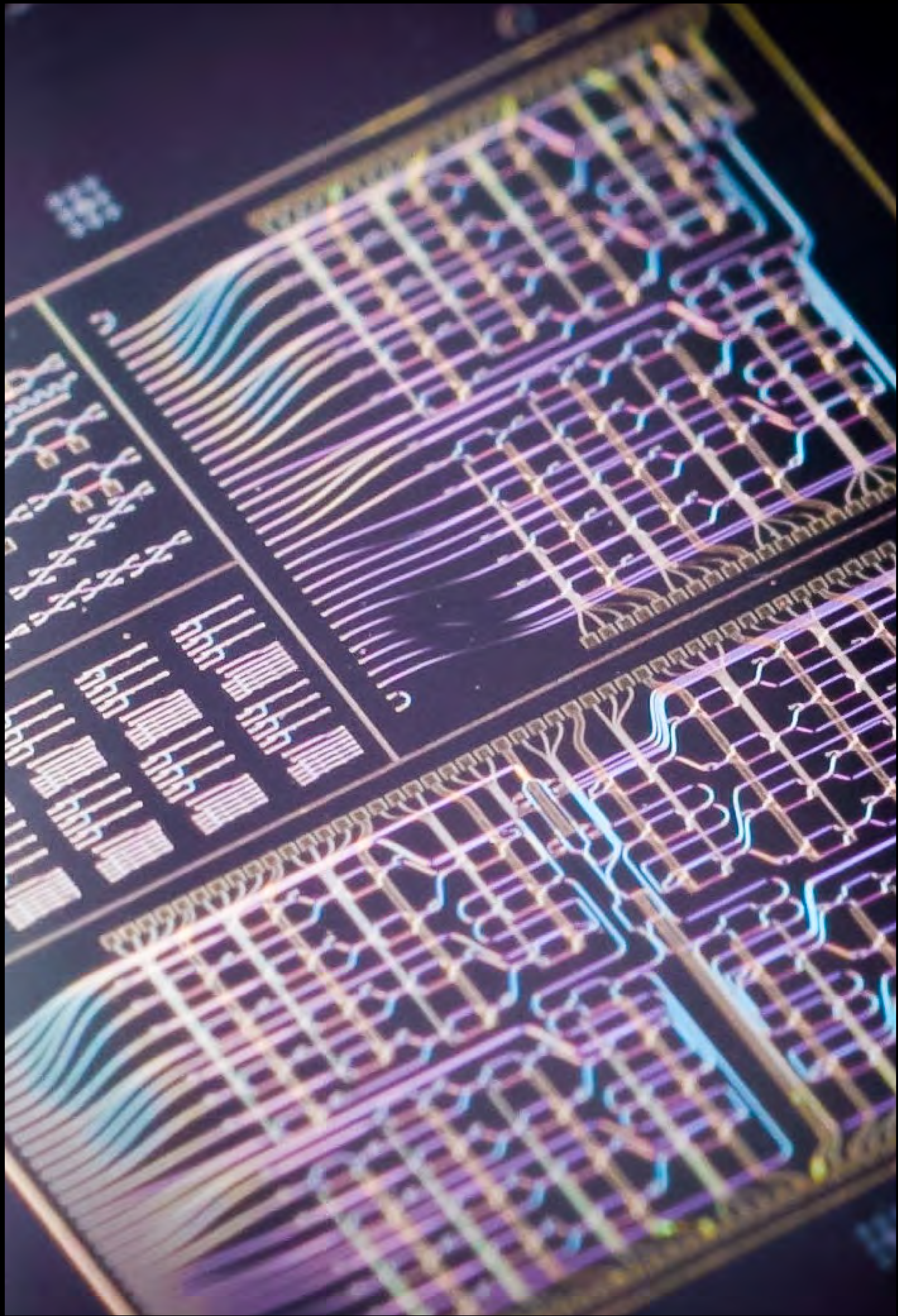
I am proud to chair The COMBS Advisory Board which plays a critical role in guiding the centre to achieve societal impact. We help the COMBS executive leadership to refine and articulate their vision and set their strategic direction – charting a course through today's rapidly changing global environment. Strategically, the Centre views its resources as a foundation—an initial investment that will enable the pursuit of larger-scale opportunities. Our focus is on supporting the Director and Centre Executive in identifying pathways for expanding translational research beyond fundamental science, ensuring that COMBS delivers societal impact. We therefore actively support efforts to explore engagement with state and federal government priorities, venture creation, entrepreneurship-focused PhD programs, and deeper industry engagement.

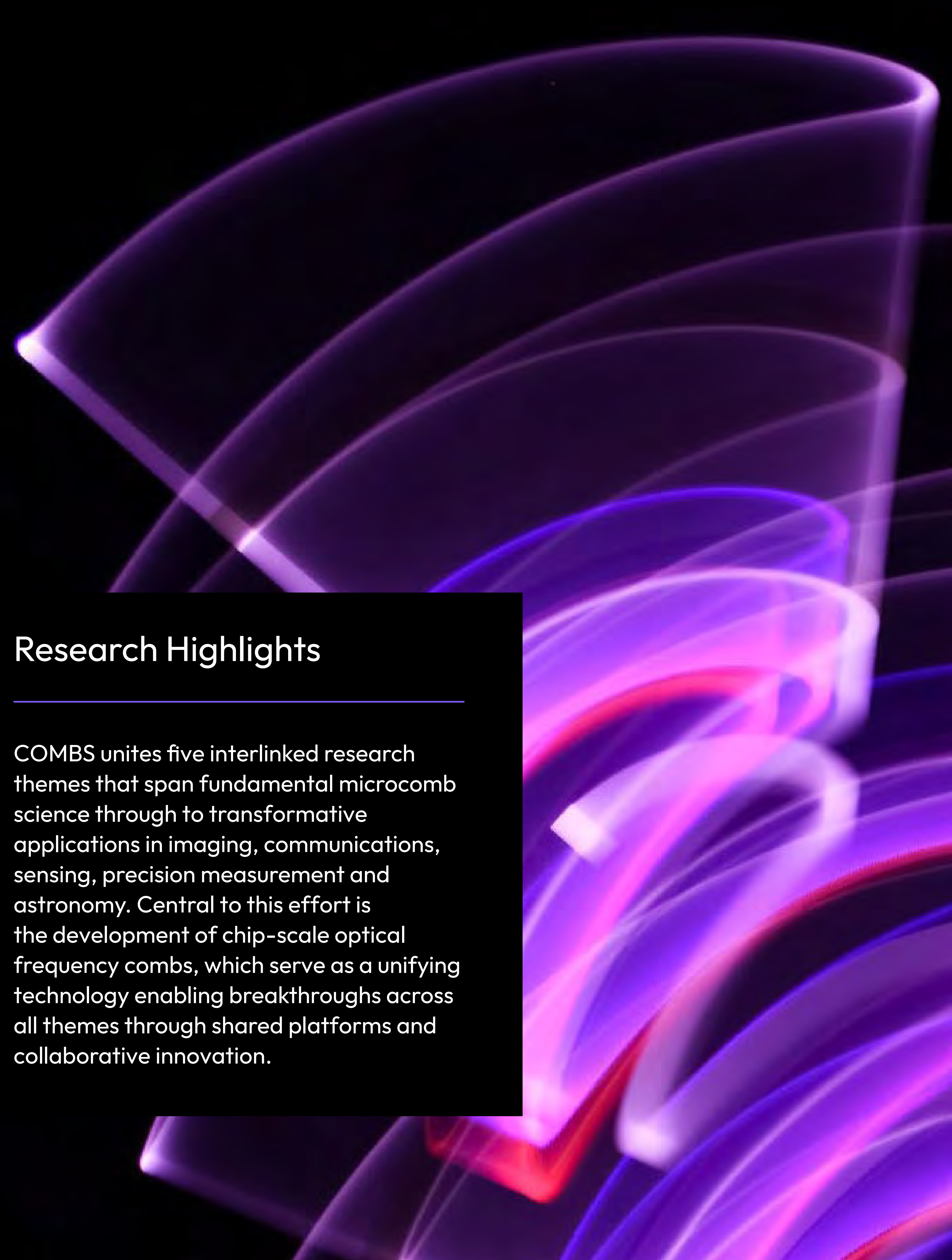
Based on the progress made in Year 1, I am excited by the potential for COMBS to grow and innovate. On behalf of the Board, I extend my congratulations to the Centre's researchers, leadership team, and partners in setting up the Centre – let's see how ambitious we can be!

Distinguished Professor Calum Drummond AO,

Chair, COMBS Advisory Board

Deputy Vice Chancellor Research and Innovation and Vice-President, RMIT University





Research Highlights

COMBS unites five interlinked research themes that span fundamental microcomb science through to transformative applications in imaging, communications, sensing, precision measurement and astronomy. Central to this effort is the development of chip-scale optical frequency combs, which serve as a unifying technology enabling breakthroughs across all themes through shared platforms and collaborative innovation.

Microcomb Science and Technology

Leader: Prof Arnan Mitchell

Coordinators: Dr Carlo Silvestri and Dr Yang Sun

Theme Chief Investigators: Moss, Ebendorff-Heidepriem, Jia, de Sterke, Lancaster, Ou, Walia, Boes, and Eggleton

Vision

The Microcomb Science and Technology theme aims to develop the world's first fully integrated optical frequency comb systems, designed to be robust, efficient, precise, and self-starting for real-world applications. By advancing microcomb stability, efficiency, and wavelength control, we will unlock their potential across diverse fields, including astronomy, biomedical imaging, and sensing. These breakthroughs will be enabled by innovations in self-starting solitons, nanomaterials, and nonlinear optical conversion, allowing for precise comb line manipulation and extending microcomb operation to the visible and mid-infrared spectrum.

Theme Leader Report

The Science and Technology theme began the year as separate capabilities: laser written doped glass in Adelaide and UniSA; soliton crystal microcombs in Swinburne and Monash; lithium niobate integrated circuits at RMIT; chalcogenide waveguides and soliton lasers with innovative dispersion at Sydney. Over the past year, we have learnt a great deal about each of these areas and are beginning to see how we can combine them to achieve the holistic vision of a fully integrated microcomb system on a chip.

Another key role for the Science and Technology theme is to engage with the other themes to discover their needs and where there might be opportunities to exploit emerging microcomb innovations. The focus workshops for each of the themes was an outstanding forum for this engagement. Together we are developing a roadmap to deliver the robust, octave spanning frequency combs reaching the ultraviolet needed by Astrocombs; convert our combs to visible and mid-IR for Microscopy and Spectroscopy and create compact reconfigurable comb manipulation systems for Information and Intelligence.

The recruitment of postdoctoral fellows has been slower than expected; however, there have still been some significant activity. The team at UniSA has discovered a new technique to realise high index contrast waveguides in their laser written platform which has enormous potential for interfacing this platform to the lithium niobate and silicon photonic chips. An application for patent protection of this technology has been submitted. The RMIT team has demonstrated periodically poled lithium niobate waveguides with sufficient nonlinear performance for wavelength conversion of optical frequency combs needed by both Astrocombs and Spectroscopy and microscopy. Simulation tools have been development by the Sydney team to model soliton oscillation in Fabry-Perot cavities that will enable design of microcomb platforms on both the lithium niobate and doped glass platforms. The Swinburne and Monash teams have realised and characterised soliton crystal microcombs systems and have deployed these in Swinburne, Monash, RMIT and recently Adelaide University [See case study].

Theme goals for 2025

- Hybrid integration of doped glass (Adelaide) and lithium niobate (RMIT) to realise gain as a modular building block of our integrated circuits.
- Interfacing of doped glass waveguide lasers (UniSA) and lithium niobate (RMIT) to create hybrid laser comb and photonic chip
- Hybrid integrate chalcogenide glass waveguides (Sydney) with lithium niobate (RMIT) to enable nonlinearity and SBS on a single chip
- Design and realise periodically poled lithium niobate waveguides (RMIT, Adelaide, Swinburne) for comb broadening from infrared (1550nm) to blue (400nm).
- Design (Sydney) and realise (RMIT) Fabry-Perot cavities on lithium niobate
- Show nano materials on photonic chips for manipulating combs (RMIT)
- Continue characterisation and deployment of 25GHz soliton crystals to COMBS nodes (Swinburne/Monash)

Towards an Australian GPS solution: Precise timekeeping and measurement in a thumbnail-sized piece of glass

Atomic clocks power our GPS, helping us to navigate and track our deliveries. But what would happen if the USA-based GPS were switched off? At COMBS, we're developing smaller, tougher atomic clocks for compact, cost-effective Australian satellites.

The Challenge

GPS powers navigation, finance and our internet, but relies on traditional electronic-based atomic clocks – precise timekeeping equipment – that are easily jammed, spoofed or disrupted. This presents a major vulnerability in contested and urban environments.

Next-generation optical atomic clocks – which instead operate at light-speed – offer greater precision and resilience.

To convert this 'light-speed signal' into an electronic signal, they require a 'translation' device called the frequency comb. But these are large, expensive, fragile and fibre-based, making them prone to breaking when operated outside of a laboratory.

Making frequency combs smaller and robust is key to scaling up these next-generation atomic clocks to enable a faster, more resilient GPS.

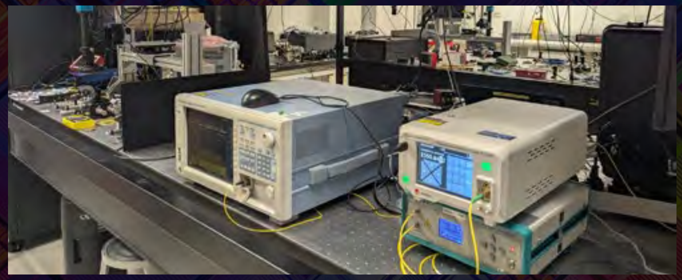
Our Response

To address the fragility of the fibre-based frequency combs, laser technology expert David Lancaster and atomic clock specialist Sarah Scholten collaborated on a more compact, stable design with less moving parts.

At the 2024 COMBS Annual Workshop, they outlined key requirements for the frequency comb to be deployed in the real-world or even in space: miniaturisation, stability, and ease of use.

David's team then fabricated his laser-based frequency comb – inscribed in a thumbnail-sized block of glass – offering a more compact, manufacturable, and turnkey solution.

A crucial first step in testing its real-world resilience was transporting the frequency comb between laboratories in a suitcase, assessing its ability to withstand real-world conditions.



The Results and Current Progress

After arriving in Sarah's laboratory*, Dave's frequency comb turned on within a few minutes – showing just how robust and transportable it is. It then remained operational after extended use, which marked another key milestone.

The next challenge is to take David's miniature lasers and integrate them into a complete optical frequency comb system on a chip the size of a fingernail.

RMIT's photonic chip technology can help, and the COMBS Science and Technology Theme will spend the next 12 months working to combine these two technologies.

With continued refinement, these frequency combs could be mass-produced, enabling smaller, more robust atomic clocks – with the key goal of creating more precise and resilient GPS.

**Sarah's Laboratory is a part of the Precision Measurement Group Labs at the University of Adelaide*

Team:

- David Lancaster, Science and Technology Theme
- Sarah Scholten, Precision Measurement and Sensing
- Aditya Dubey, Precision Measurement and Sensing
- Arnan Mitchell, Science and Technology Theme

Microcombs for Microscopy and Spectroscopy

Leader: Prof Kishan Dholakia

Coordinator: Dr Chris Perrella

Theme Chief Investigators: Ou, Kabakova, Lancaster and Mitchell

Vision

Advances in imaging technologies, such as super-resolution, hyperspectral, and at-depth imaging, have revolutionized microscopy, enabling deeper insights into the structure, composition, and metabolic activity of living cells and tissues. However, many of these systems remain large, expensive, and reliant on slow mechanical spectrometers, limiting their accessibility and real-time capabilities. By developing miniaturized, robust, and low-cost integrated microcomb systems, this research theme is overcoming these limitations to transform multi-modal spectroscopy and real-time microscopy, unlocking new possibilities for high-speed biological imaging and advanced sensing applications.

Theme Leader Report

The key highlight for the Microscopy & Spectroscopy theme for 2024 was the theme workshop. In this workshop, we were able to formulate our plans in the short to medium term. Having all the key people in one room was invaluable to progress planning and develop collaborations. Having CIs from the Science and Technology theme in the room to discuss what comb technologies are available, and plan how to get these combs into the Microscopy & Spectroscopy theme labs was crucial. This workshop led to a deeper understanding across the theme of the different microscopy and spectroscopy techniques we are all familiar with and working on allowing for collaborative projects to be planned.

A significant challenge for our theme was the lack of frequency combs available to work with, making exploratory work delving into the competitive advantage of comb assisted multi-modal microscopy and imaging difficult. At UTS, this was overcome by the delivery of a Taccor frequency comb at 780nm with a 1 GHz repetition rate, which was delivered and commissioned in November.

For the Uni Adelaide team, collaboration with CI Dave Lancaster at Uni SA lead to the 1550nm, 1GHz repetition rate, frequency comb being transported and used at Uni Adelaide for over a month without any need for re-alignment or adjustment. This frequency comb was also frequency doubled to 780nm for the first time with multi-milliwatt output achieved.

The theme also produced several key research publications including: a collaborative paper between CI Irina Kabakova and AI Thomas Cox in Advanced Science [ref 4] [see Case Study]; a cross-node publication from CI Dave Lancaster's team on fluoride glass waveguides in Optics Express selected as Editor's pick [ref 3]; a high profile Nature Methods Primers paper by CI Irina Kabakova on Brillouin microscopy [ref 9]; and a paper led by AIs Dr Sarah Scholten and Dr Chris Perrella using comb spectroscopy to measure CO_2 exhaled by yeast [ref 21].

Theme goals for 2025

- Finalise combs setup at each theme node – i.e. finish building, or broadening combs to enable measurements.
- Preliminary comb spectroscopy measurements (Absorption, Raman, Brillouin) building towards microscopy measurements.
- Greater information sharing between nodes to turbo-charge research progress (i.e. UoA & RMIT sharing experience on comb absorption measurement; UoA & UTS sharing experience with beam shaping for microscopy) and explore joint collaborations leading to novel research projects (RMIT & UoA speckle plasmonic work for healthcare; UniSA providing 1GHz combs to all nodes).
- Joint papers and conference submissions - start developing track record of high-impact works using combs for microscopy and spectroscopy

Imaging the mechanics of triple-negative breast cancer to advance treatment discovery

In a project bringing together an imaging specialist and biomedical expert, the team have used new imaging techniques that reveal – in unprecedented detail – what is fueling the aggressive spread of triple-negative breast cancer cells.

The Challenge

Triple-negative breast cancers are highly aggressive, spread quickly and have limited treatment options. Each year, 2,500 women in Australia are diagnosed with this challenging disease.

Understanding tumour composition and how cancer spreads (metastasis) could enable earlier diagnosis and treatment.

However, whilst current imaging tools can see the tumour cells, they cannot "feel" the tumour properties, such as the stiffness, which is known to be important in how tumours develop, spread and respond to therapy.

Developing new imaging approaches that can see and "feel" tumour features – including variations in tissue structure, composition and behaviour – could improve early detection and treatment strategies for this challenging disease.

Our Response

Overcoming this challenge required the joint expertise from imaging specialists and biomedical researchers.

Associate Investigator Thomas Cox (Garvan Institute) and Chief Investigator Irina Kabakova (UTS) used an imaging technique – called Brillouin microscopy - to study the tumour's mechanical properties and how that may influence the spread of tumour cells around the body.

Brillouin microscopy involves shining a laser onto different tumour regions, where it then undergoes an intricate energy exchange with the natural vibrations of the tumour tissue. This interaction creates new colours of light – like a fingerprint – revealing how stiff or soft each region is.

The Results and Current Progress

Brillouin microscopy revealed that triple negative breast cancer tumours are non-uniform, with both soft and stiff regions [ref 4].

Crucially, the team found that a cancer cell's location within these regions influenced its ability to spread. Cells from softer areas were more likely to spread and, unlike typical cancer cells that rely on sugars, these cells also used fats for fuel. The cell's unique 'fatty diet' helped them to survive and spread.

This insight has opened new treatment possibilities, including 'starving' these cells of fats to limit their ability to spread.

The team now aims to explore how microcombs could speed up Brillouin microscopy – reducing processing time from hours to seconds. This could enable real-time tumour imaging to guide surgeries and preserve healthy tissue.

Team:

- **Irina Kabakova,** Microscopy and Spectroscopy
- **Thomas Cox,** Garvan Institute
- **Elysse Filipe,** Garvan Institute
- **Hadi Mahmodi,** Microscopy and Spectroscopy

Microcombs for Information and Intelligence

Leader: A/Prof Bill Corcoran

Coordinator: Dr Taimur Ahmed

Theme Chief Investigators: Lowery, Eggleton, Walia, Moss, and Mitchell

Vision

The Information and Intelligence theme leverages microcombs to revolutionize data transmission, analogue signal processing, and machine learning, enabling scalable, high-speed, and efficient computing. By dramatically increasing optical fibre bandwidth and enabling intelligent real-time data analysis, microcombs will drive the next generation of the internet, AI computing, and sensor networks. These advances will overcome growing data capacity constraints and enable fast, adaptive, and energy-efficient processing for applications ranging from AI to real-time environmental and biomedical sensing.

Theme Leader Report

In the first year of the Centre, the Information and Intelligence theme focused on establishing a strong foundation for research activities over the next six years. We identified key aspects of our existing research that will help drive COMBS' goals forward, including rethinking stimulated Brillouin scattering in the context of frequency combs, and investigating "memory-like" materials that can operate with light at wavelengths best suited to information processing and transmission applications. We have advanced core COMBS' techologies, refining the control of information processing devices, and improving methods for making complex photonic chips integrate optimally with microcombs.

Our team is one of the most experienced in the Centre when it comes to using microcombs in the lab. We have focused on generating "soliton crystal" states in microring devices in collaboration with CI David Moss and PI Sai Chu, including expanding our phenomenological understanding of soliton crystal formation in these devices. Specifically, we are investigating the relationship between avoided mode crossings in microring devices, and the generation and stabilisation of primary comb states—a crucial precursor to functional microcombs. This work is a key step in enabling researchers without microcomb expertise to access and use these technologies more easily. You can read more about this in the "case study" below.

Key outputs from our theme in 2024 included: a paper reporting quasi-light storage on a photonic chip using an optical frequency comb and stimulated Brillouin scattering to sample and store information [ref 15]; and a "Top-scored" OFC paper reporting lasers locked to microrings for optical communications [ref 25].

Theme goals for 2025

- Demonstrate "comb unique" optical communications systems, aiming for high capacities and low energy consumption
- Use Wadley Loops as a tool to enhance the precision of swept optical frequency systems, toward implementations for DAS, photonic radar and photonic chip self-tuning
- Establish a photonic-chip-integrable capability for light-by-light "memory-like" elements in the optical communications bands, and explore photonic chip integration of similar established materials at other wavelengths useful for other themes (e.g. spectroscopy & microscopy)
- Leverage stimulated Brillouin scattering to enable low noise combs, toward applications in LIDAR.
- Expand the scope of applications (e.g. DAS) for analogue signal processing based on microcombs, leveraging new techniques developed in 2024, and exploring others.

The microcomb could transform industries – but only if more people can use them

Our microcombs have already shown revolutionary outputs for information and intelligence and led to record-breaking internet speeds on a single optical chip. At COMBS we see even greater potential – but only if more people could use them.

The Challenge

At COMBS, we aim to make microcombs an accessible tool for the world's most accurate measurements – enabling breakthroughs like earlier disease detection with handheld diagnostics or helping telescopes to find Earth-like planets.

Our team has already broken records with specific soliton crystal microcombs – enabling the world's fastest internet and high-capacity brain-like neural networks.

However, while these devices require little training in established setups, they remain too complex for new users.

To unlock their full potential, we need to make them more user-friendly – allowing astronomers, seismologists or biomedical experts to transform their work, without needing to be a PhD microcomb expert.

Our Response

Bridging fundamental research and real-world applications starts with connecting technologists and end-users.

At COMBS, we have embedded this approach, bringing microcomb experts and potential end-users from astronomy, data infrastructure and biomedical imaging together.

One end-user is Astrocombs researcher Toby Mitchell, who needs a fully stabilised, reliable reference for telescopes to find Earth-like planets or track the Universe's accelerating expansion in real-time.

To support this, COMBS microcomb experts Park Prayoonyong, Caitlin Murray and Yang (Susan) Sun developed a microcomb 'recipe card' – a how-to guide – to help Toby take the first step in using the technology.

The Results and Current Progress

Over three to four months, technologists Park, Caitlin and Susan trained Toby to use their soliton crystal microcomb. Their collaboration mirrored the real-world technologist and end-user collaboration – defining requirements, troubleshooting stability issues, and refining techniques along the way.

The team found the 'recipe card' was a good starting point, but direct expert support was crucial for troubleshooting specific issues – an essential step for future training.

Initially unfamiliar with this type of microcomb, Toby can now independently operate and generate them, enabling new astronomical experiments.

While our ultimate goal is to make microcombs as accessible as consumer electronics, this project is a key step in bringing together our microcomb experts and end-users to enable real-world impact.

Team:

- Bill Corcoran, Information and Intelligence
- Caitlin Murray, Information and Intelligence
- Park Prayoonyong, Information and Intelligence
- Yang (Susan) Sun, Science and Technology Theme
- Toby Mitchell, Astrocombs Theme
- David Moss, Science and Technology Theme
- Michael Murphy, Astrocombs Theme

Microcombs for Sensing and Measurement

Leader: Dr Andreas Boes

Coordinator: Dr Nas Meftahi

Theme Chief Investigators: Luiten, Miller, Boes, Kealy, Mitchell, Walia, Moss, and Dholakia

Vision

The Sensing and Measurement theme leverages microcombs to enable ultra-precise, compact, and cost-effective sensing technologies for tracking time, movement, and space. By miniaturizing optical clocks, acoustic sensors, and laser ranging systems, microcombs will revolutionize global positioning, Earth science, autonomous navigation, and industrial automation, even in remote environments. These advances will replace bulky, satellite-dependent systems with highly accurate, locally deployable solutions, transforming applications in transport, environmental monitoring, and telecommunications.

Theme Leader Report

In 2024, the Microcombs for Sensing and Measurement Theme focused primarily on recruitment and capacity building. A key milestone was the addition of new Chief Investigator, Professor Allison Kealy, whose expertise brings new opportunities for collaboration and potential end-user engagements for our theme. In parallel, we faced the challenge of recruiting suitable postdoctoral candidates, which required re-advertising some positions to attract the right talent. Despite these challenges, I am pleased to report that all theme CIs successfully secured high-quality postdoctoral researchers, who are expected to commence their positions in the first half of 2025. These new appointments will drive key research projects and stimulate cross-theme collaboration in the coming year.

Two exciting developments helped launch the theme's research program. Firstly, essential electro optic dual comb equipment was purchased and arrived at University of Adelaide to support investigations using microcomb-based LiDAR and hyperspectral imaging. Secondly, CI Miller's team, in collaboration with AI Bandutunga and CI Mitchell started to explore how distributed acoustic sensing (DAS) systems and field measurements could be enhanced using optical frequency combs using the "dark" (not used for information carrying) optic fibre link in Melbourne between RMIT and Monash universities.

Although we were unable to hold a Microcombs for Sensing and Measurement Theme Workshop in 2024, we will take advantage of Professor Kealy's arrival in 2025 to host our first workshop in February. This event will provide a platform for discussing the theme's annual research plan, identifying collaborative opportunities across themes and nodes, and setting strategic priorities for the year ahead.

Theme goals for 2025

- Conduct further field studies using the newly developed optical frequency comb enabled DAS system
- Initial testing of optical processing of DAS data using optical frequency combs
- Set up dedicated microcomb sources for lidar or hyperspectral imaging applications
- Explore frequency doubled dual-comb systems for hyperspectral imaging
- Investigate market opportunities for optical frequency comb-based precision navigation and timing

Uncovering what lies beneath our cities – all with our internet's optical fibres

From ensuring our homes don't crack to keeping our skyscrapers standing tall – understanding our city's bedrock is foundational. Our researchers are repurposing the optical fibres already buried beneath Melbourne to map what lies beneath – all without digging a single hole.

The Challenge

To keep our city's infrastructure in good health, we need to monitor what's happening beneath our urban environments.

However, current methods for assessing ground structure beneath busy roads, buildings and footpaths are invasive and impractical – often requiring large 'thumper trucks' or sensors buried every four meters.

Another technique called Distributed Acoustic Sensing (DAS) repurposes our existing internet's optical fibres – which are very sensitive to vibration - and turns them into cost-effective, ground motion sensors that can then be used to map the subsurface.

But in a dense urban environment, how do you get access to these optical fibres to better understand what lies beneath?

Our Response

Running from RMIT University to Melbourne's east and Monash University is a 76-kilometre loop of 'dark fibre'- optical fibre not used for everyday internet traffic, but put aside for collaborative research.

This underground lab – the Australian Lightwave Infrastructure Research Testbed (ALIRT) - makes up a very small portion of Melbourne's existing optical fibre network.

Our seismologists, Associate Investigator Voon Hui Lai and Chief Investigator Meghan Miller, connected a specialised laser to part of the fibre and 'listened in' to Melbourne's traffic, trams and even river flows – capturing vibrations to create a detailed picture of the city's underlying bedrock.

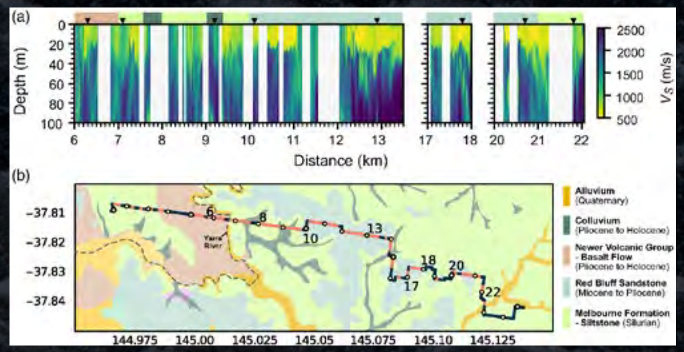


Image from *Passive Seismic Imaging of Urban Environments Using Distributed Acoustic Sensing: A Case Study from Melbourne, Australia*

The Results and Current Progress

With the testbed of dark fibre, Voon and Meghan developed a model that used the background hum of the city - trams, trains and traffic – as a 'light source' to see 10 metres beneath Melbourne's concrete jungle.

This revealed bedrock and soil types at metre resolution – distinguishing sandy, silty or volcanic layers. This precise map can help engineers predict how areas might respond during earthquakes: softer soils like alluvium amplify shaking, and dense bedrock, like bluestone, absorb it.

Our COMBS researchers are now working to use our microcombs to sharpen this resolution, improve signal clarity, extend the technique to remote and underwater areas, and streamline data processing for real-time seismic monitoring.

Team:

- Meghan Miller, Precision Sensing and Measurement
- Voon Hui Lai, Precision Sensing and Measurement
- Luke Broadley, Precision Sensing and Measurement
- Arnan Mitchell, Science and Technology
- Bill Corcoran, Information and Intelligence

Microcombs for Astronomy

Leaders: Prof Michael Murphy & Prof Jean Brodie

Coordinator: Dr Toby Mitchell

Theme Chief Investigators: Boes, Corcoran, Lancaster, Luiten, Mitchell, and Moss

Vision

Astrocombs provide a highly stable and precise wavelength reference for astronomical spectrographs, enabling long-term calibration needed to detect Earth-like exoplanets, test Einstein's field equations, and observe fundamental changes in physics over cosmic timescales. Existing astrocombs are fragile, complex, and mainly operate in infrared, whereas integrated microcombs at visible and ultraviolet wavelengths offer a robust, scalable, and cost-effective solution tailored for these critical astronomical measurements.

Theme Leader Report

An important step this year has been hiring an astrocombs postdoctoral researcher and Theme Coordinator, Dr Toby Mitchell, whose expertise spans both frequency combs and astrophysics – a rare combination, making this something of a "unicorn" hire! Most importantly, Toby has already learned how to generate the soliton crystal state in the 25 GHz microcomb chip we obtained from the Science & Technology Theme (special thanks to Bill & Park at Monash!). This represents a first for COMBS: a researcher without prior microcombs experience routinely operating their own microcomb – a first step in "getting microcombs out of the lab and into breakthrough science areas".

These achievements followed detailed planning in the first 6 months of the year, when we made the strategic decision to focus on microcombs and, potentially, mode-locked glass lasers as the foundation for future astrocombs. Our 2024 Astrocombs Workshop then explored various technical pathways for using a soliton crystal in the infrared as the 'seed comb' for a visible astrocomb. This highly productive and collaborative workshop generated key ideas that are now integrated into our Astrocombs Theme Plan.

A major challenge in 2024 has been access to lab space and time to begin work with the microcomb. Although Toby is hired at the Swinburne node, he is currently working in RMIT's lab space. However, this facility, and some of the same equipment, is also used by other COMBS researchers, limiting lab time to just 1-2 days per week. Plans are now underway to establish a dedicated astrocombs lab at the Swinburne node, complete with new equipment to support his work.

Theme goals for 2025

- Hire second Astrocombs Theme postdoc to investigate optimal calibration of existing astronomical spectrographs with existing astrocombs
- Lock the repetition frequency of the 25 GHz soliton crystal microcomb
- Move towards automating operation of the soliton crystal microcomb
- Investigate optimal methods for broadening the 25 GHz soliton crystal microcomb to translate it into visible wavelengths
- Host a dedicated Astrocombs workshop at the Keck Observatory that will bring together key researchers in astrocombs from Australia and the US.

Helping astronomical observatories never miss a night's sky

By bringing together laser physicists and astronomers – two fields that rarely intersect – our team is developing more robust and accessible measurement equipment to ensure astronomical observatories never miss a night's sky.

The Challenge

The world's best astronomical observatories need to be situated in remote areas and high above low clouds where it is often very cold.

When they're working, they have the potential to measure tiny changes in stars that could help us to discover Earth-like planets, or track cosmic gas to detect the Universe's accelerating expansion in real time.

To capture this data, the observatories' measuring equipment – called an astrocomb – needs to operate 24/7 for decades – to ensure no tiny measurements are missed.

But current measurement equipment on these observatories often breaks, causing data gaps, but also costly repairs that require specialist expertise.

Our Response

Our team is working to make astronomical observatories' measuring equipment more reliable and user-friendly, enabling uninterrupted, stable measurements of the Universe.

To overcome this technical challenge, laser physicists need to grasp real-world challenges, while astronomers need to understand the engineering constraints. This is difficult in a context where these two disciplines rarely intersect.

Thanks to the 7-year Centre of Excellence structure, which focuses on bringing wide-reaching disciplines together, these two research areas can collaborate much more easily.

An early career researcher with a background in astronomy and engineering, Toby Mitchell, is helping to bridge that gap.

The Results and Current Progress

Toby acts as the bridge between the Science and Technology and Astrocombs themes, and is able to quickly shift between the end-user and the technologist role.

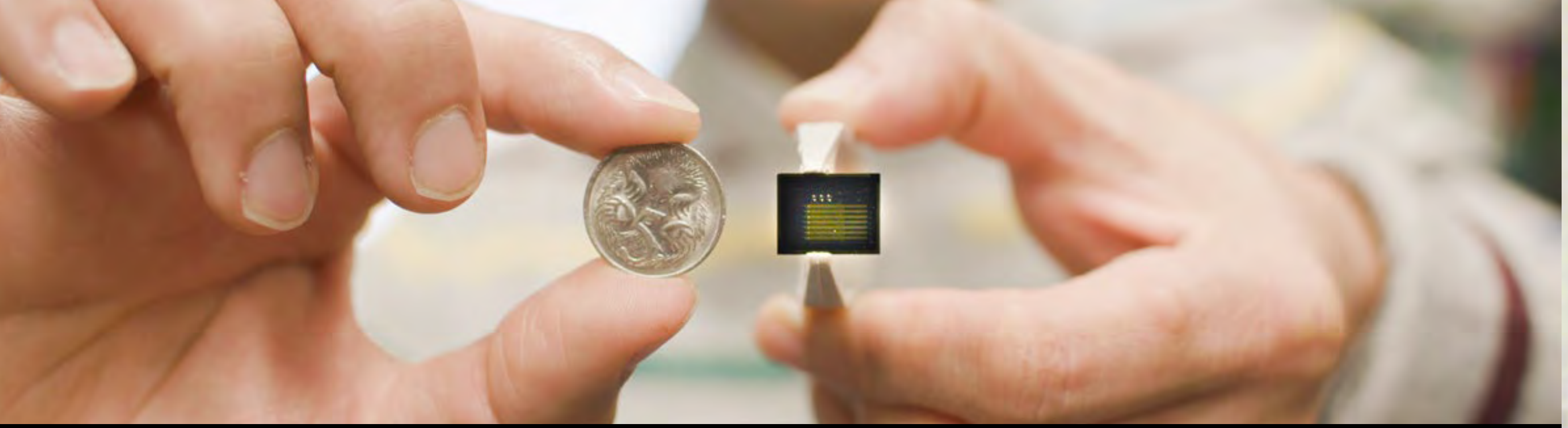
The priority is to make astrocombs more robust. Currently, even a slight touch or breath on the lab bench might stop the astrocomb working.

Pairing astrocombs with microcomb technology has already shown progress, where even after major disruptions – like banging your hand on the lab bench – a microcomb can retain operation.

The goal is to create a fully stabilised astrocomb. This could allow observatory measurement equipment to operate uninterrupted for decades – ensuring no night sky is missed in the search for Earth-like planets or real-time observation of the Universe's accelerating expansion.

Team:

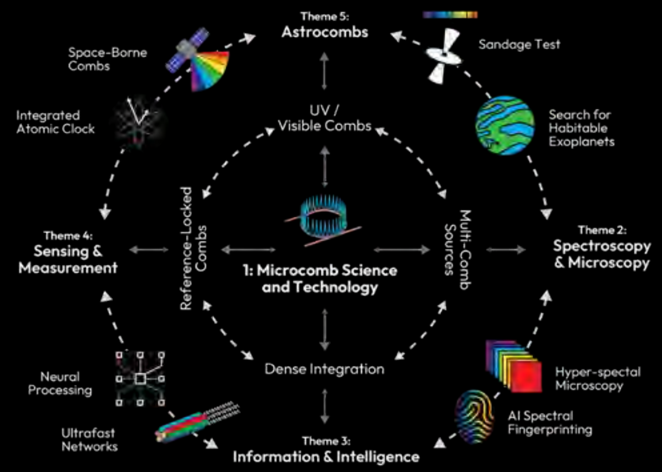
- Toby Mitchell, Astrocombs Theme
- Michael Murphy, Astrocombs Theme
- Jean Brodie, Astrocombs Theme
- Park Prayoonyong, Information and Intelligence
- Caitlin Murray, Information and Intelligence



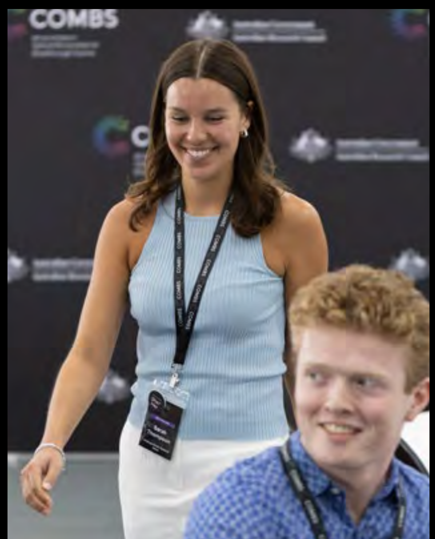
Strategic Challenges and Mitigation Strategies

Challenge 1: Breadth of COMBS

A key feature of our COMBS Centre is the highly multi-disciplinary cohort of researchers spanning from the science and technology of the microcombs themselves all the way to researchers in specific use case areas. This was a deliberate choice aiming to maximise opportunities to create real world impact, but this comes with the challenge of ensuring that this diverse group are fully engaged with the centre, can understand each other and work together.



Mitigation strategy: We have recognised that science communication is critically important and have invested in a dedicated science communicator, however we now recognise that our own researchers from different disciplines are an important target audience and are training our members to communicate effectively internally and externally. We have also established annual focus workshops for each theme with attendees from all connected themes. These initiatives ensure that research is framed in multiple different contexts breaking down barriers between disciplines.



Challenge 2: Recruitment

Our nodes began recruiting postdoctoral researchers as soon as our Centre commenced, however, we found it very difficult to attract suitable applicants which in many cases required us to readvertise. This appears to be a challenge faced by the entire STEM academic sector. Being unable to recruit staff has meant that the work could not commence, effectively putting excessive strain on our Chief Investigators who are trying to carry the load or causing research efforts to stall frustrating engagement and collaboration.

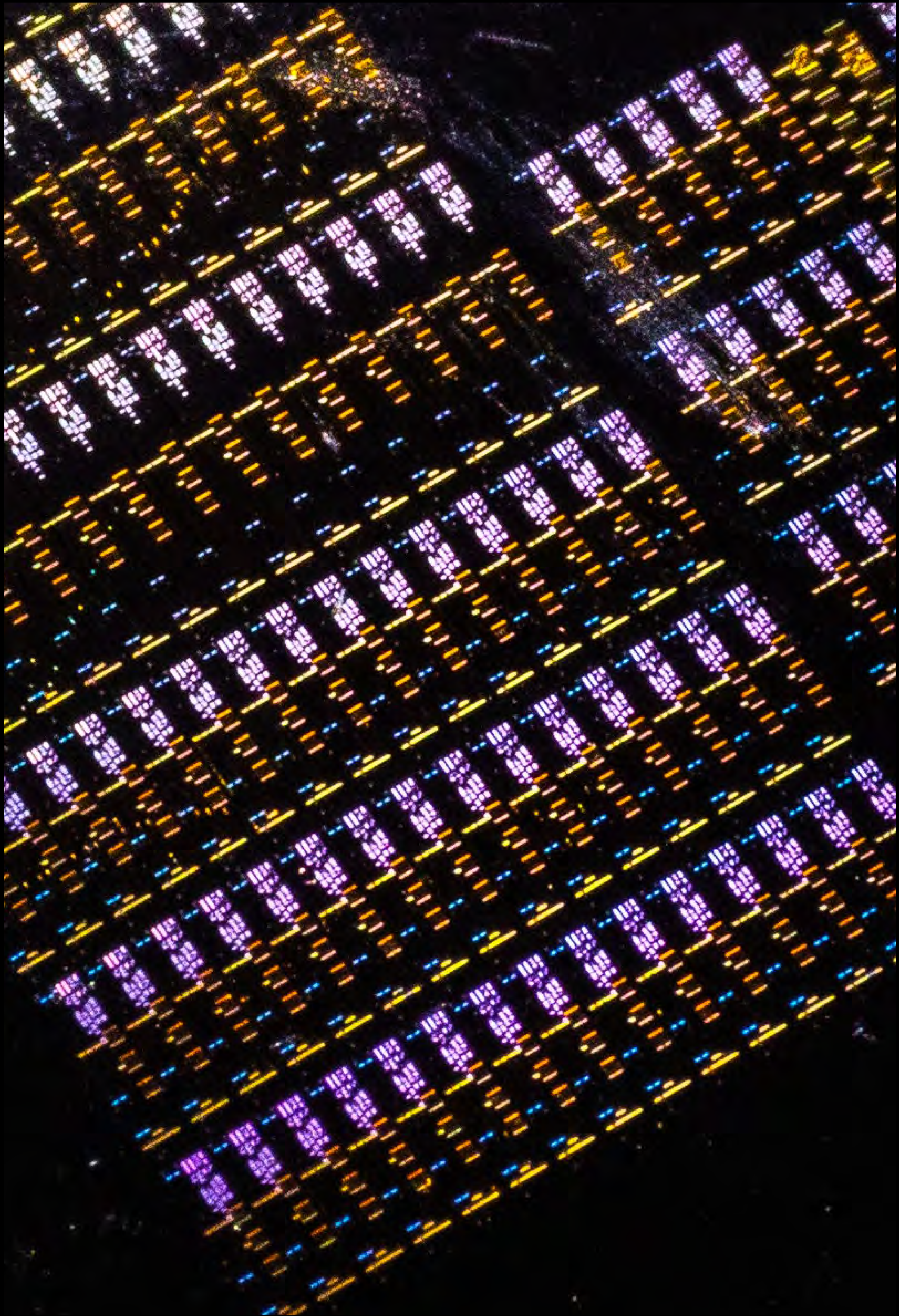
Mitigation strategy: We recognised the challenges of recruitment and the potential negative consequences and have invested in specialist targeted advertising and also reaching out and engaging directly with our international collaborators. We see word of mouth and recommendation as the most powerful means of attracting suitable talent and have invested in visiting our international colleagues to connect to their ecosystems so that we are not 'cold calling' for staff. By the end of 2024 most of the post-doctoral positions have been recruited so this is no longer a crisis, however the longer than expected set up has impacted productivity for the year.

Challenge 3: Photonic chip manufacture and prototyping

Our COMBS Centre relies on photonic chip technologies to realise the microcombs that are the foundation of our research. Our most effective microcomb platforms are currently sourced from partners overseas but with ongoing challenges in supply chains, we may not be able to rely on supply of these chips from collaborators in Asia, Europe and the USA. The technology we require is only on the cusp of being available from commercial foundries and so there is no guarantee of supply. This presents a vulnerability.

Mitigation strategy: To reduce this risk we are expanding our network of collaborators in photonic chips, particularly in Europe with collaborators in France, Germany, Sweden and Switzerland. We are investing in trialling commercial manufacture of chips from foundries to get first hand insight into the current state of the art. We are exploring new designs that could be fabricated using existing technology.

In parallel, we recognise that COMBS should be establishing a sovereign capability to realise these platforms in Australia. We are investing developing processes using tools available across the Australian National Fabrication Facility (ANFF) and are guiding the investment in new tools for the ANFF network. If we are to compete globally, we see the need to establish an industry quality photonic chip prototyping and pilot manufacturing facility in Australia. Such a facility would enable Australian researchers to prove concepts with physical prototypes and could also do small batch manufacture for industry partners, particularly in the defence sector. We are investing in the development of a business case proposal to establish the viability of an Australian photonic chip capability and based on this assessment will work collaboratively with stakeholders from ANFF, S3B and the state and federal governments to find a way to make this a reality.



Operational Reports

COMBS' four operational committees provide strategic leadership in equity, education, infrastructure, and research translation, ensuring the Centre's activities are inclusive, impactful, and well-supported. Together, they align resources and initiatives to foster a collaborative, diverse, and outward-facing research environment

Equity, Diversity and Inclusion

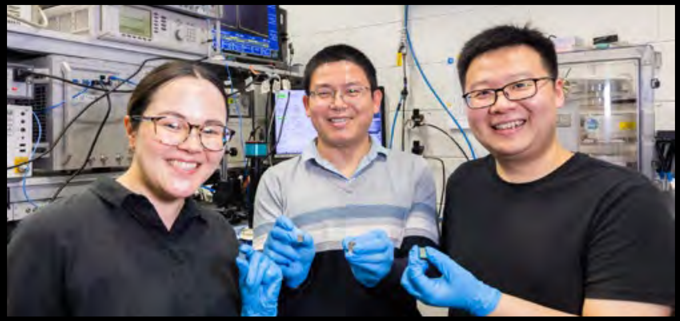
The Centre Equity, Diversity and Inclusion Committee aims to support the Centre to attract, train, and promote a diverse research community, and work to ensure the long-term sustainability of these people in COMBS-related research sectors.

Committee Report

The COMBS EDI Committee is committed to transforming the research landscape by creating a truly inclusive and supportive environment for all researchers and support staff. Our vision is to build a diverse, equitable, and inclusive research ecosystem that empowers researchers from all backgrounds, breaks down systemic barriers, and ensures equal opportunities for success.

In 2024 the EDI Committee grew in size and capability. We welcomed the addition of a new Associate Investigator, Professor Robyn Barnacle, who is an internationally recognised researcher in education, and gender equality in STEM and higher education. Robyn's insights have been essential for developing the Centre's EDI action plan, and she will supervise a PhD student to undertake research into EDI using COMBS as a model. Later in the year we also welcomed the Centre EDI Coordinator, Ruth Waterman, to support the Committee's activities. Her background spans a degree in gender studies, to work in youth advocacy, non-profit and health research. She is passionate about supporting the students and postdocs at COMBS and making the Centre and nurturing space for everyone.

The Committee developed two key initiatives during the year. The Centre Recruitment Guidelines aim to provide best practice to follow for advertising, interviewing and selecting new COMBS staff. The Career Restart Grant was conceived of to financially support researchers who want to get back into the lab after a significant career interruption. These two initiatives will be further developed and deployed in 2025.



In 2025, we will also work on developing comprehensive support programs, mentorship pathways, refining inclusive hiring practices, and developing metrics to track and improve our EDI outcomes. By embedding equity and inclusion into the core of our research culture, we aim to not only support individual researchers but also enhance the creativity, innovation, and excellence of our scientific endeavours.

Committee Plans for 2025

- Refine recruitment guidelines and associated checklists
- Develop processes for tracking and reporting on COMBS recruitment data
- Career restart grant to support researchers with significant career interruptions
- Centre Wide EDI focused events and training and support members to attend INSTEM conference
- Accidental Counsellor training for staff and students.
- Undertake a Centre-wide culture survey and provide report to Centre Exec and Board

Sustaining diversity in STEM: Addressing the leaky pipeline for breakthrough science

The Australian Research Council Centre of Excellence scheme brings together researchers to achieve breakthrough science, but to collaborate effectively, you need a full spectrum of perspectives. Diverse teams can tackle bigger questions and problems – essential for achieving society-wide impact at COMBS.

The Challenge

The seven-year Centre of Excellence scheme enables collaborations across universities to achieve breakthrough science.

However, breakthroughs need more than collaboration, they require diverse perspectives. Research shows that inclusive, respectful science is not just good practice – it drives better knowledge generation and broader societal impact.

Yet, STEM faces challenges. Many high school students start interested in STEM, but girls often disengage due to systemic barriers. Achieving gender balance at more senior levels is also challenging as women take on disproportionate family responsibilities.

The challenge isn't just attracting diversity – it's maintaining and nurturing it to build a truly diverse and self-sustaining research ecosystem at COMBS.

Our Response

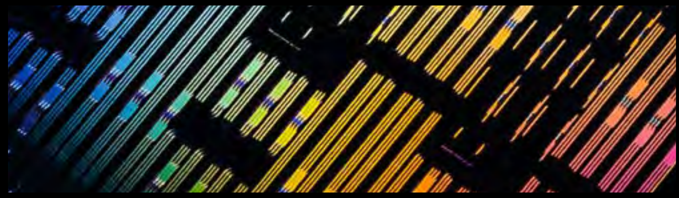
To foster a more diverse research environment, COMBS' Equity, Diversity and Inclusion Committee is committing to understand where and why diversity is lost in STEM.

Two key research initiatives are investigating this.

PhD research led by Professor Amanda Berry explores why high school students disengage from STEM and how to sustain their participation.

Research by Professor Robyn Barnacle is examining barriers to recruitment and retention, preventing diverse talent from progressing from junior to senior postdoctoral levels, while investigating effective equity, diversity and inclusion practices.

Both studies use the Centre as case study for STEM more broadly, aiming to build a more diverse and self-sustaining research ecosystem.



The Results and Current Progress

These initiatives will help the Equity, Diversity and Inclusion Committee to understand the broader context over time.

Other more immediate actions are already aiming to improve inclusivity:

- The Carer's Grant supported two researchers to attend the 2024 COMBS Workshop with their child.
- An expanded Equity, Diversity and Inclusion Committee now integrates diverse expertise and perspectives, including government relations and training.
- Inclusive recruitment guidelines are in place to attract a broader applicant pool, with further implementation support planned.

By pinpointing where diversity is lost in the leaky pipeline and finding ways to sustain it, COMBS aims to foster a research ecosystem rich in diverse perspectives. This commitment to equity, diversity and inclusion will not only drive breakthrough science, but also help COMBS to achieve society-wide impact.

Team:

- Ruth Waterman, RMIT University
- Sumeet Walia, RMIT University
- Heike Ebendorff-Heidepriem, University of Adelaide
- Bill Corcoran, Monash University
- Allison Kealy, Swinburne University
- Robyn Barnacle, RMIT University

Impact and Translation

The Translation and Impact Committee aims to build and support a culture of research translation and commercialisation within the Centre to make sure that our technology gets into the hands of those who can use it to create impact.

Committee Report

In 2024, the committee focused on strengthening COMBS' impact and translation efforts, laying the groundwork for future innovation and collaboration across partner institutions. Key achievements include the hiring of a dedicated coordinator to streamline operations, the establishment of regular committee meetings to ensure consistent progress, and the development of an Impact and Translation Framework, presented as a draft strategy document to guide future initiatives.

The committee also commenced the formation of a specialized IP Subcommittee involving our participating universities to enable COMBS to lead intellectual property (IP) translation. Committee members took the lead in fostering these relationships, in particular with RMIT's Research and Innovation team.

To support ongoing innovation, the committee initiated a Return on Investment (RoI) Tracking Process. This system actively involves research theme leaders and allows COMBS to identify market opportunities, talent, resource needs, and required partnerships. The RoI process also encourages researchers to submit RoIs through their own universities, covering critical aspects of technology and IP management.

The committee further developed entry pathways to accelerator programs, training opportunities, and support structures to help researchers move their technologies from the lab to the market. Emphasis was placed on facilitating Freedom of Information (FoI) processes, mediation, and support, ensuring

that researchers can effectively navigate university IP policies and generate meaningful impact from their work.

Looking ahead, the committee aims to build on these foundations by strengthening partnerships, refining the Impact and Translation Framework, and further enhancing pathways to commercial success for COMBS innovations.

Committee Plans for 2025

- Explore co-designed projects with COMBS industry Partner Organisations
- Develop industry internships for COMBS HDR students
- Impact and translation training for all members
- Explore novel PhD programs such as venture capital partnered, or industry portfolio PhDs
- Establish IP subcommittee meetings
- Explore more opportunities for communications and outreach related to our impact and translation outcomes
- Conduct industry focused workshop to explore opportunities for COMBS related research

Predicting the unpredictable: Investing in science and technology for the next decade

From discovering Earth-like planets to revolutionising medical imaging for earlier diagnostics – we are aiming for high-impact outcomes at COMBS. A key step in achieving this is bridging the gap between researchers and end-users to align our research with society's biggest future challenges

The Challenge

To turn research into real-world impact – like our GPS, ChatGPT or consumer electronics – we need our fundamental research to address society's biggest future challenges.

For us at COMBS, our researchers need to anticipate industry's needs five to ten years ahead, identifying where microcombs could have the greatest societal impact.

A key step is directing our research towards this market need, but a major barrier is the communication gap between researchers and industry. Both often operate in silos, speak different technical languages and can be reluctant to share their challenges openly.

This disconnect makes collaboration difficult, ultimately slowing progress in translating research into tangible, real-world solutions.

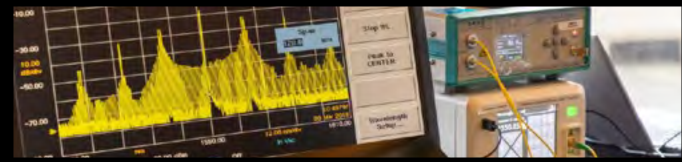
Our Response

Bridging the communication gap between researchers and industry starts with direct engagement, where they can come together to discuss their technical challenges.

The COMBS Launch in 2024 exemplified this, by bringing together researchers and industry partner Terra15 together.

A live demonstration showcased Distributed Acoustic Sensing (DAS) – which repurposes our internet's optical fibres into sensors – for earthquake monitoring, leak detection or even measuring the 'seismic activity' of the room as attendees jumped in unison.

The panel discussion between seismologist Meghan Miller and Michael Roelens from Terra15 highlighted their shared need for technology that could rapidly process vast data streams from their optical fibre sensors.



The Results and Current Progress

The panel discussion and real-world demonstration highlighted two applications where microcombs could offer a solution to Distributed Acoustic Sensing (DAS).

Meghan needs a tool to process the vast amounts of seismic data from optical fibres for real-time earthquake monitoring, while Michael (Terra15) seeks emerging technologies to improve water leak detection in pipelines. Microcombs could be a tool to address both of these challenges.

The event showcased current state-of-the-art technology and its future potential, providing a clear pathway to impact for our COMBS researchers.

Using this event as a blueprint, the Impact and Translation committee will continue to enable direct engagement – via industry days and pitch events – to ensure our research continues to align with society's biggest future challenges.

Team:

- **Arthur Lowery,** Monash University
- **Benjamin Eggleto,** University of Sydney
- **David Lancaster,** University of Adelaide
- **Adam Chrimes,** RMIT University
- **Rachael Vorwerk,** RMIT University

Infrastructure and Capability

The Infrastructure and Capability Committee oversees the coordination, development, and sustainability of the Centre's shared infrastructure and expertise, ensuring cutting-edge capabilities in optical frequency comb technology, guiding investment in critical facilities, and fostering a national ecosystem that supports sovereign capability and long-term industry translation.

Committee Report

In 2024, the Infrastructure and Capability Committee conducted a review of existing equipment across our nodes including: optical frequency comb sources and supporting equipment, and equipment that can be used for manufacturing optical frequency comb sources. This was an essential first step in mapping out what is currently available across the Centre and strategically planning for future infrastructure requirements. We have now identified where required capabilities are missing, which feeds directly into our infrastructure plans for 2025.

There also have been new optical frequency comb sources installed in 2024.

CI Irina Kabakova installed a new optical frequency comb to study chemical bonds and mechanical properties of the biochemical molecules accurately.

The Dual-comb Hyperspectral Imaging Facility (funded under ARC LE230100005) was installed at RMIT and the University of Adelaide nodes, and provides the capability of electro-optically generating dual combs with tuneable repetition rate and offset frequency. The system is designed for imaging and spectral analysis and also can employ high optical power to identify molecules, study chemical bonding and intramolecular bonds (Raman analysis), or study of mechanical properties of samples (Brillouin analysis).

Lastly, the Centre also contributed to the "Semiconductor Design Workshop", which was organised by the University of Sydney's Society of Light. The workshop brings together experts from

quantum, photonics, fabrication, and industry sectors for two days focused on the latest in semiconductor design and application. COMBS Infrastructure and Capability Coordinator, Dr. Guanghui Ren, delivered a talk introducing the COMBS Centre and the Centre's photonic integrated circuit fabrication platform which inspired much discussion amongst potential research collaborators and industrial partners.

In 2025, the Committee will coordinate the purchase of additional key equipment to ensure that microcomb sources and other essential hardware are available at all nodes for experimental use, and also train our members to design photonic integrated circuits for fabrication.

Committee Plans for 2025

- Purchase mode-locked laser comb for Victoria nodes
- Purchase small equipment, such as EDFA to drive combs
- Help to finish the installation of the dual combs in RMIT and Adelaide
- Support COMBS members to undertake training in photonic chip design
- Organize a tape out for commercial microcomb chips fabrication

Securing our supply chain: Designing for scale up from day one

Disrupted chip supply chains – exposed during COVID-19 – and slow iteration cycles significantly slow research progress in Australia. The COMBS Infrastructure Committee is working to secure diverse fabrication pathways and future-proof microcomb scalability, aiming to make them as accessible as consumer electronics.

The Challenge

At COMBS, we are integrating the optical frequency comb onto a chip the size of a fingernail – called microcombs – targeting the size and cost of modern electronics.

We currently have different 'flavours' of combs-based technologies – from benchtop laser systems to microchips – and the Infrastructure Committee provides our Centre members with training and support to use this technology.

Beyond training, is developing scalable design practices, securing diverse supply chains for chips (as was exposed during COVID-19), and working toward manufacturability in industrial foundries.

Without this foresight, Australia is vulnerable to supply chain disruption, and slow 6–9-month chip design cycles, both significantly slowing research progress.

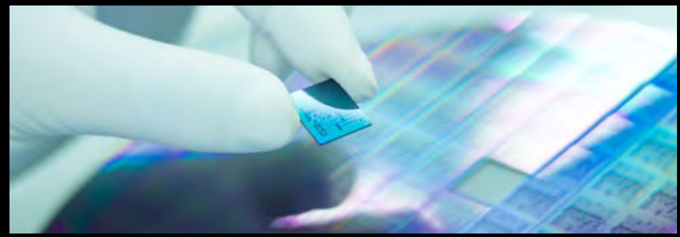
Our Response

To future-proof our combs-based technology, the Infrastructure Committee is proactively diversifying fabrication sources to accelerate development and ensure long-term accessibility.

We can make these chips ourselves, or with some of our most trusted international partners to test identical designs across platforms to compare performance and reduce risk.

Rather than waiting months for each iteration, we now design in parallel across multiple foundries, accelerating progress.

We are also developing in-house fabrication to enable rapid prototyping, cutting iteration cycles from months to weeks.



The Results and Current Progress

We have received two batches of chips from different suppliers – one performing as expected, the other requiring modifications. This highlights the value of parallel supply chains and an iterative design process.

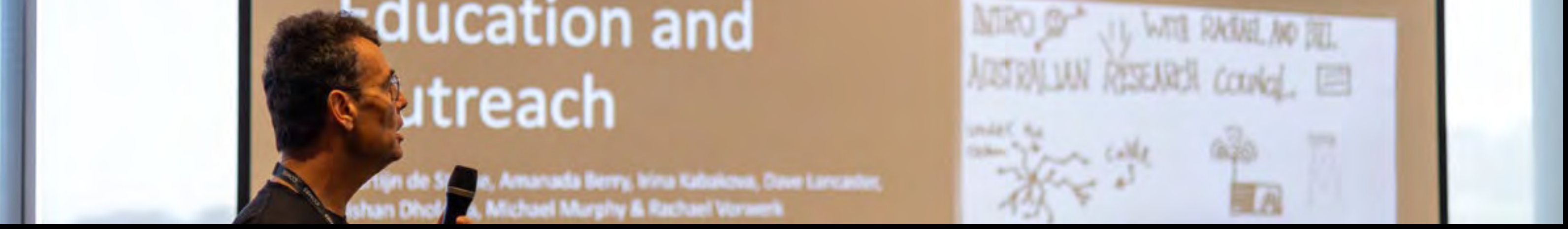
By resolving design issues early, our goal is for COMBS researchers to get functional chips the first time.

A multi-supplier approach allows faster iteration – reducing wait times from 6–9 months to a matter of weeks – dramatically improving our research progress.

In this way, the Infrastructure Committee is equipping our researchers with the skills to engage global foundries, ensuring COMBS technology remains scalable and market ready.

By strengthening our supply chain, COMBS is laying the groundwork for microcombs to become as cost-effective, scalable and manufacturable as modern consumer electronics.

Team:
- **Guanghui Ren,** Infrastructure Committee Coordinator, RMIT University
- **Arnan Mitchell,** Director, RMIT University



Education and Outreach

The Education and Outreach Committee enhances engagement and collaboration by fostering a culture of science communication, developing targeted education initiatives, supporting career development, increasing public and media visibility, engaging with policymakers, and promoting the societal and economic impact of COMBS research.

Committee Report

Being in the first year of the Centre's existence meant that the Education & Outreach Committee needed to set up initiatives which serve the long-term interests of the Centre and which can be carried forward to future years. One of the most important ones of these was the Undergraduate Internship Program. The aim of this program is to inspire undergraduate science and engineering students to do a PhD in COMBS. The participants of this program were selected from Australian and New Zealand universities via a thorough procedure. They were then invited to work for six weeks over the summer in the labs of one of COMBS' Chief Investigators. At the end of the summer, the interns come together and attend part of the COMBS workshop. This allows them to learn about our exciting research and how this research can contribute to society. In this, our first year of operation, we had 12 participants working with eight different Chief Investigators.

The Committee also initiated an internal Grant scheme for Early Career Researchers and postgraduate students. The aim of this program is to encourage cross-node research interactions. Applicants are asked to propose a modest-sized research project with researchers from another node that needs to be new to the Centre. The first-round closes in early January 2025.

In addition to these, we provided sponsorship to a number of initiatives including: funding for COMBS researchers to attend Science meet Parliament (see Case Study below); a report on the current state of the Australian & New Zealand Photonics Industry (see https://optics.org.au/2024-industry-report); a glass exhibition in Adelaide in which COMBS researcher Dr Sarah Scholten gave a public lecture about optical frequency combs; local conferences and meetings such as the Australia & New Zealand Conference on Optics & Photonics (ANZCOP), the KOALA meeting for postgraduate students, and the CONASTA science teacher conference. Finally, we planned our approach to engage with high school students and teachers, to be rolled in 2025.

Committee Plans for 2025

- Build a core group of teachers to develop and trial COMBS-related curriculum
- Support our PhD student's project milestones and Fulbright collaboration for curriculum integration
- Develop a longitudinal study to track the journey of COMBS internship students
- Create initiatives for Honours students (e.g. Poster sessions, 3 Minute Thesis-style presentations)
- Launch a Postdoc Meet and Greet online forum, career advice sessions and implement evaluation techniques
- Publish a COMBS roadmap article in the American Chemical Society (or similar)
- Establish a Government Relations sub-committee and strategy, and encourage researchers to meet their local MPs (after attending Science Meets Parliament)
- Engage with the ARC to assess the kinds of good news stories they're after

Building trust between scientists and policymakers for evidence-based decision making

As a researcher, how do you help politicians create good policy, make good decisions and invest effectively in the future of our nation? At COMBS, we're equipping our members with the skills to become trusted advisors, guiding evidence-based policies for all Australians.

The Challenge

Evidence-based policies shape the lives of all Australians, from tackling climate change to managing crises like COVID-19. Scientists play a vital role in ensuring these policies are informed and robust.

A recent study – led by ANU and La Trobe universities - found that two-thirds of Australians think scientists should actively advocate for specific policies; while more than 60 per cent think scientists should be more involved in policymaking.

This shows that Australians have strong trust in science and scientists to inform and guide evidence-based policymaking.

But how does a scientist become an advocate for science to inform policymaking?

Our Response

Training scientists is crucial to ensure they can effectively advocate for science to inform and guide policymaking.

Science Meets Parliament is one such training event, where researchers speak directly to politicians about their work, whilst learning how to engage with policymakers.

COMBS optical physicist Chris Perrella attended the event and created a step-by-step guide for engaging with Members of Parliament (MPs). But he didn't stop there – he tested the guide on himself.

From researching his local MP and finding common ground, checking his internal university processes, and emailing his MP, Chris followed the steps to see if they led to meaningful engagement.

The Results and Current Progress

After following his step-by-step engagement guide, Chris met his local MP.

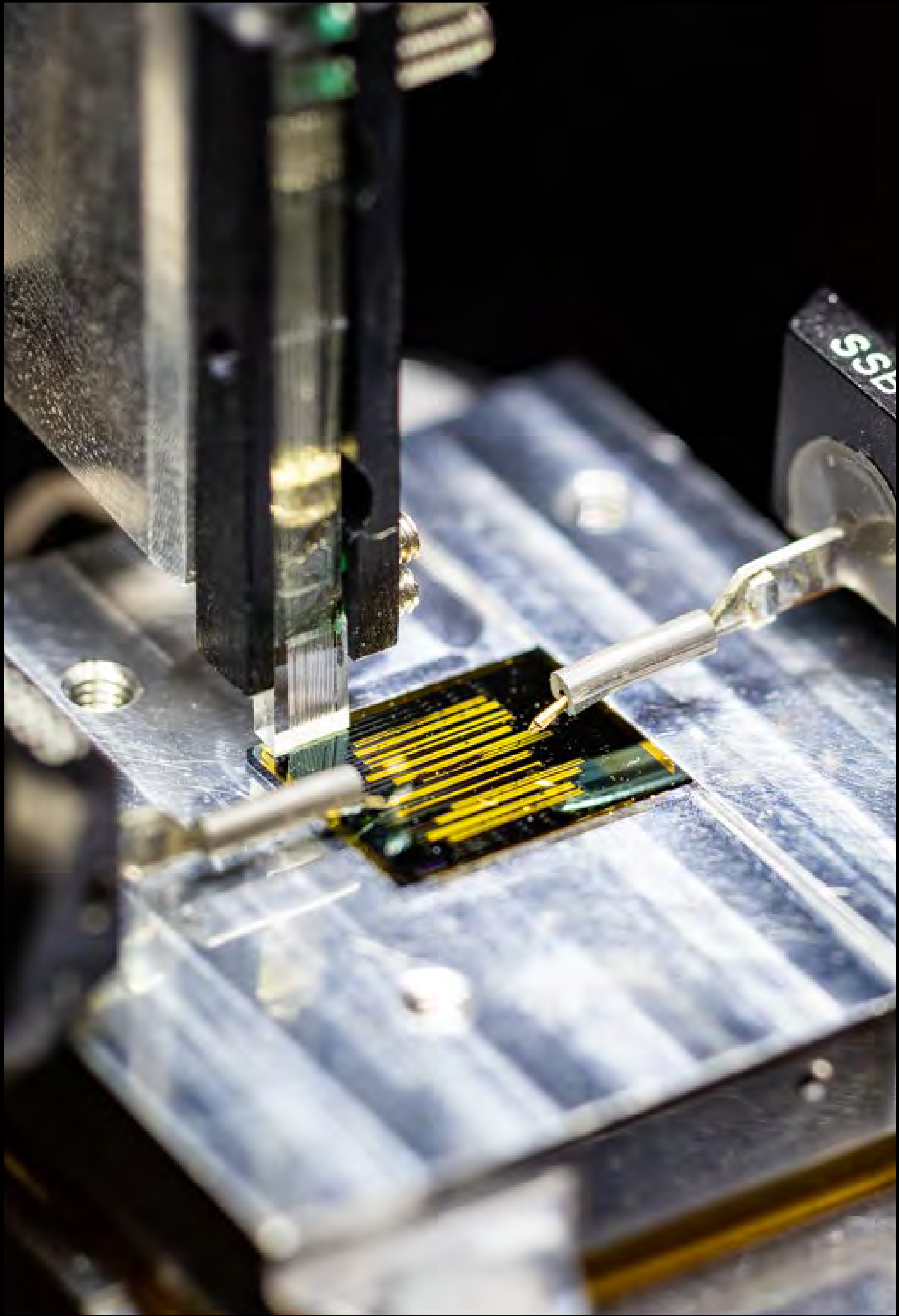
In the 20-minute meeting, Chris' engagement strategy proved successful: he went prepared with a one-page briefing note, a prop (under $100) to demonstrate his research, and a clear 'ask' (inviting the MP to an outreach event) which he crafted with the COMBS Education and Outreach team.

To follow-up on this meeting, he emailed the MP a digital version of his one-pager, reiterated his lab invitation, and shared his experience on LinkedIn. Now Chris plans on applying for Science and Technology Australia's STEM Ambassadors Program.

Chris' journey shows the beginning of how a researcher can turn into an active advocate for science. Over time, we hope to equip all our members with the skills to guide evidence-based policies for all Australians.

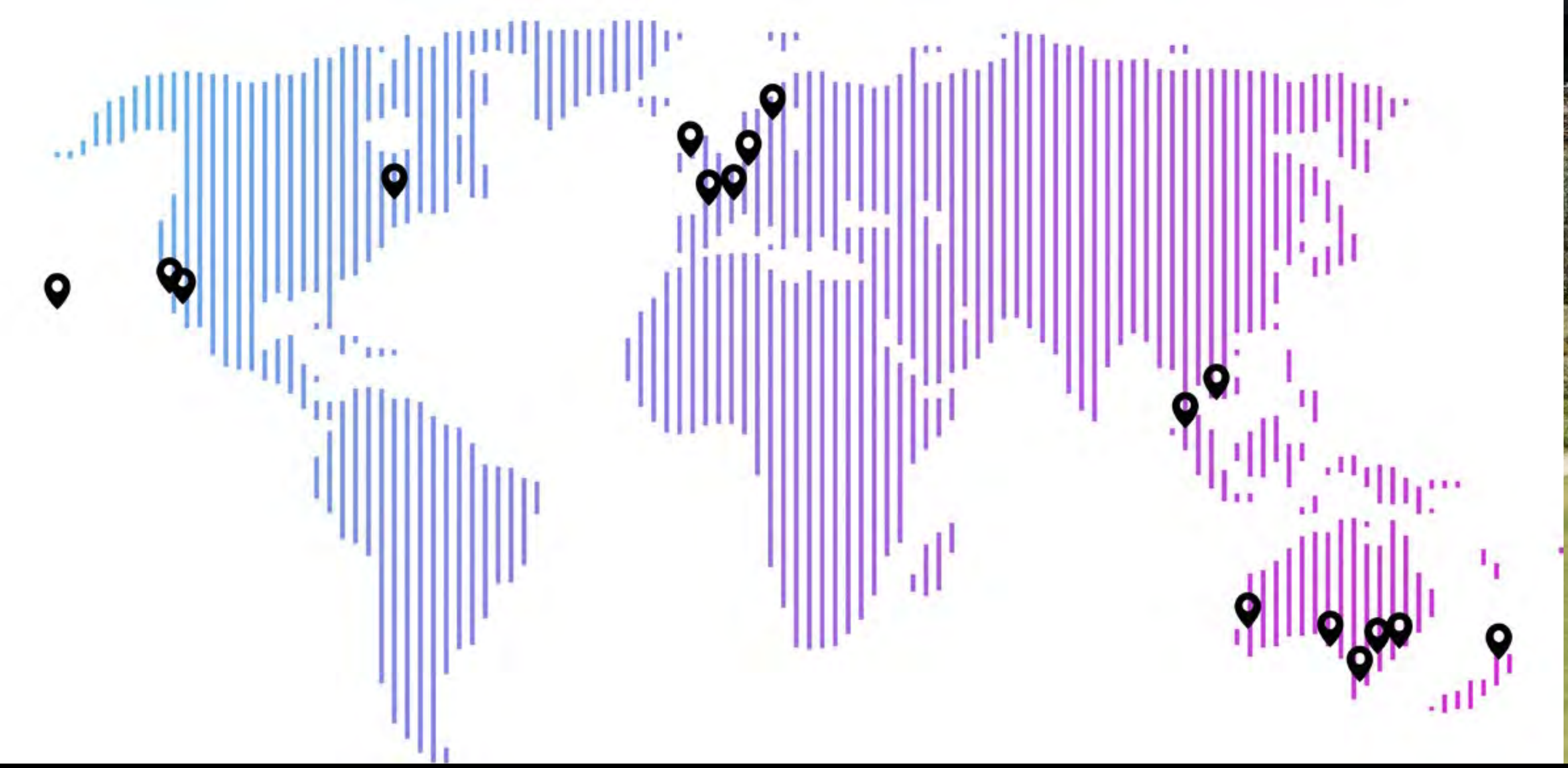
Team:

- Chris Perrella, University of Adelaide
- Rachael Vorwerk, RMIT University
- Michael Murphy, Swinburne University



Centre Outreach

In our first year, we launched a range of initiatives in 2024 to spread the word about COMBS — from staying up to date with the latest scientific advances through conferences and lab visits, to inspiring the next generation of researchers.



National and International Links

Over our first year of operation, we had several major successes in building our reputation as a globally connected, industry-engaged leader in optics and photonics research including strategic collaborations, prestigious appointments, and cross-sector partnerships.

Chief Investigator Professor Kishan Dholakia was elected Society Director for SPIE, the international Society for Optics and Photonics—bringing COMBS into closer alignment with this globally influential network.

Closer to home, COMBS researchers continued to drive the direction of optics and photonics in our region through active leadership within the Australian and New Zealand Optical Society (ANZOS). In 2024, Professor David Lancaster was elected President, Dr Moritz Merklein as Vice President, and Associate Professor Irina Kabakova as Councillor—strengthening our Centre's voice in national scientific discourse.

Our commitment to advancing industry-relevant innovation was underscored by the success of Director Arnan Mitchell and Chief Investigators Kishan Dholakia and Andy Boes in securing a major role in the new ARC Training Centre in Current and Emergent Quantum Technologies (CE-QuTech). This initiative brings together semiconductor materials and photonic chips to address emerging industrial needs, while also connecting COMBS with the ARC Centre in Quantum Biology (QUBIC), creating new opportunities for cross-disciplinary impact.

We also recognised individual excellence this year. Deputy Director Professor David Moss was awarded an Honorary Doctorate by the Danish Technical University—presented by King Frederik X of Denmark—for his pioneering contributions to optical frequency combs. Chief Investigator Heike Ebendorff-Heidepriem was named a finalist for 2024 South Australian Scientist of the Year, highlighting the calibre of leadership within our Centre.

Meanwhile, Chief Investigator Benjamin Eggleton and industry partner Critical Frequency Design were awarded an ARC Linkage Project grant to develop cutting-edge photonic chip systems with exceptional performance capabilities—demonstrating the power of research-industry collaboration to deliver transformative technologies.

Together, these achievements reflect COMBS' growing influence and its ability to forge impactful partnerships across disciplines, sectors, and borders.

COMBS Annual Centre Workshop

In late February 2024, we hosted the inaugural COMBS Annual Centre Workshop in the picturesque setting of Cape Schanck, Victoria. Over the course of four days, more than 50 presentations were delivered by our Chief Investigators, Partner Investigators, Associate Investigators, Early Career Researchers (ECRs), and students. These presentations covered a wide range of topics, including astronomy, fundamental physics, earthquake monitoring, medical diagnostic tools, and internet infrastructure.

The workshop brought together 75 attendees from across Australia, as well as France, New Zealand, Denmark, and the USA. For many, it was their first opportunity to meet in person. This gathering provided an invaluable chance to connect, exchange ideas, and develop a shared understanding of each other's scientific perspectives. It also allowed participants to start refining the big-picture challenges that the Centre aims to address through its ambitious research program.

COMBS Launch

COMBS was officially launched by Acting Chief Executive Officer Dr Richard Johnson in front of more than 100 attendees in October 2024. This event was our first outward facing event to external COMBS stakeholders.

The speakers included RMIT University Vice Chancellor and President Alec Cameron, and Director Arnan Mitchell who outlined his vision to miniaturise the optical frequency comb – the world's most accurate measurement tool – into compact devices called microcombs.

COMBS science communicator Rachael Vorwerk MC'd the event and moderated a panel discussion with a cross-section of COMBS members. The discussion covered technology applications as broad as breath analysis tool for disease detection, to using our internet's optical fibres for measuring earthquakes. Speakers included Postdoctoral Researcher Chris Perrella, seismologist and Chief Investigator Meghan Miller, and Michael Roelens from our Partner Organisation Terra15.

The event also included a real-life interactive experiment, where we asked our attendees to jump at the same time to create a 'mini-earthquake', where our Partner Organisation Terr15 recorded the seismic activity of the room via an optical fibre laid around the room – essentially capturing ground motion in real time.

A Launch video was also created to officially launch the Centre, along with an exhibition that showcased the 'evolution' and miniaturisation of the optical frequency comb from its current two-metre tall and one-metre-wide version in 2012 to a fingernail-sized chip we envision for 2030 and beyond.

International Collaboration

Several visits by COMBS researchers helped to strengthen our ties and knowledge exchange with international partners and collaborators.

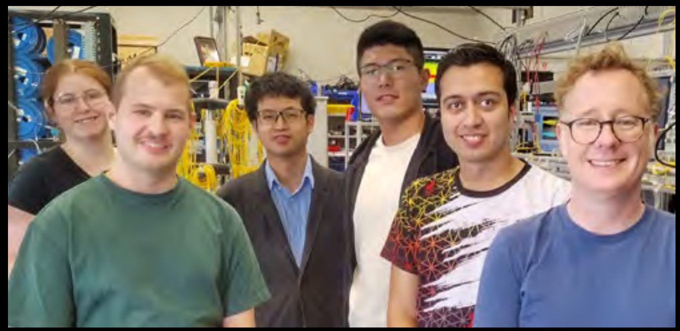
Our Director Arnan Mitchell visited Partner Investigator Professor Aleksandra Foltynowicz in Umeå, Sweden and saw her mid-Infrared comb systems for precision spectroscopy of gases like methane.

Arnan also visited Partner Investigators Christelle Monat and Christian Grillet in Lyon who are exploring mid-infrared microchip combs. A key topic of conversation was a joint Masters in microcombs to help build our pipeline of new PhDs and post-docs.

In Denmark, Deputy Director Dave Moss and Chief Investigator Bill Corcoran visited Partner Investigator Leif Oxenlowe (Technical University of Denmark – DTU) and a new co-supervised COMBS PhD student Jasper Riebesehl (who will work between DTU and Monash University) that will push the boundaries of how much information microcombs can carry. This is a step towards hosting more students from DTU as part of their "study away" portion of the PhD.

Our Partner Investigator Meghan Miller and Associate Investigator Voon Hui Lai attended a Photonics Seismology Conference in Vancouver and caught up with Partner Investigator Alireza Marandi at Caltech to discuss future collaborations.

In addition to our members travelling to overseas sites, Monash and RMIT also hosted visitors from Toyota Central Research and Development Labs, Drs Takashi Katsuno and Tetsuya Shimogaki, who worked on collaborative research projects.



Outreach, public awareness and communication with the wider community

In the first year of the Centre, the COMBS communications team focused on developing foundational materials including branding, website content, and a broad communications strategy. These resources helped lay the groundwork for future outreach by supporting a shared understanding of the Centre's vision. Before engaging with the broader community, COMBS members needed to understand that vision and feel connected to it. Building this foundation also made it easier to translate complex research into engaging content for wider audiences.

Specifically, these 'foundational' communications activities included:

- Developing our **Centre logo** – whilst gathering input from COMBS researchers to make it scientifically accurate
- **Co-designing our website** with web developers to reflect the many networking 'webs' of our Centre
- Creating **template branding materials**, including PowerPoint slides, A5 posters for Conferences, letterheads, business cards, event banners and social media templates
- **Providing branded merchandise** to COMBS members to raise our brand awareness, including t-shirts, tote bags, lanyards, notepads and pens
- Maintaining and growing our Centre **LinkedIn presence**, whilst choosing to no longer engage with **X** (previously known as Twitter).
- Building an **online presence as a Centre**, including training our researchers to update their LinkedIn profiles to reflect COMBS as a place of work and to celebrate collaborations on social media
- **Developing cross-institution branding collateral** that acknowledges each researchers' many institutions, via creating Teams/Zoom backgrounds and e-signatures that highlight each researchers' node, area of research and the COMBS logo
- Working with each research theme to distil their **broad research narrative**
- Creating **easy-to-disseminate collateral**, including A5 handouts for conferences, FAQ documents for our Centre members, and PowerPoint slides that highlight recruitment opportunities
- **Building connections with each COMBS node media team**, ready to collaborate when a media opportunity arises.
- **Creating a library of photo and video content** via photographing and video interviews with our members at various COMBS events, like the COMBS Workshop and COMBS Launch.
- **Disseminating a monthly internal newsletter** called the Fine-Tooth Comb, which helps our COMBS members to understand the broader vision and operational activities.

Public awareness initiatives

At the same time as these foundational communications were being developed, various Centre-wide public awareness initiatives, public lectures and outreach programs were happening in parallel.

Some of our COMBS Centre highlights included:

- COMBS participated in **RMIT Open Day**, showcasing a life-size optical frequency comb model to demonstrate our research narrative.
- **Director Arnan Mitchell** spoke at the Top Tech Trends Debate, positioning COMBS in future technology discussions.
- **Science Communicator Rachael Vorwerk** was featured in a science communication podcast, discussing effective research storytelling, including COMBS as a case study.
- **Chief Investigator Arthur Lowery** was featured in a Faculti podcast on photonic integrated circuits.

Public lectures

The 'COMBS word' was being spread throughout 2024 via various public lectures around our nodes, including the following.

14 May 2024: Chief Investigators Irina Kabakova and Ben Eggleton spoke at a Sydney Nano event featuring COMBS, engaging Undergraduate, PhD students, and Postdocs, in a discussion on photonics and research.

3 June 2024: Chief Investigator Professor Kishan Dholakia presented a public talk titled, 'A Trip on the Light Fantastic' as part of the International Day of Light organised by Optica Adelaide Chapter and the Australian Institute of Physics.

21 October 2024: Chief Investigator Professor Meghan Miller presented a STEMM Lecture Series.

6 – 27 November 2024: Chief Investigator Professor Heike Ebendorff-Heidepriem and Associate Investigator Dr Sarah Scholten delivered four public lectures as part of the Wednesday Wonders program in conjunction with the Chihuly in the Botanic Garden exhibition in Adelaide. These lectures included an introduction to and promotion of COMBS.

Outreach initiatives (led by the Education and Outreach Committee)

The Education and Outreach Team coordinated and implemented many outreach initiatives in 2024. We've included some highlights below:

International Day of Light campaign
Chief Investigators were part of a coordinated COMBS social media campaign that celebrated International Day of Light, with a video about how microcombs will change our lives in the future.

Joint booth at the CONASTA Science Teacher Conference
COMBS had a joint booth at the CONASTA Science Teacher Conference, paired with four other Centre of Excellences (Dark Matter, OzGrav, ASTRO3D, FLEET and Exciton Science). Our Science Communication, Education and Outreach Manager Rachael Vorwerk and PhD student Evan Diamandikos attended. The purpose of the booth was to raise awareness about our Centre and gather interest for a working group of science teachers to test COMBS-related educational resources – five enthusiastic teachers have registered.

Conference booth at the KOALA Conference
The KOALA Conference is a student conference across the fields of lasers, optics and atoms. Our presence aimed to encourage future Early Career Researchers and aspiring startup founders about the benefits of microcomb technologies. Our Infrastructure Coordinator Guanghui Ren gave the keynote about integrated silicon photonics and its applications in biosensing.

COMBS booth at the Australian Institute of Physics (AIP) Congress/ANZCOP Conference
This presence increased academic and industry engagement and raised awareness about our Centre for future recruitment.

Media hits

26 June: Bill Corcoran was cited in Particle Magazine (WA Govt's SciTech) describing the potential future of carbon-zero internet cables.

2 Nov: Deputy Director Dave Moss was featured in The Australian, recognising his research leadership.

13 May: A Research Impact Story featuring COMBS was published on the University of Adelaide website which featured microcombs of one day enabling diseases to be analysed via a handheld breath test.

16 May 2024: The future of microcombs was highlighted in a positioning piece written by Director Arnan Mitchell and Science Communicator Rachael Vorwerk, which featured in the Australian and New Zealand Optical Society (ANZOS) newsletter.

28 May 2024: Chief Investigator Meghan Miller was interviewed by the ABC to discuss the probabilities of earthquakes in Australia after two cities were hit by a magnitude of 4.3 earthquake.

9 August 2024: Chief Investigator Professor Meghan Miller was interviewed by the ABC to discuss earthquake monitoring in Japan

13 November 2024: Science Communicator Rachael Vorwerk was featured in a science communication podcast, describing her career path and role at COMBS.

4 December 2023: Chief Investigator Arthur Lowery was featured in the Faculti podcast at Monash University and spoke about the power of photonic integrated circuits.

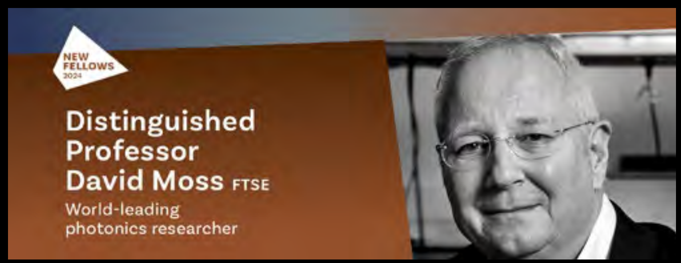
Awards and honours

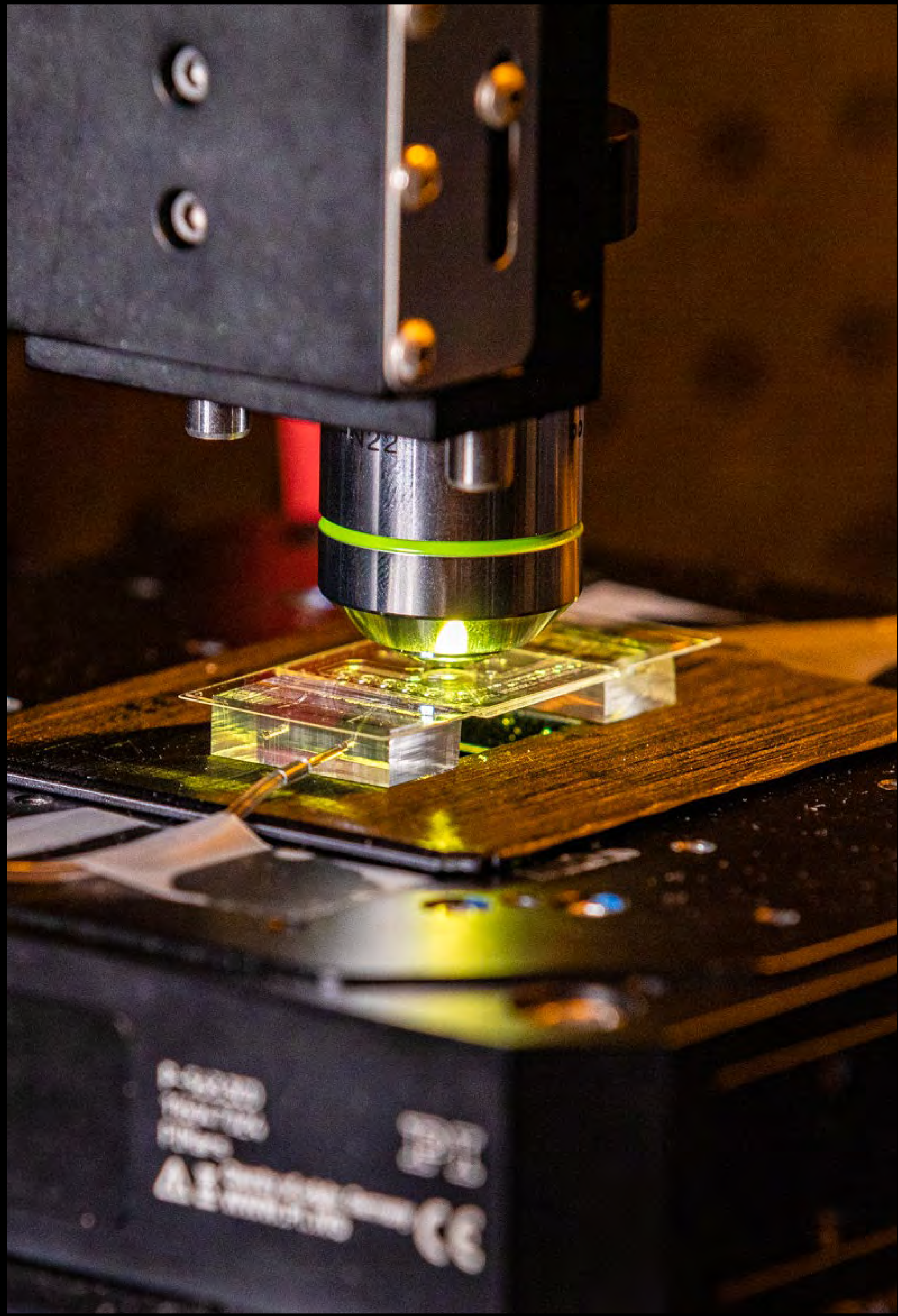
Deputy Director David Moss was Awarded an Honorary Doctorate by the Danish Technical University (DTU) in Copenhagen by King Frederik X of Denmark. The Honorary Doctorate was motivated by Partner Investigator Professor Leif Oxenløwe and was awarded for Professor Moss's long standing close relations with DTU and his contributions to nanophotonics.

Deputy Director David Moss was welcomed as a New Fellow of the Australian Academy of Technological Sciences and Engineering for his seminal contributions to photonics and optics, particularly his work with microcombs.

Chief Investigator Martijn de Sterke was awarded the W.H. (Beattie) Steel Medal, the most prestigious award of the Australian and New Zealand Optical Society (ANZOS). Martijn was recognised for this award because of his sustained record of leadership, service, and innovation in the field of optics in Australia.

PhD student Mr Yunlong Qiang from The University of Sydney was awarded the Optica-ANZOS Student Prize for a talk presented at the 2024 ANZCOP conference entitled "Pushing the limits of a novel analytic method for finding soliton solution."





Facts and Figures

Centre financial and performance data, membership and governance structure

Centre Financial Report

INCOME	Budget	Actual
ARC Grant	$4,997,941	$5,576,356
University Contributions	$1,436,656	$1,436,656
TOTAL	**$6,135,614**	**$7,013,012**

EXPENDITURE	Budget	Actual
Personnel	$5,132,334	$1,583,731
Equipment	$608,758	$182,738
Maintenance	$438,857	$295,994
Travel	$471,044	$521,995
Field Research	$10,000	$0
Teaching Relief	$0	$0
Other	$466,174	$215,828
TOTAL	**$7,127,167**	**$2,800,286**

Centre Performance

Performance Measure	Proposed	Actual
1. Number of research outputs		
Journal articles	40	29
Records of Invention	10	1
Provisional IP filings	0	0
2. Quality of research outputs		
Q1 Journal Articles %	85%	97%
Top 5% publications (e.g. Nature, Science)	3	3
3. Number of workshops/conferences held/offered by the Centre		
Training workshops on diversity and gender equality	1	1
Workshops held within Australia	1	1
Seminars held by the centre	8	2
4. Number of training courses held/offered by the Centre		
Professional training/development courses/theme based focused workshops	7	5
5. Number of additional researchers working on Centre research		
Postdoctoral researchers	18	29
Honours students	24	4
PhD Students	22	15
Associate Investigators	15	5
6. Number of postgraduate completions		
Number of PhD completions	0	0
PhD annual milestones achieved (%)	90	100
7. Mentoring		
Mentoring programs offered by the Centre	1	0
Mentors within the Centre	10	18
Mentors external to the Centre	4	2
Centre members participating as mentees	20	3

Performance Measure	Proposed	Actual
8. Number of presentations/briefings		
To the public	3	6
To government	4	2
To industry/business/end users	4	2
9. Number of new organisations collaborating with, or involved in, the Centre		
New partners/collaborators	2	0
10. Number of female research personnel		
Female	20%	34%
11. International, national, and regional links and networks		
International visitors and Visiting Fellows	20	3
Visits to overseas laboratories	20	36
Invited talks at major conferences	36	22
Cross-branded initiatives with other CoEs	3	6
12. Education and Outreach		
Media mentions (including any mention of COMBS in articles)	12	3
COMBS mentions in media releases (including media releases from other orgs)	8	3
School visits including focus visits on female only, minority and CALD groups	8	8
13. Outcomes and Linkages		
Centre personnel entrepreneurship and translation training (200 overall)	25	1
Teams put through start-up accelerator program (2 in each of years 3-7, 10 overall)	0	2
Funded engagements with industry partners	0	0
14. Communications		
Media training (no. of people)	40	1
Social media training (no. of people)	40	100
University media collaborations (ie. no. of meetings)	5	7
Unique clicks on the COMBS website (per month)	200	540
LinkedIn Centre followers	500	1100

Centre Publications

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5. Hu, J., J. Wu, W. Liu, D. Jin, H. E. Dirani, S. Kerdiles, C. Sciancalepore, P. Demongodin, C. Grillet, C. Monat, D. Huang, B. Jia and D. J. Moss (2024). "2D Graphene Oxide: A Versatile Thermo-Optic Material." Advanced Functional Materials **34**(46).
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8. Jin, D., J. Wu, J. Hu, W. Liu, Y. Zhang, Y. Yang, L. Jia, D. Huang, B. Jia and D. J. Moss (2024). "Silicon photonic waveguide and microring resonator polarizers incorporating 2D graphene oxide films." Applied Physics Letters **125**(5).
9. Kabakova, I., J. Zhang, Y. Xiang, S. Caponi, A. Bilenca, J. Guck and G. Scarcelli (2024). "Brillouin microscopy." Nature Reviews Methods Primers **4**(1).
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Centre Members

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Mr Gabriel Britto Monteiro, The University of Adelaide
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Mr Xuan Hiep Dinh, RMIT University
Mr Aditya Dubey, RMIT University
Miss Yumin Li, RMIT University
Mr Wenhao Liu, The University of Sydney
Ms Caitlin Murray, Monash University
Mr Ryan Russell, The University of Sydney
Mr Yonghang Sun, Monash University
Mr Bo Wang, RMIT University
Miss Lantian Wei, RMIT University
Mr Yisong (Ethan) Xu, Monash University
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Mr Luke Broadley, RMIT University

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Ms Sian Edwards, The University of Sydney
Mrs Angela Grande, RMIT University
Dr Scott Kolbe, RMIT University
Ms Ada Li, University of Technology Sydney
Ms Rachael Vorwerk, RMIT University
Ms Ruth Waterman, RMIT University
Ms Caitlin Zou, The University of Sydney

Visitors

Mr Henrick Hollerer, Friedrich Schiller University Jena
Mr Richard Kindler, Friedrich Schiller University Jena

Centre Governance Structure

COMBS Advisory Board

Calum Drummond, Deputy Vice Chancellor Research & Innovation, RMIT University (*Chair*)

Amanda Caples, Lead Scientist, Department of Jobs, Skills, Industry and Regions, Victorian Government

Kate Cornick, Chief Executive Officer, LaunchVic

Nadia Court, Director, Semiconductor Sector Service Bureau

Katja Digweed, Research Director, Manufacturing Business Unit, CSIRO

Karen Hapgood, Deputy Vice Chancellor Research, Swinburne University of Technology

Kathryn McGrath, Deputy Vice Chancellor Research, University of Technology Sydney

Jason Whittle, Dean of Research, UniSA STEM, University of South Australia

Arnan Mitchell, Centre Director, RMIT University

Scott Kolbe, Centre Chief Operating Officer, RMIT University (*Secretariat*)

COMBS Executive Committee

Arnan Mitchell, Centre Director, RMIT University (*Chair*)

David Moss, Deputy Director, Swinburne University (*Deputy Chair*)

Scott Kolbe, Centre Chief Operating Officer, RMIT University (*Secretariat*)

Baohua Jia, RMIT University (*Infrastructure and Capability representative*)

Heike Ebendorff-Heidepriem, University of Adelaide

David Lancaster, University of South Australia (*Impact and Translation representative*)

Bill Corcoran, Monash University (*Equity, Diversity and Inclusion representative*)

Meghan Miller, Australian National University

Irina Kabakova, University of Technology Sydney

Martijn de Sterke, University of Sydney (*Education and Outreach representative*)

Impact and Translation Committee

David Lancaster, University of South Australia (*Co-chair*)

Benjamin Eggleton, University of Sydney (*Co-chair*)

Adam Chrimes, RMIT University (*Committee Coordinator*)

Arthur Lowery, Monash University

Scott Kolbe, RMIT University

Infrastructure and Capability Committee

Baohua Jia, RMIT University (*Co-chair*)

Andy Boes, University of Adelaide (*Co-chair*)

Guanghui Ren, RMIT University (*Committee Coordinator*)

Arnan Mitchell, RMIT University

Scott Kolbe, RMIT University

Education and Outreach Committee

Martijn de Sterke, University of Sydney (*Chair*)

Rachael Vorwerk, RMIT University (*Committee Coordinator*)

Irina Kabakova, University of Technology Sydney

David Lancaster, University of South Australia

Kishan Dholakia, University of Adelaide

Michael Murphy, Swinburne University of Technology

Equity, Diversity and Inclusion Committee

Sumeet Walia, RMIT University (*Co-chair*)

Heike Ebendorff-Heidepriem, University of Adelaide (*Co-chair*)

Ruth Waterman (*Committee Coordinator*)

Bill Corcoran, Monash University

Robyn Barnacle, RMIT University

Scott Kolbe, RMIT University

COMBS Business Operations

Scott Kolbe, RMIT University (*Chief Operating Officer*)

Nicci Coad, RMIT University (*Centre Coordinator*)

Rachael Vorwerk, RMIT University (*Science Communications, Education and Outreach Manager*)

Ruth Waterman, RMIT University (*Research Training and Development Coordinator*)

Adam Chrimes, RMIT University (*Impact and Translation Manager*)

COMBS Partners

COMBS Node Universities

- UTS University of Technology Sydney
- Australian National University
- Monash University
- The University of Sydney
- RMIT University
- University of South Australia
- The University of Adelaide
- Swinburne University of Technology

Industry and Government Partners

- Advanced Navigation
- Baraja
- W. M. Keck Observatory
- Ligentec
- MenloSystems
- moglabs
- nbn
- Australian Government Department of Industry, Innovation and Science | National Measurement Institute
- terra15

International University Partners

- Caltech
- Centrale Lyon
- CityU
- DTU Technical University of Denmark
- INRS Institut national de la recherche scientifique
- Loughborough University
- UCSB
- The University of Auckland Te Whare Wānanga o Tāmaki Makaurau New Zealand
- Umeå University

COMBS